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NEW DESIGNS OF ROTORS WITH VARIABLE GEOMETRY PARAMETERS IN DYNAMICS AND THEIR EFFECTIVE USE IN AVIATION AND WIND ENERGY

НОВЫЕ КОНСТРУКЦИИ ВОЗДУШНЫХ ВИНТОВ С ИЗМЕНЯЕМЫМИ ПАРАМЕТРАМИ В ДИНАМИКЕ И ИХ ЭФФЕКТИВНОЕ ПРИМЕНЕНИЕ В АВИАЦИИ И ВЕТРОЭНЕРГЕТИКЕ

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ABSTRACT: In the report will be presented the investigation results of the working model of rotors with variable geometry parameters in dynamics. Because of aerodynamic and economic calculations, the effectiveness of use of such designs for powerful wind stations is proved. The analysis of various designs and methods of selection of that or other design for various conditions of operation of wind installations in wide range of the wind speed change is given.

Also rather effective by cost-price method of accumulation of wind energy will be suggested that is the topical world problem and for development of which are annually spent some hundreds of millions of US Dollars.

KEYWORDS: BLADE, SETTING ANGLE, BLADES TWIST, WIND ENERGY.

Recently in conditions of the abrupt increase of the growth tempo of global thaw and considerable deterioration of the ecological state the acquisition of power energy by traditional methods becomes a serious threatening to the mankind. In connection with this especially developed countries become in difficult situation in which annually with quick tempos increases the volume of industrial and accordingly the number of consumed power energy.

In this case especially must be noted those risk factors by which are characterized atomic power stations and the dissatisfaction of population that reached its peak during the disaster in Fukushima that happened in Japan in 2011.

It is known internationally that these processes became the basis of the solutions that make authorities of all countries carry out operative measurements in direction of change of the atomic energy in the general energy balance of the country by some less dangerous kind of energy.

By these processes is preconditioned the fact that in last 10-15 years almost in all countries of the world special attention is paid to updating of the existing and creation of new non-traditional methods of the energy acquisition and maximal use of the existing potential in the country.

Furthermore, the governing bodies of the international community elaborate special encouraging measurements for those countries and firms that effectively work on the development of ecologically pure and non-dangerous methods of acquiring energy.

First of all wind and solar energy refers to such kind of energy. Therefore, the designs of wind stations and technology of acquiring solar panels are extensively updated.

The extensive works in both directions are conducted at the Georgian Technical University.

For increasing of the effectiveness of wind stations several designs of rotors with the ability of change of basic geometry parameters have been created. Such parameters are the rotor diameter, i.e. the length of blades, setting angle of each blade and the law of their twist.

The preliminarily conducted aero-dynamic and economic calculations prove that as a result of use of the designs elaborated by us the annual volume of output of each wind station can be increased as minimum by 100%.

Despite multiple work of well-known companies and scientists of various countries the VGR problem has not been solved yet. There are patents that did not find a real embodiment, mainly, because of complexity and insufficient reliability of technical solutions.

It must be noted that all these companies were busy with any of one parameter. For example, Sikorsky Company was busy with change of only the rotor diameter and the Boeing Company only with blade twist change.

Georgian Technical University (GTU) proposed a combination of changes in the diameter and twist at the same time dynamics.

Initially in the phase of analysis because of separation of the investigation object, the model of the rotor with variable diameter and then the model of the rotor with variable blade twist has been designed and manufactured. After laboratory tests of their main units in the phase of the synthesis, the rotor with simultaneously variable diameter and blade twist (Fig. 1) and the stand for its tests has been created [1].

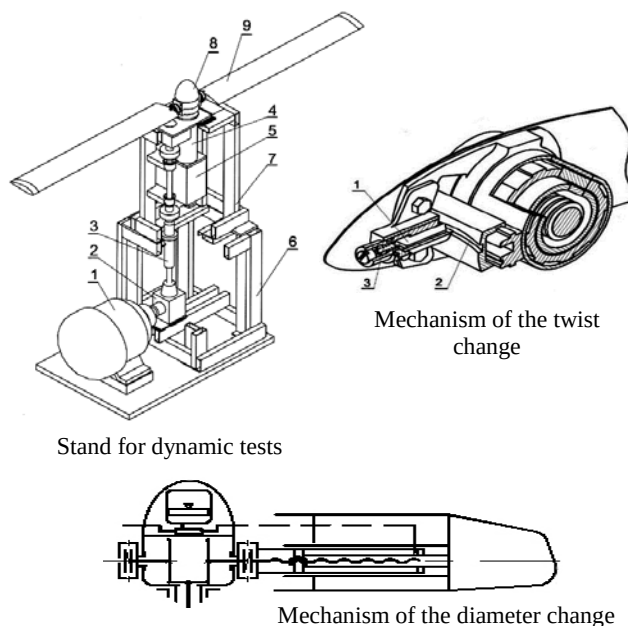


Fig. 1. Mechanisms for management of parameters of the VGR and stand for their tests.

The conducted stand tests of the VGR have shown that at high number of rotations significant centrifugal forces arise that influence on the blade movable part. They are accepted by the jackscrew. The jackscrew is the most loaded element of the rotor design and is the weak unit. The reduction of harmful influence of these forces is the very actual problem.

Therefore, a system was developed compensation of centrifugal forces. The technical approach was in conduct of the model experiment in which the stand is stationary fixed in place. At the rotor rotation at the mode of fan measuring of the thrust were implemented depending on the change of the rotor rotational speed and diameter. In accordance with the principle of reversibility, this imitates the conditions the hover mode of the aircraft. From the possible principles of compensation (mechanical, electrical and hydraulic) was chosen hydraulic (Fig. 2) as the most flexible in control [1, 2, 3].

For the design of this version of the VGR a European Patent has been received Application №/Patent 08737551.5 - 2422 PCT/IB2008001041. At present, it is being patented in the USA. All the financial costs were assumed by the European Union.

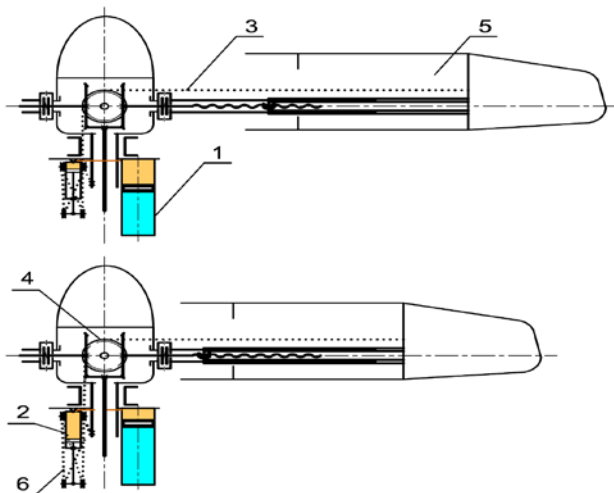


Fig. 2. Schematic arrangement of the VGR with position of the hydro-pneumo-accumulator and hydro-cylinder below the rotor hub.

1-Hydro-pneumatic accumulator, 2-Hydro-cylinder, 3-Rope, 4-Roller, 5-Blade, 6-Pulley block.

The safety of the VGR dynamic tests was provided by the reliability of the VGR units with the compensation system. For evaluation of the reliability was designed and manufactured the stand for static tests (Fig. 3) on which experimentally were imitated loads acting at various rotor rotational speeds. The blade elasticity lines were determined depending on imitated rotational speeds at retracted and extended blade and dependence of forces on the control lever of the stand from imitated rotational speeds.

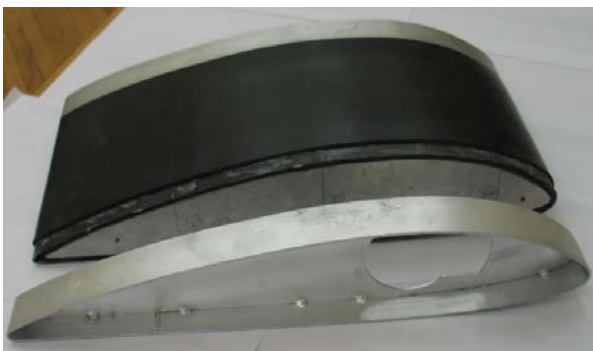


Fig. 3. Stand for static tests and blade with flexible elements and rib.

The experiments on the stand for dynamic tests (Fig. 4) were conducted by the measuring method of the airflow speed with a revolving-vane analyzer, which for this task was characterized, with a sufficient iteration of measuring results.

It has been established that in case of increase of the rotor diameter 1,4 times and the change of the blade twist within $16 \div 18^\circ$ the increase of the thrust force is provided approximately 1,6 times.

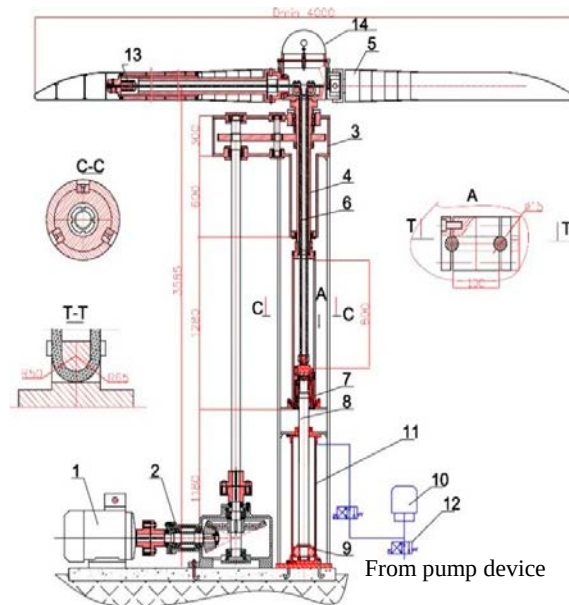


Fig. 4. Stand for dynamic tests and photo of the stand.

1-Electrical engine of direct current, 2-Conical reducer, 3-Cylindrical reducer, 4-Spindle of cylindrical reducer, 5-Blade with flexible elements, 6-Rope, 7-Unit of bearings with body, 8-Rod, 9-Piston, 10-Hydro-pneumo-accumulator, 11-Hydro-cylinder, 12-Hydro-distributor, 13-Unit of the rope mount.14-Hub.

The effectiveness of the compensation system is proved by multiple retraction-extension of the rotor blade in the all range of change of the rotational speed. It conditioned the synchronism of the VGR functioning.

Results of repeated and comprehensive investigation of the working model of air screws with changeable geometrical parameters in dynamics were saved up. In figure 5÷8 as an example, shows the results of the values of lift at maximum and minimum diameters of the rotor in a large range of the rotational speed.

The detailed analysis of the various proposed designs of rotor is carried out and on this basis recommendations of selection of this or that design for different service conditions of wind turbines in the wide range of change of speed of a wind are offered [5].

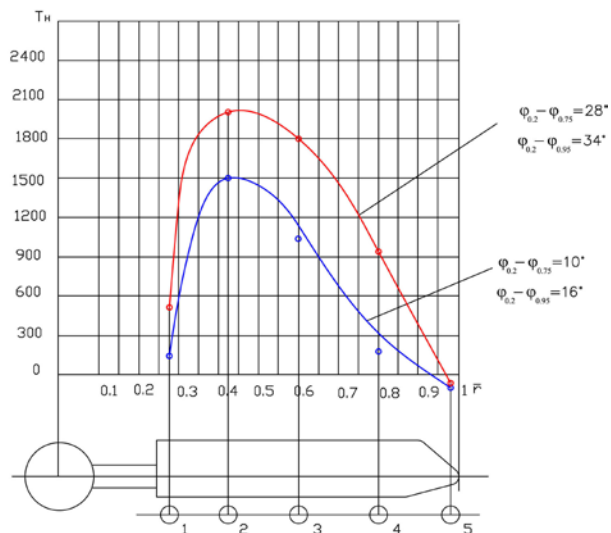


Fig. 5. Diagram of dependence of the VGR thrust from the blades twist change for the minimal diameter $D_{\min}$ of the rotor, rotational speed $n = 300$ RPM and setting angle $\varphi = 5^\circ$.

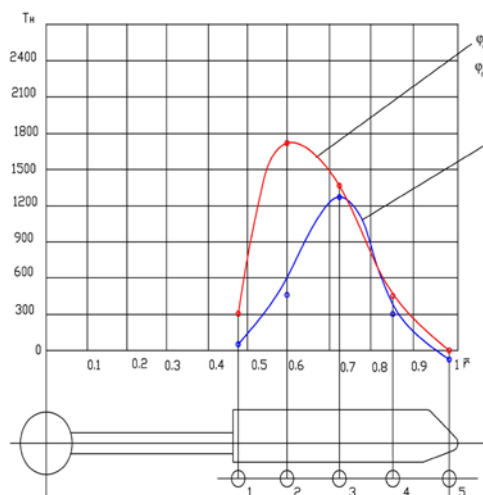


Fig. 6. Diagram of dependence of the VGR thrust from the blades twist change for the maximal diameter $D_{\max}$ of the rotor, rotational speed $n = 200$ RPM and setting angle $\varphi = 5^\circ$.

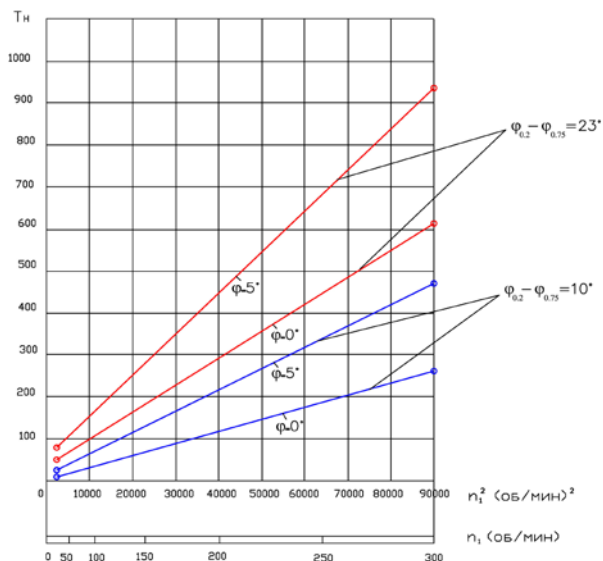


Fig. 7. Diagram of dependence of the VGR thrust from the rotor rotational speed for the minimal diameter $D_{\min}$.

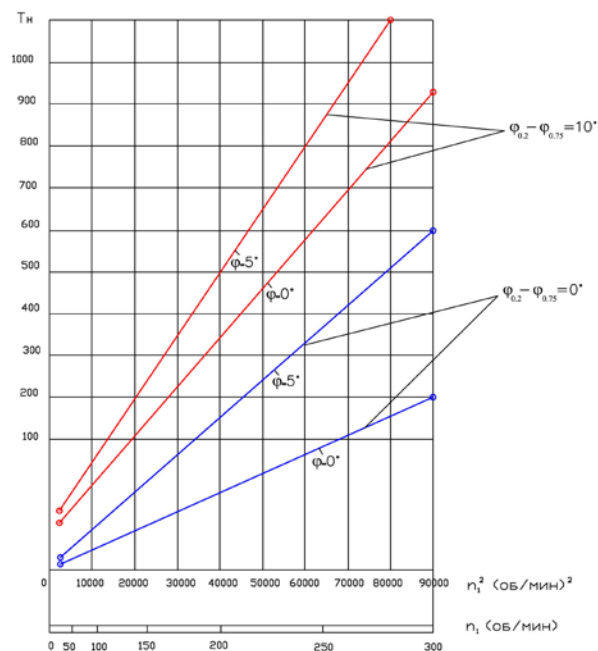


Fig. 8. Diagram of dependence of the VGR thrust from the rotor rotational speed for the maximal diameter $D_{\max}$.

As a result of manufacture and test of a demonstration model of the rotor with variable geometry parameters in dynamics we have proved that for wind energy installations especially with big powers the use of VGR will enable to extend the scale of maximal meanings of efficiency of the setting during the change of the wind speed in big scale from 3 to 20÷22 m/sec and also provide the workability of the setting during those high speeds of wind (22÷35 m/sec) (Fig. 9), at which the existing installations are unable to work [4].

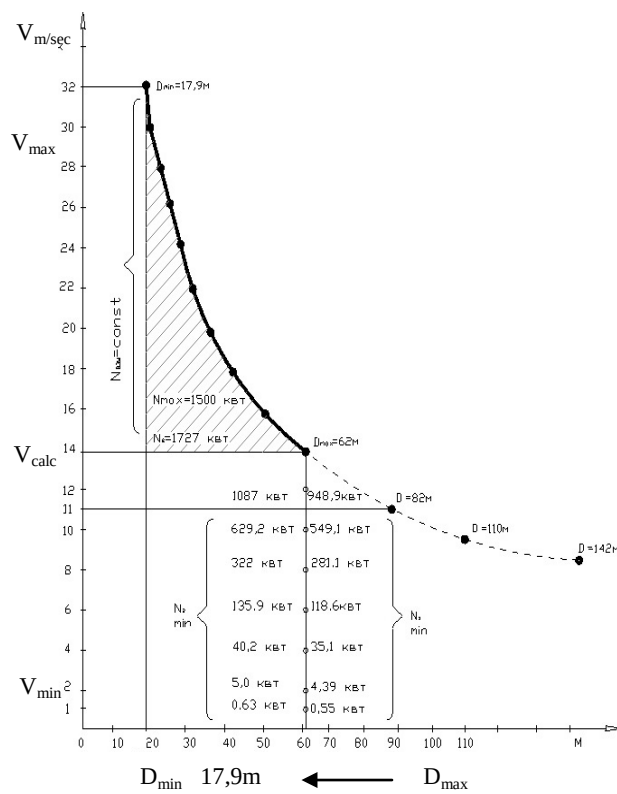


Fig. 9. Necessary combination of the rotor diameter and wind speed for acquisition of the planned power of wind station.

At present negotiations are being held with the famous German firm “ENERCON” for creation of a joint venture or its subsidiary on the territory of Georgia and manufacture along with standard rotors of new designs.

Also negotiations with “SCHMID” firm on production of solar panels are conducted.

Implementation of this project expediently as in Georgia some large enterprises for microelectronics therefore the Georgian scientists have very interesting offers on separate responsible operations of production of plates from a silicium monocrystal, and also by the principles of selection of places for installation of ready solar modules and creation of designs of the corresponding mechanisms which introduction will even more increase efficiency of solar modules functioned.

In particular, installation of these panels, for example over vineyards in in advance calculated parameters, with use of the special mechanisms allowing to change angular position of panels in big range, will give the chance along with obtaining electric energy, to protect plantations from a hail, and also from drying of brushes of grapes and the soil when air temperature constantly keeps some weeks within $35\div 40^{\circ}$ and above. It should be noted that such situation in Georgia very frequent and if it happens before process of cleaning of grapes, it strongly influences crop volume, especially for percent of an exit of grape juice.

Both protection of plantations against a hail, and regulation of process of drying of grapes before harvesting is a burning issue not only for Georgia, but also for all other countries too where there are similar plantations.

Therefore, we intensively work on development of methods of optimization of schemes of installation of solar panels over vineyards.

In fig. 10 one of versions of schemes of installation of such panels is shown.



Fig. 10. Solar panels over vineyards.

At present search of the optimum sizes of panels, schemes of their arrangement and improvement of mechanisms for regulation of their angular situation in wide range for the different period of time is conducted. Also different options of mechanization and automation of these processes are developed.

On the basis of consultations with skilled peasants it is established that use of such schemes of installation will significantly increase the volume and quality of a crop that finally will give notable economic effect.

The presented idea contains also scientific novelty that together with the German experts is already made out and in the near future European Patent will be issued.

Now the consent of our partners for gratuitous transfer about 200m² of solar panels for the purpose of the organization in Georgia of a skilled site where prototypes of solar panels will be established is reached and all necessary researches are conducted.

There is one very actual problem on which long time the leading scientists of many known scientific centers of the whole world work, however, unfortunately the effective solution of this

problem till today doesn't exist. The question concerns a method of the accumulation received solar and wind energy for which decision some hundreds of millions of US dollars are annually spent.

We have in our opinion the interesting offer for the solution of this problem in those countries where there are hydroelectric power stations with average and with big capacities, i.e. where there are already constructed high dams and reservoirs.

It is known that all such power plants have big deficiency of water and that volume which, is gained generally in the spring, then gradually, the whole year according to the special schedule is very economically spent.

The essence of our offer is that it is possible to mount the greatest possible number of wind stations and solar panels round a reservoir. When there is an order for electric energy they will work for its development and when orders are not present, to work for water pumping back from the lower reservoir in its top part. It will give the chance that all power sources worked constantly for profit, day and night, daily and all the year round.

In fig. 11 the approximate scheme of configuration of such constructions where the mounted one small group of wind-driven generators and solar modules is visible is shown. It is also visible that round a reservoir it is possible to place still such some groups.

Consultations with leading experts of power show that after creation of such skilled object and improvement of its separate knots and system of their management it will be wide, successful and effective to be used in many countries of the world.



Fig. 11. Approximate option of composition of aggregates and system of their management for accumulation of the received wind and solar energy.

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PRESENT OPPORTUNITIES FOR APPLICATION OF FRACTURE MECHANICS IN DETERMINING THE SECURITY OF WELDED STRUCTURES

АКТУАЛНИ ВЪЗМОЖНОСТИ ЗА ПРИЛОЖЕНИЕ НА МЕХАНИКАТА НА РАЗРУШАВАНЕ ПРИ ОПРЕДЕЛЯНЕ НА СИГУРНОСТТА НА ЗАВАРЕНИТЕ КОНСТРУКЦИИ

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Abstract: Clarified have been the formulations of fracture mechanics (FM) included in the present applied standards for welded structures (Eurocode 3, EN 13445, EN 13480). Considered have been the main criteria of fracture mechanics for analytical assessment of structural integrity against brittle fracture of the elastic-plastic materials, while special space has been devoted to the concepts of the “FAD” and the “Master-curve”. The opportunity has been shown to use the conventional toughness criterion, shock toughness as per Charpy-V, by means of correlation relationships with the FM criteria.

Key words: FAD, MASTER-CURVE, REFERENCE TEMPERATURE T_{100} , MEDIAN VALUE K_m OF FRACTURE TOUGHNESS K_{JC} ,

1. Introduction

The structural integrity of a given weld joint depends primarily on the rational solution of its weldability, i.e. on the optimum combination of its three components: the correct selection of main materials (materials *weldability*) which, at smallest technological limitations as regards the welding process (process *weldability*), guarantee the secure operation of the welded structural component (safety *weldability* of the structural component). The problem of weldability - quality, respectively, can only be aggregately solved in the phases of design, fabrication, and operation of welded products, as has been set in quality assurance standards, the БДС EN ISO 9000 [1] and БДС EN ISO 3834 [2]. Fracture mechanics (FM) offers a powerful analytical-and-experimental methodology of structural integrity assessment against fracture (brittle and tough-and-brittle) of the weld joints during their fabrication and in their operation. It is well known that the engineering foundations of FM have been laid in the second half of the XX century and are inextricably bound up with the problems of welded structure safety. Classical examples thereof are the catastrophes with the welded hulls of the ships “Liberty” (USA) during World War II, the bridges of the Albert channel (Belgium), the numerous failures of gas and petrol lines in the USSR, the USA, Italy, etc. [6], [7]. For the contemporary stage of technics, especially for its high responsibility regulated sectors, as nuclear technology, pressure vessels, the off-shore and ship structures, etc., the application of FM is inevitable [11], [13]. In this respect, most indicative is that for the first time in the latest versions of some applied (product) standards the postulates of FM are being used.

In engineering circles in our country still some controversial opinions exist about the applicability of FM. Some of them are of an objective nature, for instance that higher engineering qualifications are needed for conducting analytical assessments, as well as more expensive instrumental equipment for testing mechanical parameters of the materials with the methods of FM (FM-parameters). In many cases, however, the negative attitudes are due to inadequate knowledge of the present opportunities for practical application of FM methods, which is also the subject of this article.

2. Formulation and Discussion

2.1 How Are the FM Formulations Included in Present Applied Standards?

Some of the present applications of the assessment of structural integrity in FM have been developed in the 90-es of the previous century and verified to an “implementation in practice” level as a constituent part of strength assessments set in steel structure standards Eurocode 3/EN 1993-1-10 [3], such for unfired pressure vessels EN 13445 [4] and pipelines EN 13480 [5].

The EN 13445 Standard

It contains a formulation of FM in Part 2: “Materials”, in the informative Annex B “Requirements for Prevention of Brittle Fracture at Low Temperatures”, respectively. The concept of the standard is reduced to the opportunity one of the following three methods to be used independently:

According to **method 1 “Code of Practice”**, based on the practical tests of FM, the requirements are based on the definition $T_R = T_{27J}$, i.e. the reference temperature T_R needed for designing is actually the temperature T_{27J} of testing the material by means of the Charpy-V-notch tests at which the Charpy impact energy KV is equal to 27 J.

According to **method 2 “Flexible Method”**, the selection of steel is based on FM. This method is applied for a broader range of structural thicknesses and operational temperatures, in comparison with method 1, while it is not compulsory T_R to be equal to T_{27J} . The necessary reference temperature T_R is read from respective diagrams depending on the reference thickness e_B (determined from tables), on the steel grade, and on $KV \geq 27J$.

Method 3 “Fracture Mechanics Analysis” applies FM directly in the following cases:

- with materials not included in the harmonized European Standards;
- with low temperature applications, when the requirements of methods 1 and 2 cannot be met;
- when during non-destructive testing (for instance RT and UT) flaw spots have been found with dimensions exceeding the admissible values determined by EN 13445-5:2009;
- when materials are proposed with thicknesses exceeding the admissible dimensions for low temperatures.

For the analysis of FM, the producer may use the limiting conditions, proposed by the standard concerning the dimensions of the control flaw and the stress condition around it.

In fact, the three material selection methods indicated in EN 13445-2:2009 give the opportunity:

- ❖ after the “Charpy impact energy KV” criterion to make a table-aided selection of appropriate material (method 1 and method 2) based on the FM structural integrity concept;
- ❖ the FM analysis of structural integrity at limit conditions found to be directly used; analogous is the approach in the EN 13480 standard.

The EN 1993-1-10 Standard (Eurocode 3)

The prevention of brittle fracture in designing support steel structures according to Eurocode 3 also consists in the appropriate selection of material. At that, the selection consists in applying the FM concept of structural integrity envisaging the determination of the minimum operational temperature T_{Rd} , at which the loading can be taken, expressed through the transition temperature T_{27J} . The structural integrity assessment is considered verified if the following condition is fulfilled:

$$(1) \quad T_{ed} \geq T_{Rd},$$

where the impact temperature T_{ed} is determined as a sum of several temperature components accounting for the impact of factors reducing the material toughness, i.e. increasing the transition temperature T_{27J} .

Proceeding from the modified Sanz-correlation, the resistance of the structural part is determined in the form of the lowest temperature T_{Rd}

$$(2) \quad T_{Rd} = T_{100} = (T_{27J} - 18) + \Delta T_{27J},$$

where T_{100} is the temperature at which the “fracture toughness” (FM-parameter) assumes its minimum admissible value of 100 MPa.m^{1/2}, and ΔT_{27J} is a component accounting for the non-homogeneous toughness of the material, times its thickness.

Finally, the Eurocode 3 methodology allows from a table the maximum admissible thickness of the structural component to be determined, depending on: the steel grade and the steel sub grade, the maximum stress level σ_{ed} (as a percentage part of the yield strength f_y), the reference temperature T_{ed} and the temperatures T_{27J} , T_{30J} and T_{40J} , respectively (table 1).

It is evident that in the present applied standards the main formulations of FM have been included in ready user form, without revealing the individual details of the structural integrity concept. The latter, however, are necessary, especially when the use of *method 3* is imperative.

Table 1: Maximum Admissible Thickness of the Structural Component (mm) according to EN 1993-1-1

Steel grade	Sub-grade	Charpy energy CVN		Reference temperature T _{Ed} [°C]																				
		at T [°C]	J _{min}	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50
				σ _{Ed} = 0,75 f _y (t)							σ _{Ed} = 0,50 f _y (t)							σ _{Ed} = 0,25 f _y (t)						
S235	JR	20	27	60	50	40	35	30	25	20	90	75	65	55	45	40	35	135	115	100	85	75	65	60
	J0	0	27	90	75	60	50	40	35	30	125	105	90	75	65	55	45	175	155	135	115	100	85	75
	J2	-20	27	125	105	90	75	60	50	40	170	145	125	105	90	75	65	200	200	175	155	135	115	100
S275	JR	20	27	55	45	35	30	25	20	15	80	70	55	50	40	35	30	125	110	95	80	70	60	55
	J0	0	27	75	65	55	45	35	30	25	115	95	80	70	55	50	40	165	145	125	110	95	80	70
	J2	-20	27	110	95	75	65	55	45	35	155	130	115	95	80	70	55	200	190	165	145	125	110	95
	M,N	-20	40	135	110	95	75	65	55	45	180	155	130	115	95	80	70	200	200	190	165	145	125	110
	ML,NL	-50	27	185	160	135	110	95	75	65	200	200	180	155	130	115	95	230	200	200	200	190	165	145
S355	JR	20	27	40	35	25	20	15	10	10	65	55	45	40	30	25	25	110	95	80	70	60	55	45
	J0	0	27	60	50	40	35	25	20	15	95	80	65	55	45	40	30	150	130	110	95	80	70	60
	J2	-20	27	90	75	60	50	40	35	25	135	110	95	80	65	55	45	200	175	150	130	110	95	80
	K2,M,N	-20	40	110	90	75	60	50	40	35	155	135	110	95	80	65	55	200	200	175	150	130	110	95
	ML,NL	-50	27	155	130	110	90	75	60	50	200	180	155	135	110	95	80	210	200	200	200	175	150	130
S420	M,N	-20	40	95	80	65	55	45	35	30	140	120	100	85	70	60	50	200	185	160	140	120	100	85
	ML,NL	-50	27	135	115	95	80	65	55	45	190	165	140	120	100	85	70	200	200	200	185	160	140	120
S460	Q	-20	30	70	60	50	40	30	25	20	110	95	75	65	55	45	35	175	155	130	115	95	80	70
	M,N	-20	40	90	70	60	50	40	30	25	130	110	95	75	65	55	45	200	175	155	130	115	95	80
	QL	-40	30	105	90	70	60	50	40	30	155	130	110	95	75	65	55	200	200	175	155	130	115	95
	ML,NL	-50	27	125	105	90	70	60	50	40	180	155	130	110	95	75	65	200	200	200	175	155	130	115
	QL1	-60	30	150	125	105	90	70	60	50	200	180	155	130	110	95	75	215	200	200	200	175	155	130
S690	Q	0	40	40	30	25	20	15	10	10	65	55	45	35	30	20	20	120	100	85	75	60	50	45
	Q	-20	30	50	40	30	25	20	15	10	80	65	55	45	35	30	20	140	120	100	85	75	60	50
	QL	-20	40	60	50	40	30	25	20	15	95	80	65	55	45	35	30	165	140	120	100	85	75	60
	QL	-40	30	75	60	50	40	30	25	20	115	95	80	65	55	45	35	190	165	140	120	100	85	75
	QL1	-40	40	90	75	60	50	40	30	25	135	115	95	80	65	55	45	200	190	165	140	120	100	85
	QL1	-60	30	110	90	75	60	50	40	30	160	135	115	95	80	65	55	200	200	190	165	140	120	100

2.2 What Is the Essence of the Structural Integrity Against Brittle Fracture Concept of FM?

The essence of this concept is reduced to determining the quantitative connection between loading (static, dynamic/shock, or cyclical), the dimensions of a given crack and the material parameter defined as resistance against the introduction and development of the crack.

With the availability of such interconnection, it would be possible to determine the critical dimensions of a given flaw, the critical stress, respectively, leading to fracture, or the necessary toughness of the material guaranteeing non-fracture. Most generally, necessary are at least two of the three input values (flaw size, toughness, and stress) to determine the third value. As is familiar, the “non-fracture” condition is given by linear-elastic fracture mechanics (LFM), by means of the expressions:

$$(3) \quad K_{Ic} > K_I = \sigma \times Y(a, Geo) \times \sqrt{\pi \times a} \Leftrightarrow a_c \geq \frac{1}{Y^2(a_c, Geo)} \times \left(\frac{K_{Ic}}{\sigma} \right)^2$$

where K_I is the linear elastic stress intensity factor (in MPa.m^{1/2}); K_{Ic} - critical linear elastic stress intensity factor $\equiv$ fracture

toughness (material criterion); σ - loading stress (accounts for the rated stress condition); $Y(a, Geo)$ - geometric function (accounting for the configuration of the crack-shaped flaw and the geometry of the structural component); a - characteristic crack length; a_c - critical crack length determining the moment of its unstable spread.

According to FM, the assessment against fracture, as generally required in every strength assessment, is reduced to comparing the loading (S) and the material resistance (R_{mat}), where three cases are distinguished:

- $S - R_{mat} < 0$ admissible loading (**non-fracture, structural integrity**)
- $S - R_{mat} = 0$ limit case
- $S - R_{mat} > 0$ inadmissible (**failure, fracture**).

The material resistance R_{mat} is represented by the fracture toughness K_{Ic} , and the loading, S , by the intensity of the stress condition at the crack tip K_I , respectively. A large number of geometric functions $Y(a, Geo)$ have been developed for various shapes of structural components and cracks, that are relatively easily applicable in practice [15], [16]. The use of LFM, however, is quite limited, since very few metal materials behave linear-

elastically. An exception is made by the high strength spring steels, the high strength cast irons, and some dispersedly strengthened non-ferrous alloys. On the other hand, the development of geometrical functions for cases lying beyond the scope of LFM, i.e. in the non-linear fracture mechanics (NFM) realm, is very complex and time consuming.

Therefore, for the materials having elastic-plastic behavior, other criteria for defining the condition around the crack tip have been created. These are the so-called *J-integral* and *CTOD* (*Crack Tip Opening Displacement*). The *J-integral* (in Nm/m^2) is an energy based value determining the summary local plastic energy around the tip of the crack at certain intensity of the stresses. *CTOD* (δ) (in mm) is a physical criterion by which the opening of the crack at its tip is defined. The critical values of these two criteria, J_c and δ_c , respectively, serve as indicators of the elastic-plastic resistance for the material. Thus, for instance, for weld joints of high strength steel 10Г2CAФ (corresponds to 10MnSiVN8-4), values for δ_c from 0.10 to 0.17 mm have been obtained [8].

So that the available geometric functions of LFM can be used for the needs of NFM, correction functions are introduced. Meanwhile, this has lead to the development of the diagram most often used in engineering practice: the so-called *FAD* (*Failure-Assessment-Diagram*) also called “2-criterion procedure” or „R6-method”, created within the framework of a large European network project, “FITNET” [9] (Fig.1).

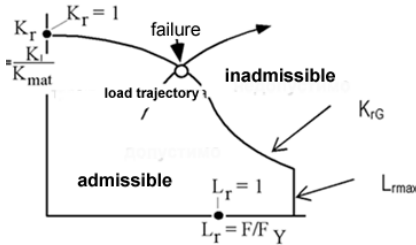


Fig.1 Schematic presentation of a FAD with a K_{rG} limit curve

In the diagram, a failure limit function (curve) is plotted, simultaneously controlled by the strength and toughness material behavior. A given product is assumed to be secure, if the resulting loading pair (L_r , K_r) is located under the limit curve $K_{rG}(L_r)$. On the X-axis (abscissa), the rated loading is plotted or the so called loading factor - the ratio of applied load to yield or proof load $L_r = F/F_Y$, where F is the actual load, and F_Y is the yield limit load. The loading factor on the Y-axis (ordinate) is in itself the ratio at the crack tip $K_r = K_I / K_{mat}$, where K_I is the linear elastic stress intensity factor at the crack tip, and K_{mat} is the fracture toughness of the material. In the “admissible” area, the available crack is not critical (it is safe), the selfsame grows stably under cyclical loading, respectively. The limit function $K_{rG}(L_r)$ is defined by the following equation:

$$(4) \quad K_{rG}(L_r) = (1 - 0.14L_r^2) \cdot (0.3 + 0.7 \cdot e^{-0.65L_r^2})$$

In conformity with the *FAD*, the assessment equation for the “non-fracture” case, reads:

$$(5) \quad K_{rG}(L_r) \geq K_I / K_{mat}$$

For L_{rmax} , an additional limit value is introduced depending on the material, by means of which the ductility displacements in the area of the crack are limited:

$$(6) \quad L_{rmax} \geq \sigma_{ref} / \sigma_Y = F / F_Y$$

where σ_{ref} is the reference stress in the crack plane that accounts for the cross section of the support part reduced by it; σ_Y is the current material yield strength in the area of the crack while in a number of cases it is assumed to be equal to $(R_e + R_m)/2$.

The thermal stresses and the stresses caused by the production technology are accounted for when calculating K_I . Provided that the

crack stability of the material K_{mat} is familiar, the “non-fracture” condition (3) and (5) may be presented in the following manner:

$$(7) \quad K_{rG}(L_r) \geq \frac{Y(a, Geo) \cdot \sigma \cdot \sqrt{a \cdot \pi}}{K_{mat}}$$

Since the material resistance K_{mat} of the weld joint depends, together with the other factors, also on the additive material and the linear welding energy, it is evident that with this methodology the opportunities for optimizing the conditions for security of welded products increase considerably. The most significant advantage of the *FAD* approach is that it allows the assessment of cracks beyond the action sphere of LFM. By means of the accurate and relatively easy for application analytical K-solutions of LFM (the conventional geometric functions) elastic-plastic materials can be analyzed too [15], [10]. For that purpose, the given K-solution undergoes additional correction for elastic-plastic behavior of the material which is reduced to increasing the intensity of stresses in front of the crack tip (for instance, for S235 steel it increases by about 15%). The physical sense of the correction is that the linear elastic stress intensity factor already depends not only on the magnitude of stresses but also on the energy spent for deforming the material in the vicinity of the crack tip. The *FAD* has been verified by practice and represents a comparatively easily applicable calculation methodology.

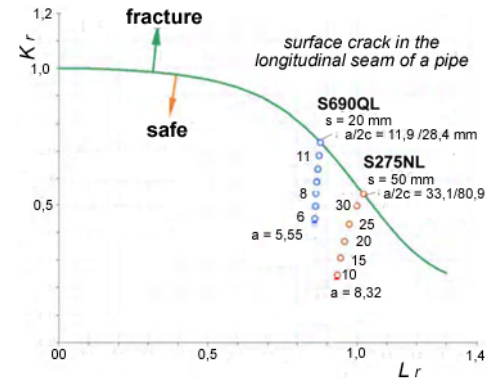


Fig.2 “FAD” with calculated values of the limit condition (the points lying on the K_{rG} curve) and of the safety condition (the points lying under the limit curve)

As an example, on fig. 2, through the *FAD*, the results of the calculations of the stress stability of two subjected to equal internal pressure pipes of S275NL and S690QL steels with thicknesses of 50 mm and 20 mm, respectively, and with availability of surface cracks in the longitudinal seam having various sizes (a : crack depth and $2c$: crack length), are indicated.

For the determination of K_{mat} , on principle the following opportunities exist: ① testing by means of the standardized experimental methods of FM; ② use of ready literature data; ③ application of the “Master-curve” procedure, while using the minimum values of the material mechanical parameters from the technical conditions of the procurement.

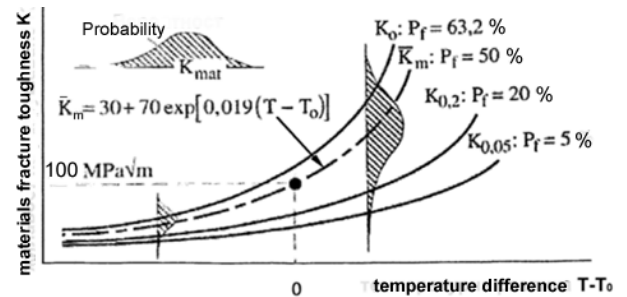


Fig.3 Probability plotting of the Master-curve as per Zerbst [18]

The “Master-curve” concept developed by Wallin [14] is a very strong tool for applying FM in evaluating the structural integrity of welded structures of ferrite steels with yield strength

between 275 and 825 MPa: carbon, non-alloy, and alloy steels with the typical structures of: bainite, tempered bainite, tempered martensite, and ferrite-perlite. It represents a statistical assessment procedure of the “fracture toughness – temperature” function which treats the fracture mode of the material: brittle and/or tough-brittle. The probability of brittle fracture is determined by the material value of “ T_0 reference temperature” (temperature at which the fracture toughness is equal to $100 \text{ MPa}\cdot\text{m}^{1/2}$), (Fig.3). This temperature may be determined by testing a relatively small number of FM samples for which a defined level of stable crack development is assumed.

The procedure for determining T_0 is standard and has been described in [9]. The probability failure P_f follows the tri-parametrical Weibull distribution, where K_0 is a scaling parameter corresponding to K_{Jc} at failure probability of $P_f = 63.2\%$, and K_{Jc} is the critical fracture toughness determined for the case of planar deformation condition, by means of the J -integral. The temperature dependency of the *Master-curve* is assigned by the median value of the fracture toughness $K_{Jc,med} \equiv \bar{K}_m$, corresponding to $P_f = 50\%$ failure probability:

$$(8) \quad K_{Jc,med} = 30 + 70 \cdot \exp[0.019 \cdot (T - T_0)]$$

From here, the relationship follows for determining the reference temperature T_0 :

$$(9) \quad T_0 \text{ (or } T_{100}) = T - \left(\frac{1}{0.019} \right) \cdot \ln \left[\frac{K_{Jc,med} - 30}{70} \right]$$

Where T_0 (in $^{\circ}\text{C}$) refers to the median value of the fracture toughness of $100 \text{ MPa}\cdot\text{m}^{1/2}$; T - the testing temperature.

Since the probability of fracture occurrence depends to a considerable degree on the thickness of the samples used in testing, then the obtained values of the fracture toughness from differing in thickness samples $K_{Jc(B)}$ must be standardized in relation to a reference sample having a thickness of $B_0 = 25,4 \text{ mm}$. In this manner, in the analysis it is possible to include also samples with thicknesses smaller than the natural size of the structural part.

$$(10) \quad K_{Jc(B_0)} = K_{min} + (K_{Jc(B)} - K_{min}) \cdot [B/B_0]^{1/4}$$

On Fig.4, an exemplary *Master-curve* has been shown, for the S355, S460, S690 and S890 steels, obtained by Langenberg [14]. It is evident that with the increase of temperature, i.e. by moving away from the lower plateau (the brittle condition of the metal) the dispersion of results for K_{Jc} increases.

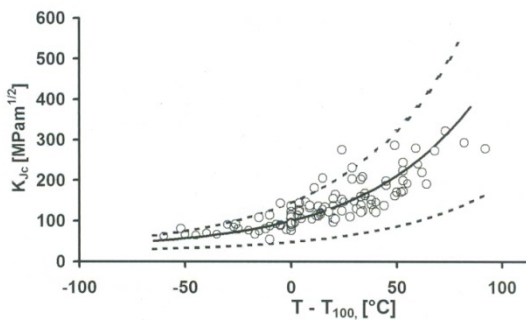


Fig.4 “Master-curve” [14]

The obtained results for K_{mat} with the aid of the *Master-curve* concept are used directly for assessment of the structural integrity after the two-criterion method of “FAD”. In a number of cases, however, no FM data are available for steels but only the Charpy impact energy (KV) at impact loading as per Charpy-V. The Charpy-V test has been developed more than 100 years ago and is the engineering testing method with the most experience accumulated. Unfortunately, its results are more of a qualitative, and not quantitative nature, since the registered Charpy impact energy is of an integral nature. This means that in Charpy-V testing the phases of initiation, development, and stoppage of the crack are distinguished. Its characteristic criteria are the transition

temperature, for instance T_{27J} , T_{41J} or the toughness in the lower plateau.

These considerations are at the base of the further development of the “*Master-curve*” concept looking for a correlation between the criteria of transitional behavior of steels established through FM ($T_{100\text{MPa}}$) and through the conventional method of testing, Charpy-V (T_{27} , T_{41} , resp.):

$$(11) \quad T_{100\text{MPa}} = T_{27J} - 18^{\circ}\text{C}$$

$$(12) \quad T_{100\text{MPa}} = T_{41J} - 24^{\circ}\text{C}$$

With the help of this correlation, it is possible the transition temperature found by the Charpy-V samples to be transformed into the analogical criterion $T_{100\text{MPa}}$ of FM. Thus the results of testing the impact toughness as per Charpy-V may be applied in the assessment of the structural integrity of the weld joints against brittle fracture by means of the “*Master-curve*” and the “FAD”. In its essence, this concept has been set in the formulations for security against brittle fracture of the standards Eurocode 3, EN 13345 and EN 13480.

On Fig.5, an example has been given for graphically expressed correlation for steels and their weld joints from Fig.4.

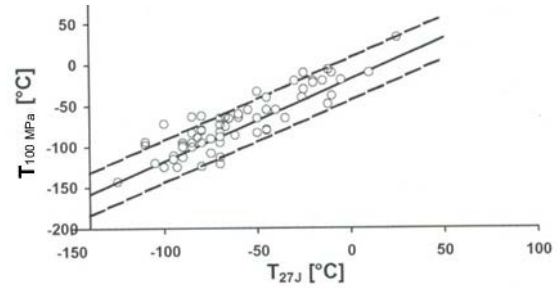


Fig.5 Correlation $T_{100\text{MPa}}-T_{27J}$ as per Langenberg for S355, S460, S690, S890 steels [14]

Essential is also the role of FM for forecasting the life span (the safety resource) with cyclical loading of the weld joints in the cases when at a given moment t_0 a crack with a_0 (5 mm) size has been found, and which is growing stably (Fig.6).

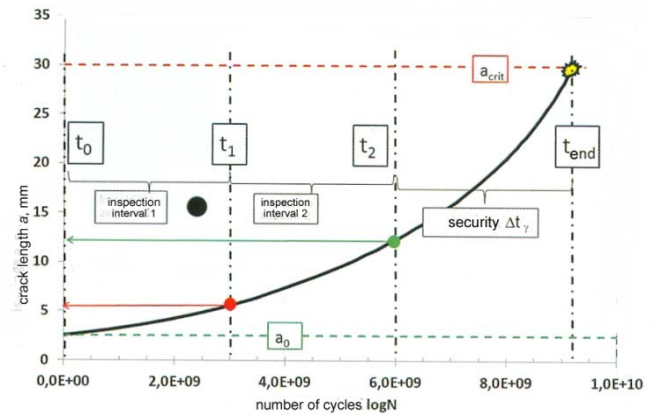


Fig.6 Curve of stable growth of the crack with plotted inspection intervals for maintaining the safety resource

After calculating the critical length of the crack a_{crit} (30 mm), it is possible to determine also the residual resource of time for safe operation t_{end} i.e. the remaining number of loading cycles N until reaching the critical size of the crack a_c . According to the law of Paris, these are determined [15] by the formula:

$$(13) \quad N = \frac{1}{c(\Delta\sigma)^2 \pi Y(a, Geo)} \ln \frac{a_{crit}}{a_0}$$

where $\Delta\sigma$ is the characteristic value of stress range with cyclical loading; c - a constant (for instance $6,04 \cdot 10^{-14}$).

It is expedient, the time resource t_{end} to be subdivided into inspection intervals for maintaining security, for instance t_1 and t_2 , while being based on the presumption that if, after the expiry of the first interval, it has not been possible, for one reason or another, to establish the change in the length of the crack, then after the expiry of the second interval too still the critical length of the crack will not have been reached [14]. In this manner, an interval Δt_i is reserved in advance, within which all permitted inaccuracies and unforeseen circumstances may be covered, both regarding the registration and monitoring of the crack, as well as of the analytical assessments (calculations).

3. Conclusion

The FM postulates may on principle be applied in the following fields of welding:

- selection, optimization, and creation of main and additive materials;
- strength assessment (designing) of structures with the assumption of crack availability. The admissible stress in this case is determined by means of the *fracture toughness*;
- additional dimensioning of already designed and fabricated welded products with registered crack-shaped flaws. In this case, the *critical magnitude of the flaw* is determined;
- analysis of occurred failures of welded structures and the ensuing prevention measures for avoiding future failures.

Currently, in world practice, the “FAD” concept has won recognition, designated for elastic-plastic materials, for instance the structural weldable steels. It is being served by the so-called “Master-curve” by which the necessary FM-parameters of the material are determined. Besides these, also the conventional parameter of material toughness - “Charpy impact energy KV”, determined by the *Charpy-V* test, confirmed in practice since many years, may be used.

For the successful application in engineering practice of the FM methodological apparatus that has been envisaged in the present applied European standards (Eurocode 3, EN 13445, EN 13480, etc.) it would be appropriate to broaden the specialized training on fracture mechanics (for instance within the Master’s degree level) in the technical universities in our country, in first place for the civil and mechanical engineering specialties.

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OPTIMISING TECHNOLOGY FOR PRODUCTION OF HIGH FREQUENCY WELDED PIPES MADE OF X60 STEEL

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ABSTRACT: In this research work the Welding technology that implements high frequency contact welding process (HFCW), is presented as a method for automatic steel pipes production. The pipes produced by the HFCW are meant to be used for natural gas transportation. X60M steel coils with thickness of 6.5 mm are used as a raw material. The outer pipe diameter is $\varnothing 508$ and the length is 12000 mm. The preliminary welding procedure is based on the personal experience, technical knowledge and the expert judgment. A special attention has been paid to the most important welding parameters such as: current frequency, voltage and welding speed. After the welding was finished, an additional heat treatment (normalization) of the welded pipes (joints) was performed at the temperature of 900°C.

In order to justify the proposed welding technology a complex analysis is applied. The first analysis was the chemical analysis of base metal. The next was the nondestructive testing consisted of a visual inspection, and ultrasound testing of the pipes. The destructive testing was consisted of tensile testing, bend testing and the hardness measurement. Besides the analysis of the micro and macro structure of the welded joints, a metallographic analysis is performed as well. Moreover a hydrostatic test and a flattening test were performed as an integral part of the entire testing process. The test results confirmed that the pipes produced with the predicted welding parameters completely fulfilled standard requirements. The manufacturing process for the pipes for natural gas transportation is ready to begin.

KEYWORDS: HIGH FREQUENCY, WELDING, CONTACTORS, X60 STEEL, PIPES, MICROSTRUCTURE

1. Introduction

Over the past few decades' severe demand were placed to the pipes manufacturer with respect to the development and processing of the material for the pipelines. Generally longitudinally welded steel pipes are used for gas and oil transportation because of the high safety and as an economical method of manufacturing. Because of the conditions where the pipes are used such as high ground pressure, they must possess high strength and toughness [1].

More than eight millions tons of steel pipe are produced in the world every year. Most of them are produced from standard steel grades. The bigger challenge for the pipe producers is the manufacturing the pipes from X60, X70 and X80 which on the other hand requires special efforts and measures [2,3].

High frequency tube welding is one of the most forgiving industrial processes nowadays, and it is possible to produce acceptable tubing for most purposes. High frequency welding is a form of electrical resistance welding (ERW). A voltage is applied (HF contact) or induced (HF induction) across the edges of the open tube just prior to the point of closure. This voltage causes a current to flow along the edges to the point where they meet, causing rapid heating of the metal. Pressure is applied by the weld rolls, which forces the heated metal into contact, forming a hot diffusion bond. The pressure also forces the molten metal and any impurities out of the weldment [4]. The only real difference between high frequency contact and induction welding is that with contact welding, the voltage is applied directly to the strip edges by means of sliding contacts, whereas in the case of induction welding, the voltage is induced by the magnetic flux surrounding the coil. The reason for using a higher frequency is that in the case of induction welding, it is desirable to keep the size of the coil reasonably small. The higher the frequency, the less flux is required. The higher frequencies also affect the behavior of the current that flows in the "vee". As the frequency is increased, the current tends to concentrate closer and closer to the edges of the strip. This is partly due to the "skin effect" which causes the current to flow on the surface of conductors at high frequency, and partly due to the "proximity effect" which causes the current on the adjacent conductors to concentrate at the adjacent surfaces. Both of these effects are caused by distortion or interaction between the magnetic fields associated with the current flow [5,6]. Frequencies used for tube welding are in the range between roughly 100 kHz to 800 kHz, with lower frequencies being used for large, heavy wall tube, and the upper range being used for small, thin walled products, especially those using nonferrous material. The current that flows along the edges of the strip to the apex of the "vee" heats the strip to the welding temperature. The current will also tend to flow around the inside circumference of the open tube. This heats the entire tube, and does not contribute to the

welding process. Thermo-mechanical control process (TMCP) is one of microstructural control techniques, combining controlled rolling and controlled cooling, to obtain excellent properties of the steel plates, such as high strength, excellent toughness and weld ability [7]. The controlled rolling and the controlled cooling are to satisfy the high strength and high toughness requirements, which could only be achieved conventionally by off-line heat treatment. Located close to the mill, the practical operation type also gives an opportunity for higher productivity and shorter production time that are always demanded in industrial products [8].

The large-diameter steel pipes are produced by high frequency seam-welding followed by induction-assisted heat treatment. The pipes for oil and the gas transmission are made from low-alloy steels designated X60, X65, X70 etc. depending on the strength and toughness required and the intended application. One of the methods of fabricating pipes from these materials is by high-frequency contact seam-welding [9-11].

The toughness of the line pipes is paramount in their suitability for application. The joint resulting from the contact welding is quite narrow, with a central 2 mm wide region, but it also represents a source of weakness. That is why the welding process is immediately followed by induction heat treatment. The intention of the latter is to refine the microstructure by reutilization at a lower temperature [12].

One of the TMCR are the alform series i.e. thermo mechanically rolled, weld-able and bendable fine grain structural steels. The plates made of these steels combine the good toughness properties of the thermo-mechanically rolled fine-grain steels according to EN 10025-4 with the excellent cold forming properties of the cold forming steels according to EN 10149-2. The alloying concept provides very low carbon contents and low carbon equivalents, which aims to a very good weld-ability. In particular, the high-strength grades provide special advantages in areas, where weight the savings are of a great importance. Although the heat-treatment improves the toughness of the welded region, the increase is not as large as might be expected from the reduction in the scale of the microstructure [13].

Therefore the basic idea of this research work is to verify the proposed welding technology (using HFCW process) for production of the steel pipes (for natural gas transportation) made of micro alloyed steel X60M.

2. Material and experimental

Raw material

The raw material used (steel coils) for the pipes production was micro alloyed steel with designation X60M PSL2. The designation of steel is according to API 5, 45th Edition/ISO3183. Explanation of

the designation is the following: X means steel for pipe production according API. Digits 60 ksi concern to yield strength of the steel i.e. to 420 MPa. M means that steel is produced by thermo mechanical rolling process. PSL refers to the product specification level where PSL2 provides a more extensive chemical composition complete with a mandatory minimum. The chemical composition and mechanical properties of the raw material are given in the tables 1-3.

Table 1 Chemical composition of the raw material measured and according API standard requirement

El.%	Measured	Standard
C	0.074	0.12
Si	0.184	0.45
Mn	1.17	0.16
P	0.012	0.025
S	0.004	0.015
Cu	0.0233	
Cr	0.024	
N	0.007	
V	0.0403	
Nb	0.0357	
Ti	0.0111	

Table 2 Mechanical properties of the raw material and weldment

Tensile test			
	Rp0.2	Rm	A%
BM	527	588	32.7
WM	530	584	-

Table 3 Impact toughness of raw material weld metal and HAZ

Charpy V-notch, 0°C				
	1	2	3	Av
BM	210	208	207	205
WM	190	180	165	179
HAZ	203	200	185	196

Table 4 Typical parameters used for welding of HFRW

Welding parameters	Values
Welding speed (m/min)	22
Voltage (kV)	14,3
Current intensity (A)	23-24
Current	400
Frequency Hz	
Generator power kW	600
Voltage index	57-58

The raw material used for the steel pipe production was in a form of coils. The coils had to be exact width-ness in order to allow the proposed diameter of $\phi 508 \times 6.5$ to be achieved. The coils are delivered to the starting point of the technological line (Figure 3a) from the store. (Figure 1). Then the coils are moved (Figure 2a) to the technological production line by cranes. The round shape of the pipe is achieved with the rolling mill technology where the rolled strips are formed into a circular cross section by funnel arrangements of rolls. The size of the rolls is chosen as per the diameter of the pipe and the thickness of the material. (Figure 2b) The pipes are then welded implementing the electro resistance contact welding process. (Figure 2c.) The beginning of the pipe welding process and the V-wedging are given in (Figure 3b). The parameters of the welding wedge play a very important role in terms of the quality of the welded joint. The softened and melted edges of the pipes are connected by the pressure of the squeezing rolls (Figure 3). The excesses material and impurities are squeezed

out on the inner and the outer pipe surface. (Figure 4). The removal of the material (slag) is performed with special knives located on the inner and outer side of the pipe. After the excess material is taken off, the welded pipes are cut in the length of 12 meters. A circular mechanical saw is used for cutting the pipes. (Presented in Figure 2d).

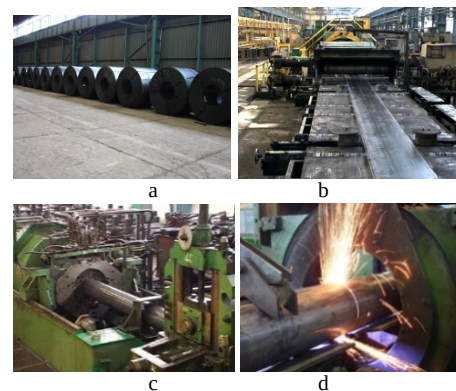


Figure 1(a-d) Production of steel pipe from the raw material API X60 steel
a. Store for raw material b. involving raw material in the production line c. welded pipe d. cutting of the pipe

As is shown in the figure 5, the welded pipes are then additionally exposed to a heat treatment (normalization) in order to improve the properties of the welded joints (relaxation of stress, microstructure....). Normalization is performed at the temperature of 900 °C by 6 inductors. The width of normalized layer is about 20 mm.

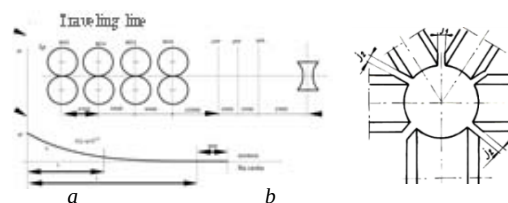


Figure 2 a Technological line for contact welded pipes production b. final forming of pipe before welding b. formed pipe before HFCW

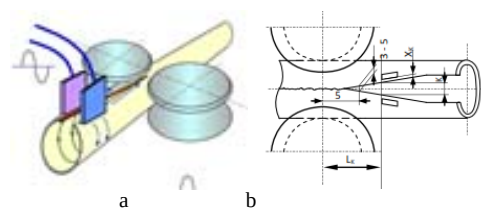


Figure 3 Electro resistance contact welding of pipes a. Contactors b. Welding start point and V-wedge

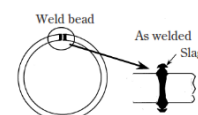


Figure 4 Pipe with excess material (slag)

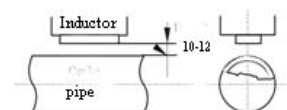


Figure 5 Induction heating of weld with 6 inductors

Evaluation of the preliminary welded pipes

Many complex testing and evaluations were performed in order to confirm quality of the welded joints. A welded pipe was subject to

hydrostatic testing under the pressure of 10 bar for period of 10s. There was no leakage after the testing. For the flattening test, two segments of 200 mm were cut and tested under pressure. Position of the welds during the testing is shown at (Figure 6). Applying the pressure to the segment last until the opposite sides of the pipe touch each other. No defect like cracks were detected during testing.

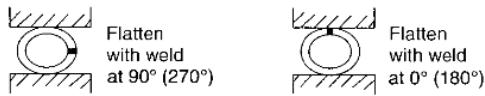


Figure 6 Flattening test of pipe segments

A visual inspection was performed as well in order to detect surface defects or the geometrical misalignment of the pipes edges. The testing was performed as per the BS EN ISO 17637:2011, and no any defect were detected.

From the tested pipe specimens were cut for mechanical testing. Transferral tensile testing of the welds was performed according the EN ISO 4136. Another three specimens were prepared for the perpendicular tensile testing of the welded joint. The result are given in (Table 2). During the all tests the breakage of specimens was out of the welded joint. The obtained testing values are almost identical with the base metal properties.

The bend testing was performed according to the EN ISO 5173:2010+A1:2011 standards. The results of testing are given in the (Table 5). As a result the all tested probes fulfilled regulation requirement.

Table 5 Results of bend testing of welded joint

Nr.	Type of test	Dimension of specimen	Bending angle	Results
1	TFB	6.5x30	180 ⁰	good
2	TFB	6.5x30	180 ⁰	good
3	TFB	6.5x30	180 ⁰	good
4	TRB	6.5x30	180 ⁰	good
5	TRB	6.5x30	180 ⁰	good
6	TRB	6.5x30	180 ⁰	good
7	LRB	6.5x30	180 ⁰	good
8	LFB	6.5x30	180 ⁰	good
9	SB	6.5x6.5	180 ⁰	good
10	SB	6.5x6.5	180 ⁰	good

Meaning of the abbreviations is the following:

TFB – transferral face bend, TRB – transferral root bend, LFB – longitudinal face bend, LRB – longitudinal root bend, SB – side bend.

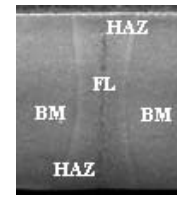
The impact toughness testing was performed according to the EN ISO 9016:2012 and EN ISO 148-1:2010. Besides the base metal, the weld metal and HAZ were tested too. The results from testing are given in the (Table 3). Impact testing was performed at temperature of 0°C. It has to be point out that approximation of obtained results was performed. The reason is that nonstandard Charpy specimen were used because the thickness of the pipe was 6.5 mm, which is nonstandard. The charpy specimens has to be with thickness of 10 mm.

Macrostructure of HF welded joint is presented in the (Figure 7). On the same specimen was performed hardness testing according to the EN ISO 9015-1. The hardness testing was performed across the line parallel with the welded surface. Vickers method (HV10) for hardness measurement was implemented. The highest hardness was noticed in the weld metal and the lowest in the base metal. As per our expectations, the normalization lower the hardness of the welded joint.

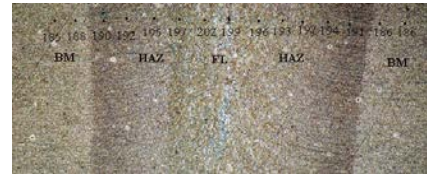
From the macro photo can be clearly seen characteristic area in the welded joint. In the middle of the joint is the fusion line after that is HAZ and the base metal which does not suffer from welding heat input. No allowed welding defects are detected. It can be seen that

the flux i.e excess material is formed during the welding. As can be seen from the macro photo squeezed metal is cut (removed).

Typical welding defects which can be formed during HF electric welding like cold laps, entrapped inclusions, cold weld, open weld, cross weld, cracks in the weld porosity cracks in the welding zone.



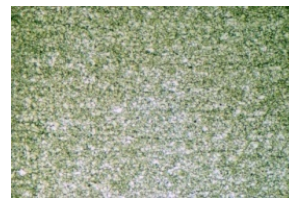
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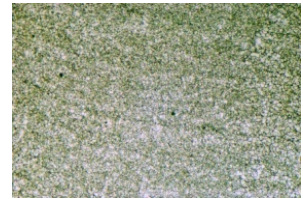
b

Figure 7(a and b) Macro photos of welded joints

Microstructure of the base metal is presented in the figure a. It is fine grain ferritic-bainitic. The fine grain HAZ zone can be seen in the (Figure 8b). Both microstructures are very similar. Deformation of the microstructure as result of the pressure of the forming rolls can be noticed in (Figure 8b). The fusion line co- called ferritic line is given in the (Figure c), where can be seen that the microstructure is coarser. As a dominant microconstituent in this area is block ferrite.



a



b



c

Figure 8 (a-c) Microstructure of the welded joint

3. Discussion

The experimental welding was performed as per the previously set parameters, based on the technical knowledge and the experience from the similar application. After finishing the experimental welding, an additional heat treatment (normalization) is performed on the welds of about 20 mm wide.

A variety of measures are taken to ensure that the finished steel pipe meets specifications. In order to check the properties of the pipes very complex mechanical, chemical microstructural and technological testing and evaluation were performed. (Mainly according the API 5L standard). The quality of the raw material was checked before the welding starts and was done exactly as the regulation required. The visual inspection showed that there were no geometrical defects of the pipe or of surface welded area. The automatic ultrasonic testing was done directly in the production line, and didn't detect any volumetric welding defects. The hydrostatic test of the pipe at the pressure of 10 bar/10s didn't show leakage in the weld or any visible cracks. The flattening test of the pipe segment, 200 mm wide didn't reveal any defects in the welded joint as well. The hardness test showed that the max hardness is in the WM, slightly better hardness was measured in the HAZ and

normally base material showed the lowest values. On the contrary the measured impact toughness values were quite opposite so the best values has the BM than the HAZ and the lowest value has the fusion line. However all the values are much higher than the current standards require. The tensile testing showed that the results are similar to those of the raw material, no matter the breakage of the probe was always in the base metal.

4. Conclusion

This report shows that the welding technology implementing high frequency contact welding process (HFCW), is a suitable method for automatic steel pipes production. During the research process a special attention was given to the key parameters which affect the quality of the final product. Numerous tests and valuation of the results was conducted in order to define the key parameters and their values.

The results showed that X60M pipes manufactured with high frequency contact welding process (HFCW) meet the requirements of the API 5L standards. Therefore the manufacturing of the pipes is ready to begin.

5. Literature

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COLD DRAWING OF PURE MAGNESIUM WIRE

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Abstract:

Pure magnesium is a material with very high functionality, however, the cold drawing of this material is very difficult, because it has a hexagonal crystal structure and until this day there is no optimal cold wire drawing conditions. In this research, the goal is to create the optimal cold drawing conditions for pure magnesium wires. The first step is the investigation of the annealing temperatures by using tensile testing of the annealed wires, which will allow is to optimize the manufacturing of magnesium. Following the results listed below, the most suitable annealing temperature was 250°C for a reduction of 10% per pass. After the reaching the drawing limit and examining the drawn wires, cracks in the center of the wires, that is why suppressing their occurrence by applying a middle annealing to the process is needed. Consequently, it is possible to produce a cold fine drawn pure magnesium wire, without cracks or defects on the surface or hindering its medical properties.

Keywords: PURE MAGNESIUM, COLD WIRE DRAWING, ANNERLING, DIAMOND DIE

1. Introduction

Magnesium is a very light high functionality material that has high vibration absorbency, heat dissipation, electromagnetic wave-shielding and recycling efficiency. However proper cold wire drawing conditions haven't been establish, that is why warm or hot processing is commonly used. As a result, strength improvement of the wires is not possible, that is why the production of medical tools is disregarded. If it were possible to cold draw magnesium wires, the applications for material products would expand.

In this research, an investigation regarding the optimal cold drawing conditions of pure magnesium wire, the changes in the mechanical properties of the material after drawing and the problems that might occur during processing is conducted, the aim of which is to produce pure magnesium wire.

2. Preconditions and means for resolving the problem

2. 1. Tested wire and annealing conditions

Table1 shows the sample material and the annealing condition.

Table1 Tested material and annealing condition

Tested material	Pure magnesium
Diameter [mm]	2.58
Annealing conditions	300°C , 250°C , 200°C keep 1 hour

2. 2. Wire drawing process

In this research, the used material is pure magnesium wire with a diameter of 2.58mm. It was subjected to wire drawing with a reduction per pass (R/P) of 10%, 15% and 20%. The wire drawing process is explained in Fig. 1 and equations (1), (2). The drawing speed used was 300 mm/min, the drawing dies were tungsten carbide dies and diamond dies with a half-angle of 6 degree and for the wire drawing process teflon resin lubricant AGP8H and Na-soap powder were used.

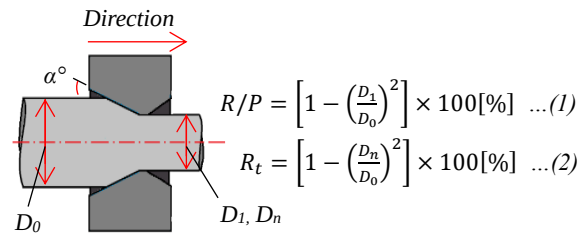


Fig.1 Definition of pass reduction and total reduction in wire drawing

3. Solution of the examined problem

In order, the present goal to be achieved, narrowing down the optimum drawing conditions for drawing of pure magnesium wires was needed. The low formability of pure magnesium prevents it from having a high drawing limit, following this, the improvement of the drawing limit can be achieved with proper annealing of the wires before and during the wire drawing processing, for that purpose the annealing conditions that were examined were 200°C, 250°C and

300 °C. The second thing that needed optimization was the reduction per pass, the following R/P were suggested for this experiment 10%, 15% and 20%. Finally, the last thing that needed confirmation was the material of the drawing dies, in this case the tested dies were tungsten carbide die and poly-crystal diamond die.

After comparing the different wire drawing conditions, an optimum drawing method was chosen and used in order to fabricate wires for medical tests.

4. Results and discussion

4. 1. Tensile test of the annealed pure magnesium wires

Firstly, tensile test was performed on the drawn pure magnesium wires, in order to investigate their mechanical properties, following this a Stress-Strain curve was build using the results. The Stress-Strain curves can be seen in Fig. 2.

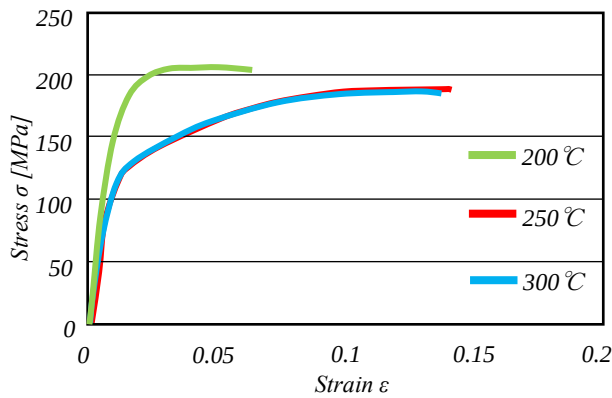


Fig.2 Stress-Strain curve of magnesium wire in tensile test

The highest tensile strength exhibited by the drawn wires was of 208.2MPa for the annealed wire at 200°C, compared to the 250°C with 187.6Mpa and 300°C with 186.8Mpa, but the elongation at fracture for that wire was only 3.87%, which is almost three times smaller than 11.5%(250°C) and 11.2%(300°C).

In the drawing processing, high ductility materials are more suitable for drawing than more brittle materials, following the results shown in Fig. 2, the most suitable annealing temperature for the drawing of pure magnesium wires is 250°C, based on the high elongation in tensile test.

In the SEM (Scanning Electron Microscope) image of the break side of the annealed wire, it can be seen that the 200°C and 300°C has a relatively brittle surface, compared to the 250°C wire, which has dimple fracture surface. It can be concluded that by using the 250°C annealing temperature, a high ductility material can be achieved.

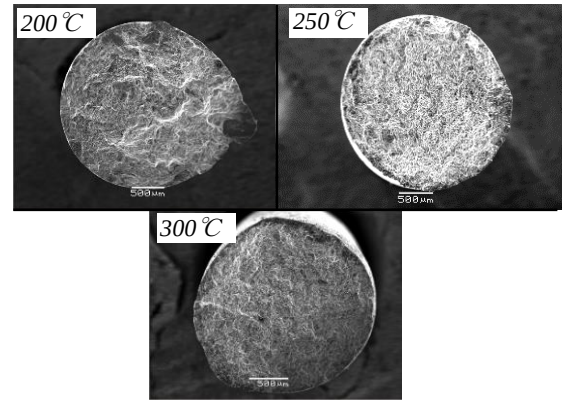


Fig.3 SEM image of magnesium wire surface after tensile test

4. 2. Changes of the drawing limit a wire with different annealing temperatures

In order to investigate the drawing limit of the pure magnesium, each of the annealed wires were used with the three different R/P and were drawn using tungsten carbide dies. The results are shown in Fig. 4.

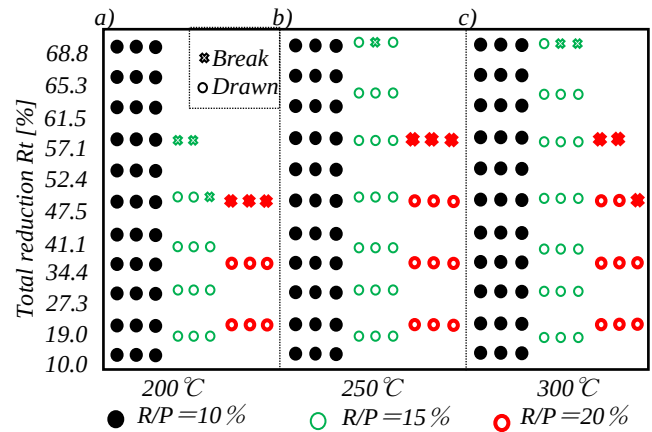


Fig.4 Drawing limits of magnesium wire

After drawing of all annealed wires, the wires that used 10% R/P were able to be drawn up to the goal of Rt=68.8%. For the 20% R/P the 200°C, 250°C and 300°C were drawn up to Rt=47.5% for 200°C and Rt=57.1% for 250°C and 300°C, but in the case of 300°C there was a breaking that occurred at the 47.5%, as the 250°C were successfully drawn until 57.1%. Finally for R/P of 15%, only the annealed wire at 200°C broke at Rt=56.1%, as the 250°C and 300°C were able to be drawn up to the drawing limit of Rt=68.8%, but in the 300°C's case two breaks occurred at the finishing diameter, but 250°C's case only one of the samples broke.

4. 3. Internal defect which is occurred in drawn wire

After drawing the pure magnesium wires while using the optimum drawing conditions that were chosen after the previous experiments – annealing temperature of 250°C, R/P=10%, , it was discovered that internal defect in the center of the wire occurred, as seen in Fig. 5.

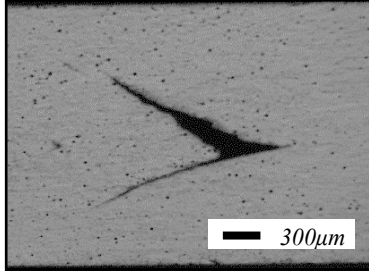


Fig.5 Internal defect in drawn wire

($\alpha = 6^\circ$, $R/P=10\%$, $R_t=68.8\%$)

Due to the occurrence of internal defect, cupping in the wire, it becomes unfit to be used as a production material.

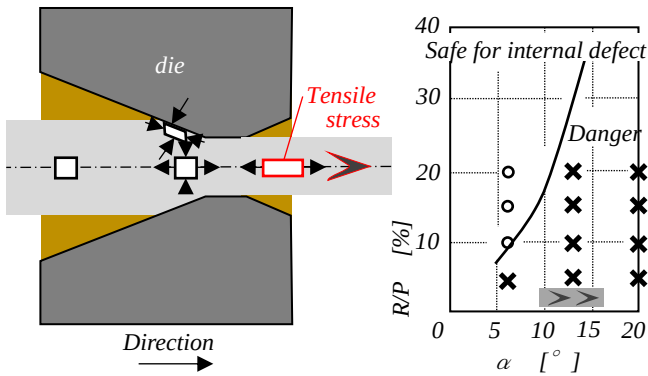


Fig.6 Occurrence of cupping in the wire¹⁾

In Fig. 6 it is shown that the cause of inner cracks is due to the tensile stress in the center part of the wire. It is possible to suppress its occurrence by lowering the half-width of the die or by increasing the reduction per pass, because by the reduction of the friction force is necessary. Based on the graph in this Fig. 6, it was determined that any higher angle than 6° was unsuitable, also to further decrease friction diamond dies were suggested for this experiment.

4. 4. Drawing process using a diamond dies

Table 2 Difference in drawing stress between tungsten carbide dies and diamond dies

pass	Tungsten carbide dies [MPa]	Diamond dies [MPa]	Difference [%]
1	55	48	12.7
3	66	62	6.1
5	70	67	4.3

In Table 2, the drawing stress using tungsten carbide and diamond dies, for reduction of 10% can be seen, the diamond dies had a lower drawing stress of about 7-8%. After drawing the pure magnesium wires annealed at 200°C , 250°C and 300°C while using R/P of 10%,

reaching the drawing limit of $R_t=68.8\%$ was possible for all wires, that is why in order to compare the increase of drawing limit and decrease of drawing stress by using diamond dies, the R/P used was 20% to establish the effectiveness of using diamond dies. In this case, the results can be seen in Fig. 7.

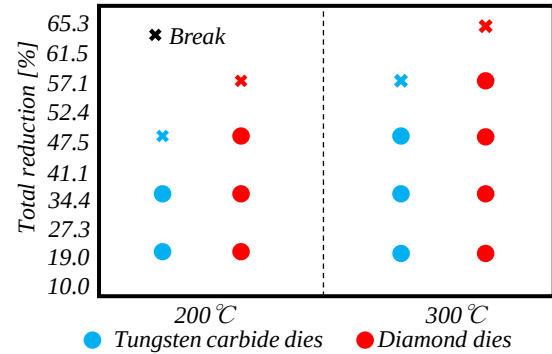


Fig.7 Drawing limits of magnesium by using a diamond dies

($\alpha = 6^\circ$, $R/P=20\%$)

Furthermore, after drawing the wire to $R_t=68.8\%$ with a $R/P=10\%$ and annealing temperature of 300°C , the finishing wires were examined by using SEM, in order to observe the difference between the drawn wires' surfaces between the tungsten carbide and diamond dies. The results can be seen in Fig. 8.

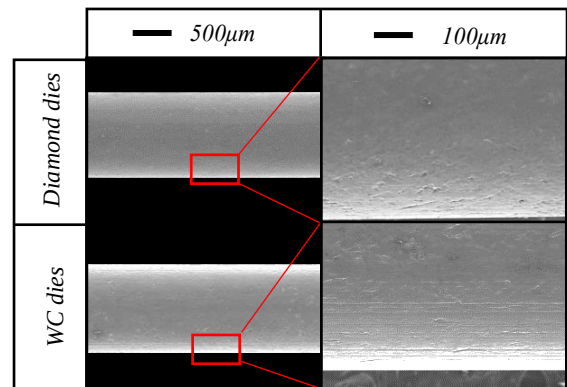


Fig.8 SEM image of drawn wire surface with the WC dies and diamond dies ($\alpha = 6^\circ$, $R/P=10\%$, $R_t=68.8\%$)

There are many defects on the surface of the tungsten carbide die drawn wire, such as surface flaw and die marks, after reaching the drawing goal, but in the case of the diamond die, after drawing it exhibits much finer surface compared to the tungsten carbide die and a lack of die marks.

Following this, it can be concluded that the diamond dies present much better effectiveness for drawing of pure magnesium wires, with higher drawing limit, lower drawing stress and a finer surface of the finishing drawn wire, but even after the application of diamond dies, the occurrence of cupping still persisted, which led to the introduction

of an intermediate annealing for further increasing the workability of the material.

4. 5. Effect of the intermediate annealing

The drawing of pure magnesium wires with two intermediate annealing points ($R_t=34.4\%$ and $R_t=57.1\%$) and a single intermediate annealing point ($R_t=34.4\%$; $R_t=41.1\%$; $R_t=47.5\%$), were examined for a total reduction of $R_t=68.8\%$ and the changes of mechanical properties were summarized in the stress-strain diagram of Fig. 9.

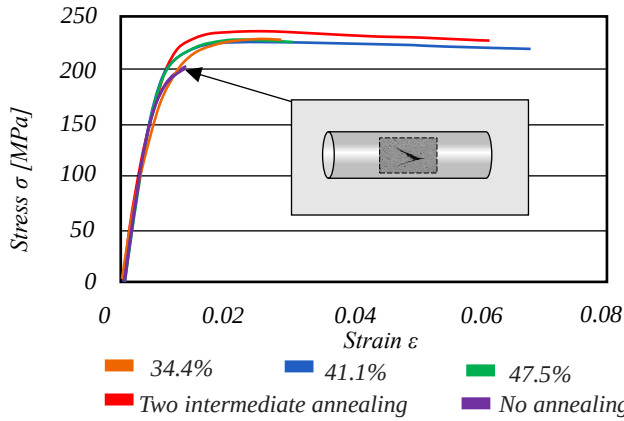


Fig.9 Stress-Strain curve of intermediate annealed wire ($R_t=68.8\%$)

In the case of single annealing with $R_t=41.1\%$, the elongation at fracture was about 0.067 and total tensile strength was around 230Mpa. The case of the two intermediate annealing the tensile strength was higher by comparison with 237Mpa, but the elongation at fracture was 0.06, which is lower than the single annealed wire at $R_t=41.1\%$. Also in the case of all other annealed wires, the tensile strength of the drawn finishing wire was close to the previously mentioned wires, but the elongation at fracture was much lower. Following these results, the annealing most suitable for this wire drawing, is the single annealing at $R_t=41.1\%$

In addition, it the inner section of the drawn wires were checked to confirm the presence of defects in the center of the drawn wires. In Fig. 10, the comparison between intermediate annealing of $R_t=41.1\%$ and $R_t=47.5\%$.

After observing the wire drawn with an intermediate annealing with $R_t=47.5\%$, it was determined that just like the case of Fig. 5, it exhibits cupping in the center of the wire, rendering it unsuitable for production of medical tool. In the case of the $R_t=41.1\%$, after closely examining the center of the drawn wire along its length, no trace of cupping was spotted. Based on this, it was concluded that by using intermediate annealing of $R_t=41.1\%$ for cold drawing of pure magnesium with a total reduction of $R_t=68.8\%$, the occurrence of

cupping can be prevented, leading to a more suitable material for the needed purposes.

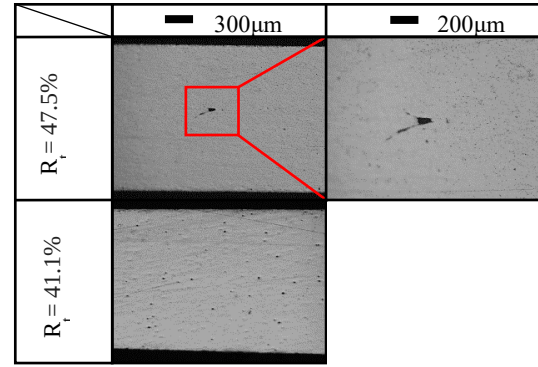


Fig.10 The internal defect that occurred to the annealed drawn wire ($R_t=68.8\%$)

5. Conclusion

For the wire drawing of pure magnesium, the most suitable annealing temperature was decided at 250 ° C, and very effective means is using a diamond die, also by using a diamond die, a reduction per pass of 10% and by performing an intermediate annealing at a cross-section reduction rate of 40%, it was possible to achieve a diameter of 1.44, without the occurrence of inner cracks in the center of the wire, which is suitable for the production of medical tools.

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VIBRATION POWER GENERATION WITH PIEZOELECTRIC ELEMENT USING COUPLING WITH CYLINDRICAL SOUND FIELD ENCLOSED BY END PLATES HAVING DIFFERENT THICKNESS

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Abstract: This paper describes the electricity generation characteristics of a new energy-harvesting system with piezoelectric elements. The proposed system is composed of a rigid cylinder and thin plates at both ends. The piezoelectric elements are installed at the centers of both plates, and one side of each plate is subjected to a harmonic point force. In this system, vibration energy is converted into electrical energy via electro-mechanical coupling between the plate vibration and piezoelectric effect. In addition, the plate vibration excited by the point force induces a self-sustained vibration at the other plate via mechanical-acoustic coupling between the plate vibration and an internal sound field into the cylindrical enclosure. Therefore, the electricity generation characteristics should be considered as an electro-mechanical-acoustic coupling problem. Actually, the plate on the excitation side is lower than that on the non-excitation side in the natural frequency because of the influence of a vibrator to apply the point force to the plate, so that both natural frequencies are not identical and the effect of mechanical-acoustic coupling is not clarified very well. Then both frequencies are close by tuning the natural frequency due to thinning the plate on the non-excitation side. As a result, it is expected that the electricity generation characteristics are improved by promoting mechanical-acoustic coupling in comparison with the inherent situation.

Keywords: MECHANICAL-ACOUSTIC COUPLING, CYLINDRICAL STRUCTURE, THIN END PLATE, INTERNAL SOUND FIELD, PLATE VIBRATION, NATURAL FREQUENCY, PIEZOELECTRIC ELEMENT

1. Introduction

To deal with a depletion of fossil fuels and to materialize a low-carbon society, not only the improvement of energy saving technologies but also the creation of new energy sources have been attempted in a lot of studies. Scavenging untapped vibration energy and converting it into usable electric energy via piezoelectric materials has attracted considerable attention and has been regarded as one of new energy sources¹. Typical energy harvesters adopt a simple cantilever configuration to generate electric energy via piezoelectric materials, which are attached to or embedded in host structures, and the behavior is governed by electro-mechanical coupling phenomena.

To enhance the conversion efficiency, two methods have been adopted in many cases: the optimization of piezoelectric element placement and the use of a large element or many elements. To further improve the conversion efficiency, a mechanical impedance matching method, which was derived from using spacers between the piezoelectric element and beam structure and tuning for the size of the piezoelectric element, was proposed². These structural vibrations are caused by vibrators and various power sources. For instance, a self-sustained oscillation caused by placing a plate into a flow whose critical velocity was overpassed (so-called ‘fluttering’) is a well-known phenomenon. To utilize such a fluttering phenomenon for energy-harvesting, the plate on which the piezoelectric elements were arranged was used, and the effect of their arrangement along the flow axis was considered. Then an optimization of the arrangement was performed among some positions and dimensions of piezoelectric elements³.

To develop a new electricity generation system using mechanical-acoustic coupling, we adopt analytical and experimental models that consist of cylindrical structure and both end plates, because the vibration area of the model on which piezoelectric elements can be installed is twice as large as that in the case of a single plate. The cylinder length is varied over a wide range while changing the plate thickness, while the harmonic point force is applied to one end plate and its frequency is selected to cause the plate to vibrate in the fundamental mode. The plate vibration induces electricity generation via electro-mechanical coupling with the piezoelectric effect of the surface-mounted piezoelectric element, while the plate vibration of the excitation side oscillates the other plate via mechanical-acoustic coupling. Consequently, the electro-mechanical-acoustic coupling problem must be considered and is estimated from the electric power caused by the electricity generation, the mechanical power supplied to the plate, and the

electricity generation efficiency that is derived from the ratio of both powers.

Actually, the plate on the excitation side is lower than that on the non-excitation side in the natural frequency because of the influence of a vibrator to apply the point force to the plate, so that both natural frequencies are not identical and the effect of mechanical-acoustic coupling is not clarified very well. Therefore, both frequencies are gotten closer by tuning the natural frequency due to thinning the plate on the non-excitation side, so that we verify that the performance of the proposed system is improved by promoting mechanical-acoustic coupling in comparison with the inherent situation.

2. Experimental apparatus and method

Figure 1 shows the configuration of the experimental apparatus used in this study. The structure consists of a steel cylinder with circular aluminum end plates. Plate 1 is subjected to the point force, whose frequency makes the plate excite in the (0,0) mode; and amplitude F is controlled to be 1 N, excited by a small vibrator. The position of the point force r_1 is normalized by radius r_c and is set to $r_1/r_c = 0.4$. The thickness h_{c1} of plate 1 is fixed at 3.0 mm, whereas those of 2.5 and 3.0 mm are adopted for plate 2 to change vibration characteristics. The cylinder has an inner radius of 153 mm, and the length L can range from 500 to 2000 mm to emulate the analytical model.

In the excitation experiment, to estimate the mechanical power P_m supplied to plate 1 by the small vibrator, an acceleration sensor is installed near the position of the point force on plate 1, and P_m is predicted from the point force and acceleration a_1 . The phase difference between the plate vibrations is also measured owing to the installation of the acceleration sensor at the same position on plate 2, resulting in significant effects on the mechanical-acoustic coupling. To estimate the internal acoustic characteristics, the sound pressure level in the cavity is measured using condenser microphones with a probe tube. The tips of the probe tubes are located near the plates and the cylinder wall, which are the approximate locations of the maximum sound pressure level when the sound field becomes resonant.

To perform the electricity generation experiment, the piezoelectric element is used. It is comprised of a piezoelectric part constructed of ceramics and an electrode part constructed of brass, which have radii r_p and r_b of 12.5 and 17.5 mm and thicknesses h_p and h_b of 0.23 and 0.30 mm, respectively. The piezoelectric elements are installed at the centers of both plates, as shown in

Fig.1(a). The electric power P_{e1} and P_{e2} generated by the expansion and contraction of the piezoelectric elements on plates 1 and 2 are discharged through the resistance circuit, which consists of three resistors having resistances R_v , R_i , and R_c , as shown in Fig. 1(b). R_v and R_i are the resistances of the voltmeter and ammeter, which are built-into the wattmeter, and are 2 M Ω and 2 m Ω , respectively; while R_c is the resistance of the resistor connected outside the wattmeter and is 97.5 k Ω . To grasp the effect of mechanical-acoustic coupling on energy harvesting, the electric power and other data are also measured without the cylinder (i.e. in the electricity generation under the vibration of only plate 1) and are estimated in comparison with those with cylinder. In such an estimation, electricity generation efficiency is used and is derived from the electric power normalized by the mechanical power P_m supplied to plate 1 by the vibrator. However, the electricity generation efficiencies, which are obtained from P_{e1} , P_{e2} , and their total electric power P_e , are denoted by P_{em1} , P_{em2} , and P_{em} , respectively.

3. Results and discussion

3.1. Fundamental characteristics of electricity generation

Figure 2 shows the theoretical and experimental accelerations a_1 at the excitation point as functions of the excitation frequency f . Before obtaining these results, we carried out experimental modal analysis and made sure of the natural frequency of plate 1. Then the actual condition adopts $T_n = 10^8$ and $R_n = 10^1$ to get closer to the experimental support condition⁴. Because this support condition brings the natural frequency to 280 Hz, the corresponding a_1 reaches the peak at the natural frequency. However, the point force is applied to plate 1 via a stick whose natural frequency is shifted to a lower frequency region than that of plate 1 to avoid the effect on the (0,0) mode and higher-order modes. Therefore, the characteristics of the entire vibration system contain the behavior of the stick, so that such a variation in a_1 never takes place in the actual results.

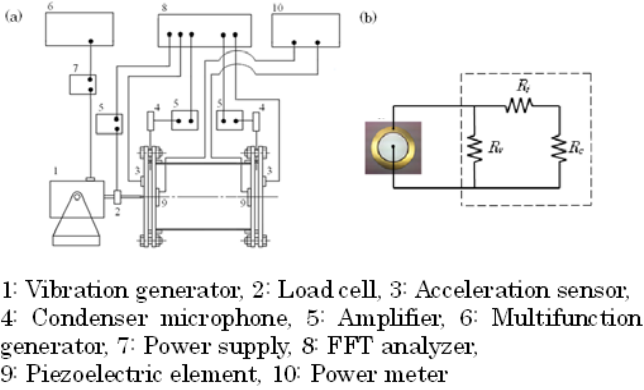


Fig.1 Experimental apparatus.

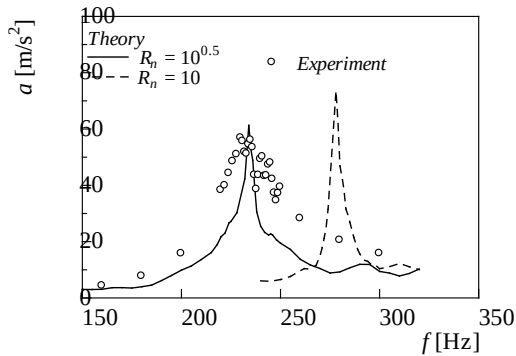


Fig.2 Acceleration as function of excitation frequency.

Since it is difficult to theoretically express the actual situation, a theoretical consideration is attempted by shifting the natural frequency of plate 1 to the experimental peak frequency. The theoretical a_1 has peaks at $f = 234$ and 280 Hz that are derived from $R_n = 10^{0.5}$ and 10^1 , respectively, and the experimental a_1 is maximized around $f = 230$ Hz.

The cylinder and plate 2 are added to the above theoretical and experimental models which were introduced in the previous section, i.e. they are models as shown in Figs. 1. In the analytical model, the dimensions and so on of plate 2 are identical to those of plate 1, the support condition adopts $T_n = 10^8$ and $R_n = 10^1$ in both plates, and the point force F is set to 1 N. The cylinder has the same radius as that of plates 1 and 2, and its length L ranges from 100 to 2000 mm.

Figure 3 shows the sound pressure level L_{pv} , which is averaged over the entire volume of the cavity and is maximized at each L when h_{c1} , h_{c2} , and f are set to 3 mm and 280 Hz, respectively, and the phase α_2 ranges from 0 to 180° as functions of L . The theoretical level L_{pv} peaks at 610, 1230, and 1840 mm. The peaks are caused by the promotion of mechanical-acoustic coupling between the plate vibration and acoustic modes. Then the acoustic modes are the (0,0,1), (0,0,2), and (0,0,3) modes whose plane modal shape is similar to that of plate vibration mode (0,0). To validate these theoretical results, the sound pressure levels L_{p1} and L_{p2} , which are measured near plates 1 and 2, are also indicated. The experimental peaks occur around the lengths where L_{pv} peaks, whereas L_{p1} decreases remarkably around $L = 950$ and 1600 mm in the process of shifting acoustic modes because of a changing L .

To consider the effect of mechanical-acoustic coupling on electricity generation characteristics, Fig. 4 shows the experimental accelerations a_1 and a_2 of plates 1 and 2 as functions of L under the above coupling. Since plate 1 is excited at $f = 280$ Hz via the stick connected with the vibrator, a_1 remains low and almost constant over the entire range of L , having small increases at $L = 620$, 1250, and 1880 mm. These results can be also predicted from those in Fig. 2. On the other hand, the cylindrical sound field connecting with

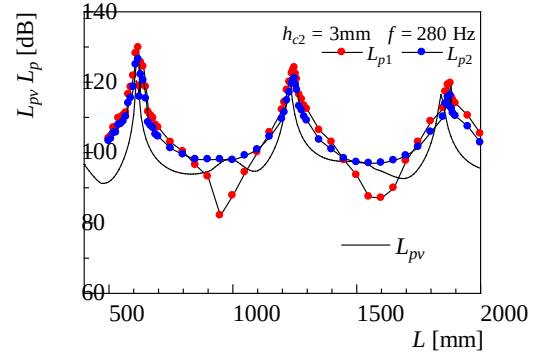


Fig.3 Sound pressure level as functions of cylinder length.

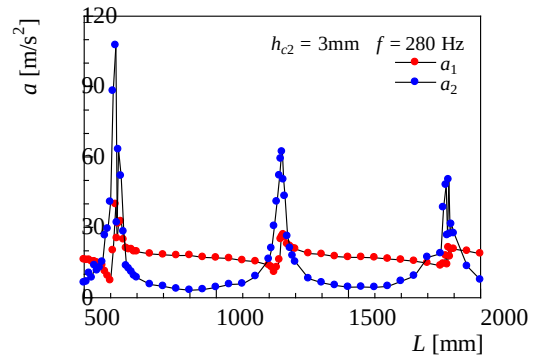


Fig.4 Acceleration as functions of cylinder length.

plate 1 is formed via mechanical-acoustic coupling, and plate 2 is excited by the sound field without the point force. As a result, a_2 of plate 2 has specific peaks at $L = 620, 1250$, and 1880 mm, suppressed in the other ranges of L , because the natural frequency of plate 2 becomes 280 Hz. Figure 5 shows the voltages v_1 and v_2 based on the electricity generations of plates 1 and 2 as functions of L . v_1 and v_2 are directly proportional to a_1 and a_2 , respectively, depending on the in-plane strain of the plate that is determined by the out-of-plane deflection of the plate. Therefore, v_1 and v_2 have a tendency that is similar to that of a_1 and a_2 ; in particular, v_2 is much larger than v_1 at $L = 620$ mm, at which coupling with the $(0,0,1)$ mode is promoted, as well as the behavior of a_1 and a_2 .

The electricity generation efficiencies P_{em1} and P_{em2} are calculated from the relationship between electric power via the piezoelectric element and mechanical power supplied to plate 1. They are shown with changing L in Fig. 6. They are derived from the above results so that P_{em1} of plate 1 remains almost constant over the entire range of L , and P_{em2} of plate 2 increases greatly at $L = 620, 1250$, and 1880 mm.

3.2. Mechanical-acoustic coupling with plates having different thickness

To consider characteristics of the electricity generation using mechanical-acoustic coupling in the previous section, the analytical and experimental models, in which the thicknesses of plates 1 and 2 are identical, were adopted as the fundamental model. Then plate 1 was subjected to the point force of the natural frequency in its free vibration, so that the acceleration of plate 1 was suppressed in comparison with that of plate 2 since the actual natural frequency of plate 1 affected by the small vibrator was lower than the excitation frequency. Here, plate 1 is excited in such an actual natural frequency and the thickness of plate 2 is adjusted to get its natural frequency closer to the actual natural frequency.

Figure 7 shows the and experimental sound pressure levels L_{p1} and L_{p2} as functions of the cylinder length L , when both thicknesses remain 3.0 mm and the excitation frequency f is set to 230 Hz by referring to Fig. 2. L_{p1} and L_{p2} are also maximized around $L = 745$

and 1485 mm by the promotion of coupling as well as Fig.3, whereas their lengths are longer than those in Fig. 3 due to bringing the excitation frequency to the lower range. Under the function of mechanical-acoustic coupling, the acceleration a_1 and a_2 behaves as shown in Fig. 8. Although the acceleration also increases around the above specific lengths, a_1 is considerably larger than a_2 , with the result that these tendencies are opposite to those in Fig. 4. This is because the natural frequency of plate 1 is closer to f than that of plate 2. If f were gotten closer to the natural frequency of plate 2, mechanical-acoustic coupling would be promoted and a_2 would be larger than the present situation.

Then the same experiment is carried out with setting f to 235 Hz and the results of the sound pressure level are shown in Fig. 9. In this case, L_{p2} remains large and almost constant over the entire range of L , whereas L_{p1} has relatively large variation in comparison with L_{p2} and approaches L_{p1} at $L = 1500$ mm, increasing rapidly and extremely. These characteristics are completely different from those in Figs. 3 and 7. Figure 10 shows a_1 and a_2 as functions of the cylinder length L under the same situation. a_1 and a_2 change greatly with L and have the respective periods. Therefore, these characteristics are also different from those in Figs. 4 and 8 and have opposite tendencies in the ranges of 500 mm to 750 mm, of 1000 mm to 1450 mm, and of 1750 mm to 2000 mm, respectively. However, a_1 remains large and a_2 increases sharply at $L = 1500$ mm, and then both accelerations increase $L = 700$ mm, deviating from the above tendencies. These mean that the promotion of coupling occur not only at $L = 1500$ mm but also at $L = 700$ mm, at which we can make sure of small peaks of L_{p1} and L_{p2} .

3.3. Improvement of electricity generation characteristics

As described in the above sections, the vibrations characteristics of plates 1 and 2 are strongly affected by the shift in the natural frequency of plates 2 and the excitation frequency. It is natural that such an effect is reflected in the electricity generation characteristics. Here, the section takes up the three cases: the respective thickness h_{c2} of plate 2 are 3.0 mm when the excitation frequency f is 280 Hz, $h_{c2} = 3.0$ mm when $f = 230$ Hz, and $h_{c2} = 2.5$ mm when $f = 235$ Hz.

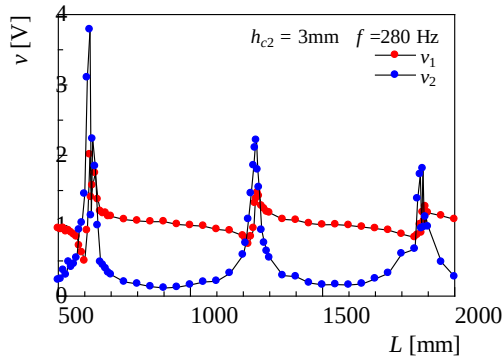


Fig.5 Voltage as functions of cylinder length.

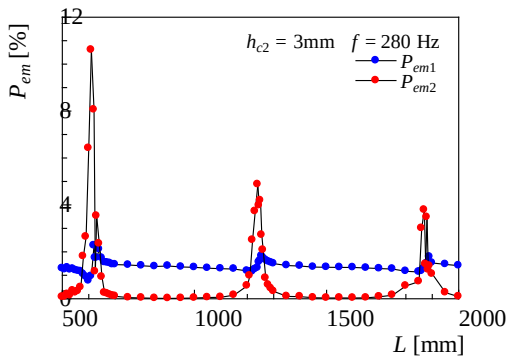


Fig.6 Electricity generation efficiency as function of cylinder length.

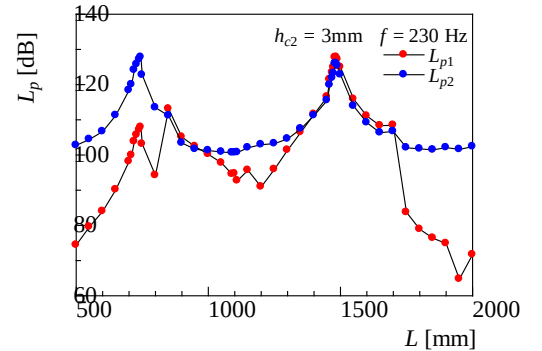


Fig.7 Sound pressure level as functions of cylinder length.

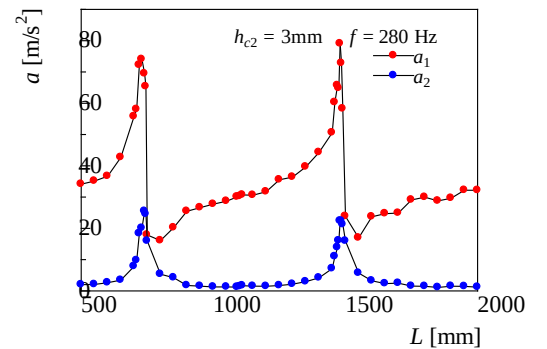


Fig.8 Acceleration as functions of cylinder length.

Figure 11 shows the electricity generation efficiency P_{em} , which is obtained from total electric power P_e , as functions of the cylinder length L . In the case of $h_{c2} = 3.0$ mm and $f = 280$ Hz, P_{em} peaks at $L = 620, 1250$, and 1880 mm by the derivation of P_{em2} of plate 2 and remains almost constant and low in the other ranges of L by the derivation of P_{em1} of plate 1, as shown in Fig. 6. The efficiency peaks decrease with shifting the acoustic modes, such as the (0,0,1), (0,0,2), and (0,0,3) modes. When $h_{c2} = 3.0$ mm and $f = 230$ Hz, P_{em} peaks at $L = 740$ and 1480 mm where mechanical-acoustic coupling is promoted, whereas P_{em} is occupied by P_{em1} and its peaks do not decrease with shifting the acoustic modes, because this coupling is controlled by the vibration of plate 1. Moreover, when $h_{c2} = 2.5$ mm and $f = 235$ Hz, P_{em} remains large over the entire range of L , because this coupling is controlled by the vibrations of both plates. In particular, P_{em} increases greatly in the vicinities of the specific lengths where the accelerations a_1 and a_2 increase simultaneously as shown in Fig. 10 and exceeds greatly P_{em} on the other conditions.

Figure 12 shows variations in P_e , which is employed to obtain P_{em} , with L on the above condition. In the cases of $h_{c2} = 3.0$ mm and $f = 230$ and 280 Hz, variations in P_e are similar to that in P_{em} . The maximum P_{em} at $f = 230$ Hz is somewhat less than that at $f = 280$ Hz, because the mechanical power P_m supplied to plate 1 by the vibrator is suppressed due to the discrepancy between the natural and excitation frequencies. However, the maximum P_e at $f = 230$ Hz is larger than that at $f = 280$ Hz, because the electricity generation characteristics depend on the vibration of plate 1, whose natural frequency is close to the excitation frequency. On the other hand, P_e at $h_{c2} = 2.5$ mm and $f = 235$ Hz exceeds considerably those on the other conditions, as well as P_{em} , and the maximum P_e is obtained at $L = 1500$ mm. This is because mechanical-acoustic coupling is strongly promoted, having significant contribution of both plate vibrations whose natural frequencies are the closest to the excitation frequency among all conditions.

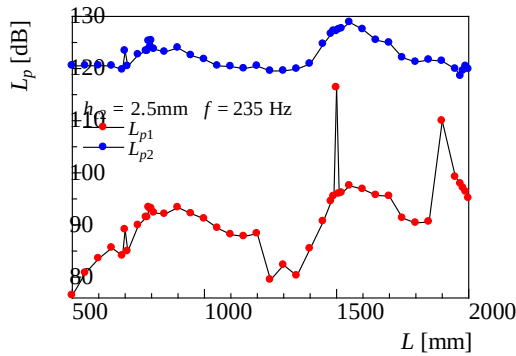


Fig.9 Sound pressure level as functions of cylinder length.

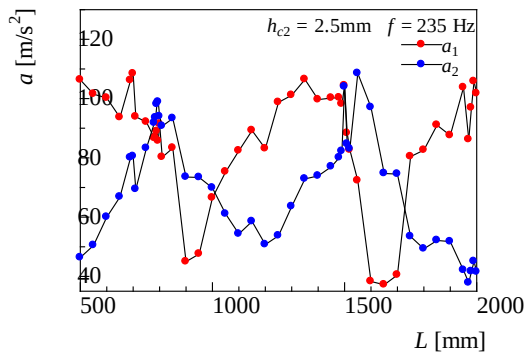


Fig.10 Acceleration as functions of cylinder length.

4. Conclusion

In this study, a new electricity generation system, which consisted of a cylinder with circular end plates on which a piezoelectric element was installed at the center, was proposed. To improve the performance of the proposed system, the effect of mechanical-acoustic coupling on energy harvesting was considered by changing the plate thickness and the excitation frequency and was estimated from the electric power via the piezoelectric element, mechanical power supplied to the plate, and electricity generation efficiency.

The electric power increases by means of making the excitation frequency get closer to the natural frequency of the excitation side, which is considering the influence of a vibrator to apply the point force to the plate. In particular, it is effective measures that both plate vibrations contribute strongly to mechanical-acoustic coupling by getting the natural frequencies of both plates closer to the excitation frequency, so that the electric power and electricity generation efficiency are improved considerably.

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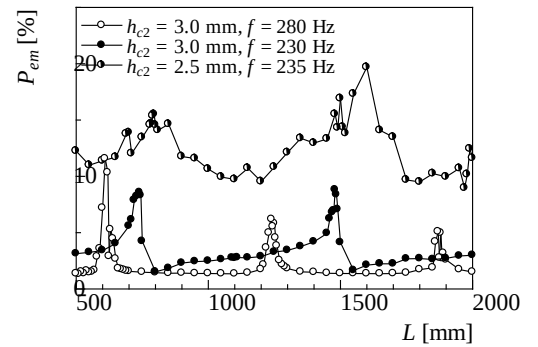


Fig.11 Electricity generation efficiency as function of cylinder length.

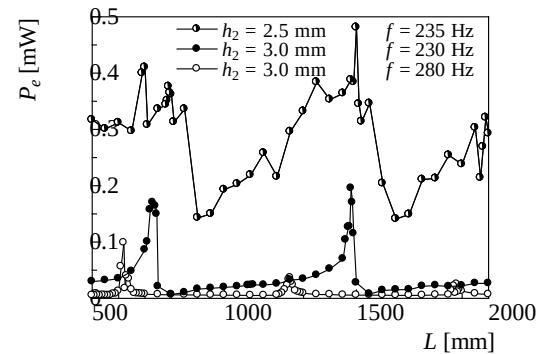


Fig.12 Electric power as function of cylinder length.

MODELING EFFECTS OF IMPACT (SHOCK) -ABRASION WEAR OF IRON BASED HARDFACING

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Abstract: The paper contains results for wear in conditions of impact between a standard welded and tested specimen realized in the presence of a layer of abrasive particles trailing in the contact zone. It gives an idea about the specifics of this type of wear depending on the impact force and the particle size of the abrasive at various hardness achieved by hard-facing with alloys with different carbon equivalent and a degree of hardening of the layer after the test. Based on an experimental research it was proved that the impact-abrasive wear has its specific features expressed via respective graphical relations. The research was funded by Fund "Scientific Research" at the Ministry of Education and Science of the Republic of Bulgaria.

Key words: IMPACT-ABRASION WEAR; IRON BASED HARD-FACING; NUMERICAL APPROACHES;

1. Introduction

The mechanism and the basic laws of impact-abrasive wear are determined by a series of factors, the main ones being the energy of the impact and the hardness of the working parts and also the size of the abrasive powder. This type of wear has been introduced by Russian scientists V. N. Vinogradov and G. M. Sorokin [1]. In the overall assessment of the impact-abrasive wear, there must be taken into consideration the strengthening of the layer which in most cases has a favorable effect on the work of the equipment.

Using the research of strengthening of various welded layers it is possible to determine conditions that prevent the occurrence of brittle cracks, their development and the subsequent merger with others that decrease the wear resistance of the metal in the event of an impact.

The creation of engineering methodologies for calculating the intensity of impact-abrasive wear is an important need related not only to the dependencies of wear on the physical and mechanical properties but also to the strength characteristics and the micro-geometry of the tested surface. In the process for improving an existing stand [2] within a separate project (No.1242/11 funded by Todor Kableshkov University of Transport) there was performed a full modification of the construction and the mechanics of movement in conducting the experiments; also there was implemented advanced electronic control which expands the range of the tested-materials types (fig. 1.).

The timeliness of the research is reinforced also by the fact that taking into account the differences in the tribological research methods there cannot be made any analogy between the impact-abrasive wear and the methods of wear for sliding.

The direct dynamic implementation of solid abrasive particles on the surface of the contact creates favorable conditions for the emergence of cracks in the top metal surface that are easily merged with other similar cracks during the penetration of adjacent grains. Under these conditions, the most negative are the influence of the heterogeneous properties of the surface layer as well as the presence of brittle phases and locally hardened layers. These factors lead to the emergence of brittle cracks, their development and the subsequent merger with others that decrease the wear resistance of the metal in the event of an impact.

The creation of engineering methodologies for calculating the intensity of impact-abrasive wear is an important need related not only to the dependencies of wear on the physical and mechanical properties but also to the strength characteristics and the micro-geometry of the tested surface.

The new solution of the stand imitates the process of wear that occurs after a direct blow to the tested body with a standard specimen in direct contact with free falling abrasive particles in

the form of a sand table. The subsequent plastic deformation is heterogeneous and localized in separate micro volumes. On impact part of the energy and sometimes all the energy is absorbed by the metal.

It is spent for deformation strengthening which as a general property of the metal is manifested as a resistance against the subsequent deformation. The research of strengthening is of interest due to changes in the microstructure of the material.

The purpose of the present paper is to summarize the results of the experimental research which are related to the basic factors of testing in the newly created stand by application of a methodology from an established standard [2].

2. Defining the parameters of passive designed experiment

In Majlesi Branch of Islamic Azad University in Iran, there were welded with three types of electrodes of chemical compositions cited in Table.1, 30 pieces of standardized samples which were a subject of same technological conditions.

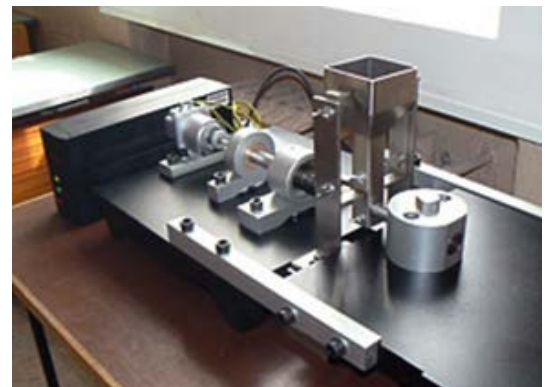


Fig.1. General View of the stand for impact-abrasion wear



Fig.2 rough



Fig.3 processed

General view of hard-facing samples

Fig. 1 shows the impact abrasion test device according to Gost 23.207-79 Russian Standard. Fig.2, fig.3 shows the general appearance of the rough and processed samples. Tabl. 1 shows the chemical composition of Iron based Hard facing electrodes that produced by Iranian AMA electrode company.

Table 1. Chemical composition of the electrodes used for hard-facing

Electrode	C	Mn	Si	Cr	Mo	V	W	C _{ekv}
1105	0,9	0,5	0,5	4,2	8,5	0,9	1,1	3,305
1600	0,5	0,3	0,4	7	0,5	0,5		1,640
1622	0,2	0,4	0,5	2,8				1,440

An essential task of this section is to establish the possibility to find a possible relation between the loss of weight /LW/ and the four parameters of the experimental research.

- Layer hardness /HRC/;
- Impact energy /PI/;
- Size of the abrasive material / GS /;
- Carbon equivalent /C_{ekv}/ of the welded material.

Tabl.2 shows the combinations of the explored experimental controlling factors and the values of the respective fixed meanings for the loss of weight

Table 2. Relations between controlling managing factors and the examined factor

Nº	X ₁ (HRC)	X ₂ (PI)	X ₃ (GS)	X ₄ (C _{ekv})	LW [g 10 ⁻⁴]	HRC after IAW	%Δ HRC
1.	0.543	-1	-1	1	13	58,8	12,21
2.	0.850	-1	-1	-0.786	9	57,3	0,70
3.	-0.734	-1	-1	-1	23	42,54	26,23
4.	0.509	-1	-0.137	1	22	66,16	27,48
5.	0.372	-1	-0.137	-0.786	21	64,44	29,14
6.	-0.454	-1	-0.137	-1	25	38	0,53
7.	0.549	-1	1	1	101	62,16	18,40
8.	0.522	-1	1	-0.786	114	65,64	25,99
9.	-0.713	-1	1	-1	100	47,3	39,12
10.	0.563	0	-1	1	18	62,02	17,69
11.	0.468	0	-1	-0.786	16	65,98	28,62
12.	-0.993	0	-1	-1	27	45,1	50,84
13.	0.672	0	-0.137	1	49	60,98	12,30
14.	0.843	0	-0.137	1	48	62,56	10,14
15.	0.358	0	-0.137	-0.786	55	57,9	16,50
16.	0.556	0	-0.137	-0.786	59	60,76	15,51
17.	-0.679	0	-0.137	-1	97	44,0	27,54
18.	-0.904	0	-0.137	-1	125	45,0	44,23
19.	0.515	0	1	1	258	60,8	16,92
20.	0.256	0	1	-0.786	260	59,86	24,19
21.	-0.700	0	1	-1	255	36,28	6,08
22.	1	1	-1	1	48	65,52	10,86
23.	0.052	1	-1	-0.786	35	66,46	27,81
24.	-0.973	1	-1	-1	64	41,62	37,81
25.	0.529	1	-0.137	1	156	54,2	3,83
26.	0.420	1	-0.137	-0.786	106	65,98	30,40
27.	-0.474	1	-0.137	-1	125	43,72	16,59
28.	0.884	1	1	1	418	65,0	13,24
29.	0.427	1	1	-0.786	403	60,98	20,28
30.	-1	1	1	-1	510	33,74	13,22

The conversion key from coded meanings to normed ones is in Tabl.3; in this Table, there is also the range of change of the controlling parameters of the process.

Table 3. Range of change of controlling factors

Factors	Variation levels of controlling factors		
	Code [-1]	Code [0]	Code [1]
X1 (HRC),[/]	29,80	44,45	59,10
X2 (PI), [J/sm ²]	0,48	1,30	2,12
X3 (GS), [mm]	0,196	0,728	1,26
X4 (C _{ekv}), [/]	1,44	2,372	3,305

As a result of an implemented standardized procedure [5,6] at defining an experimental basis from Tabl.2, there was determined a regression model for the loss of weight depending on the specified above controlling factors the coefficients of which are presented in Tabl.4.

Table 4. Coefficients of the model and its adequacy validations

	For Loss of weight	For strengthening
b(00)=	272.775	103.911
X ₁	-62.5362	-32.8925
X ₂	85.2068	-6.22308
X ₃	122.241	-1.85656
X ₄	36.4447	18.5948
X ₁ ²	8.93410	24.5241
X ₁ X ₂	-17.6384	11.3752
X ₁ X ₃	-15.7202	7.27488
X ₁ X ₄	33.6166	-5.52689
X ₂ ²	16.6244	-6.52608
X ₂ X ₃	77.1357	-5.62072
X ₂ X ₄	12.9030	-6.46953
X ₃ ²	49.7648	-2.41272
X ₃ X ₄	4.68954	-1.38608
X ₄ ²	-213.794	-93.1205
	R = 0.9933	R = 0.8596
	79.1201>2.4274 (a=0.05;14;15)	3.0328>2.4274 (a=0.05;14;15)

The estimation of the approximation-models quality is made on the basis of the regression coefficient R and Fisher F-criterion between the actually observed experimental and modeled values of resulting quantities. The meanings of these checks are contained in the last two rows of Tabl.4.

3. Results and discussion.

The analysis is supported by a copperplate research of each group. There can be found in [7] the microstructures of explored samples with similar dendritic microstructures of specimens welded with electrode materials 1105 and 1600. They represent martensite and carbide in the inter-dendritic spaces. The microstructure of the specimen welded with electrode 1622 is of a cell type and with bainite in the cell volumes.

It is possible to prove important statements as a consequence from an organized and planned parameter changes at impact-abrasive wear. They are deduced on the basis of the obtained regression model for the loss of weight (Tabl.4) and they follow the natural logic of this type of wear. As it is clear from the graphs in Fig.4, the big loss of weight is observed at low hardness and at high impact energy. The bigger particle size of the abrasive, the bigger wear value; this is confirmed by the graph on Fig.6 b) and c).

GS – 0.196 [mm]; C_{ekv} – 2.372 GS–0.848 [mm]; C_{ekv} – 2.372

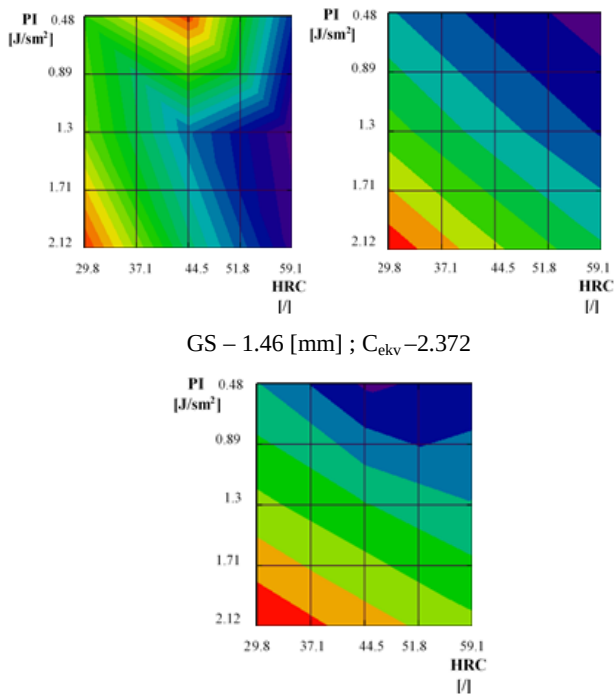


Fig.4. Dependence of loss of weight for IAW (impact-abrasive wear) on the variation of hardness and the impact energy

Regardless of the fact that hard-facing samples with electrodes 1105 and 1600 possess similar dendritic microstructures, the included alloying elements create different conditions of wear. It is clear from Fig.5 that the most intensive wear occurs for coated electrodes 1600 forming C_{ekv} near to 2.37. This statement is confirmed also by the graph in Fig.6 a).

GS–0.196 [mm]; PI–1,3 [J/sm²] GS–0.848 [mm]; PI–1,3 [J/sm²]

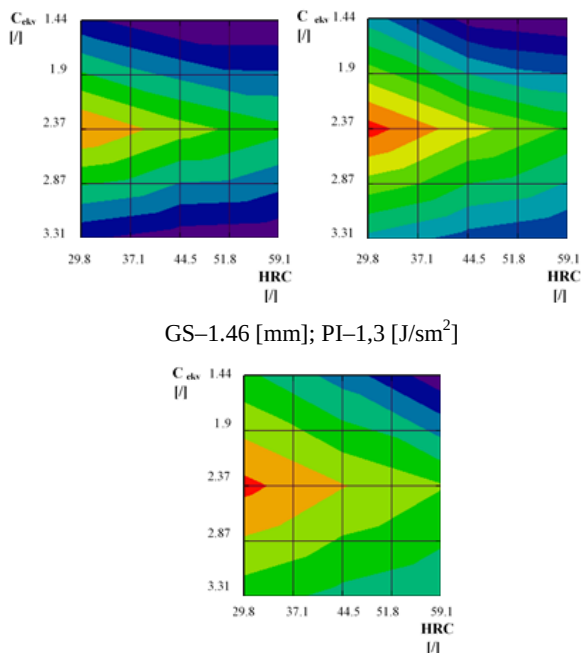
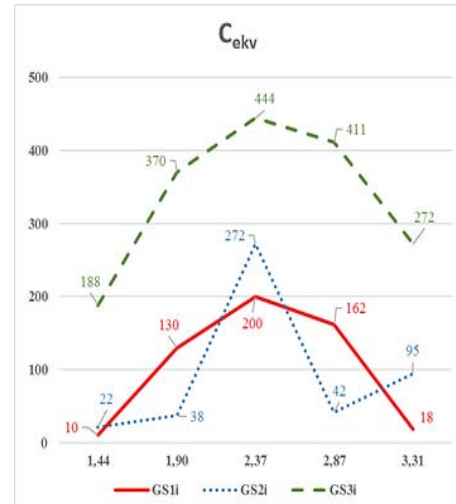


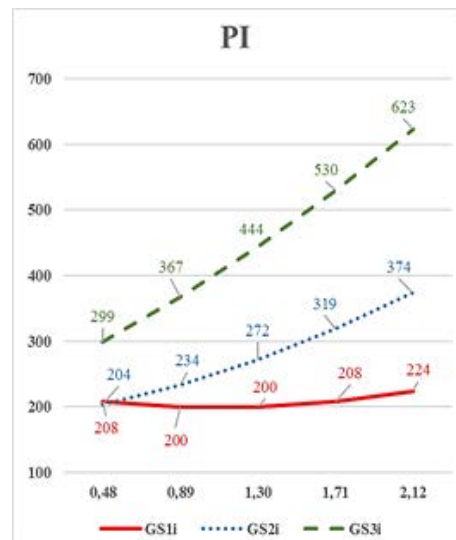
Fig.5. Dependence of loss of weight for IAW on hardness and the carbon equivalent of welded metal

The analysis of the model for strengthening shows that it is stronger expressed for the smaller initial hardness of the welded surface. It is strongly influenced by the structure of the welded

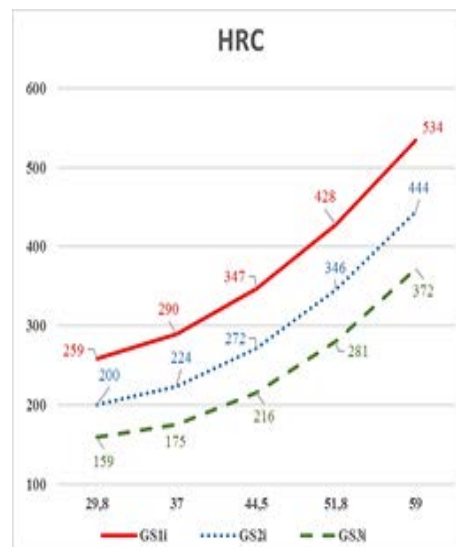
material; most hardened layers are obtained with electrode 1600. This can be seen in Fig.7.



a) carbon equivalent



b) impact energy



c) hardness

Fig.6. Dependence of loss of weight for IAW on carbon equivalent, impact energy and hardness

The analysis of the model for strengthening shows that it is stronger expressed for the smaller initial hardness of the welded surface. It is strongly influenced by the structure of the welded material; most hardened layers are obtained with electrode 1600. This can be seen in Fig.7.

Table 5. Multi criteria decisions determined on the basis of the regression models

SOLUTION PARAMETER	1.	2.	3.	4.	5.	6.
X1 (HRC) ,[/]	29,8	29,8	44,45	59,1	59,1	51,27
X2 (PI),[J/sm ²]	0,48	0,89	1,3	1,71	2,12	0,48
X3 (GS) ,[mm]	0,196	0,728	0,196	0,462	0,196	0,994
X4 (C _{ekv}) ,[/]	3.305	3.305	2.372	2.372	2.372	2.372

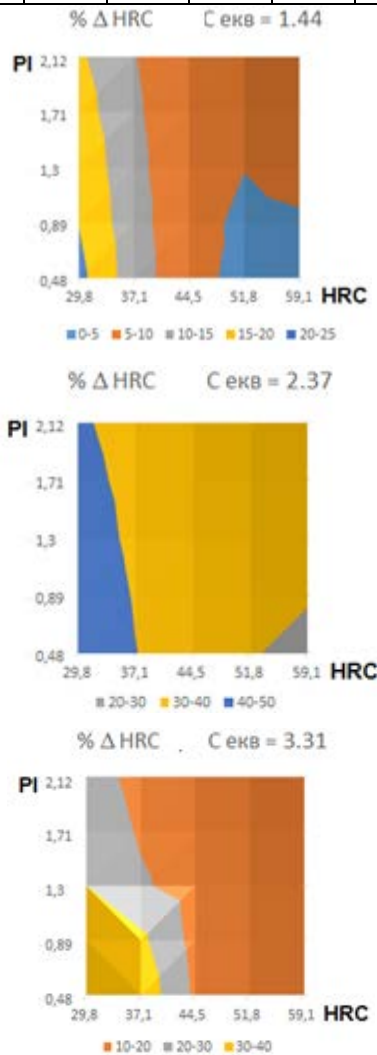


Fig.7. Dependence of strengthening in IAW on the variations of hardness, the impact energy and the carbon equivalent

It is proven in [7] that most intensive wear refers to coated electrodes 1600 which forms C_{ekv} near to 2.37. This contradiction between the most intensive wear and strengthening of this electrode leads to a solution to a multi-criteria problem. The formulation of its goal is related to the determination of input parameters for testing at IAW guaranteeing the minimal loss of weight and the maximal strengthening. Tabl.5 contains the solutions of this problem. The values of the controlling IAW parameters guarantee strengthening bigger than 35% and wear less than 30%.

4. Conclusion.

The paper presents a designed experiment with four factors of variation during the tests – coating hardness, impact energy, abrasive-material size and carbon equivalent of the hard-facing material. Based on the vast experimental database from the research there have been drawn conclusions about the influence of various factors on the loss of weight and the hardening of the layer. There have been obtained regression dependencies and there have been built graphical dependencies that allow a precise analysis of the loss of weight due to impact-abrasive wear. There have been determined six technological solutions that guarantee the minimal loss of weight, stability, and the maximal strengthening.

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ADVANCED COMPUTING FOR HIGH SPEED BRIQUETTING OF METAL CHIPS AND POWDERS

СЪВРЕМЕННИ ПРЕСМЯТАНИЯ ЗА ВИСОКОСКОРОСТНО БРИКЕТИРАНЕ НА МЕТАЛНИ СТРУЖКИ И ПРАХОВЕ

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Abstract: In the paper is investigated the possible to produce briquettes from chips of aluminum alloy and iron powder. Chips of different shapes and sizes are compared, some of which are free of water and oil (cleaned chips), while the rest are left without cleaning (soiled chips). Upsetting and reverse extrusion of the briquettes were studied. The results show that may be accomplished a large extent of deformation of the briquettes when using processes with predominant compressive stresses. Preparation of briquettes of metal chips with good density and quality is of great importance for the efficiency of this process. The results of impact briquetting of grey cast iron chips with rectangular shape and dimensions 15x25x1 mm are presented. Density and quality of briquettes of these chips are compared with those obtained in another work of the authors using cast iron chips with smaller sizes. It has been found that by using a rectangular chips with a large size are produced briquettes with a very low density and poor quality.

Keywords: IMPACT, IRON POWDER COMPACTING, POWDER METALLURGY, ROCKET ENGINE

of a rocket engine makes it possible to work with impact force P_i which changes in accordance with the lines 2-4 shown in Fig. 3.

1. Introduction

Obtaining of metal powder parts have a number of advantages over other methods of processing - use of 95% of the raw material (40% -50% in the other processing technologies), low energy consumption, producing of composite materials with large range of properties and these advantages of powder metallurgy increased by using impact and high velocity compacting (HVC). Research in this area in recent years have shown higher density and increase of the mechanical properties of the powder metallurgy parts [1]-[4].

In [1] is used hydraulic hammer for HVC (impact velocity 13.2 m/s). The density of the obtained cylindrical specimens using iron powder is 7.4 g/cm³ (the density of monolithic material is 7.54 g/cm³). This density is obtained with a pre-compaction to a density of 5 g/cm³.

Fig.1 shows the scheme of HVC and Fig.2 shows the impact force change in HVC process [1]. From Fig.2 it can be seen that after first impact has 6 rebounds of the hammer to complete consumption of the impact energy. As a result part of the impact energy is spent on the rebound and this reduces the efficiency of the impact.

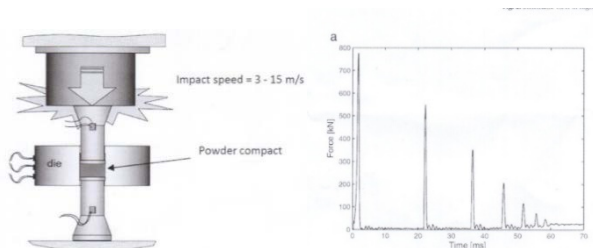


Fig.1. Scheme of high velocity a HVC

Fig.2. Impact force change during compaction experiment with an impact energy of 2.7 kJ

Controlled impact compacting (CIC) is an innovative technology that is possible when using a hammer propelled by industrial rocket engine [5]. The received force at work on a rocket engine (trust R) is $R = 2000$ kg when supplied with kerosene (hot rocket engine) and $R = 300$ kg in supplying with compressed air (cold rocket engine). The maximum impact energy is 35 kJ and impact velocity is 5-16 m/s. The opportunity to control the runtime

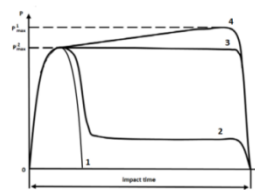


Fig.3. Change of impact force P_i at the impact time: 1 – ordinary impact; 2, 3, 4 – controlled impact

2. Methods

Iron powder AS29-100 is used. The distribution of particle size is shown in Fig. 4 (Fritch Analysette 22 Nano Tec+). For obtaining a better grip 1% zinc stearate is added.

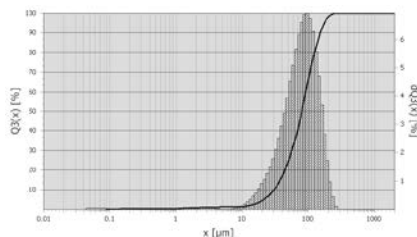


Fig. 4. Distribution of iron powder particle size

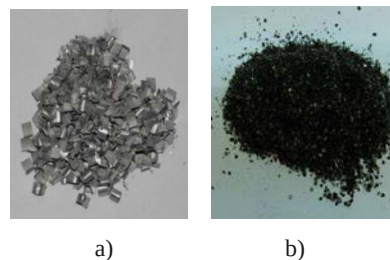


Fig. 5. a- chips used in present paper (type A); b – chips used in [8] (type B)

The metal powder green body is with diameter of 20 mm. Used powder mass is 4, 3.5, 3 grams, as of each type were prepared 3 specimens. After compacting the specimens mass are measured on an analytical balance. The diameter and high of the specimens are measured with accuracy of $1\ \mu\text{m}$ (on X-ray 3D tomograph XTH 225) and the volume is calculated. Then the density ρ is determined by the ratio

$$\rho = \frac{m}{\Theta}, \quad \text{g/cm}^3, \quad (1)$$

where m is the mass and Θ is the volume of the specimen. The hammer impact velocity V_i is about 7 m/s and impact energy E_i is about 240 J. Change of the force P_i corresponds to the line 2 of Fig. 3 ($R = 226\text{ N}$).

To determine the impact force is used record of the impact process with high-speed camera Nac Memrecam HX6. Vicasso 2009 software is used for calculation of path S , velocity V and acceleration a . The force P_i is determined by the dependence

$$P_i = a_i m, \quad \text{N}, \quad (2)$$

where a_i is the impact acceleration.

The specific impact energy E_s is calculated by the ratio

$$E_s = \frac{E_i}{\Theta}, \quad \text{J/sm}^3, \quad (3)$$

where $E_i = \frac{MV_i^2}{2}$, and M is the mass of the hammer ram ($M = 9.12\text{ kg}$). This indicator can be used to compare the results when study the compacting process in different conditions.

In Fig.5 are shown used cast iron chips. Their average sizes are: length 25 mm, width 15 mm, thickness 1 mm. Diameter of the produced briquettes is 20 mm, as it is the hole of the die for briquetting. Diameter of the punch is 19.6 mm. The gap between the die and the punch is left out to ensure exit of the air that remains between the chips in the filling into the die. To account for the influence of the size and type of chips used in the present work (type A) are compared with those of work [7] (type B). In order to investigate the influence of the residual water and oil on the density of the briquettes produced by the impact briquetting part of the type A chips were cleaned (type AC) while others had been left uncleaned (type AUC). Both type of chips are from gray cast iron with 2.8 % C. In order to investigate chips density and structure the obtained briquettes are measured, weighed on an analytical balances and pictured on 3D X-ray tomography (Nikon XTH 225 Compact Industrial CT Scanner)–Fig. 6. [8], [9].

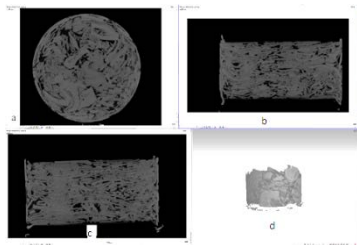


Fig. 6. X-ray tomography images of gray cast iron briquettes a - cross-section in the middle of the briquette height; b, c - orthogonal vertical sections through the center of the briquette; d - 3-D image efficiency is higher when using controlled impact.

Impact process is recorded with a high-speed camera NAC Memrecam HX6. The video is processed with the software Vicasso 2009 which defines impact speed (V_i) and acceleration (a_i).

The impact force P_i and impact energy E_i are calculated by formulas

$$P_i = a_i m, \quad \text{N}, \quad (4)$$

$$E_i = \frac{mV_i^2}{2}, \quad \text{J}, \quad (5)$$

where m is the mass of the falling part, in kg.

The specific impact energy for briquetting is calculated by the formula

$$E_s = \frac{E_i}{\Theta} \text{ J/cm}^3, \quad (6)$$

where Θ , sm^3 , is the briquette volume. The use of this indicator makes it possible to compare the results obtained under different conditions of briquetting.

3. Intercriteria decision making approach

The presented multicriteria decision making method is based on two fundamental concepts: intuitionistic fuzzy sets (9), (10) and index matrices (11). It is called 'InterCriteria decision making'.

Intuitionistic fuzzy sets (9) represent an extension of the concept of fuzzy sets (10), exhibiting function $\mu_A(x)$ defining the membership of an element x to the set A , evaluated in the $[0; 1]$ - interval. The difference between fuzzy sets and intuitionistic fuzzy sets (IFSs) is in the presence of a second function $\nu_A(x)$ defining the non-membership of the element x to the set A , where:

$$\begin{aligned} 0 &\leq \mu_A(x) \leq 1, \\ 0 &\leq \nu_A(x) \leq 1, \\ 0 &\leq \mu_A(x) + \nu_A(x) \leq 1. \end{aligned} \quad (7)$$

The IFS itself is formally denoted by:

$$A = \{ \langle x, \mu_A(x), \nu_A(x) \rangle \mid x \in E \}. \quad (8)$$

Comparison between elements of any two IFSs, say A and B , involves pairwise comparisons between their respective elements' degrees of membership and non-membership to both sets.

The second concept on which the proposed method relies is the concept of index matrix, a matrix which features two index sets, [6]. Here we will start with the index matrix M with index sets with m rows $\{C_1, \dots, C_m\}$ and n columns $\{O_1, \dots, O_n\}$:

$$M = \begin{array}{c|cccccc} & O_1 & \dots & O_k & \dots & O_l & \dots & O_n \\ \hline C_1 & a_{C_1, O_1} & \dots & a_{C_1, O_k} & \dots & a_{C_1, O_l} & \dots & a_{C_1, O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_i & a_{C_i, O_1} & \dots & a_{C_i, O_k} & \dots & a_{C_i, O_l} & \dots & a_{C_i, O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_j & a_{C_j, O_1} & \dots & a_{C_j, O_k} & \dots & a_{C_j, O_l} & \dots & a_{C_j, O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_m & a_{C_m, O_1} & \dots & a_{C_m, O_k} & \dots & a_{C_m, O_l} & \dots & a_{C_m, O_n} \end{array}$$

where for every p, q ($1 \leq p \leq m, 1 \leq q \leq n$), C_p is a criterion (in our case, one of the twelve pillars), O_q in an evaluated object, $a_{C_p O_q}$ is the evaluation of the q -th object against the p -th criterion, and it is defined as a real number or another object that is comparable according to relation R with all the rest elements of the index matrix M , so that for each i, j, k it holds the relation $R(a_{C_k O_i}, a_{C_k O_j})$. The relation R has dual relation $\bar{R}$, which is true in the cases when relation R is false, and vice versa.

For the needs of our decision making method, pairwise comparisons between every two different criteria are made along all evaluated objects. During the comparison, it is maintained one counter of the number of times when the relation R holds, and another counter for the dual relation.

Let $S_{k,l}^{\mu}$ be the number of cases in which the relations $R(aCkOi, aCkOj)$ and $R(aCkOi, aCkOj)$ are simultaneously satisfied. Let also $S_{k,l}^{\nu}$ be the number of cases in which the relations $R(aCkOi, aCkOj)$ and its dual $\bar{R}(aCkOi, aCkOj)$ are simultaneously satisfied. As the total number of pairwise comparisons between the object is $n(n-1)/2$, it is seen that there hold the inequalities:

$$0 \leq S_{k,l}^{\mu} + S_{k,l}^{\nu} \leq \frac{n(n-1)}{2} \quad (9)$$

For every k, l , such that $1 \leq k \leq l \leq m$, and for $n \geq 2$ two numbers are defined:

$$\mu_{C_k, C_l} = 2 \frac{S_{k,l}^{\mu}}{n(n-1)}, \quad \nu_{C_k, C_l} = 2 \frac{S_{k,l}^{\nu}}{n(n-1)}. \quad (10)$$

The pair constructed from these two numbers plays the role of the intuitionistic fuzzy evaluation of the relations that can be established between any two criteria C_k and C_l . In this way the index matrix M that relates evaluated objects with evaluating criteria can be transformed to another index matrix M^* that gives the relations among the criteria:

$$M^* = \begin{array}{c|ccc} & C_1 & \dots & C_m \\ \hline C_1 & \langle \mu_{C_1, C_1}, \nu_{C_1, C_1} \rangle & \dots & \langle \mu_{C_1, C_m}, \nu_{C_1, C_m} \rangle \\ \vdots & \vdots & \ddots & \vdots \\ C_m & \langle \mu_{C_m, C_1}, \nu_{C_m, C_1} \rangle & \dots & \langle \mu_{C_m, C_m}, \nu_{C_m, C_m} \rangle \end{array} \quad (11)$$

The final step of the algorithm is to determine the degrees of correlation between the criteria, depending on the user's choice of μ and ν . We call these correlations between the criteria: 'positive consonance', 'negative consonance' or 'dissonance'. [6]

Let $\alpha, \beta \in [0; 1]$ be given, so that $\alpha + \beta \leq 1$. We call that criteria C_k and C_l are in:

(α, β) - positive consonance, if $\mu_{C_k, C_l} > \alpha$ and $\nu_{C_k, C_l} < \beta$;

(α, β) - negative consonance, if $\mu_{C_k, C_l} < \beta$ and $\nu_{C_k, C_l} > \alpha$;

(α, β) - dissonance, otherwise.

4. Conclusions

The conducted study of briquetting of cast iron chips with controlled impact showed that the shape and size of the chips is essential for producing of high quality briquettes. Can be drawn the following important conclusions. It has been found that at impact briquetting of the chips with rectangular shape their location on the peripheral wall of the briquette is such that prevents Top of Form. Comparison with briquettes produced by impact of chips with small size indicates that by using of small size chips re produced briquettes with good density and quality. This means that large chips must first be ground to obtain chips with smaller dimensions. Depending on the trust R of the used rocket engine the process of compacting can be conducted in accordance with the curves 2,3,4 of Fig. 3. When operating in accordance with curve 2 ($R < P_1$) is observed reducing of the number of rebounds, which resulted in increasing of impact efficiency. When operating in accordance with curve 3 and curve 4 ($R \geq P_1$) it becomes possible to realize the impact without rebound (sticking impact) and increasing the time of action of the impact force. It is necessary to continue the research in this area using industrial rocket engines with a higher power.

Acknowledgments

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NEW TYPE OF INNOVATIVE LIFTERS

НОВ ТИП ИНОВАТИВНИ ЛИФТЕРИ

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Abstract: In this article the new shape of lifters for Semi-Autogenous Grinding (SAG) and autogenous mills has been investigated. Lifters are designed for lifting, separating the grinding bodies (at SAG mill) and the grinding material to the required height of separation, crushing and grinding of the material in order to achieve the required output particle size. The main purpose of these mills is material grinding and crushing. Lifters are most used in the mining industry. Hence, attention is paid to analysis of different working regimes of mills with new lifter shape.

Key words: LIFTERS, SAG MILL, AUTOGENOUS MILL, GRINDING.

1. Introduction

Grinding process is mostly applied in ball mills, and it is a major technological function in many industries such as: production of cement, metallurgy, mining and etc. This process is extremely energy-intensive (globally 20% of energy is used for grinding processes), and it requires overall testing and optimization of the milling technology, the shape of the grinding bodies and the parameters of the grinding media. The expected results of grinding process are improvement in the quality of the starting material, reducing energy costs, increasing productivity [1-3].

The aim of this article is analysis of new type of lifters for SAG and autogenous mills.

2. Manuscript Preparation

The most commonly used form of lifter shape includes head, edges and face (Fig. 1) [4]. Lifters are located in the inner surface of the cylindrical shell of the mill, rigidly mounted. The head lifter body is exposed to friction surface with a non-linear profile. Also, there are three linear parts: the top of the lifter head, a lower portion to the lifter base, a middle portion between the upper and lower part, and upper part with flat end and a smaller size.

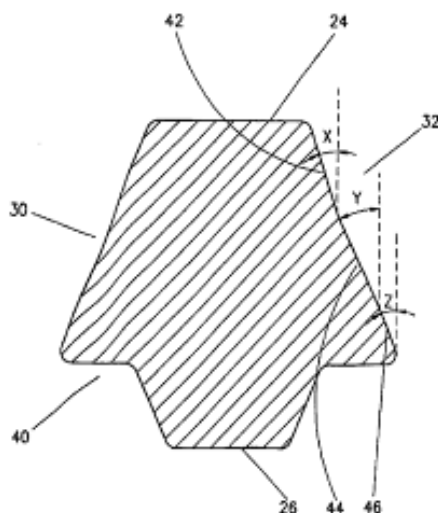


Fig. 1. The most commonly used form of lifter [4].

Also, other shape of lifter is investigated – inverted trapezoid, shown on Fig. 2. Narrow side of lifter is in contact with the inner wall of the mill (drum). Thus, the trapezoid shape and pockets on the sides of the trapezoid allow to the material to elevate higher. F. The pockets are placed on the both sides of the lifter. This enables rotation of the mill in both directions (clockwise and

counterclockwise). In this variant, the material for grinding and the grinding bodies are elevated to a higher angle. Consequently, the material falls in the central part of the mill and falls on the filling material and grinding bodies [5].

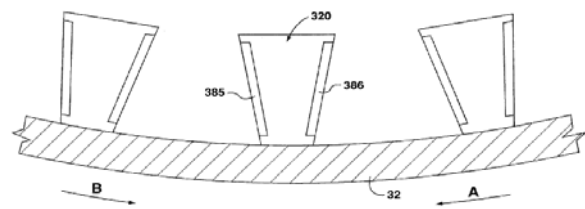


Fig. 2. Lifter with inverted trapezoid shape [5].

3. Analysis of the New Shape of Lifter

The new lifter shape for SAG and autogenous mill is designed for lifting, separating the grinding bodies (at SAG mill) and the material for grinding to the required level. The new design of lifter shape helps for fragmentation and crushing material in order to achieve the required particle size.

The new body form aims to achieve a high degree of crushing and grinding material for the mining industry.

Lifters type of spheroidal tetrahedron Reloe can be used for autologous and SAG mills, as well as in ball mills. The shape of the body includes a spheroid shape with slightly rounded edges.

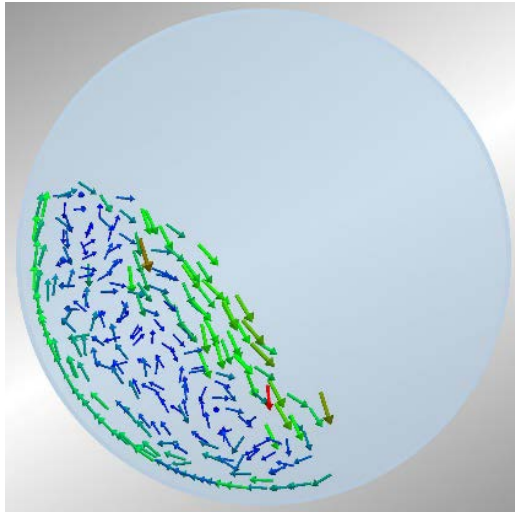
The advantage is that the output material, achieved of the device with new lifter shape, has an increased crushing of the material. The main crushing will be accompanied by the entry of material grinding on the sharpened edge.

Another advantage is that the spherical surfaces contribute to the dissipation of energy produced by the impact of material grinding lifters, to avoid damage of the lifter edge.

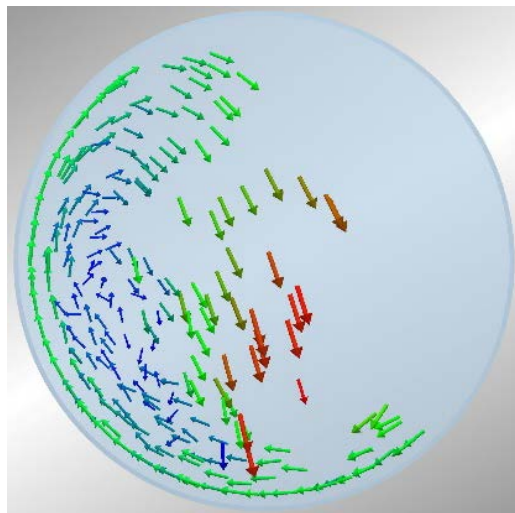
In practice and literature are known different modes (regimes) of grinding [1, 2]. These modes can be achieved by separation inside the mill, as well as landing at certain angles. Fig. 3 shows different grinding modes.

Cascade regime is used for fine grinding (Fig. 3a). The most used regime is cataract regime, shown on Fig. 3b. The crushing of the material is achieved in the opposite part of the mill (red arrows). This regime provides also milling in the “blue part” of the drum. The centrifugal regime is shown on Fig. 3c [1-3].

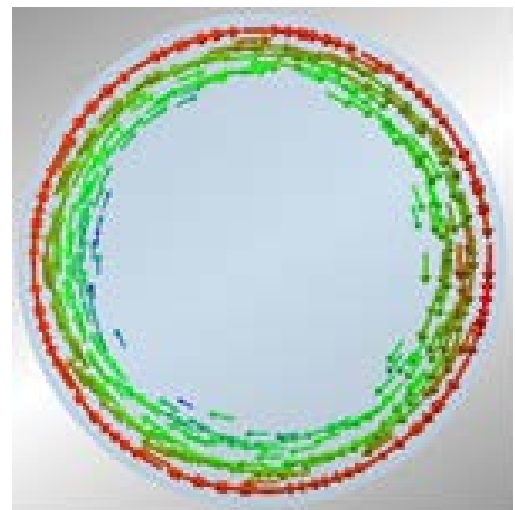
The lifter [6], shown in Fig. 4 consists of body 1 with head 2 and base 3. The head 2 is a triangle with spheroidal walls 4 and pointed tip 5. The base 3 is of a smaller size than the head 2 and the head 2 ends with a perpendicular wall 6 to the base 3. The space between the wall of the base 3 and the perpendicular wall 6 forms a pocket 7. Axially on forehead 8 of the base is made a hole 9 for fixing the lifter to the drum of the mill through a hole 11 in the drum 10



a) Cascading



b) Cataracting



c) Centrifugal

Fig. 3. Work regimes in ball mills.

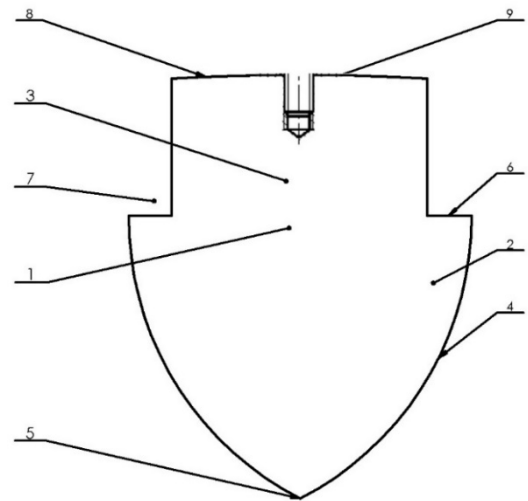


Fig. 4. New lifter form [6].

The behavior of the new type of lifter, including grinding bodies in cascade mode is shown in Fig. 5.

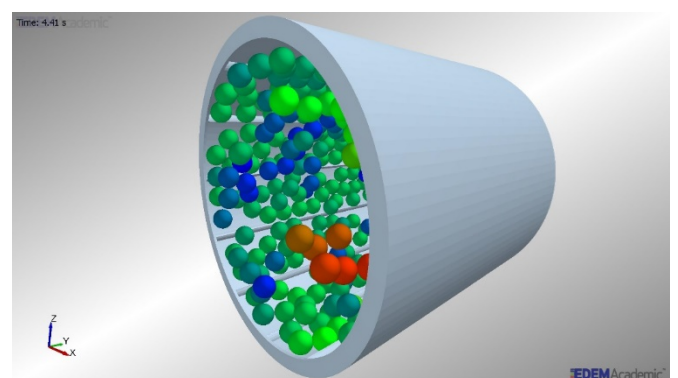


Fig. 5. Behavior of the new type of lifter, including grinding bodies.

4. Operating principle

In supplying hole of the mill is fed the material for grinding. According to the type of mill feeding with material can be discontinuous and continuous cycle. With the movement of the drum with a certain speed, the material for grinding begins to rotate with the mill. With the help of the lifters, the material rises to a certain height. After that it separates from the wall of the drum mill and a goes into mode of free fall, then falls on the drum bottom. When falls on lifters or drum bottom, the material is crushing. According to the desired output size of the material for grinding is determined and as well as operating time of the mill. On Fig. 6 is shown mill with new shape of lifter.

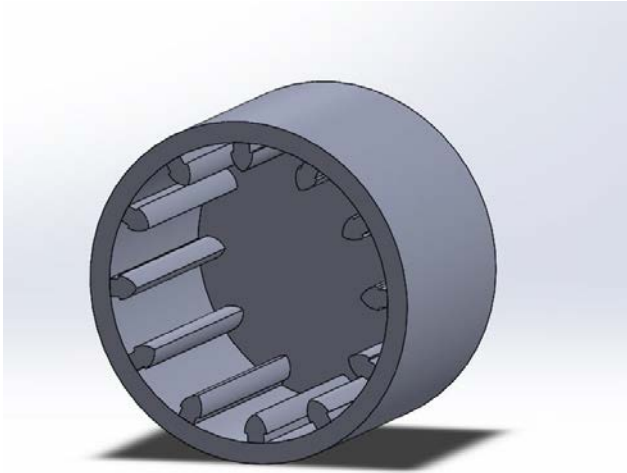


Fig. 6. Mill with new shape of lifter.

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5. Conclusion

By changing the size of lifters, the angle of separation and landing angle changes. The angle of separation and angle of landing depends also from: changing the size of the material for grinding; changing the size of the grinding bodies (at SAG mill); changing the speed of the mill; wet or dry grinding.

The lifter body and the edge facilitate the crushing of the material. Pocket for retaining material helps to uplift the material to a higher point of separation, which increases productivity.

Acknowledgment

This work was supported by the project "Investigation and optimization of grinding processes via innovative forms of grinding bodies and environments", grant DFN-96/04.05.2016, funded by the Bulgarian Academy of Science, program for supporting young scientist.

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ROBOT CONTROL AND MODERN ICT FOR ENERGY EFFICIENCY AND BETTER QUALITY OF INNOVATIVE TECHNOLOGICAL PROCESSES USING SMART LAB EQUIPMENT

УПРАВЛЕНИЕ НА РОБОТИ И МОДЕРНИ ИКТ ЗА ЕНЕРГИЙНА ЕФЕКТИВНОСТ И ПО-ДОБРО КАЧЕСТВО НА ИНОВАТИВНИ ТЕХНОЛОГИЧНИ ПРОЦЕСИ С ПОЛЗВАНЕ НА УРЕДИ ОТ SMART LAB

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Abstract: The paper is concerned with the innovative technological processes of mobile robots with infrared thermo camera for inspection, group wireless control of autonomous luggage carriers, shafts renovation based on nonelectric chemical laying of a nickel coating with included nanoparticles, graphical Braille screen using permanent magnet linear electromagnetic actuator for driving a needle, high speed forging processes with a new industrial rocket engine applicable for a high-speed forging hammer, new type milling bodies - spheroidal tetrahedron. A modern Smart Lab equipment for advanced research activities is presented.

Keywords: CONTROL OF MOBILE ROBOTS, NANOPARTICLES, SHAFTS RENOVATION, BALL MILLS, FORGING HAMMER. LINEAR MICRODRIVE, BRAILLE SCREEN, ROCKET ENGINE, MILLING BODIES

1. Introduction

Innovative processes are often associated with some of the following effects: mobile robotics and group control, ICT, environmental protection, energy efficient production, new materials and technologies, quality of life.

The Institute of Information and Communication Technologies (IICT-BAS) has successfully conducted scientific research and applied developments related to one or more of the above effects. In IICT-BAS there is unique modern laboratory equipment. Unique to south-eastern Europe Smart Laboratory is equipped with industrial computer 3D tomography, 3D scanner and 3D printer, infrared camera, high speed camera, laser measurement of particles in nano range, Discrete Element Method software (DEM) etc.

Scientific tasks, types of activities and expected results are based on previously performed scientific research and development in IICT, the available unique research equipment and planned activities.

On this basis, the team will strengthen the research and development on the above cited innovative topics and expand the fields of application of the results.

2. Research of innovative processes

Chemical nickel coatings by inclusion of nanoparticles for shafts renovating

In IICT BAS we have developed technology for chemical (electroless-autocatalytic) plating the working surface of the shaft (Fig. 1) for extruding a film with the inclusion of nano-particles in a matrix of nickel in order to improve the hardness and wear resistance of the coating with thickness up to 25 μm at 250 μm chrome plating, [1], [8].

There have been experimental studies of nano diamonds with 4-20 nm. Methods are developed for testing the hardness and chemical durability of nickel coatings including nanoparticles. The plating of test samples was performed (Fig. 2). Several of the samples A and B were used for preliminary tests for chemical staining / oxidation of nickel-phosphor coatings. To conduct long

term durability tests of models of shafts in operating conditions ($T = 200^{\circ}\text{C}$, maintained by computer control of industrial heater) suitable test stand was designed (Fig. 3).



Fig. 1. - Calender shaft



Fig.2. Plating of test samples

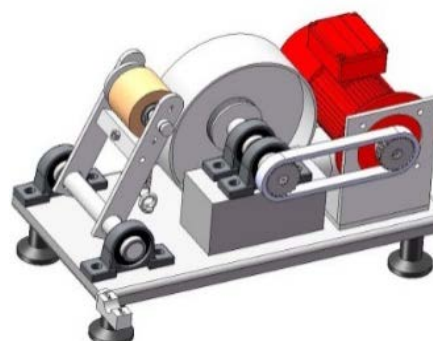


Fig. 3. The Stand

Graphical Braille matrix for visually impaired to use graphical computer interface

In IICT-BAS a technology is developed to build graphical Braille display (Braille matrix – Fig. 4.) Based on linear

electromagnetic micromotor (Fig. 5) lifting and holding the moving parts (pins) through which in the aggregate are plotted symbols (icons) that visually impaired person can perceive through touch. Studied are static, dynamic and thermographic characteristics of the constructed graphical field. It is working on the optimization of sample size and power consumption when operating with graphical Braille display using energy-efficient control model. A Braille matrix linear electromagnetic micromotor is developed to drive the needles, [2].

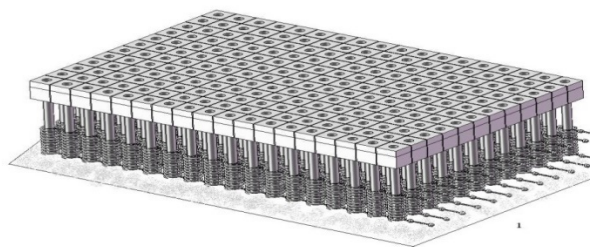


Fig. 4. A matrix of tactile Braille display

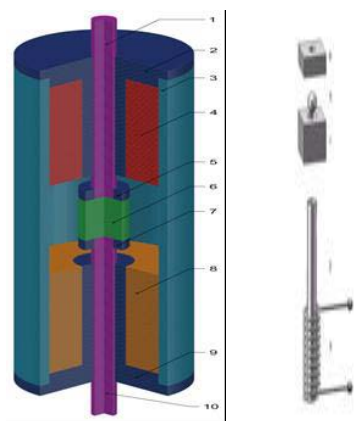


Fig. 5. Variants of linear microdrive

Plastic deformation of metals by rocket propulsion of high speed hammers

In IICT-BAS the team has made modeling, simulation and testing the processes of impact forming of metal parts with high-speed presses, powered by an industrial rocket motor - Fig. 6, [3], [9], [10], [11]. Geometry and speed parameters of the system were optimized. Process management is optimized with the aim of energy efficiency. A bench model is developed to study the dynamic deformation and thermal process parameters.



Fig. 6. Rocket motor, rocket hammer and a detail

Optimization of grinding processes by grinding bodies with new form

In IICT BAS the team has made modeling, simulation and testing the processes of grinding, using grinding bodies of spherical and spheroidal tetrahedron shape - Fig. 7. Geometric parameters of the new body were optimized. The milling process management is optimized with the aim of energy efficiency. By using a Bond mill and the spheroidal tetrahedrons as grinding bodies, it has been demonstrated a more rapid milling of the material in the same desired size or finer milling of the material in comparison with the grinding results with spherical grinding bodies,[4], [12].

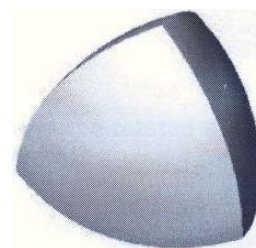


Fig. 7. The milling body

3. New methods and means

In the area of the topics described here, as a continuation of our previous studies by available methods and tools, using the Smart Lab devices, we plan to do the following scientific and applied research and development:

New materials

In the area of new materials and nano technologies related to environmental protection, we will do the following:

- Development of novel chemical nickel coating with nano elements included on the basis of Al_2O_3 , SiC, and etc.. in the crystal grid of nickel.
- Conducting research with various chemical nickel coatings with included nano components - Al_2O_3 , SiC etc. under laboratory conditions, tribological tests.
- Conducting research to abrasion, mass and linear wear of coatings developed with the involvement of nanoelements based on Al_2O_3 , SiC and others.
- Conducting research on the wear resistance of coatings developed with the involvement of nanoelements based on Al_2O_3 , SiC and others.
- Development of criteria and methods for assessing the quality of the species of tested coatings with inclusion of nanoelementi - Al_2O_3 , SiC and others.

With a resolution of $3\text{ }\mu\text{m}$ we shall examine the developed coatings (thickness $25\text{ }\mu\text{m}$) with 3D tomograph for uniformity of internal structure, surface smoothness, etc. - Fig. 8. Using a thermal camera (up to 2000°C) we shall explore the influence of nanoparticles in the electrode on the quality of welding and the uniformity of the metal cooling -Fig. 9. Using 3D tomograph we

will explore internal 3D structure of industrial parts in order to detect micro-cracks, irregularities, harmful inclusions, bubbles and more. - Fig. 10. With nano granulometer and EDEM we will explore and model the evolution of bio materials.

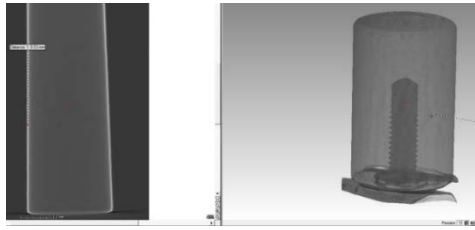


Fig. 8. 3D image of a thin coating

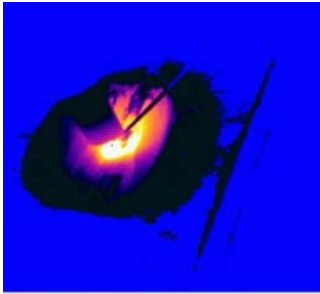


Fig. 9. Thermogram of welding

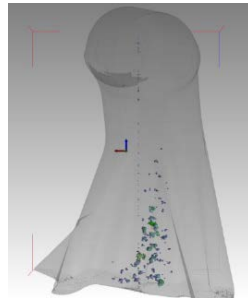


Fig. 10. Structure

Increasing the quality of life

Based on the Braille matrix, driven by linear electromagnetic micro motors we will:

- Minimize the amount of linear electromagnetic micro motors
- Examination of static and dynamic characteristics of new drives
- Optimization of electromagnetic forces and fields of linear micro motors
- Reducing the mutual influence between the fields of individual micro motors
- Energy efficient management of micro motors by switching action
- Increasing the number of the micro motor and the amount of Braille matrix.

In order to examine and test the circuit scheme of Braille matrix, we will use the developed and protected by patent micromanipulator with piezo-driven joints - Fig. 11. Micromanipulator includes mobile units consisting of shoulder and embedded in the actuator piezoceramic element – actuator. We will use a thermal camera for research and optimization of the circuit diagram of the Braille matrix to reduce the thermoemissions.

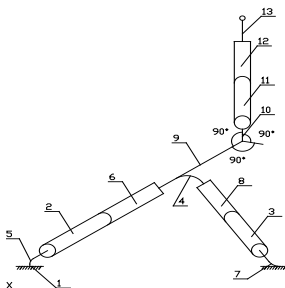


Fig. 11. Micromanipulator



Fig. 12. Driving pilots

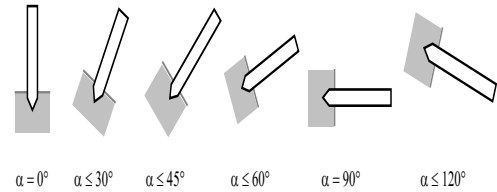


Fig. 13. Driving non-vertical piles

New technologies

On the basis of the developed high-speed rocket propulsion, we will perform research and development with the application of a combined impact (with an additional force of a rocket motor). Except for deformation of metals (pressing), we will examine the effects of application of high-speed rocket propulsion in the following cases:

- *driving in of piles.* Within the current technology, driving in of pilots to strengthen land areas is performed through an impact on the pilot by a freely falling solid body with a certain mass - Fig. 12. We will study the influence of the combined effect of the impact on the rate of subsidence of the pilot in various soils. It is expected that by analogy with stamping, when driving in with high speed (due to further acceleration of the falling mass of rocket engine) it will be obtained a reduction of the friction between the surface of the pilot and the land mass. As the rocket motor may continue to act after the impact, the force applied by it should lead to a greater penetration depth of the pilot in terms of reduced friction. Moreover, in a further independent driving we can increase the angle of non-vertical driving of pilots - Fig. 13, which now depends on gravity.

Energy efficient production

One way to increase efficiency when working with ball mills is by replacing the spherical grinding bodies with bodies of other form, [5], [13]. It will be modeled with FEM the intense-deformation state under impact of various elements from the surface of the ball-shaped spheroidal tetrahedron on a massive slab or a similar body, and it will be determined the magnitude of the moment of impact (Fig. 14). We will also seek methods and tools to optimize the control with the aim of grinding energy efficiency. Also with the aid of the laser nano granulometer, the size of grained particles will be tested.

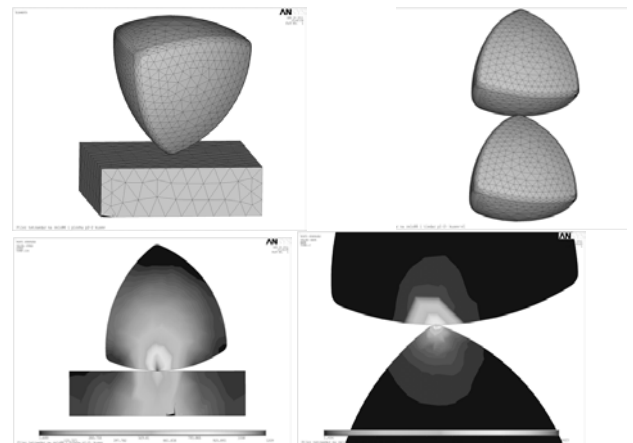


Fig. 14. Scheme of bodies using finite elements and istribution of intensity of exertions.

4. Robotics and ICT

In the area of mobile robots and group control we have research as follows:

Optimizing the navigation of mobile robot for inspection by using Robot Operating System, [14] and a thermo camera FLIR P640–Fig. 15, [6]. For simultaneous localization and mapping is used Kinect sensor – Fig. 16. The algorithm for navigation creates a map of the environment (Fig. 17), after that generate a path to the desired destination and navigate the robot. The mapping is very useful for navigation. All maps can be used in the Navigation stack for better orientation and precision. The navigation stack requires that the robot be publishing information about the relationships between coordinate frames using “tf”. The “tf” library enables sensor data. The navigation recognize if there are obstacles and avoid them. The robot can be controlled distantly over internet or it's Wi-Fi. The navigation was tested in indoor with static and dynamic obstacles.

We develop also an autonomous luggage carrier as a personal porter that follows an operator around to wherever the destination may be using wireless connectivity to the user via hand bracelet worn by the user – Fig. 18. The luggage carrier will be capable of but not limited to stop and travel in busy lines. It will also be capable of following the user to distant terminals at variable speeds. In addition to the usage in airport applications, it may also be implemented in many other settings, such as for transporting medical equipment in hospitals, usage at cruise ports, nursing homes or assisted living facilities, and many other miscellaneous personal use. The applications of this device also tailor to allowing more freedom to handicapped or elderly individuals who want to assert their independence. Still another use of this device is for laborers/professionals who are often going back and forth on job sites consuming valuable time simply transporting their equipment. A group wireless control is developed, [7].

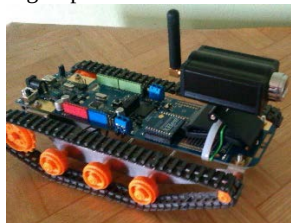


Fig.15.The robot

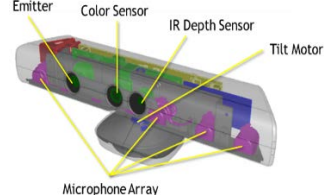


Fig.16.Kinect sensor

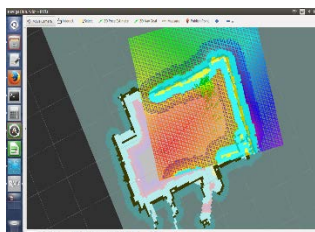


Fig.17.Generated map

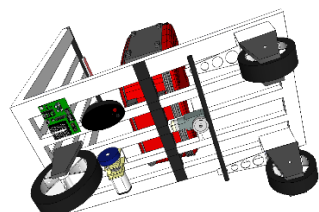


Fig.18.Luggage carrier

5. Conclusions

Using Smart Lab equipment and modern ICT we develop new methods and means for energy efficient innovative technological processes in the areas of robotics and ICT, nano materials, quality of life and environmental protection.

Acknowledgments

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MOLECULAR SIMILARITY IN THE FRAMEWORK OF A BIOISOSTERISM STUDY

ИЗСЛЕДВАНЕ НА МОЛЕКУЛЯРНА СЪВМЕСТИМОСТ В СРЕДА НА БИОИЗОСТЕРИЗЪМ

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Abstract: Bioisosterism is a strategy of Medicinal Chemistry for the rational design of new drugs (bioisosterism is also known as quantum similarity). The success of this strategy in developing new substances which are therapeutically attractive has observed a significant growth in distinct therapeutic classes, being amply used by the pharmaceutical industry to discover new analogs of therapeutic innovations commercially attractive, and also as a tool useful in the molecular modification. In this work, the concept of quantum similarity in the signed particle formulation of quantum mechanics is introduced. This concept was suggested very recently and was studied for the particular case $n=1$. Therefore, we extend the mathematical expression of similarity to the case $n>1$, with particular attention to the differences brought in this new context.

Keywords: QUANTUM SIMILARITY, MOLECULAR DESCRIPTOR, BIOISOSTERISM.

1. Introduction

The notion of molecular quantum similarity was proposed in 1980 and, since then, a growing interest has been shown towards this concept [1]. As a matter of fact, nowadays it is utilized for practical purposes in many different fields such as organic, quantum and physical chemistry. It is interesting to note that different definitions of a quantum similarity can be provided depending on the context. For example, organic chemists may define two similar molecules when they have similar reactivity in certain reactions, while quantum chemists may focus on the molecular features, etc. Therefore, it is not surprising that it is difficult, if not impossible, to provide a universal definition of quantum similarity. In spite of that, it is important to have a practical definition even though it may be related to a particular context. For instance, in a pharmaceutical context molecular quantum similarity may provide a systematic way to investigate the relation between the structure of a molecule and its chemical reactivity, thus drastically easing the process of drug design and minimizing the occurrence of side effects.

While the concept of quantum similarity is becoming widespread in many communities and different definitions are being provided, to the best of our knowledge it seems that all directions taken so far are based on the Schrödinger (or standard) formulation of quantum mechanics [2]. However, different formulations exist which may offer a different perspective on the concept of quantum similarity [3–7]. In practice, in order to concretely (mathematically) define the concept of molecular quantum similarity, one has to define a molecular descriptor first. While an infinite set of options is available, for many practical and theoretical reasons, the electron density has become the most common choice [1].

Recently, a new definition of quantum similarity has been proposed based on the concept of quasi-distribution functions [8]. This novel approach exploits the Wigner formulation of quantum mechanics which belongs to the class of phase-space formalisms and has been implemented in the framework of the Wigner Monte Carlo method [8]. On the other hand, a new formulation of quantum mechanics has recently been suggested which is based on the intuitive concept of (signed) classical particles [10]. These particles are contemporaneously provided with a position and a momentum, and therefore this formalism belongs to the class of phase-space formulations of quantum mechanics. In particular, it is able to reconstruct the corresponding Wigner quasi-distribution function of a given quantum system which, in turn, represents the molecular indicator chosen in [8]. Again, one should note that the common molecular indicator utilized in quantum chemistry is represented in the vast majority of studies by the probability density in the real

space (also referred to as electronic structure). While our definition of quantum similarity is a drastic departure from the common definition, the reader should also note that it actually corresponds to its generalization.

2. Bioisosterism

Bioisosterism is a strategy of Medicinal Chemistry for the rational design of new drugs (see reference [1] below, bioisosterism is also known as quantum similarity). The success of this strategy in developing new substances which are therapeutically attractive has observed a significant growth in distinct therapeutic classes, being amply used by the pharmaceutical industry to discover new analogs of therapeutic innovations commercially attractive, and also as a tool useful in the molecular modification. A way to achieve reliable bioisosteric analysis is by means of quantum simulation of given molecules. As a matter of fact, without simulation capabilities, this analysis would be limited to experimental observations which cannot always be provided, not to mention the high cost of such experiments. Furthermore, quantum simulations allow researchers to access to an amount of details which is practically impossible nowadays. Indeed, energy levels, electronic structure, molecular orbitals, exchange-correlation energies (just to mention a few of them) cannot be easily measured with the actual laboratory technology.

While quantum simulations for the study of bioisosterism is already available the visualization of the results obtained from these simulations is still a tricky and complex task. Indeed, it is clear that the use of a three-dimensional screen would strongly improve the understanding of bioisosteric molecules. What remains to be clarified is the way visualizations should be done to obtain an intuitive and efficient analysis. Furthermore, one of the main outcome of this investigation would be the development of a know-how that could be utilized by physicists and chemists for this particular kind of chemical/medical investigation. Finally, at least one publication about the developed technique would be published in a peer reviewed international scientific journal. An important aspect of this publication may be represented by the potential of attracting pharmaceutical and medical companies. Several simulation will be ran and a couple of several numerical experiments will be performed in order to validate the new definition. A set of molecules and crystal structures which could be used to benchmark this new framework. One of these could be the Graphene, Silicene and Titanium Dioxide which have an incredible amount of possible applications (Graphene is raising a lot of interest as one of the European H2020 Flagship Projects). The task is to create a three-dimensional visualization of meaningful molecular

orbitals which vibrate in a way which is not visible on a normal screen. This opens the door towards real-time three-dimensional visualization and manipulation of quantum objects.

A way to achieve reliable bioisosteric analysis is by means of quantum simulation of given molecules. As a matter of fact, without simulation capabilities, this analysis would be limited to experimental observations which cannot always be provided, not to mention the high cost of such experiments. Furthermore, quantum simulations allow researchers to access to an amount of details which is practically impossible nowadays. Indeed, energy levels, electronic structure, molecular orbitals, exchange-correlation energies (just to mention a few of them) cannot be easily measured with the actual laboratory technology. While quantum simulations for the study of bioisosterism is already available the visualization of the results obtained from these simulations is still a tricky and complex task. Indeed, it is clear that the use of a three-dimensional screen would strongly improve the understanding of bioisosteric molecules. What remains to be clarified is the way visualizations should be done to obtain an intuitive and efficient analysis. Furthermore, one of the main outcome of this investigation would be the development of a know-how that could be utilized by physicists and chemists for this particular kind of chemical/medical investigation. Finally, at least one publication about the developed technique would be published in a peer reviewed international scientific journal. An important aspect of this publication may be represented by the potential of attracting pharmaceutical and medical companies.

3. Molecular descriptor

In more details, in order to mathematically define the concept of molecular quantum similarity in a particular context, one must first select a significant molecular descriptor. In practical applications, this descriptor will depend on the particular simulated system and on the specific task one wants to achieve. Thus, a universal choice good for any situation is simply not possible.

In practice, one may arrange the most common descriptors in use nowadays in several main classes [10]:

- Feature counts. This is the simplest class of descriptors which consists of counting a certain feature in a molecule. An example is represented by the number of certain atomic species in a molecule.
- Physicochemical parameters. In this class, one finds the descriptors defined in terms of specific physical and/or chemical features. A good example is the partition coefficient (logP).
- Fragment descriptors. These descriptors are based on molecular two-dimensional connection tables and three-dimensional descriptions of the structure for substructure searches.
- Topological indices. This represents a wide range of atom based descriptors expressed in terms of indices. Examples are represented by the Wiener index (sometimes referred to as Wiener number).
- Field-based descriptors. Descriptors in this class are based on fields such as the electron density, the electrostatic potential, etc. This represents, at the present time, the frontline in the field of molecular quantum similarity. These descriptors can be subdivided into two sub-categories: measurable and non-measurable.
- Others. Further classes can be given [11].

Although the list of descriptors seems to be enormous, to the best of our knowledge, it seems that they all have one thing in common: they are all based on the Schrödinger formulation of quantum mechanics. No attempt to define a molecular descriptor and, thus, the notion of a molecular quantum similarity in the context of the Wigner formalism seems to have been done. Moreover, the electron density $\rho(x)$ appears, so far, to play a fundamental role in the definition of molecular quantum similarity (note that the density is usually time-independent in this context).

The focus is aimed at on defining a molecular descriptor based on the Wigner quasi-distribution function $f_W = f_W(x; p; t)$, and we investigate the possible advantages in doing so (note that the function f_W is time-dependent). In this respect, we define a new field-based molecular descriptor.

In a previous research of the author was found an intuitive definition of quantum similarity which is expressed in terms of distribution functions (in the Wigner formalism) instead of a simple probability density function (as it is done usually in other formulations of quantum mechanics). In particular, a great deal of attention has been put in the visualization of the multi-dimensional distribution functions to understand what quantities should be properly exploited. The new definition defines the similarity of two quantum systems by means of the similarity they achieve in the multi-dimensional phase-space. In practice, our new definition of quantum similarity based on the utilization of quasi-distribution functions reads:

$$d_{AB}^n(t) = \int dx \int dp \left| \left(f_W^A(x; p; t) \right)^n - \left(f_W^B(x; p; t) \right)^n \right|^{\frac{1}{n}}$$

with n an integer (taken equal to 1 in [8]). It is trivial to see that, by simulating quantum systems by means of the signed particle formulation, one can reconstruct the quasi-distribution function of two given systems and, therefore, compute their similarity.

As a matter of fact, after running several simulations, it became quickly clear that a definition in the phase-space brings several non-negligible advantages. In fact, the existence of systems which would be considered similar when the old definition is applied, but very different when the new definition is applied (because they are not similar energetically speaking) was discovered. By means of visualization tools, in particular VisIt (LLNL) and paraview (Kitware), it was possible to explain why the new definition is actually superior.

Finally, several numerical experiments have been performed in order to further validate the new definition, focusing on simple controllable chemical systems such as a free electron in vacuum and the H₂ molecule, and, in order to keep the concepts simple and clear, the validation is performed between the initial conditions and the actual conditions of a quantum system. The results clearly show that the new definition is, at least in several cases, superior.

In this project, we want to focus on the above formula and modify the integer $n=1$ to $n=2, 3, 4$. We observe that different values of this integer brings different ways of measuring the quantum similarity between two (or more) quantum systems. Such investigation will not only help us to understand what is the best possible mathematical expression of quantum similarity in the context of phase-space formulations of quantum mechanics, it will also offer a practical tool exploitable by chemistry base companies such as, for instance, pharmaceutical companies, electronics, materials, etc.

In practice, we mathematically define the new molecular quantum similarity in the following way. Given two molecules A and B described, respectively, by the quasi-distribution functions f_W^A and f_W^B , their quantum similarity is defined as:

$$d_{AB}(t) = \int dx \int dp \left| f_W^A(x; p; t) - f_W^B(x; p; t) \right|$$

where the integration is performed over the phase-space simulation domain. Obviously, this is not the only possible choice and one may consider the definition above as a special case of

$$d_{AB}^n(t) = \int dx \int dp \left| \left(f_W^A(x; p; t) \right)^n - \left(f_W^B(x; p; t) \right)^n \right|^{\frac{1}{n}}$$

with $n = 1$. It is clear from this definition that $d_{AB} \geq 0$ and two molecules are said to be similar only when their distance d_{AB} is close or equal to zero. Conversely, the bigger the number $d_{AB}(t)$ the less similar the molecules are.

The quantum system taken into account for our numerical experiments consists of an hydrogen atom in the Bohr-Oppenheimer approximation. This system is considered going from the ground state and vice versa and the quantum similarity between this two states is computed in function of time. Fig. 1 shows what the orbitals of an electron in such system look like (these results are obtained by means of the signed particle formulation [2]). In particular, the left-hand side shows the electron in the 1s state while the right-hand side shows the same electron in the 2s state.

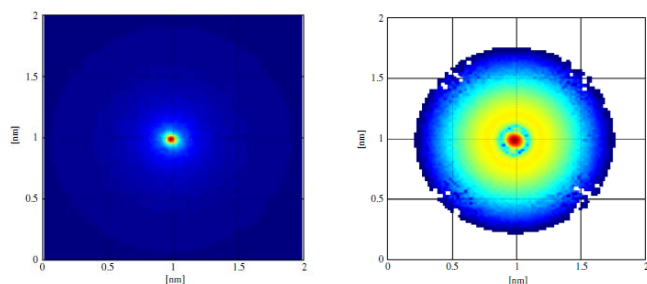


Fig. 1 Electronic orbitals in a hydrogen atom corresponding to 1s and 2s

4. Results

A wide range of outcomes is expected. As a preliminary application of our suggested approach, we show in Fig.2 the similarity in time coming from a system of Gaussian wave-packets interacting with an external potential [1].

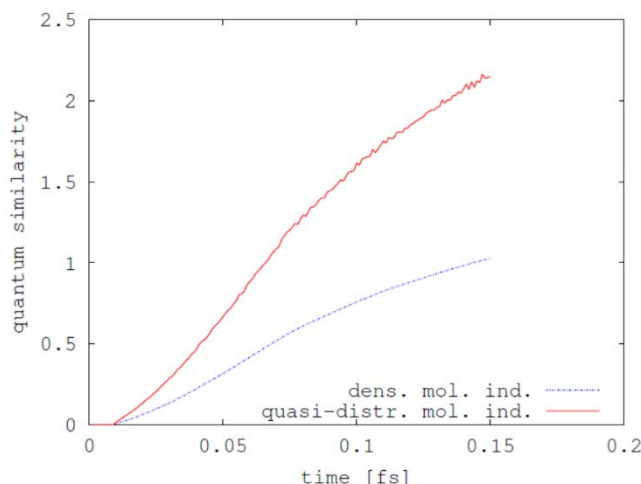


Fig.2 Comparison of quantum similarities with two different molecular descriptors for a H2 molecule. The dashed (blue) curve corresponds to the density probability as the molecular descriptor, while the continuous (red) curve corresponds to the quasi-distribution function as the descriptor [1].

Acknowledgments

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ELECTRIC DISCHARGE SYNTHESIS OF TITANIUM CARBIDE

ЭЛЕКТРОРАЗРЯДНЫЙ СИНТЕЗ КАРБИДА ТИТАНА

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Abstract: Peculiarities of titanium carbide obtainment by high voltage electric discharge synthesis (HVED) are considered in present paper. Mathematical and physical modelling of processes that occur during HVED impact on “Ti powder – hydrocarbon liquid” disperse system is performed. HVED creates thermodynamic conditions for pyrolysis of hydrocarbon liquid with formation of solid-phase carbon and gaseous hydrogen and for synthesis of titanium carbide during reaction of carbidization between titanium and carbon particles. Regularities of connection between HVED parameters and changes of dispersity and intensity of titanium carbide formation

KEYWORDS: HIGH VOLTAGE ELECTRIC DISCHARGE, PLASMA, CARBIDIZATION, POWDERS, TITANIUM

1. Introduction

Scientific interest to titanium carbide and to development of less expensive methods of its production in particular is connected with a set of unique properties that this material has. First of all, it is a high melting point and hardness, which contributed to fast development of industrial production of tungsten-free hard alloys based on titanium carbide. In its turn relatively high heat resistance and high temperature strength caused the development of methods of tools and constructional products coating with titanium carbide. It is worth noting that recently titanium carbide is increasingly used as an abrasive material [1].

Method of high voltage electric discharge treatment of titanium powder in hydrocarbon liquid [2, 3] is one of the most prospective electric discharge technologies of submicro- and nanosized TiC powders obtainment. Particular attention should be paid to multifactor impact during cyclical HVED treatment of elementary titanium powders which includes thermal impact of low-temperature plasma of discharge channel and electromagnetic and hydrodynamic impact on treated medium. Thermal impact of discharge channel plasma leads to pyrolysis of hydrocarbon liquid with formation of solid-phase carbon and gaseous hydrogen. Synthesized carbon nanoparticles can enter reaction of carbidization with Ti powder particles, with their surface layers in particular, including fresh-formed during impact destruction of Ti 3D-structures.

As the prospect of the use of HVED treatment of titanium powder in hydrocarbon liquid in order to disperse and activate powder as well as to synthesize titanium carbide, has been proven in papers [2,3], it is important to determine the factors which have the most impact on carbidization process and to define the dependences of dispersity and phase composition on impact parameters.

Because of this, the goal of present is to find the regularities of dependence of dispersity and intensity of titanium carbide formation on HVED parameters.

2. Preconditions and means for resolving the problem

2.1. Thermodynamic analysis of “Ti powder – hydrocarbon liquid” system under HVED impact

It is known that during HVED temperature of plasma in discharge channel can reach up to $\sim 4 \cdot 10^4$ K and pressure - up to ~ 1 GPa [4]. In order to evaluate processes while taking into account processes of possible reactions and formation of their final products, thermodynamic analysis of equilibrium processes, which is used in theory of metallurgy and welding for forecasting of the course of reactions, was used. Usage of this method allows assumption that, despite short duration of the process, high temperature of metal

heating and large specific area of contact ensure thermodynamic equilibrium [5]. Moreover, in paper [6] it is stressed that during electric discharge treatment thermodynamic processes can be considered adiabatic because of pulses short duration. Thermodynamic calculations are based on values of enthalpy H , entropy S , heat capacity C_p and Gibbs energy G for chemical compounds. The nature of Gibbs energy change gives an indication of the fundamental possibility of considered process. Methods of thermodynamic analysis are considered in [7] in details.

For all components of kerosene model analog for reactions of decomposition to carbon and hydrogen evaluated ΔG value is negative for decomposition of both liquid and gaseous phase. Generally, HVED impact on hydrocarbon medium by plasma channel allows obtainment of carbon in different phase states.

The inner temperature of the plasma in discharge channel which reaches up to $\sim 4 \cdot 10^4$ K is only slightly dependent on value of energy and time of its release [4]. Energy, released inside discharge channel, is mainly spent on heating of substance inside discharge channel and on the work of channel expansion on surrounding liquid. It turns out that energy, spent on heating of substance, is concentrated in relatively equally heated area of channel, while energy stored in thin transition layer between plasma and liquid is relatively small. Its thickness δ can be evaluated as $\delta \sim 2\sqrt{\chi \cdot \tau}$, where χ – coefficient of thermal conductivity, m^2/s ; τ – duration of first semiperiod of discharge, s [4].

For discharges in kerosene thickness of transient layer is microns (for example, for temperature of 900 K and pressure of 4 MPa $\chi = 1,7 \cdot 10^{-7} \text{ m}^2/\text{s}$, at $t = 5 \mu\text{s}$ thickness of layer is $\delta \approx 1,85 \mu\text{m}$), which is enough for correct evaluation of processes occurring in this area. Therefore, to achieve efficient carbidization, it is necessary to create conditions at which plasma channels will be distributed through all volume of reactor.

In considered system, the most probable reaction is formation of titanium carbide TiC (see Fig. 1) in wide temperature range.

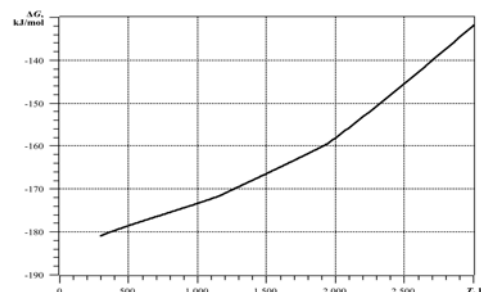


Fig. 1 Dependence of Gibbs energy change of $\text{Ti} + \text{C} \rightarrow \text{TiC}$ reaction on temperature

2.2. Methods of research

A flat, transparent discharge chamber was manufactured for physical modelling of electric discharge processes that occur in Ti powder layer, which allowed photo registration of discharges in layer of powder [9, 10]. Ti of $d_m=100\text{ }\mu\text{m}$ fraction in kerosene was an object of study. Distance between chamber walls was $D=5\text{ mm}$. A tip – plane electrode system was used for modelling. A reflex photo camera with shutter speed set in range from 2 up to 3 s was used for photography.

Experimental studies of the impact of HVED parameters on regularities of change of dispersity and phase composition of Ti powder were conducted on experimental stand, described in details in work [11], with variation of specific treatment energy in range from 10 up to 40 MJ/kg. Studies of hydrodynamic characteristics of HVED were performed in discharge chamber by waveguide pressure sensor (WPS) [12,13].

Optic and electron microscopes BIOLAM-I (БИОЛАН-И) and REMMA-102 (РЭММА-102) were used for evaluation of HVED impact on powders particles size. Phase analysis was performed on D8 Bruker ADVANCE X-ray diffractometer ($\text{CuK}\alpha$) and analog-to-digital converter. Analysis of obtained X-ray diffraction patterns was performed in QualX software with PDF-2 and POW_COD bases [14].

2.3. Physical modelling of distribution of plasma formations during HVED in kerosene – Ti powder system

Studies have shown that plasma formation appearance is observed during treatment of “titanium powder – hydrocarbon liquid” disperse system (see Fig. 2). In the beginning of studies plasma formations were observed in areas adjacent to anode and cathode (see Fig. 2, a, b) which lead to increase of gap between anode and powder layer. On the photo of 10th pulse it worth noting that local plasma formations begin appearing between particles in powder layer and that diameter of plasma formation in near-anode area increases, which indicates the increase of fraction of energy released in region between anode and powder layer. Further increase of fraction of energy released in this region leads to increase of hydrodynamic impact of gas-vapor cavity on the medium, mixing of powder and formation of Ti particles suspension in kerosene (see Fig. 2, c). Plasma formations in central part of chamber, united in channels, slowly displace powder to chamber corners, decreasing concentration of solid phase in central region which leads to increase of interelectrode gap resistance value (see Fig. 2, c, d).

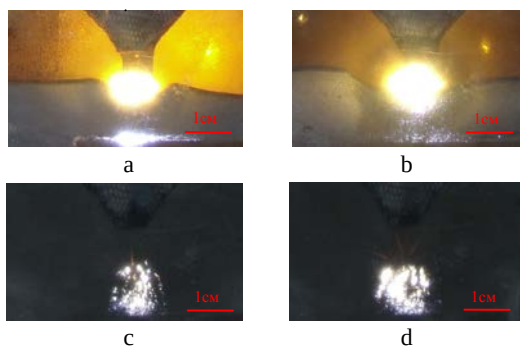


Fig. 2 Integral photos of discharge in “Ti powder – kerosene” disperse system with single discharge energy $W_1 = 90\text{ J}$ and initial dispersity $d_m = 100\text{ }\mu\text{m}$ after 5th (a), 10th (b), 50th (c) u 100th (d) pulses

Fig. 2, c, d clearly shows the multifactoriness of electric discharge impact on disperse powder – thermal impact of low-temperature plasma of discharge channel and hydrodynamic impact. Integral shots of discharges in disperse system show, that changes

of solid phase concentration in discharge gap leads to significant change of plasma formations distribution in volume of discharge chamber. Decrease of solid phase concentration in interelectrode gap leads to increase of hydrodynamic impact while electroerosion destruction of particles – removal of liquid-phase metal from treated particles surface under the impact of electrodynamic forces – weakens. It is also worth noting that decrease of concentration of solid phase in interelectrode gap leads to unnecessary intensification of carbon formation processes.

Therefore, to choose regimes of powders treatment it is necessary to find connection between pressure amplitude and concentration of solid phase and discharge circuit parameters.

2.4. Study of hydrodynamic characteristics of HVED in “kerosene – Ti powder” system

Analysis of results if experimental study of pressure amplitude during HVED in kerosene (see Fig. 3) indicates the tendency of pressure amplitude increase from ~10 to ~25 MPa as a result of increasing capacitors capacity from 0.4 to 1.6 μF .

In case of variation of capacitors capacity in range from 0.4 to 1.6 μF during HVED in kerosene with addition of Ti powder (S:L rate 1/18) values of pressure amplitude (see Fig. 3, curve 3) decrease ~1.8 times in average if compared to HVED in kerosene in similar regimes (see Fig. 3, curve 1). Experimental values of pressure amplitude in regime with $C=1.6\text{ }\mu\text{F}$ during HVED in kerosene and in kerosene with addition of Ti powder (S:L rate 1/18) are ~26 and ~13 MPa respectively (13 MPa difference) while the standard deviations of the respective data sets are 8.84 and 2.76 MPa respectively.

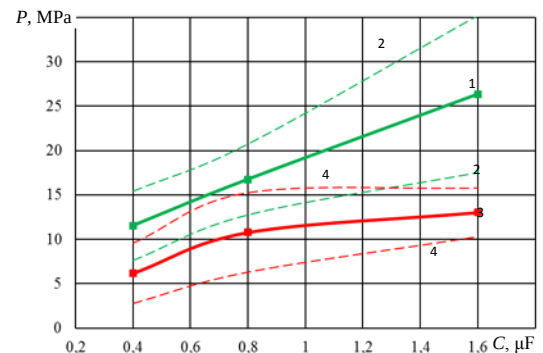


Fig. 3 Pressure amplitude during HVED with the use of kerosene as continuous medium

1 – pressure amplitude during HVED in kerosene; 2 – standard deviation of data set of HVED in kerosene; 3 – pressure amplitude during HVED in kerosene with addition of Ti powder (S:L rate 1/18); 4 – standard deviation of data set of HVED in kerosene with addition of Ti powder (S:L rate 1/18)

During HVED in kerosene in regimes with $C=0.4$ and $0.8\text{ }\mu\text{F}$ pressure wave front velocity matches speed of sound in kerosene ($v = 1330\text{ m/s}$) within margin of error. Increase of capacitors capacitance leads to increase of average pressure wave front velocity to 1363 m/s which indicates formation of shock waves.

Addition of Ti powder in kerosene (S:L rate 1/18) leads to decrease of pressure wave front velocity in regime with $C=0.4\text{ }\mu\text{F}$ to 1270 m/s (see Fig. 4, curve 3), which is less than speed of sound in kerosene. Increase of capacitors capacitance to 1.6 μF doesn't lead to significant changes of experimentally registered pressure wave front velocity. Yet, as it was mentioned earlier (see Fig. 3), amplitude of pressure on WPS in this regimes rises from 10 to 13 MPa, which confirms the assumption of interaction between pressure wave front and particles of disperse phase suspended in continuous medium.

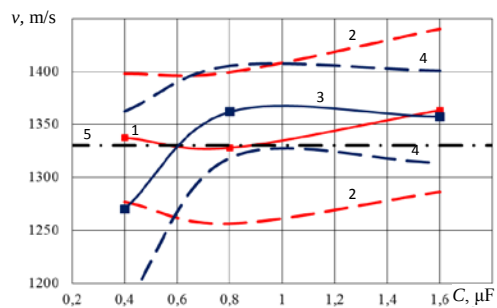


Fig. 4 Velocity of pressure wave front during HVED with the use of kerosene as continuous medium
 1 – pressure wave front velocity during HVED in kerosene;
 2 – standard deviation of data set of HVED in kerosene;
 3 – pressure wave front velocity during HVED in kerosene; with addition of Ti powder (S:L rate 1/18); 4 – standard deviation of data set of HVED in kerosene with addition of Ti powder (S:L rate 1/18); 5 – speed of sound in kerosene

2.5. Study of changes in phase composition and dispersity

Dynamics of processes of carbidization of Ti powders was studied by X-ray diffraction phase analysis (see Fig. 5) of powders while increasing specific treatment energy in range from 2 up to 20 MJ/kg.

It was found out that treatment with specific energy $W_{sp}=2$ MJ/kg leads to synthesis of titanium carbide phase (see Fig. 5, b) and its content is ~11 %. Increase of specific HVED treatment energy to $W_{sp}=10$ MJ/kg leads to significant increase of quantity and intensity of titanium carbide TiC peaks (see Fig. 5, c) and its content rises to 40 %. Further increase of specific energy to $W_{sp}=20$ MJ/kg leads to increase of titanium carbide content to ~71 % and increase of TiC peaks intensity (see Fig. 5, d).

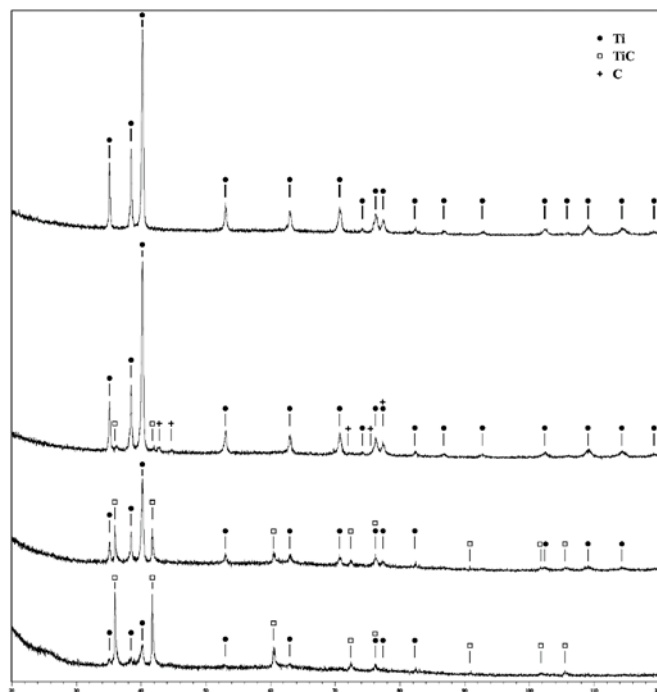


Fig. 5 X-ray diffractograms of Ti powder, initial (a) and after HVED treatment with specific energy W_{sp} 2(b), 10 (c) and 20 MJ/kg (d)

Dependence of titanium carbide quantity change (calculated with X-ray diffractograms) on specific treatment energy (see Fig. 6) can be evaluated by power function:

$$C_{Ti} = 6.335 \cdot W_{sp}^{0.805} \quad (1)$$

where C_{Ti} – is a quantity of titanium carbide, %; W_{sp} – specific treatment energy, MJ/kg. This function allows calculation of specific treatment energy necessary for carbidization of titanium powder.

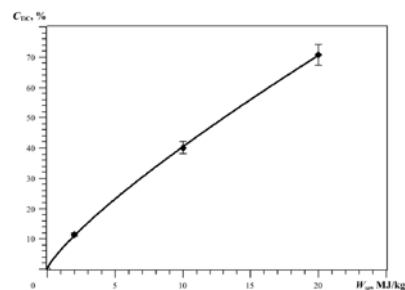


Fig. 6 Dependence of quantity of synthesized titanium carbide on specific treatment energy

It is clear that carbidization processes are accompanied by powders dispersion and activation. Results of studied have shown that the most intense 12 times grinding of treated powder (see Fig. 7) during HVED occurs after treatment with specific energy of 10 MJ/kg, maximal peak of particles sizes of 37 % lies in range of 1.3μm (see Fig. 8), which, as was mentioned earlier, contributes to carbidization and formation of ~40 % TiC. As a result, dispersed and activated titanium powder actively reacts with synthesized nanocarbon particles, forming titanium carbide.

Further increase of specific energy to 30 MJ/kg dispersion intensity decreases, but grinding continues to size of 0.3μm and is 40 %. Further increase of specific energy to 40 MJ/kg impacts value of mean diameter insignificantly, but peak of particles size distribution moves to point of 0.3 μm and is 47 % (see Fig. 9)

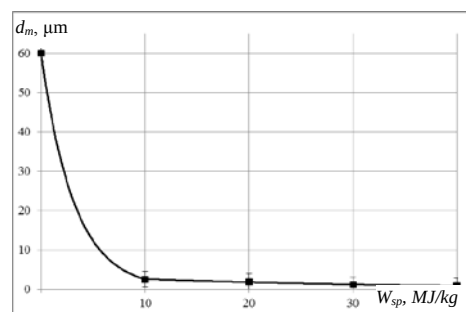


Fig. 7 Dependence of Ti powder mean diameter after HVED treatment on specific treatment energy

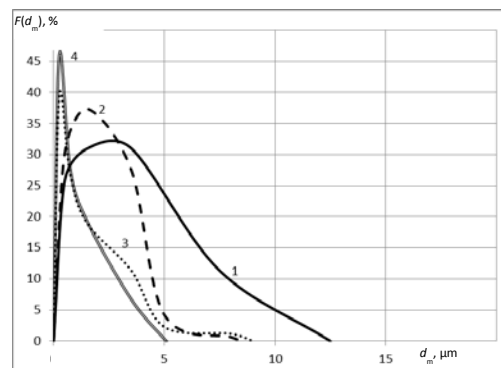


Fig. 8 Distribution of percent content $F(d_m)$ of Ti powder particles by values of mean diameter d_m after HVED treatment with specific energy W_{sp} 10 (1), 20 (2), 30 (3) and 40 MJ/kg (4)

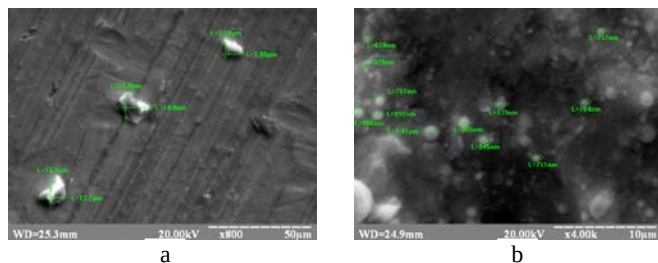


Fig. 9 Microelectronic photos of Ti powder, initial, magnification $\times 800$ (a) and after treatment with $W_{sp}=40$ MJ/kg, magnification $\times 4000$ (b)

3. Conclusion

Conditions, necessary for efficient electric discharge synthesis of titanium carbide, are theoretically justified and experimentally confirmed.

Conducted studies allowed finding regularities of connection between kinetics of processes of dispersion, activation and synthesis of titanium carbide and HVED treatment parameters

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THE EXPERIMENTAL VALVE DEVICE FOR THE GRAIN CONSUMPTION REGULATION

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Abstract: For the ensuring of uniform grain supply the silo has to be equipped with various portioning devices. The feature of the most widespread locks is the fact that at each lock opening – closing, the grain is damaged. In the article the authors describe the experimental valve device consisting of two regulating shutters: vertical and rotary. The developed experimental valve device minimizes grain damage at each cycle of an opening - closing. The statistical mathematical model is developed considering the influence on grain consumption of unloading crack height and a rotation angle of a rotary shutter. The obtained results will be used in the development of the automatic control system of grain consumption.

Keywords: VALVE DEVICE, SILO, MODEL

1. Introduction

For grain consumption control there are two types of locks which are the most widespread: rack and pinion gate and rotary valve. The peculiarity of these locks is that they disregard the difference of granular materials properties from the properties of ideal liquid. I.e., the same locks can be also applied to the water consumption regulation.

Pressure from the granular materials upon the vertical and inclined planes according to the formulas of construction mechanics [1] differs from the hydrostatic pressure as in granular materials there is the internal friction coefficient that is different from the internal friction in liquids and gases, besides, there is a friction between a wall and freight and the discontinuity of the loading application – an emptiness between freight elements and other factors. Therefore at the rational design of a locking device (taking into account that granular materials have an angle of natural slip), for a change of a lock internal cross section it'll take less energy.

The feature of the most widespread locks is the fact that at each lock opening – closing, the grain is damaged. And the more opening - closing cycles, the more grain is damaged. In Vinnikov's A.N. thesis. "Efficiency improvement of the regulation process of a self-flowing grain stream by a flexible drift locks" [2] it is investigated a possibility of the considerable reduction of the damaged grain by the application of a flexible drift lock. At the same time the hypothesis is accepted that unlike the ideal liquids at certain tilt angle of a sliding surface, the expiration of granular materials stops at the expense of the friction forces. At all its advantages the flexible drift lock has one essential shortcoming – its length has to be at 7-13 times more its diameter.

2. Research object

The research object is the experimental valve device (EVD) for the grain consumption regulation [3] developed by the staff of the North Kazakhstan state university named after M. Kozybayev (figure 1). EVD has two regulating shutters: one vertical for the regulation of an unloading crack height from 0 to 80 mm (an unloading crack width is 260 mm), and one rotary – with the length of 100 mm and an angle of rotation (from vertical position) ranging from 0° (completely closed shutter) to 135° (completely open shutter). Both shutters are made of organic glass. The developed EVD minimizes the grain damage at each cycle of opening - closing and in comparison with Vinnikov's A.N. flexible drift lock at the equal internal cross section has much smaller length that is the undoubted its advantage.

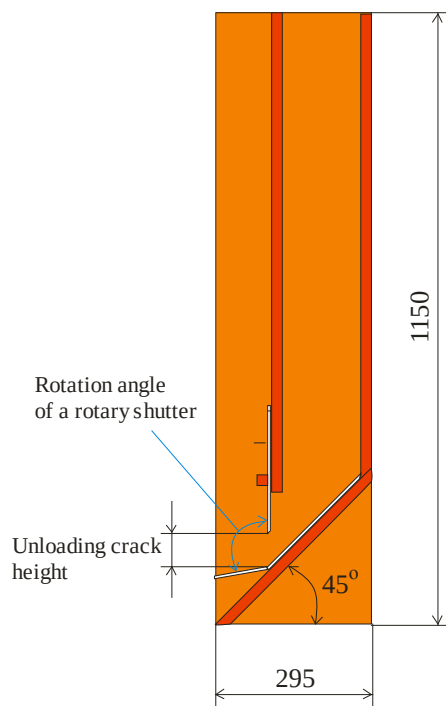


Fig. 1 Scheme of the experimental valve device.

3. Experimental part

2.1 Research of unloading crack height (in mm) influence on a rotation angle of a rotary shutter (in degrees) at which the grain continuous movement starts through unloading crack.

Fig. 2 illustrates that the relationship between unloading crack height and a shutter rotation angle, at which the grain movement starts is nonlinear and it is well described by a polynomial of the second degree:

$$\alpha = -0.0069h^2 + 0.0925h + 108.75, \text{ degrees.} \quad (1)$$

Substituting the various values of the unloading crack height (in the range from 20 to 80 mm) in the received equation it is possible to calculate the corresponding angle of a shutter rotation at which the grain movement starts with a big reliability. If to set an angle of rotation less than it was calculated on a formula (1) (with this height of unloading crack), then the movement of grain will stop.

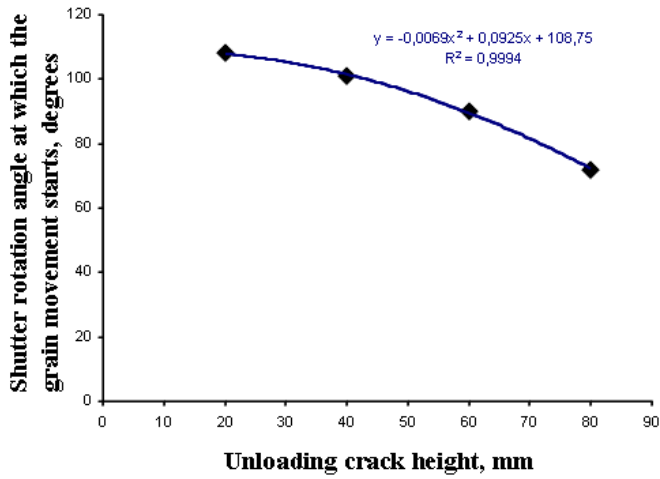


Fig. 2 The chart of relationship between unloading crack height and an angle of a shutter rotation.

The provided experiments demonstrate that the grain movement through unloading crack, when lowering a rotary shutter, starts at the grain slope angle more than $32^\circ - 34^\circ$. The grain movement is carried out when the grain slope angle is more than $32^\circ - 34^\circ$, otherwise the grain movement stops. In figure 3 the grain slope angle is shown by the size 33° at three various values of unloading crack height and rotation angles of a rotary shutter calculated on a formula (1).

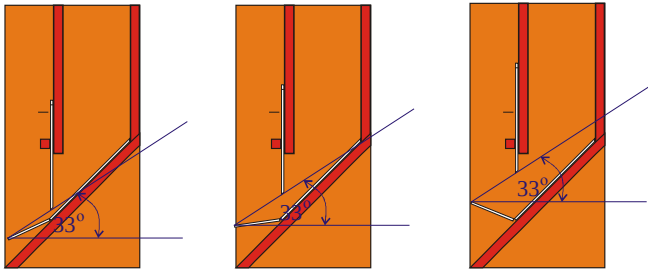


Fig. 3 Grain slope angle by the size 33° at three various values of unloading crack height.

2.2 Research of unloading crack height (in mm) influence on grain consumption through unloading crack (in t/h) at a completely open rotary shutter (an angle of rotation 135°)

Fig. 4 shows that the relationship between unloading crack height and grain consumption is linear and it is well described by the equation:

$$Q = 0,3217h - 4,283, \text{ tons/hour.} \quad (2)$$

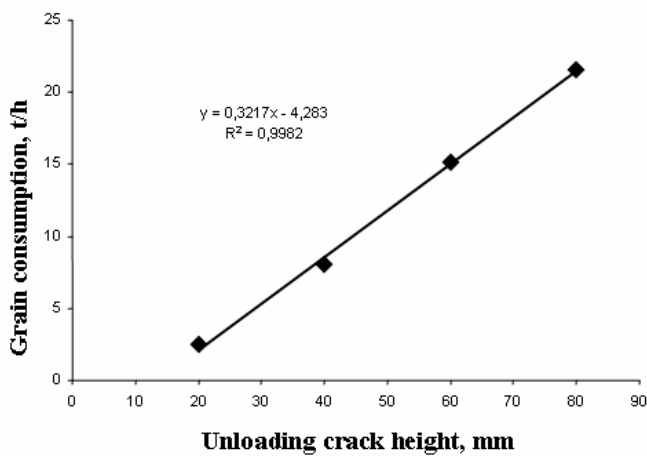


Fig. 4 The chart of relationship between unloading crack height and grain consumption.

Substituting the various values of unloading crack height (in the range from 20 to 80 mm) in the received equation it is possible to calculate grain consumption through an unloading crack with a big reliability.

2.3 Research of a rotation angle of a rotary shutter (in degrees) influence on grain consumption through unloading crack (in tons/hour), with a height of unloading crack of 60 mm

Fig. 5 illustrates that the relationship between shutter rotation angle and grain consumption is nonlinear and it is well described by a polynomial of the second order (equation (3)):

$$Q = 0.0054\alpha^2 - 0.8678\alpha + 34.45, \text{ tons/hour.} \quad (3)$$

Substituting the various values of a shutter rotation angle (in the range from 90° to 135°) in the received equation it is possible to calculate grain consumption through an unloading crack with a big reliability.

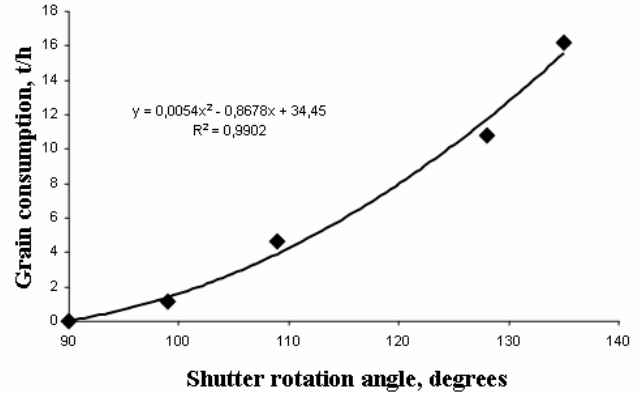


Fig. 5 The chart of relationship between shutter rotation angle and grain consumption.

3. Mathematical model of a self-flowing grain stream process regulated by means of the experimental valve device

Throughout the preliminary experiments the significant effect on grain consumption from the experimental valve device of such parameters as unloading crack height (h , mm) and a rotation angle of a rotary shutter (α , degrees) was established. Also, throughout the search experiments it was found that the loaded grain mass into EVD in the range from 3 to 9 kg doesn't influence on grain consumption from EVD value.

Taking all this into account, when planning full-factorial experiment, only the unloading crack height and a rotation angle of a rotary shutter (Table 1) were considered as input parameters.

Table 1: Plan of experiment.

№	α , degrees	h , mm
1	115°	20
2	115°	50
3	115°	80
4	125°	20
5	125°	50
6	125°	80
7	135°	20
8	135°	50
9	135°	80

According to the technique described in the work [4], the mathematical model is presented in the form of the generalized Protodyakonov's semi-empirical equation:

$$Q = \frac{(0.3081 \cdot h - 3.4784) \cdot (0.1029 \cdot \alpha - 0.9337)}{11.9244}, \text{ tons/hour.} \quad (4)$$

Substituting the various values h (in the range from 20 to 80 mm) and α (in the range from 115° to 135°) in this mathematical model it is possible to calculate grain consumption at the self-flowing expiration through an unloading crack of the experimental valve device with a high degree of reliability.

3. Results and discussion

Throughout the experiments it has been established that the grain movement through an unloading crack starts at grain slope angle more than $32^\circ - 34^\circ$. If at a rotary shutter raising the grain slope angle becomes less than $32^\circ - 34^\circ$, then the grain movement stops.

Equation was established that describes the relationship between the unloading crack height and a rotation angle of a rotary shutter at which the continuous movement of grain through an unloading crack starts. Substituting the various values of unloading crack height (in the range from 20 to 80 mm) in the received equation it is possible to calculate grain consumption through unloading crack with a high degree of reliability.

The described mathematical model of the regulation process of self-flowing grain stream allows to calculate grain consumption for various values of h (in the range from 20 to 80 mm) and α (in the range from 115° to 135°) with a high degree of reliability.

4. Conclusion

The object of the research is the experimental valve device (EVD) for the grain consumption regulation [3]. EVD has two regulating shutters: one vertical for the regulation of unloading crack height from 0 to 80 mm, and one rotary – with an angle of rotation (from vertical position) ranging from 0° (completely closed shutter) to 135° (completely open shutter).

Throughout the experiments it's defined:

A) The relationship between unloading crack height and a rotation angle of a rotary shutter at which the continuous movement (expiration) of grain through unloading crack starts;

B) The relationship between unloading crack height and a consumption of grain through unloading crack at completely open rotary shutter;

C) The relationship between a rotation angle of a rotary shutter and grain consumption through unloading crack with unloading crack height of 60 mm.

Based on the results of the full-factorial experiment it's developed the statistical mathematical model considering the influence on grain consumption of unloading crack height and a rotation angle of a rotary shutter.

The obtained model will be useful for the development of the automatic control system of grain consumption by means of the experimental valve device.

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MODERNIZATION OF EXPERT SYSTEM BASED ON THE THEORY OF IDENTIFICATION MEASUREMENT

МОДЕРНИЗАЦИЯ ЭКСПЕРТНОЙ СИСТЕМЫ НА ОСНОВЕ ТЕОРИИ ИНДЕНТИФИКАЦИОННЫХ ИЗМЕРЕНИЙ

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Abstract: *The article presents the results of research in improving the reliability of the vibration-based diagnostics test results of industrial equipment. It is possible to achieve such results through the modernization of the expert system by applying the theory of identification measurement signals. It is proposed the conversion of vibration signals into the table clusters of standard names with known distribution laws. The technique of intelligent processing of vibration signals and measurable technology to create a special database connection clusters of quantitative and qualitative evaluation of a diagnostic condition of the equipment are considered in the article.*

KEYWORDS: VIBRATION DIAGNOSTICS, EXPERT SYSTEMS, COMPUTER APPLIANCES, IDENTIFICATION OF MEASUREMENT

1. Introduction

Many years of practical experience has shown that vibration method is one of the most informative in order to control the technical condition of machinery components.

The term "analysis of vibration signals" [1] involve the study of the functional dependence of the measured vibration parameters from one or more independent variables, moreover, time, frequency, spatial coordinate or the serial number in the group of independent vibration measurements are used more often as variables.

There are many methods for the analysis and processing of vibration signals [2]. Conventionally, they are divided into two groups according to the parametric representation:

- in the time domain: mathematical analysis of the waveform and the natural oscillations, statistical and correlation analysis;
- in the frequency domain: filtering, spectral and cepstral analysis, spectral analysis of the envelope, etc.

At present, on the basis of the above methods there is the introduction of "intellectualization" in vibration diagnostic equipment through the creation of expert systems for the condition monitoring and diagnostic of vehicles and machinery using wireless technology.

At present, the effect of the introduction of the expert systems for the condition monitoring and diagnostic of equipment is significant and is as follows [3]:

- reducing the amount and cost of repairs in 2-4 times;
- decrease in the quantity of spare parts due to a previously known nomenclature;
- decrease in the total duration of repairs, because they are planned in advance;
- exclusion of replacing non-defective parts.

Temporary and frequency analysis methods of vibration signals are implemented in the expert system. Quantitative vibration settings: vibro, velocity and acceleration are defined due to the temporary methods. When they are compared with the established critical values by a decision of the need to repair and remedy the defect equipment.

The basis of the frequency methods are the following: the analysis of the spectral envelope, the shock pulse method, the control of the state in a given frequency band, the analysis of the direct spectrum, etc. The main way to solve the vibration diagnostics involves the ability of frequency filtering of the informative component of the measurement signal, which then could be used as diagnostic indicators.

In particular, the appearance of the equipment defect is accompanied by a harmonic component in vibration signals of a certain frequency and amplitude, the proportional degree of a

defect influence. Consequently, the defect type and degree of wear can be set by filtering of vibration signals.

Despite the advantages of the expert systems use for vibration diagnostics, their work is considered to be insufficiently effective, as only 60-70% of the defects are recognized, the forecast accuracy reaches 0.6, they are highly specialized [4, 5]. The main reasons for the ineffectiveness of the existing expert systems are:

- significant methodological difficulties in building of an expertise database that reflect the skills of experienced professionals - experts;
- the complexity of creating a knowledge base and database, which would take into account all external actions of random disturbing factors, incomplete information about the object state, fuzzy information, vague judgments and decisions of administrative staff;
- the effect of the nature of the dynamics of industrial activity: change of the objects and products position in the space or change the status of objects and materials in time connected with the treatment processes;
- in spite of the significant advances in the field of artificial intelligence (AI), there is still a certain technological gap between technical developments, the AI software, and the possibilities of their practical application more widely;
- diagnosis and control of the state are carried out only on the statistical parameters of vibration and power consumption, however, more effective diagnosis and monitoring should be carried out on the dynamic changes of the parameters.

The authors propose to increase the effectiveness of vibration diagnostics of expert systems by applying the theory of identification measurement tools (ThIMT) to eliminate the above-mentioned reasons.

2. Preconditions and means for resolving the problem

ThIMT - a suite of intelligent technologies (methods and computer tools) identification, recognition and digital signal processing [6, 7]. The ThIMT content are the form measurement technology - the distribution of the instantaneous values and variability - the distribution of temporary signal intervals and its characteristics with the processing of the identification parameters in the structure of global standards using the identification scale (Figure 1), consisting of identification parameters testers (IdP-testers), database (DB) and the logic analyzer (LA).

IdP-testers convert the arrays of input signal characteristics of the IdP (identification parameters), which properties are subjected to the principles of scale invariance, equivalence and coherent order.

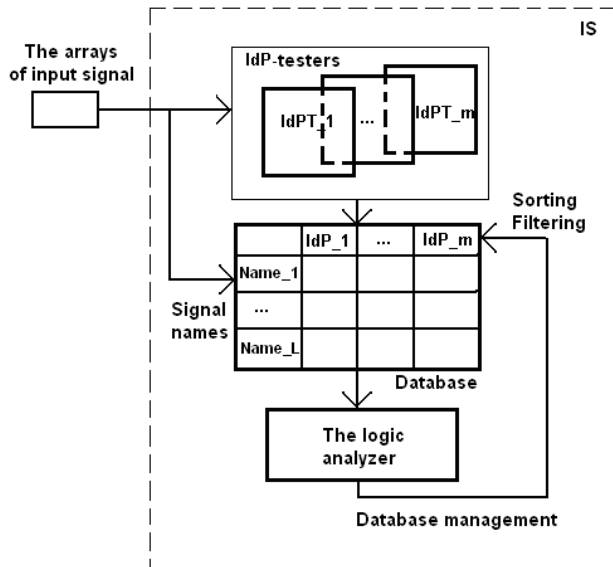


Fig. 1 Block diagram of the identification scale (IS)

Built-in database contains the values of identification parameters and the assorted names of shapes and variability of standards. The standards can act as signal characteristics of the object of certain conditions or signals with known distribution laws.

LA work is built on the issue of expert assessments (qualitative and quantitative), or recommendations of the identification measurement signal research and its characteristics, the use of methods and algorithms for sorting and filtering standards, comparison of the identification parameters of signals with reference values.

The feature of identification measurement is the ability to identify and recognize common characteristics of the composite signal and its increments: time, spectral, probability, correlation, wavelet, and most importantly, linguistic.

For research it is used the expert diagnostic system software, "IDS Kamerton- D" [8], developed by "ROS" scientific and production enterprise.

In contrast to the existing, the expert systems "ROS" SPE can be regarded as a class of intelligent systems with the following functions: measurement registration, automatic detection of object parameters, predicting failures and defects, making recommendations on the maintenance, preservation and maintenance of archive measurement records.

Mean square value (MSV) is used in orthogonal directions in the frequency range from 10 Hz to 1 kHz as parameters for the study of vibration, MSV vibration displacement and vibration acceleration in the relevant frequency band is exposed additional rationing.

Temporal and spectral characteristics of the vibration in orthogonal directions are formed as a diagnostic result. Examples of the diagnostic results at different measuring points on the centrifugal pump NM 12500-210 №12 of the pump unit are shown in Figure 2 - the real time characteristics of vibration signals and in Figure 3 - spectral characteristics of acceleration.

As seen in Figure 2, the temporal characteristics of vibration signals have a complex shape containing stationary and non-stationary components and describe their mathematical relations, internal linking structure of signals, is difficult.

However, using data ThIMT measuring signals are systematized and are suitable for the identification and recognition.

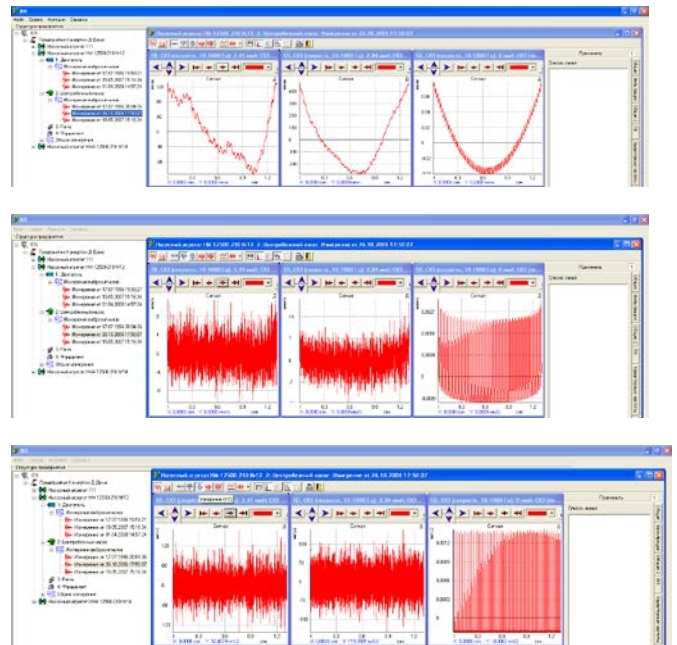


Fig. 2 The diagnostic signals in a centrifugal pump, the pump unit HM 12500-210 №12: the top row - characteristics of vibration displacement, medium - vibration, lower - acceleration.

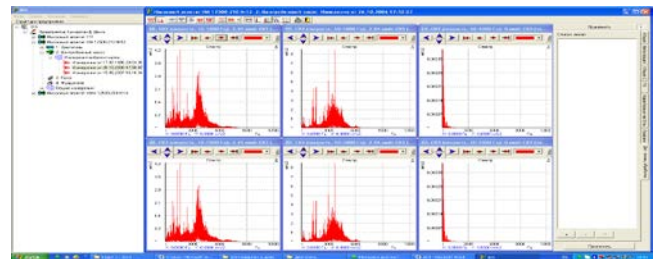


Fig. 3 Spectral characteristics of acceleration in the centrifugal pump, the pump unit NM 12500-210 №12

3. Results and discussion

The authors have been developed the intelligent computer system for the research. Its structure (Figure 4) was based on the main provisions of the theory of identification measurement and consists of a signal reader (SR), an identification signal analyzer (ISA), the comparator (C), the database of the reference signal (DBRS) tabular and hierarchical classifier (TC-HC), and the interpreter.

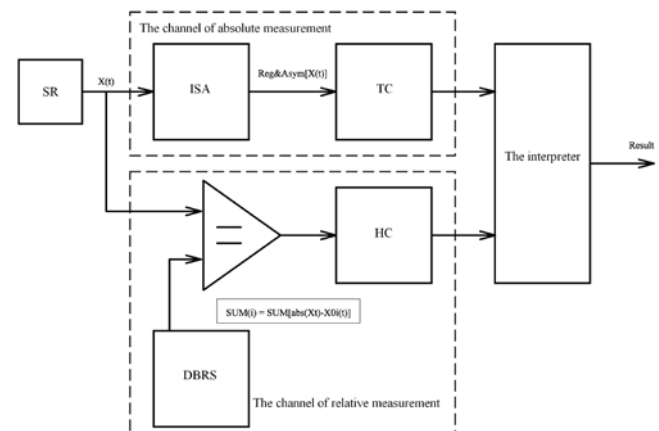


Fig. 4 Structural Studies scheme

The developed system is embedded in an expert system diagnostic software, "IDS Kamerton-D". The temporal characteristics of vibration signals from the software module "IDS Kamerton-D" are entered in an intelligent system with the help of the SR.

The test signals are analyzed by two channels: absolute and relative measurement (CAM and CRM). ISA unit measures some integrated identification parameters of signals, using which is possible to build a two-dimensional tabular classification (TC unit) – which was not used during the research.

The Comparator and DBRS are used to measure variations of the input signals from the system of 17 reference signals with the known distributions of instantaneous values: 2mod – two-modal; asin – arcsine; bern-l – Bernoulli, left; bern-r – Bernoulli, right; binom – binomial; even – uniform; exp-l – exponential, left; exp-r – exponential, right; GAMM – gamma; gaus – normal; kosch – Cauchy; lapl – bilateral exponential; pois – Poisson; rele – Rayleigh; simp – triangular; trap – trapezoidal distribution.

To estimate the total variance values study and reference signals have the same number of samples. The table of the average deviations values of all standards is automatically created as a result of the analysis. The HC unit sorts the reference signals of deviations for each of the input signals in order to be constructed then the classification tree out of the standard names.

The structure of the research system has been implemented as a computer device in LabVIEW environment. A number of relational databases has been produced in the form of tables in the EXCEL environment of identification measurement results – form view of temporal characteristics by different parameters as a result of the research. All of them are quite informative for coding, identification and detection of vibration signals.

In the interpreter (Figure 4), by sorting and filtering of database records, it is possible to build linear and tree classification linking signals filenames with diagnosable state of the object.

As a result of the research, the authors of the project developed the research computer device implementing data mining based on the identification measurements. A computer device is an intellectual analyzer, because it contains a built-in database of standards – assorted distribution of instantaneous values, automatically adjusts to a certain volume of the test sample of the input signal.

Figure 5 shows the front panel of the intellectual system. Vibration signals are automatically entered with the software module "IDS Kamerton-D" of the multi-channel diagnostic system.

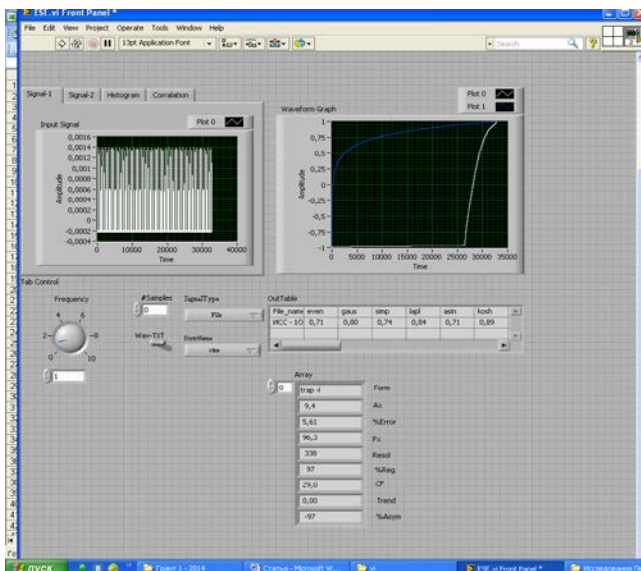


Fig. 5 Front Panel of the designed computer device

The monitor displays shows:
- a form of research signal;

- quantitative characteristics of the signal, required for analysis (amplitude, frequency characteristic, identifying the parameters of shape and variability of signal indicators and trend randomness, etc.);

- standard names of deviations from the distributions of instantaneous values of the test signal.

A lot of the time characteristics of vibration signals had been received as a result of the research. Their analysis of identification measurements using led to the following conclusions.

1. All items of diagnosis objects and every complex shaped vibration signal on the principle of assignment of the standard name with minimal deviation to the studied temporal characteristics can be represented in the form of a table cluster LC [N * M] – identification table with linguistic characteristics of LD (the names of standards with known distribution laws). Each cluster of N – number of control points, M – the number of measurement parameters.

Table 1 shows examples of 4-cluster table 2 elements (motor and pump) with two characteristic states: "defect-free state" and "Defect - bearing runout" pump set HM 12500-210 №12. For each cluster table N = 6, M = 3.

Table 1: Examples of table clusters states NM 12500-210 №12

< Defect-free state >						
CP	Motor			Pump		
	D _V	V _V	a _V	D _V	V _V	a _V
1V	fract	fract	simp	even	gaus	gaus
1O	rele	fract	simp	rele	rele	gaus
1P	rele	rele	simp	even	gaus	lapl
2V	rele	even	simp	even	gaus	gaus
2O	even	kosh	simp	rele	rele	exp-l
2P	trap	trap	simp	even	gaus	exp-l
< Defect - bearing runout >						
	Motor			Pump		
	D _V	V _V	a _V	D _V	V _V	a _V
1V	gamm	fract	simp	pois	fract	even
1O	pois	rele	simp	rele	gaus	even
1P	rele	rele	rele	gaus	even	lapl
2V	even	even	simp	rele	gaus	gaus
2O	even	kosh	pois	gaus	gaus	exp-l
2P	kosh	rele	simp	exp-l	even	exp-r

*D_V – vibration displacement, V_V – velocity, a_V – vibration acceleration, CP – control points

2. Cluster representation of the objects elements state of diagnostics by the linguistic characteristics is convenient for the constructing of the volumetric bases of vibration diagnostic information data, thus to work with clusters it is required a simple mathematical apparatus.

3. Cluster representation of complex vibration signals has led to the possibility of modernization of the existing expert system (EES). Modernize EES structure is shown in Figure 6.

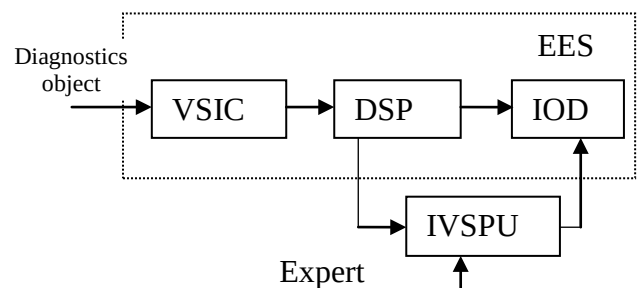


Fig. 6 Modernize expert system

EES includes the following elements: a block of vibration acoustic sensors with information converters (VSIC), multi-channel diagnostic signal processing (DSP) and an information output

display (IOD). Modernization was carried out by the inclusion of additional intellectual vibration signals processing unit (IVSPU), built on the basis of the developed computer device (Figure 5) with minor structural changes to be embedded into the EES.

In the diagnosis of EES it operates independently of IVSPU according to the established techniques and algorithms by the expert system developers, providing the expert with a diagnostic information in the form of graphs and numerical values of vibration parameters.

IVSPU operates in two modes: training and diagnostics. In the first case, it is created a special base table clusters LC [N * M] E (I) describing the state and defects of the diagnosed equipment and which subsequently act as standard. The initial information to create the database is a recommendation of an expert in non-destructive testing and diagnostics of the results obtained with the help of EES.

In the diagnostic mode, the analyzed signal is converted to a table cluster LC [N * M] X. With the method of element-wise comparison of the test cluster with clusters of standards recorded in the database, with LC [N * M] X = LC [N * M] E (I) the operator is provided a description of the equipment state with possible defects and recommendations for their elimination. In the absence of overlapping clusters IVSPU goes into teaching mode.

Thus it is conducted a comprehensive diagnosis with EES and intellectual processing of vibration diagnostic signals on the basis of identification measurements.

4. Conclusion

Modernization of vibration diagnostic expert system based on the application of the theory of identification measurement signals allow to offer a computer device that implements the conversion of vibrations into the table clusters. In this way it is possible to perform intelligent processing of vibration signals and create a special measurable database of clusters connection with quantitative and qualitative assessment of the complex objects state. The device is a complete intelligent device that is compatible with real multi-channel diagnostic complex software, "IDS Kamerton-D". During the experimental work it was found that the efficiency of diagnosis and monitoring is increasing. In particular, when the pump unit is studied, NM 12500-210 №12 accuracy assessment of the state and the probability of detection of defects increased by an average of 10%.

Intellectual power of the computer device depends on the number of used standards. Do this requires a number of technical measures for software modernization. However, in this form, the system allows us to solve many problems associated with the quantitative and qualitative assessment of the complex objects state.

It is considered the possibility of the developed technique using for the diagnosis of another type of equipment: pumping units, compressors and other rotating oil and gas equipment.

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ON A MATHEMATICAL MODEL DESCRIBING THE MOTION OF SOLID PARTICLES OF MICRO- AND NANO-SIZE IN GAS FLOW

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Abstract: In the present article, a mathematical model is developed to describe the motion of solid particles of micro- and nano-size in a gaseous medium. The model is represented by certain integro-differential equation with appropriate initial and boundary conditions. A probabilistic interpretation of the model is provided and its solvability is studied. We find that unique solution exists at certain sufficient condition. It is shown that the Fokker-Planck equation can be obtained from the integro-differential equation. Finally, a generalization to the 2D case is performed.

Keywords: NANOPARTICLES, GAS FLOW, MATHEMATICAL MODEL, FOKKER-PLANCK EQUATION

1. Introduction

Modelling the thermophoretic force acting on the flow of solid micro- and nanoparticles is difficult due to the challenge of developing a trap to ensnare the particles and agglomerates without the use of electromagnetic and chemical influences. In this paper, the construction of a 1D model of the behaviour of micro- and nanoparticles in the gaseous medium is proposed following three major assumptions ([1]):

- ♦ the influence of micro- and nanoparticles on the gas is negligible;
- ♦ the direct influence of micro- and nanoparticles on each other is negligibly small in comparison to the influence of the gas on the particles;
- ♦ micro- and nanoparticles in the gaseous medium can move both forward and backward. This restriction is imposed so that the changing current location of micro- and nanoparticles may be performed at every fixed period of time to move the micro- and nanoparticles in the gaseous medium only to a neighbouring position.

These three assumptions are quite natural assumptions, for example, if the volume and the mass concentration of micro and nanoparticles in the gaseous medium is small enough, and if there are no external system interactions (e.g., electromagnetic), which is typical for many practical applications. In addition, in this paper, we assume that the main factor affecting the micro- and nano-sized particles from the gas is Brownian motion due to thermal pressure fluctuations in the gas. If the temperature around the micro- and nanoparticles is distributed uniformly, the time average of the Brownian fluctuations is zero. If the surrounding micro- and nanoparticles have a temperature gradient, the thermal fluctuations affect the particle in different ways from different sides, and there is a thermophoretic force, biasing the average position of the particle (see, for instance, [2], [3] and the corresponding references therein). Obviously, with the assumptions made, various solid micro- and nanoparticles in the gaseous medium may have the same coordinates.

In this paper, under the above assumptions, we first construct a discrete 1D model, and then under certain additional assumptions, the purpose of which is provisioning mathematical rigor, we make a limiting process from a discrete model into a continuous, non-deterministic model, constructed in the form of an initial-boundary value problem with an integro-differential equation. Then, the solvability of the resulting integro-differential model is investigated; it is the condition of a qualitative nature in the form of

an integral inequality, the satisfaction of which ensures the existence and uniqueness of the constructed mathematical models; given the probabilistic interpretation of the constructed model and the results obtained. In addition, in the paper it is shown that under certain conditions of the constructed integro-differential model, we can obtain the initial-boundary value problem for the Fokker-Planck equation (see [3]).

2. Mathematical models

Construction of particular discrete 1D model and the question of the correct limiting process in preparing the continuous 1D model

So we begin with the behaviour of solid particles of micro- and nano-sized in a gaseous medium. We make the following two basic assumptions:

Assumption A: At any time moment $t = 0, \Delta t, 2 \cdot \Delta t, 3 \cdot \Delta t, \dots$ any micro- or nanoparticle may have one of the arbitrary coordinates $0, \pm \Delta x, \pm 2 \cdot \Delta x, \pm 3 \cdot \Delta x, \dots$;

Assumption B: If any micro- or nanoparticle has a time coordinate $n \cdot \Delta t$, then at a subsequent time moment $(n+1) \cdot \Delta t$ the same micro- and nanoparticle can have either $(i-1) \cdot \Delta x$ or $(i+1) \cdot \Delta x$ with the probability of finding micro- and nanoparticles at these two points being equal, i.e.

$$P\{x = (i-1) \cdot \Delta x\} = P\{x = (i+1) \cdot \Delta x\} = \frac{1}{2}.$$

Thus, with the two assumptions outlined above, we examine the problem of non-deterministic movements of micro- and nanoparticles, assuming that each micro and nanoparticle through each point in time may be randomly in one of two adjacent points (the distance between the points equals to Δx), regardless of the behaviour of the rest of the micro- and nanoparticles and regardless of the history of their own behaviour. As accurately predicting the location of each individual micro- and nanoparticles is not possible, the question arises whether we can find a pattern in the behaviour of the "particle-gas" system as a whole? In other words, can we determine the gas flow distribution of the micro- and nanoparticles, having only information about the initial distribution of the micro- and nanoparticles in the stream?

Consider each point / particle from the general system of micro and nanoparticles with coordinates $m \cdot \Delta x$ ($m = 0, \pm 1, \pm 2, \dots$). Let the number of micro- and nanoparticles in the gas flow at each point $m \cdot \Delta x$ be much greater than one. Then, with relative high

accuracy, we can assume that half of the micro- and nanoparticles, which are at time moment $n \cdot \Delta t$ at point $m \cdot \Delta x$, during Δt will move forward on the axis OX at a distance Δx , and the other half will move in the opposite direction. If we introduce a new feature $U(m, n)$, $m = 0, \pm 1, \pm 2, \dots$; $n = 0, 1, 2, \dots$ that means the number of micro nanoparticles at a time $n \cdot \Delta t$ at the point with coordinates $m \cdot \Delta x$, then assuming that the above assumption is performed accurately, the following is obtained:

$$U(m, n+1) \approx \frac{U(m-1, n) + U(m+1, n)}{2}. \quad (1)$$

The equation (1) indicates that at any given time and coordinate, there are half the number of micro and nanoparticles that were in the previous time station at the points to the left and right combined. In the formula (1) the left and right sides cannot be equated, as this assumption is not always unconditionally true. For example, if the value of $U(m, n)$ is small, then the formula (1) with the strict equality sign is in conflict with the fact that the values of $U(m, n)$ must be integers and, moreover, the number of micro and nanoparticles on the edge of the considered gas flow volume for each time step Δt must be divisible in half, i.e. it should be an even number.

So, if we know the initial distribution $U(m, 0)$ of micro- and nanoparticles in a volume of gas flow, then the recursive formula (1) can approximately find the required distribution of micro- and nanoparticles in all subsequent time moments. The equation (1) implies a property that determines the behaviour of the distribution of micro- and nanoparticles with time. Indeed, when the number of micro- and nanoparticles at a certain some point becomes smaller than the arithmetic mean values of neighbouring points, then the number increases, and vice versa. In addition, because of (1) it is clear that if an interval number of micro- and nanoparticles obeys a linear distribution law, then the interior points of the segment number of micro- and nanoparticles for some time remained constant. Indeed, if $U(m, 0) = C_1 \cdot m + C_2$, where C_1, C_2 are some constants, the recursive formula (2) gives us $U(m, i) = U(m, 0), \forall i \in \mathbb{N}$. In other words, the number of micro- and nanoparticles included in the considered interval left / right is equal to the number of micro- and nanoparticles, leaving the left / right of this segment. It should be emphasized that this property is only true in the case, when the segment is not "washed out" at the edges. However, in the process of this scheme the possible initial asymmetry between the points with even and odd numbers cannot be aligned. This becomes especially clear if we consider that all of the micro- and nanoparticles at the initial time moment were concentrated at a single point. To eliminate this asymmetry we can, for example, consider scheme of walks in which micro- and nanoparticles can not only move to adjacent points, but with a certain probability stay in the same place. This circumstance does not allow us to go without some updates from the discrete formula (1) to the process under study, the continuous model, as Δx and Δt go to zero.

As we know, in physics, at the transition from the system consisting of a large number of particles in a continuous medium the concept of the linear density of a medium $\rho_m = \lim_{\Delta x \rightarrow 0} \frac{\Delta m}{\Delta x} = \frac{dm}{dx}$, is introduced, that is the mass "portion" of micro- and nanoparticles, going over a small portion of the axis per length unit of the segments OX . It is obvious that the linear density of a medium is different at various points of the axis OX and at various times t , i.e. $\rho = \rho(x, t)$. On the other hand, we can enter this density as the "density of micro- and nanoparticles"

$\rho_U = \lim_{\Delta x \rightarrow 0} \frac{\Delta U}{\Delta x} = \frac{dU}{dx}$, where U is the number of micro- and nanoparticles in a small segment of the considered gas flow. Another method of introducing the concept of linear density ρ_U synthesizes a discrete (as U is considered) and continuous (as U is differentiated by the variable x) approach to the system of "particles-gas." In both cases, it is obvious that dx should be sufficiently small compared to the characteristic length of the system as a whole, i.e. $dx \ll l$, but much larger than the characteristic distance between adjacent micro- and nanoparticles, i.e. $dx \gg \frac{l}{U}$. To continue, we were able, without loss of

understanding, to use a linear density introduced through the m - "mixing intensity of the of micro- and nanoparticles", and, through "the number of micro and nanoparticles", prove that the linear density of the number of micro- and nanoparticles is proportional to the mass density (i.e. the intensity of the mixing capacity) of the micro- and nanoparticles. In other words, we need to make sure that the linear density of the number of micro- and nanoparticles and the mass density of micro- and nanoparticles are linearly dependent. In fact, if all of flow particles have the same mass, m_{const} , then

$$dm = m_{const} \cdot dU. \text{ Hence, we obtain } \rho_U = \frac{dU}{dx} = \frac{1}{m_{const}} \cdot \rho_m, \text{ i.e.}$$

ρ_U and ρ_m differs by a constant m_{const} , which is the proportionality factor.

It was said above about the "hollowing out" of the edges of the considered segment and the inapplicability of the initial asymmetry between the points with even and odd numbers. As already noted above, the recursive formula (1) cannot go to the limits for $\Delta x \rightarrow 0, \Delta t \rightarrow 0$, without requiring the fulfilment of certain conditions in the case when on the axis OX edges of the boundaries of the segment with the passage of time, as it were "blurred". It is necessary to mathematically formulate the condition referred to in the recursive formula (1), for it to be possible to carry out the limiting processes for $\Delta x \rightarrow 0, \Delta t \rightarrow 0$. Thus, we require that the value is such that "jumps" (if there are such jumps) in the initial distribution of micro- and nanoparticles have time to dissipate so that the change in the gas flow of micro- and nanoparticles in a single time step will be substantially smaller than the characteristic values of this number. This requirement means mathematically that $n \gg 1$. The second requirement is that the boundaries of the segment are not "sprawling" on the axis OX over time, or if such a "spread" borders takes place, we (i.e. foreseeable part of the segment) are far from it. The second requirement mathematically means that $(n - |m|) \gg 1$. These two requirements enable us to realize the limiting processes in the formula (1). Indeed, if we rewrite (1) in the form

$$U(m, n+1) - U(m, n) = \frac{1}{2} \cdot [U(m-1, n) - 2 \cdot U(m, n) + U(m+1, n)],$$

then we obtain

$$\frac{U(m, n+1) - U(m, n)}{\Delta t} = \frac{(\Delta x)^2}{2 \cdot \Delta t} \cdot \frac{U(m-1, n) - 2 \cdot U(m, n) + U(m+1, n)}{(\Delta x)^2}.$$

Further, taking into account in this equation the notation $x = m \cdot \Delta x, t = n \cdot \Delta t$ and

$$\rho(x, t) = \frac{m_{const}}{\Delta x} \cdot U(m, n), \quad (2)$$

(the physical meaning of (2) is obvious: the density of the medium composed of micro and nanoparticles), and implementing the limit as $\Delta x \rightarrow 0$, $\Delta t \rightarrow 0$, we get

$$\frac{\partial \rho(x, t)}{\partial t} = \frac{h^2}{2 \cdot \omega} \cdot \frac{\partial^2 \rho(x, t)}{\partial x^2}, \quad (3)$$

where $\frac{h^2}{2 \cdot \omega} \stackrel{def}{=} \lim_{\substack{\Delta x \rightarrow 0 \\ \Delta t \rightarrow 0}} \left(\frac{\Delta x}{\sqrt{2 \cdot \Delta t}} \right)^2 > 0$ is called the coefficient of sensitivity.

Obviously, the sensitivity factor may be interpreted as the number of micro- and nanoparticles passing per time unit through a length unit of a segment (area) density gradient of micro- and nanoparticles equal to one. In this interpretation, the sensitivity factor reflects the rate of the random motion of micro and nanoparticles, which is determined by the properties of the 1D gaseous medium.

If the movement of micro- and nanoparticles is not included in its equilibrium state, i.e. if the number of micro- and nanoparticles arriving / to any segment included consideration of gas flow per volume unit per time unit is not equal to the number of micro- and nano particulate departing from this segment, the sensitivity factor is a function of time: $\frac{h^2}{2 \cdot \omega(t)}$. Generally speaking, the coefficient

of sensitivity to the actual process of random motion micro- and nanoparticles is an unknown factor. Moreover, considering it constant, we are quite strongly limiting the assumption of unchanged during the entire interval of time sensitivity factor of observations, and the assumption of a known value of this constant is a purely statistical assumption not fully reflects the characteristics of the process of random motion of micro and nanoparticles in the gaseous medium. Therefore, there is just only the problem of determining the sensitivity factor under some additional conditions on the distribution and micro- and nanoparticles. This question, which is an independent inverse problem, is not considered in this paper.

Note that the equation (3) can also be obtained in another way if we use the notation (2) and the recursive relation (1). Indeed, by multiplying (1) by $\frac{m_{const}}{\Delta x}$, and using the item (2), we obtain

$$\rho(x, t + \Delta t) = \frac{1}{2} \cdot [\rho(x - \Delta x, t) + \rho(x + \Delta x, t)].$$

Hence we have the equality

$$\begin{aligned} \sum_{n=0}^{\infty} \frac{(\Delta t)^n}{n!} \cdot \frac{\partial^n \rho(x, t)}{\partial t^n} &= \\ &= \frac{1}{2} \cdot \left[\sum_{n=0}^{\infty} (-1)^n \frac{(\Delta x)^n}{n!} \cdot \frac{\partial^n \rho(x, t)}{\partial x^n} + \sum_{n=0}^{\infty} \frac{(\Delta x)^n}{n!} \cdot \frac{\partial^n \rho(x, t)}{\partial x^n} \right], \end{aligned}$$

in which the values of the function ρ and its derivatives, are taken with the values of the arguments x and t . In the last equation, in view of the uniform convergence of the present series, we can combine these terms series. Then we get

$$\Delta t \cdot \frac{\partial \rho(x, t)}{\partial t} + o((\Delta t)^2) = \frac{(\Delta x)^2}{2} \cdot \frac{\partial^2 \rho(x, t)}{\partial x^2} + o((\Delta x)^4), \quad (4)$$

or ignoring small quantities of higher order Δx and Δt , we finally obtain the equation (3). The equation (3) is an equation for the

density $\rho(x, t)$ of the micro- and nanoparticles in the 1D gaseous medium. As mentioned above, the sensitivity coefficient (3), in general, depends on time and is an unknown to be determined. If we assume that the sensitivity coefficient is constant and is known, by the same token, we accept that h and ω are constants. In this case, it is easy to formulate some interesting consequences:

- ♦ parameter ω is of the order h^2 (it is also seen from (4));
- ♦ if we assume that at the initial time all micro- and nanoparticles are concentrated in a finite interval under consideration per volume unit of the gas flow, as time increases the edge of the "front" of the segment will diverge at a rate of $\vartheta = \lim_{\substack{\Delta x \rightarrow 0 \\ \Delta t \rightarrow 0}} \frac{\Delta x}{\Delta t} = \lim_{\Delta x \rightarrow 0} \frac{\Delta x}{o((\Delta x)^2)} = \infty$, i.e. in a

small time interval velocity increases indefinitely. In other words, in the limit, it can be found out that micro- and nanoparticles are moving per unit of time as far as desired. In fact, the mean absolute coordinate increment value of micro- and nanoparticles per time unit is finite, as in conditions where the direction of movement is random, the probability that all these movements are performed in one direction (in the limit to one point), tends to zero as $\Delta t \rightarrow 0$.

So, we have constructed a continuous 1D model (3) to uniquely identify the density of micro and nanoparticles in the gaseous medium. Now, we find out if built spared continuous 1D model from unsmoothed of initial asymmetry between the points with even and odd numbers, which was mentioned in the derivation of the discrete model (1). For this purpose, suppose that for some $t = t'$,

the density $\rho(x, t)$ of micro- and nanoparticles at some point $x = x'$ is lower than the arithmetic mean value of the density $\rho(x, t')$, then for all symmetric points of small ε -neighbourhood of the point under consideration $x = x'$, i.e.

$\forall x'' \in B_\varepsilon(x') \stackrel{def}{=} \{x : |x - x'| < \varepsilon \square 1\}$, we have the inequality

$$\rho(x', t') < \frac{\rho(x' + x'', t') + \rho(x' - x'', t')}{2}. \quad \text{Since}$$

$\rho(x', t') = \rho\left(\frac{(x' - x'') + (x' + x'')}{2}, t'\right)$, we have

$\rho\left(\frac{x' - x''}{2} + \frac{x' + x''}{2}, t'\right) < \frac{\rho(x' - x'', t') + \rho(x' + x'', t')}{2}$, which

shows the convexity of the function $\rho(x, t')$, $x \in B_\varepsilon(x')$ in at the specified time moment $t = t'$. If the function $\rho(x, t')$ is convex downwards, then $\frac{\partial^2 \rho(x, t')}{\partial x^2} > 0$. Having regard to this inequality

in the equation (3), we obtain the inequality $\left. \frac{\partial \rho(x, t)}{\partial t} \right|_{t=t'} > 0$,

which means an increase in the function $\rho(x, t)$ (here argument t' is replaced by t because of its arbitrariness). Similarly, if for

$\forall x'' \in B_\varepsilon(x') \stackrel{def}{=} \{x : |x - x'| < \varepsilon \square 1\}$ we have

$$\rho(x', t') > \frac{\rho(x' + x'', t') + \rho(x' - x'', t')}{2},$$

then by identical

reasoning we find that the function $\rho(x, t')$ is convex upwards, i.e.

$\frac{\partial^2 \rho(x, t')}{\partial x^2} < 0$. Consequently, $\left. \frac{\partial \rho(x, t)}{\partial t} \right|_{t=t'} < 0$ and the density

$\rho(x, t)$ decreases. So, we get that in both cases the function $\rho(x, t)$ as a function of a variable x is either flattened out to the linear dependence not being a constant, or to a constant. In the first case it is obvious that for $t \rightarrow \infty$ the density and flux of micro- and nanoparticles at each point are not time dependent, i.e. the process goes into a stationary state, and in the second case the mass flow of micro- and nanoparticles at each point is equal to zero, that is the process proceeds in a statistical equilibrium again. It is obvious that the continuous 1D model (3) will possess an above-described stationary state, if, for instance, at the left / right endpoint of the concerned line segment micro- and nanoparticles enter into the system "particles-gas" with constant intensity, and at the right / left endpoint of this segment micro- and nanoparticles leave the system "particles-gas" with the same intensity. The resulting flux of micro- and nanoparticles will be the same at all points of the volume unit of gaseous medium.

Probabilistic interpretation of constructed particular models and their solutions

As the continuous 1D model (3) under certain assumptions has been obtained from the discrete model (1), and the discrete model (1) is a non-deterministic model of the walks of the micro- and nanoparticles in a gaseous medium with the assumptions A and B (precisely the assumption B makes the constructed models particular), then the discrete function $U(m, n)$ and the continuous function $\rho(x, t)$ obtained from $U(m, n)$ should have probabilistic interpretations. Furthermore, other functions and parameters of the constructed mathematical models introduced above (the discrete model (1) and the continuous model (3)) must also have probabilistic characteristics. Indeed, if it is assumed that the initial distribution of the micro- and nanoparticles in a gaseous medium is unknown and the value $U(m, 0)$ is the mean value of the number of the micro- and nanoparticles in the position $m \cdot \Delta x$ at the initial time moment $t = 0$, then this will mean that the value of $U(m, 0)$ is the mathematical expectation of a random variable, which is the "number of micro- and nanoparticles" at any node of the discrete grid $\{m = 0, \pm 1, \pm 2, \dots; n = 0, 1, 2, \dots\}$. Then the mean value $U(m, 1)$ of the number of micro- and nanoparticles at time moment $t = \Delta t$ in the position $m \cdot \Delta x$ is expressed in terms of the initial values for the recurrent formula (1), in which is taken $n = 0$. Consequently, by the newly found mean values we can calculate the mean value $U(m, 2)$, etc. It is obvious that with such probabilistic interpretation these mean values $U(m, n)$ are no longer required to be integers. Summarizing, we can say that the recurrent relation (1) is the exact relation (i.e. there is strict equality sign in the (1)) between the mathematical expectation of the number of micro- and nanoparticles at the fixed time moment in the fixed place. If there is only a micro- and nanoparticle and if it is studied its "single motion" on the axis OX , then $U(m, n)$ will be signified the probability of detection of this micro and nanoparticle at the time moment $n \cdot \Delta t$ in the position $m \cdot \Delta x$. Since for the "single jump" from one node to another neighbouring node of the discrete grid, the average value of the increment of spatial coordinates is zero $((\Delta x + (-\Delta x))/2)$, then the variance of such "single jump" would be equal to $(\Delta x)^2$. Since summing up independent random variables their variances are summed up, and, obviously, during the time $t \square \Delta t$ the micro- and nanoparticle will perform exactly $\frac{t}{\Delta t}$ independent jumps, then the variance of total increment of the spatial coordinate of the micro- and nanoparticle at time moment t

will equal to $\frac{t}{\Delta t} \cdot (\Delta x)^2 = 2 \cdot t \cdot \left(\frac{\Delta x}{\sqrt{2 \cdot \Delta t}} \right)^2 = \frac{h^2 \cdot t}{\omega(t)}$. Therefore,

per time unit the variance of this total increment is equal to $\frac{h^2}{\omega(1)}$.

In other words, the sensitivity factor can be interpreted as half the variance of the total increment of coordinates of micro- and nanoparticle with the independent "jumps" in nodes of a discrete grid $\{m = 0, \pm 1, \pm 2, \dots\}$ per time unit. Now we can interpret from the probabilistic point of view also the nature of the limiting process $\Delta x, \Delta t \rightarrow 0$ from discrete 1D model (1) to a continuous 1D model (3). Indeed, as mentioned above, the parameter ω in the expression the sensitivity coefficient has the order h^2 , i.e. $\omega \square h^2$. And that, by the virtue of the described above probabilistic interpretation, is equivalent to the total variance of the increment of the spatial coordinates of micro- and nanoparticle in a fixed time t remaining a constant during the implementation of a limiting process $\Delta x, \Delta t \rightarrow 0$. This property is really a bit of a surprise and at the same time we find that the total path traversed by each micro- and nanoparticle in a fixed time t (all movements of micro- and nanoparticles, irrespective of their directions of movement, are

summed over their absolute values), is $\Delta x \cdot \frac{t}{\Delta t} = \frac{(\Delta x)^2}{\Delta t} \cdot \frac{t}{\Delta x}$ and,

therefore, for the limiting process $\Delta x, \Delta t \rightarrow 0$ the length of this path tends to infinity. This shows that the closer to the limit (of course, figuratively speaking), the greater the "instantaneous speed" of the micro- and nanoparticle. That is why in the limit the edge of the "sprawling" segment diverges completely, instantly "leaving" to infinity. After performing the limiting process from the discrete model (1) to the continuous model (3), the probabilistic interpretation of the sensitivity coefficient is the same as interpreted above. Note that the density $\rho(x, t)$ of micro- and nanoparticles in the gaseous medium after the above probabilistic interpretation of the discrete model (1) can be interpreted as the density of the mathematical expectation of "the mass of micro- and nanoparticles". In the case studying "random motion" of only one micro- or nanoparticle, the function $\rho(x, t)$ implies the probability density, i.e. is understood as a function of the probability distribution of finding this micro and nanoparticle: then, of course, should be satisfied the necessary condition of normalization $\int \rho(x, t) dx \equiv 1$. In particular, if we formulate for the equation (3) the initial boundary value problem

$$\left\{ \begin{array}{l} \frac{\partial \rho(x, t)}{\partial t} = \frac{h^2}{2 \cdot \omega} \cdot \frac{\partial^2 \rho(x, t)}{\partial x^2}, \quad 0 < x < l, \quad 0 < t \leq T; \\ \rho(x, t) \Big|_{t=0} = \rho_0(x), \quad 0 \leq x \leq l; \\ \left[\frac{\partial \rho(x, t)}{\partial x} - \lambda_i \cdot \rho(x, t) \right] \Big|_{x=x_i} = \rho_i(t), \quad 0 \leq t \leq T \\ \left[\rho'_0(x) - \lambda_1 \cdot \rho_0(x) \right] \Big|_{x=x_1} = \rho_1(t) \Big|_{t=0+0} \\ x_1 = 0+0, \quad x_2 = l-0, \end{array} \right. \quad (5)$$

then Green's Function

$$G^{(Newton)}(x, \xi; t, \tau) = \sum_{n=1}^{+\infty} \frac{G_n \cdot \sqrt{(\lambda_1^2 + \theta_n^2) \cdot (\lambda_2^2 + \theta_n^2)}}{\theta_n^2} \times \\ \times \cos(\theta_n \cdot x - \beta_1) \cdot \cos(\theta_n \cdot \xi - \beta_2) \cdot e^{-\frac{(h \cdot \theta_n)^2 \cdot (t - \tau)}{2 \cdot \omega}},$$

$$G_n = \frac{2 \cdot \theta_n^2 \cdot (\theta_n^2 + \lambda_2^2)}{\lambda_1 \cdot (\theta_n^2 + \lambda_2^2) + \lambda_2 \cdot (\theta_n^2 + \lambda_1^2) + l \cdot (\theta_n^2 + \lambda_1^2) \cdot (\theta_n^2 + \lambda_2^2)},$$

$$\theta_n > 0: \quad tg(\theta_n \cdot l) = \theta_n \cdot \frac{\lambda_1 + \lambda_2}{\theta_n^2 - \lambda_1 \cdot \lambda_2},$$

$$\beta_i (i=1,2): \quad \cos \beta_i = \frac{\theta_n}{\sqrt{\lambda_i^2 + \theta_n^2}},$$

present in the solution of the boundary value problem (5)

$$\rho(x, t) = \int_0^l G(x, \xi; t, 0) \cdot \rho_0(\xi) d\xi - \frac{h^2}{2 \cdot \tau} \cdot \left(\int_0^t G(x, 0; t, \tau) \cdot \rho_1(\tau) d\tau - \int_0^t G(x, l; t, \tau) \cdot \rho_2(\tau) d\tau \right) \quad (6)$$

as a function of instantaneous sources (or as an influence function for $\xi = 0$ и $\tau = 0$) equals the probability density of finding a micro- or nanoparticle at time moment $t > 0$, only if that the micro- or nanoparticle at time moment $t = 0$ was located in a sufficiently small neighbourhood of point $x = 0$.

Considering for the equation (3), the Cauchy problem

$$\begin{cases} \frac{\partial \rho(x, t)}{\partial t} = \frac{h^2}{2 \cdot \tau} \cdot \frac{\partial^2 \rho(x, t)}{\partial x^2}, & x \in \square^1, \quad 0 < t \leq T, \\ \rho(x, t)|_{t=0} = \rho_0(x), & x \in \square^1, \end{cases} \quad (7)$$

then for $\forall t > 0$ and $\forall x \in \square^1$ the corresponding influence function

$$G^{(Cauchy)}(x, \xi; t, \tau) = \sqrt{\frac{\omega}{2 \cdot \pi \cdot h^2 \cdot (t - \tau)}} \cdot e^{\frac{\omega(x - \xi)^2}{2 \cdot h^2 \cdot (t - \tau)}}$$

(this function is a solution of the problem (7) with the initial condition $\rho_0(x) = \delta(x - \xi)$) at point $(\xi = 0, \tau = 0)$ equals

$$\sqrt{\frac{\omega}{2 \cdot \pi \cdot h^2 \cdot t}} \cdot e^{-\left(\frac{x}{h}\right)^2 \frac{\omega}{2t}}, \quad \text{i.e. the influence function is the}$$

probability density of the micro- and nanoparticle in the gaseous medium at time moment $t > 0$, only if the micro- or nanoparticle initially at time moment $t = 0$ was located at point $x = 0$. Further, it is easy to calculate the average absolute increment of the coordinates of the micro- and nano-particle in the gaseous medium

$$\text{during } t: \quad \int_{\square^1} \sqrt{\frac{\omega}{2 \cdot \pi \cdot h^2 \cdot t}} \cdot e^{-\left(\frac{x}{h}\right)^2 \frac{\omega}{2t}} \cdot |x| dx = \sqrt{\frac{4 \cdot t}{\pi}} \cdot \sqrt{\frac{h^2}{2 \cdot \omega}}. \quad \text{In}$$

other words, the average absolute increment of coordinate for the considered "single" micro- and nanoparticle is proportional to the square root of the proportionality coefficient (between the intensity and density gradient of micro- and nanoparticles in the 1D gaseous medium) and to the value $\sqrt{t}$. This result is consistent with the mean square increment of coordinate of micro- and nanoparticle found above.

Returning to the recurrent formula (1), we emphasize again that it describes a discrete "wandering" of micro- and nanoparticles in an unit of volume of the 1D gaseous medium and was derived from the assumption that in each subsequent time moment in any point of the considered unit of volume of the gas flow there will come exactly half of the micro- and nanoparticles which were in the previous time moment in the adjacent points to the left and exactly half of the micro- and nanoparticles which were in the previous time moment in the adjacent points to the right. In other words, as the discrete model (1), and the continuous model (3) (or initial boundary value problem (5) for this model) derived from this discrete model by the

use of a limiting process (under certain additional restrictions), describe the dynamics of the distribution of micro- and nanoparticles in an unit of volume in the gas flow of the 1D medium, when the random walk of micro- and nanoparticles are allowed only to available adjacent locations on the left or right of the current location of each micro- and nanoparticle. In other words, the constructed discrete model (1) and continuous model (3) (or (5)) are mathematical models of the walk of micro- and nanoparticles in an unit of volume of the gas flow "with equally probable preference." However, in the future, we will use the term "wandering with preference" instead of a more correct term "wandering with equally probable preference", although it should be emphasized that the case, when the movement "with preference" of micro- and nanoparticle is not equally probable to neighbouring nodes of the discrete grid, the discrete model (1) (and, therefore, the continuous model (3)) will not describe this case – instead of the recurrent formula (1) there will be another recurrent formula, that differs significantly from the formula (1).

To conclude this subsection, using (5), (6) we can explain the mechanism of behaviour of the continuous 1D model (5) derived from the discrete model (1) with the strict equality sign. Indeed, taking $t = 0$, we can say that the solution of the discrete model (1) at the left end of the considered segment, i.e. at point $x = 0$, identically equals to zero, since the model (1) with the sign of the strict equality is the model of the evolution of density of micro- and nanoparticles in the gaseous medium "concentrated" for $t = 0$ in a small neighbourhood of the left edge of the considered segment. At the same time, as it can be seen from the formula (6), for all values $x \in [0, l]$ the solutions $\rho(x, t)$ are strictly positive. Hence, near the edges of the "blurred" segment, the continuous 1D model (6) loses its adequacy of being the true model, even if approximate, to determine the density of micro and nanoparticles in an unit of volume of the gas flow.

Construction of the general discrete 1D model and the question of the correct limiting process in obtaining the appropriate continuous 1D model

As has been mentioned in the previous sub-section, constructed particular models are models describing the dynamics of "with preference" micro- and nanoparticles in the gas flow of the 1D medium. Now we abandon the previous assumptions that are allowed the micro- and nanoparticles to locomote in the gaseous medium only to the neighbouring free places with respect to the current location of each micro- and nanoparticles per a volume unit of gas flow. Namely, we will make the following four basic assumptions:

Assumption C: At each time moment $t = 0, \Delta t, 2 \cdot \Delta t, 3 \cdot \Delta t, \dots$ each of the micro- and nanoparticles per volume unit of the gaseous medium can have one of coordinates $0, \pm \Delta x, \pm 2 \cdot \Delta x, \pm 3 \cdot \Delta x, \dots$

Assumption D: If any of the micro- or nanoparticles in the volume unit of the 1D gas flow has coordinate $i \cdot \Delta x$ ($i \in \square$) at time moment $n \cdot \Delta t$ ($n \in \{0 \cup \square\}$), then at the next time moment $(n+1) \cdot \Delta t$ ($n \in \{0 \cup \square\}$) the same micro- or nanoparticle can have any of the coordinates $j \cdot \Delta x$ ($j \in \square$) (not only neighbouring with the cell $i \cdot \Delta x$ coordinates $(i-1) \cdot \Delta x$ or $(i+1) \cdot \Delta x$) with probability

$$p_{n,i,j} \stackrel{def}{=} p(n; i, j) \quad (n \in \{0 \cup \square\}; \quad i, j \in \square); \quad (8)$$

Assumption E: The transition probabilities correspond to the Markovian process: for each micro- and nanoparticle in the volume unit of the gaseous medium the probability $p_{n,i,j}$ of its location in

the cell $i \cdot \Delta x$ ($i \in \square$) at the time moment $n \cdot \Delta t$ ($n \in \{0 \cup \square\}$), and in the cell $j \cdot \Delta x$ ($j \in \square$) at the next time moment $(n+1) \cdot \Delta t$ ($n \in \{0 \cup \square\}$), obeys Markov property. It means that the probabilities $p_{n;i,j}$ ($n \in \{0 \cup \square\}$; $i, j \in \square$) do not depend neither on the "gas-particles" system state at the previous time moments, nor on the behaviour of other micro- and nanoparticles in the same volume unit of the gaseous medium;

Assumption E: In the considered "particle-gas" system the micro- and nanoparticles are assumed to be almost homogeneous, and it is believed that the physical properties of the system do not depend on the direction of the walk of the micro- and nanoparticles in the gaseous medium.

Obviously, that the first of the listed four assumptions coincides with the principal assumption A made in the first subsection deriving the discrete model (1): namely the assumption A, which generates the linearity property (for the addition of initial distribution of micro- and nanoparticles in the gas flow, distribution at arbitrary time moment and subsequent time moment are summed up too), allowing to apply the principle of superposition. Looking ahead, we note that the latter assumption (i.e. assumption F), unlike the other assumptions, will not be active for the construction of the mathematical model, however, this assumption will be essential for the investigation of the constructed mathematical model, namely, for the proof of the constructed mathematical model having versatility in a certain sense (see the following subsection). Assumptions D and E, as it will be shown below, radically change the base of the considered probabilistic process of random walk of micro- and nanoparticles in the gas flow, which was also used as a base in the previous subsection for construction of mathematical models (1) and (3) (or (5)). Indeed, due to the fact that in this system of "particle-gas" each micro- or nanoparticle must be somewhere, we can write

$$\sum_{j=0, \pm 1, \pm 2, \dots} p_{n;i,j} \equiv 1 \quad \forall n \in \{0 \cup \square\}; \quad \forall i \in \square. \quad (9)$$

However, by analogy with the identity (9) we cannot say that $\sum_{i=0, \pm 1, \pm 2, \dots} p_{n;i,j} = 1$, since the value of $\sum_{i=0, \pm 1, \pm 2, \dots} p_{n;i,j}$ can take a value larger than one if the point $j \cdot \Delta x$ ($j \in \square$) of the considered segment $[-l, +l]$ is preferable for specific micro- and nanoparticle in the gas flow; and this sum may be less than one if, on the contrary, the point $j \cdot \Delta x$ ($j \in \square$) is not preferable for specific micro- and nanoparticle in the gas flow. By analogy with the function $U(m, n)$ introduced in the first subsection we introduce a new function $U(m, n) \stackrel{\text{def}}{=} U(m \cdot \Delta x; n \cdot \Delta t)$, $\Delta x \equiv \text{const.}$; $\Delta t \equiv \text{const.}$; $m \in \square$; $n = \{0\} \cup \square$, which is the number of micro- and nanoparticles in the gas flow at a time moment $n \cdot \Delta t$ in the point with coordinate $m \cdot \Delta x$. Within time interval $[n \cdot \Delta t, n \cdot \Delta t + \Delta t]$, $n \in \{0\} \cup \square$ the number of micro and nanoparticles, passing from point $m_1 \cdot \Delta x$ ($m_1 \in \square$) on the considered segment of length $2 \cdot l$ to any other point $m_2 \cdot \Delta x$ ($m_2 \in \square$; $m_2 \neq m_1$) of the same segment will be equal to $U(m_1, n) \cdot p_{n;m_1,m_2}$. Within the same time interval, in the opposite direction, i.e. from the point $m_2 \cdot \Delta x$ ($m_2 \in \square$) to the point $m_1 \cdot \Delta x$ ($m_1 \in \square$; $m_1 \neq m_2$), there will go exactly $U(m_2, n) \cdot p_{n;m_2,m_1}$ micro- and nanoparticles. Therefore, we can

write the "micro- and nanoparticles balance" by the following recursive relation:

$$\begin{aligned} U(m_1, n+1) &\approx U(m_1, n) - U(m_1, n) \cdot \sum_{\substack{m_2 \in \square \\ m_2 \neq m_1}} p_{n;m_1,m_2} + \\ &+ \sum_{\substack{m_2 \in \square \\ m_2 \neq m_1}} \{U(m_2, n) \cdot p_{n;m_2,m_1}\} = U(m_1, n) + \\ &+ \sum_{\substack{m_2 \in \square \\ m_2 \neq m_1}} \{U(m_2, n) \cdot p_{n;m_2,m_1}\} - \{1 - p_{n;m_2,m_1}\} \cdot U(m_1, n) = \\ &= \sum_{m_2 \in \square} \{U(m_2, n) \cdot p_{n;m_2,m_1}\}. \end{aligned}$$

So;

$$U(m_1, n+1) \approx \sum_{m_2 \in \square} \{U(m_2, n) \cdot p_{n;m_2,m_1}\} \quad (\forall m_1 \in \square). \quad (10)$$

Sense of (10) is quite obvious: any micro- and nanoparticle in the considered volume unit of gas flow at time moment $n \cdot \Delta t + \Delta t$ ($n = 0, 1, 2, \dots$) must come from somewhere to the point with coordinate $m_1 \cdot \Delta x$ ($m_1 \in \square$). It is appropriate to note that the discrete model (1) built in the first subsection is a special case of the discrete model (10). Indeed, assuming in (10) that

$$\forall m_1, m_2 \in \square : p_{n;m_2,m_1} = \begin{cases} \frac{1}{2}, & \text{if } |m_1 - m_2| = 1; \\ 0, & \text{if } |m_1 - m_2| \neq 1, \end{cases}$$

we get the recurrence formula (1).

Absolutely in the same manner as in the first subsection in the discrete model (1) the limiting processes $\Delta x \rightarrow 0$ and $\Delta t \rightarrow 0$ were performed, we can also implement the relevant limiting processes $\Delta x \rightarrow 0$ and $\Delta t \rightarrow 0$ in the discrete model (10). This can occur together with the following two situations:

Situation A: If the average "jump" of each micro- and nanoparticle in the considered gas flow for one time step also tends to zero for $\Delta x \rightarrow 0, \Delta t \rightarrow 0$, then the limiting processes $\Delta x \rightarrow 0, \Delta t \rightarrow 0$ in the discrete model (10) again lead to a differential equation with respect to the required density $\rho(x, t)$ of micro- and nanoparticles in the gas flow, and in the equation (in particular, equation (3)) only those micro- and nanoparticles of the gas flow will be "connected" which form a kind of a continuous medium in which the micro and nanoparticles do not collide (do not interact), but are "infinitely close" to each other. For example, if determined by the formula (8) discrete function $p_{n;i,j}$ does not depend on $n \in \{0 \cup \square\}$ (i.e. $p_{n;i,j} \equiv p_{i,j}$ for $\forall n \in \{0 \cup \square\}$) and has the form $p_{i,j} = p(i-j)$, $i, j \in \square$, then, obviously, the average "jump" of each micro- and nanoparticle in the given volume unit of the gas flow for one time step tends to zero;

Situation B: If the average "jump" of each micro- and nanoparticle for one time step does not obligatory tend to zero for $\Delta x \rightarrow 0, \Delta t \rightarrow 0$, then the limiting processes $\Delta x \rightarrow 0, \Delta t \rightarrow 0$ in the discrete model (10) will lead to an integral (total) ratio relative to the required density $\rho(x, t)$ of micro- and nanoparticles in the gas flow, i.e. in this case for $\Delta x \rightarrow 0, \Delta t \rightarrow 0$ sums will turn into partial derivatives, but integrals.

We will not examine the situation A, but study the situation B. However, after examining this situation we will return to the situation A in two different ways, namely, in the results obtained in the situation B, we will directly assume that the situation A holds.

So, we assume that the situation B holds. Then, we rewrite the discrete model (10) in the following form:

$$U(m_1, n+1) - U(m_1, n) \approx \sum_{\substack{m_2 \in \mathbb{Z} \\ m_2 \neq m_1}} \{U(m_2, n) \cdot p_{n; m_2, m_1}\} - \\ - U(m_1, n) \cdot \sum_{\substack{m_2 \in \mathbb{Z} \\ m_2 \neq m_1}} p_{n; m_1, m_2}.$$

Dividing this equation by Δt , and then taking into account the notation (2) from the first subsection in this expression, we have

$$\frac{\Delta x}{m_{const.}} \cdot \Delta \rho(m_1 \Delta x, n \Delta t) / \Delta t = \\ = \frac{\Delta x}{m_{const.}} \cdot \left\{ \sum_{\substack{m_2 \in \mathbb{Z} \\ m_2 \neq m_1}} \rho(m_2 \Delta x, n \Delta t) \cdot K(n \Delta t; m_2 \Delta x, m_1 \Delta x) - \right. \\ \left. - \rho(m_1 \Delta x, n \Delta t) \cdot \sum_{\substack{m_2 \in \mathbb{Z} \\ m_2 \neq m_1}} K(n \Delta t; m_1 \Delta x, m_2 \Delta x) \right\}, \quad (11)$$

where $K(n \Delta t; p_1 \cdot \Delta x, p_2 \cdot \Delta x) \stackrel{\text{def}}{=} \frac{p(n \Delta t; p_1 \cdot \Delta x, p_2 \cdot \Delta x)}{\Delta t}$

and $p_i \in \{m_1, m_2\}$, $i = 1, 2$.

Now, denoting in the equation (11) $x = m_1 \cdot \Delta x$, $y = m_2 \cdot \Delta x$, $t = n \cdot \Delta t$, and then performing limiting processes $\Delta x \rightarrow 0$, $\Delta t \rightarrow 0$, we obtain the following integro-differential equation with the respect to the required density $\rho(x, t)$ of micro- and nanoparticles in the 1D gas flow:

$$\frac{\partial \rho(x, t)}{\partial t} = \int_{-l}^{+l} K(t; y, x) \cdot \rho(y, t) dy - \\ - \rho(x, t) \cdot \int_{-l}^{+l} K(t; x, y) dy; \quad x \in (-l, +l), \quad t \in (0, T], \quad (12)$$

where function $K(t; z_1, z_2) \geq 0$, $t \in [0, T]$, $z_i \in [-l, +l]$, $i = 1, 2$ is the kernel of the integro-differential equation (12), and is interpreted as follows: the probability that each micro- and nanoparticle in the gas flow which at time moment $t \in [0, T]$ was in the point $z_1 \in [-l, +l]$, at the next time moment $t + \Delta t$ will be in the interval $[z_2, z_2 + dz_2] \subset [-l, +l]$ ($z_1 \neq z_2$), is equal to $K(t; z_1, z_2) dz_2 dt$. In other words, kernel $K(t; z_1, z_2)$ is defined as the probability density of "jump" (taken relative to unit of time) of micro- and nanoparticles in the gas flow from point $z_1 \in [-l, +l]$ to point $z_2 \in [-l, +l]$ ($z_1 \neq z_2$) at time moment $t \in [0, T]$. In other words, the function $K(t; z_1, z_2)$ is the relative velocity of such a random "jump" of each of the micro- and nanoparticles in volume unit of gas flow at time moment t . It is worth to note that in (12) (and further throughout this paper), the value T , which means the end of the time interval within which the random movement of the dynamics of micro- and nanoparticles in the gas flow is studied, can be equal to infinity. Note that passing from the discrete equation (10) to the continuous equation (12), a well-known principle of continuous medium was used.

Thus, the integro-differential equation (12) with the initial condition $\rho(x, t)|_{t=0} = \rho_0(x)$, $x \in [-l, +l]$ (13)

is a 1D model of random walk with "no preference" of micro- and nanoparticles in the gas flow in which the unknown function is the density $\rho(x, t)$, $x \in [-l, +l]$, $t \in [0, T]$ of micro and nanoparticles. Recall that this mathematical model was obtained under the assumption of having the situation B: the average "jump" of each micro- and nanoparticle for one time step does not tend to zero for $\Delta x \rightarrow 0$, $\Delta t \rightarrow 0$. It is interesting to find out what result can be obtained if in the integro-differential equation (12), which is obtained during implementation of the situation B, the situation A will be implemented? In fact, this question implies that we want to find out to which extent the constructed mathematical model (12), (13) is a more general model (in some sense, a universal model for the considered class of "particle-gas" models) to determine the density $\rho(x, t)$ of micro- and nanoparticles in the gas flow.

Obviously, if the model is more general than, for instance, the continuous 1D model (3) of random walk of micro- and nanoparticles "with equally probable preference," then there appears the question of finding conditions under which a transition can be made from the model (12), (13) to other models, in particular, to the model (3). In the following subsections, along with other issues, we will investigate this question.

Investigation of the continuous 1D model (12), (13)

To find out whether it is possible to directly assume in the built integro-differential equation that the average "jump" of each micro- and nanoparticle in the given volume unit of the gas flow for one time step also tends to zero for $\Delta x \rightarrow 0$, $\Delta t \rightarrow 0$, we first transform the equation (12). To do this, we use the well-known formula $f(y) = \int \delta(x - y) \cdot f(x) dx$, where $\delta(\square)$ is the Dirac delta function. In this formula as the function $f(\square)$ we choose the function $\int_{-l}^{+l} K(t; \square, \xi) d\xi$. Then we obtain the identity

$$\int_{-l}^{+l} \left\{ K(t; y, x) - \delta(x - y) \cdot \int_{-l}^{+l} K(t; x, \xi) d\xi \right\} dx = 0, \quad y \in [-l, +l].$$

Let's consider this identity in the equation (13):

$$\frac{\partial \rho(x, t)}{\partial t} = \int_{-l}^{+l} \tilde{K}(t; y, x) \cdot \rho(y, t) dy, \quad (14)$$

where $\tilde{K}(t; y, x) \stackrel{\text{def}}{=} K(t; y, x) - \delta(x - y) \cdot \int_{-l}^{+l} K(t; x, \xi) d\xi,$

$$\forall x \in (-l, +l), \forall t \in (0, T].$$

The integro-differential equation (14) is equivalent to the integro-differential equation (12). Therefore, the model (14) is also a 1D model of random walk with "no preference" of the micro- and nanoparticle in the given volume unit of gas flow in respect with the required density $\rho(x, t)$, $x \in [-l, +l]$, $t \in [0, T]$ of micro- and nanoparticles, and this model is constructed under the assumption that the average "jump" of each micro- and nanoparticle for one time step does not tend to zero for $\Delta x \rightarrow 0$, $\Delta t \rightarrow 0$. Now in (14), we assume that the average free "jump" of each micro- and nanoparticle for one time step tends to zero $\Delta x \rightarrow 0$, $\Delta t \rightarrow 0$, i.e. in (14) we assume that the kernel $\tilde{K}(t; y, x)$ (or the kernel $K(t; x, y)$, if an equivalent integro-differential equation (12) is considered) for any fixed x and t as a function of one variable y is

different from zero only in a small neighbourhood of the point x :
let $t = t_0 \in [0, T]$, $\forall x = x_0 \in [-l, +l]$ and

$$\tilde{K}(t_0; y, x_0) = \begin{cases} \bar{K}(y) \neq 0, & \text{if } y \in B(\varepsilon; x_0), \\ 0, & \text{otherwise,} \end{cases} \quad (15)$$

where $B(\varepsilon; x_0) \stackrel{\text{def}}{=} \{z : \forall \varepsilon > 0 \mid |z - x_0| < \varepsilon\}$ is a ε -neighbourhood of the point $x_0 \in [-l, +l]$.

The assumption we just have made allows to state that the main contribution of the integral from the equation (14) in the region $B(\varepsilon; x_0)$ is carried out over the variable y . Therefore, we can use the expansion of the density function $\rho(y, t)$ in Taylor's series at

$$\text{point } x \in B(\varepsilon; x_0): \quad \rho(y, t) = \sum_{i=0}^{\infty} \frac{\partial \rho^i(x, t)}{\partial x^i} \cdot \frac{(y-x)^i}{i!}.$$

Substituting this expansion to the right side of the integro-differential equation (14), and then taking into account assumption F (which in the language of mathematics can be written as follows: $K(t; z_1, z_2) = K(t; |z_1 - z_2|)$, $\forall z_i \in [-l, +l]$, $i = 1, 2$):

$$\begin{aligned} \frac{\partial \rho(x, t)}{\partial t} &= \rho(x, t) \cdot \int_{-l}^{+l} \{K(t; y, x) - K(t; x, y)\} dy + \\ &+ \sum_{i=1}^{\infty} \frac{1}{i!} \cdot \frac{\partial \rho^i(x, t)}{\partial x^i} \cdot \int_{-l}^{+l} K(t; y, x) \cdot (y-x)^i dy = \\ &= \sum_{i=1}^{\infty} \frac{1}{i!} \cdot \frac{\partial \rho^i(x, t)}{\partial x^i} \cdot \int_{-l}^{+l} K(t; |y-x|) \cdot (y-x)^i dy = \\ &= \sum_{i=1}^{\infty} \frac{1}{(2 \cdot i)!} \cdot \frac{\partial \rho^{2i}(x, t)}{\partial x^{2i}} \cdot \int_{-l}^{+l} K(t; |y-x|) \cdot (y-x)^{2i} dy. \end{aligned}$$

Thus, under the conditions that

- ◆ the average free "jump" of each micro- and nanoparticle for one time step tends to zero for $\Delta x \rightarrow 0$, $\Delta t \rightarrow 0$,
- ◆ the "particles-gas" system is homogeneous, and the physical properties of the system do not depend on the direction of random walk of micro- and nanoparticles in the gas flow,

we have obtained the following result: regardless of the particular type of kernel $K(t; z_1, z_2)$ (recall that the kernel $K(t; z_1, z_2)$ is defined as the probability density of the "shift" (taken relative to unit of time) of the micro- and nanoparticles from point $z_1 \in [-l, +l]$ to point $z_2 \in [-l, +l]$ ($z_2 \neq z_1$) at time moment $t \in [0, T]$), the density $\rho(x, t)$, $(x, t) \in (-l, +l) \times (0, T]$ of micro- and nanoparticles satisfies the integro-differential equation

$$\frac{\partial \rho(x, t)}{\partial t} = \sum_{i=1}^{\infty} \frac{1}{(2 \cdot i)!} \cdot \frac{\partial \rho^{2i}(x, t)}{\partial x^{2i}} \cdot \int_{-l}^{+l} K(t; |y-x|) \cdot (y-x)^{2i} dy. \quad (16)$$

From the equation (16), it is now easy to deduce the 1D model (3), which describes the walk "with equally probable preference" of micro- and nanoparticles in the gas flow. Indeed, from (16), it follows

$$\frac{\partial \rho(x, t)}{\partial t} = \frac{1}{2} \cdot \frac{\partial \rho^2(x, t)}{\partial x^2} \cdot \int_{-l}^{+l} K(t; |y-x|) \cdot (y-x)^2 dy +$$

$$\begin{aligned} &+ \sum_{i=2}^{\infty} \frac{1}{(2 \cdot i)!} \cdot \frac{\partial \rho^{2i}(x, t)}{\partial x^{2i}} \cdot \int_{-l}^{+l} K(t; |y-x|) \cdot (y-x)^{2i} dy = \\ &= \frac{1}{2} \cdot \frac{\partial \rho^2(x, t)}{\partial x^2} \cdot \int_{-l}^{+l} K(t; |z|) \cdot z^2 dz + o((y-x)^3) = \\ &= \frac{\partial \rho^2(x, t)}{\partial x^2} \cdot \int_0^{+l} K(t; z) \cdot z^2 dz + o((y-x)^3). \end{aligned}$$

In this equation, ignoring $o((y-x)^3)$ (which is justified by assumption (15)) and introducing the function (at this stage, formally) $a(t) \stackrel{\text{def}}{=} \int_0^{+l} K(t; z) \cdot z^2 dz > 0$, $\forall t \in (0, T]$ we obtain the

$$\text{equation (3), in which } a(t) = \frac{h^2}{2 \cdot \omega(t)}.$$

The method by use of which we obtained model (3) from the equation (16) allows to obtain other continuous 1D models from the same equation (16). Precisely in this context, the equation (16) is (under the assumptions made) the general equation for determining the required density $\rho(x, t)$ of micro and nanoparticles in the gas flow. It should be emphasized that, from the point of view of mathematical rigor, introducing the function $a(t)$ was purely formal, because the issue

of the convergence of the integral $\int_0^{+l} K(t; z) \cdot z^2 dz$ was not clarified: from the equation (12) (or (14)), only the convergence of $\int_0^{+l} K(t; z) dz$ follows directly, but the convergence $\int_0^{+l} K(t; z) \cdot z^2 dz$ cannot be guaranteed. That is why the question of

rate of decrease of the kernel $K(t; z)$ with the growth of z for any fixed parameter $t = t_0 \in (0, T]$ arises. In other words, it is necessary to find a condition satisfying which would guarantee the influence of the kernel $K(t = t_0; z)$ concentrating in a small neighbourhood of zero (it is the same as the influence of the kernel $K(t = t_0; y, x = x_0)$ concentrating in $B(\varepsilon; x_0)$, $\forall \varepsilon > 0$, $\forall x_0 \in [-l, +l]$). To find this desired condition, we note that in the right-hand side of the equation (16) ignoring the term

$$\frac{\partial \rho^{2i}(x, t)}{\partial x^{2i}} \cdot \int_{-l}^{+l} K(t; |y-x|) \cdot (y-x)^{2i} dy, \quad i \in \mathbb{N}$$

is possible only if the following inequality holds:

$$\begin{aligned} &\frac{1}{(2i)!} \left| \frac{\partial \rho^{2i}(x, t)}{\partial x^{2i}} \right| \int_{-l}^{+l} K(t; |y-x|) \cdot (y-x)^{2i} dy \ll \\ &\frac{1}{(2i)!} \left| \frac{\partial \rho^{2(i+1)}(x, t)}{\partial x^{2(i+1)}} \right| \int_{-l}^{+l} K(t; |y-x|) \cdot (y-x)^{2(i+1)} dy, \quad i \in \mathbb{N}. \end{aligned}$$

Consequently, for the legitimacy of introducing the function $a(t)$ and, consequently, for the correctness of the equation (3), it is

sufficient to satisfy the condition

$$12 \cdot \left| \frac{\partial \rho^2(x, t)}{\partial x^2} \right| \cdot \int_0^{+l} K(t; z) z^2 dz \square$$

$$\square \left| \frac{\partial \rho^4(x, t)}{\partial x^4} \right| \cdot \int_0^{+l} K(t; z) z^4 dz, \forall x \in [-l, +l], \forall t \in (0, T]. \quad (17)$$

Since the resulting inequality (17) features functions $\left| \frac{\partial \rho^2(x, t)}{\partial x^2} \right|$ and $\left| \frac{\partial \rho^4(x, t)}{\partial x^4} \right|$, it is obvious that condition (17) is of little use from a practical point of view: in the specific tasks checking its implementation is impossible due to the presence of two unknown functions in it, because the density function $\rho(x, t)$ is the required function. However, in many cases the average variation range of the density $\rho(x, t)$ of micro- and nanoparticles in the gas flow can be easily measured, and using this characteristic of the considered "particles-gas" system it is easy to obtain from the relation (17) sufficient conditions for the transition from the model (16) to the model (3). Indeed, taking the value Δx as the average interval of "jump" of micro- and nanoparticles in the gas flow and taking $\Delta \rho$ as the average density variation range of micro- and nanoparticles in this interval of "jump", it can be supposed that for each $i \in \square$ the function $\left| \frac{\partial \rho^i(x, t)}{\partial x^i} \right|$ is of the order $\frac{\Delta \rho}{(\Delta x)^i}$.

Therefore, instead of unsuitable conditions (17) we can write the easily verifiable condition

$$12 \cdot (\Delta x)^2 \cdot \int_0^{+l} K(t; z) z^2 dz \square$$

$$\square \int_0^{+l} K(t; z) z^4 dz, \forall x \in [-l, +l], \forall t \in (0, T]. \quad (18)$$

Despite the fact that conditions (17) and (18) look similar, they have another significant difference (apart from the above difference that in (17), in contrast to (18), there are no unknown functions): condition (18) connects the kernel $K(t; y, x)$ to the average range of change in the density of micro- and nanoparticles, and from condition (17) this fact cannot be established, because functions $\left| \frac{\partial \rho^2(x, t)}{\partial x^2} \right|$ and $\left| \frac{\partial \rho^4(x, t)}{\partial x^4} \right|$ appearing in it are unknown, consequently, they do not lend themselves to the comparative analysis.

Condition (18) is a sufficient condition for obtaining the model (5) from the integro-differential equation (16). In addition to it, condition (18) allows one to establish the following useful property of the equation (16): even if the kernel $K(t; |y - x|)$ remains unchanged (see the probabilistic interpretation of the kernel, which was made immediately after deducing the equation (12)) for two random walk problems of micro- and nanoparticles in one of which, the value of the average interval Δx of "jump" of micro- and nanoparticles in the gas flow is relatively smaller than the corresponding values of Δx in the other problem, then the integral-differential equation (16) can lead to completely different models.

Extension of results for the 2D gaseous medium

In this subsection, generalizing the results obtained in the previous subsections, we offer a 2D model with respect to the probability density $\rho(x_1, x_2, t)$ of micro- and nanoparticles in the

gas flow in the 2D medium:

$$\begin{cases} \frac{\partial \rho(x_1, x_2, t)}{\partial t} = \int_{-l_1}^{+l_1} dy_1 \int_{-l_2}^{+l_2} K(t; y_1, y_2; x_1, x_2) \rho(y_1, y_2, t) dy_2 - \\ - \rho(x_1, x_2, t) \int_{-l_1}^{+l_1} dy_1 \int_{-l_2}^{+l_2} K(t; x_1, x_2; y_1, y_2) dy_2, \\ (x_i, t) \in (-l_i, +l_i) \times (0, T] \quad (i = 1, 2); \\ \rho(x_1, x_2, t) \Big|_{t=0} = \rho_0(x_1, x_2), \quad (x_1, x_2) \in S, \\ S \stackrel{\text{def}}{=} [-l_1, +l_1] \times [-l_2, +l_2]. \end{cases} \quad (19)$$

In (19), the function $\rho_0(x_1, x_2)$ is the primary distribution of micro- and nanoparticles of gas flow in the considered volume unit in the 2D medium; function $K(t; z_1; z_2) \geq 0$, where $z_j = (z_1^j, z_2^j) \quad (j = 1, 2)$, $z_i^j \in [-l_i, +l_i] \quad (i, j = 1, 2)$, $t \in [0, T]$, is the kernel of the integro-differential equation (19), which can be interpreted as follows: the probability that a micro- or nanoparticle in the 2D gas flow which at time moment $t \in [0, T]$ is at point $z_1 \in S$, at next time moment $(t + \Delta t)$ will be at area $S \stackrel{\text{def}}{=} [z_2, z_2 + dz_2] \subset S \quad (z_2 \neq z_1)$ is equal to the value $K(t; z_1; z_2) dz_1^2 dz_2^2 dt$. In other words, the kernel $K(t; z_1; z_2)$ is defined as the probability density of "jump" (taken relative to unit of time) of the micro- and nanoparticles in the gas flow from 2D point $z_1 \in S$ to point $z_2 \in S \quad (z_2 \neq z_1)$ at time $t \in [0, T]$. This means that the function $K(t; z_1; z_2)$ describes the relative speed of such random "transfer" of micro- and nanoparticles in volume unit of 2D gas flow at time moment t . Next, having similar arguments and calculations, as it was done in the previous subsection in the preparation of (18) now we can write the following:

$$12(\Delta s)^2 \int_0^{+l_1} dz_1 \int_0^{+l_2} \tilde{K}(t; z_1; z_2) (z_1^2 + z_2^2) dz_2 \square$$

$$\square \int_0^{+l_1} dz_1 \int_0^{+l_2} \tilde{K}(t; z_1; z_2) (z_1^2 + z_2^2)^2 dz_2, \quad \forall s \in S,$$

which allows to obtain a 2D equation of heat and mass transfer from the model (19), and

$\exists t \in [0, T] \quad \forall x = x_0 = (x_2^0, x_2^0) \in S$ such that

♦ if $y \in B(\varepsilon; x_0) \subset S$, then

$$0 \neq \tilde{K}(t; y) \stackrel{\text{def}}{=} K(t; y; x_0) - \delta(x_0 - y) \int_{-l}^{+l} K(t; x_0; \xi) d\xi;$$

♦ if $y \notin B(\varepsilon; x_0) \subset S$, then

$$K(t; y; x_0) = \delta(x_0 - y) \int_{-l}^{+l} K(t; x_0; \xi) d\xi.$$

Here $B(\varepsilon; x_0) \stackrel{\text{def}}{=} \{z = (z_1, z_2) : \|z - x_0\|_{R^2} < \varepsilon, \quad \forall \varepsilon > 0\}$

denotes ε -neighbourhood of $(x_2^0, x_2^0) \in S$; the function $\delta(\cdot)$ is the Dirac function.

3. Conclusions

In the present work, first we built up a discrete 1D model based on the following assumptions: the influence of the gas on the micro- and nanoparticles is negligible; the influence of the micro- and nanoparticles on each other is negligibly small as compared to the influence of gas on the particles; micro- and nanoparticles can move in the gas flow in different directions. At each time step a particle moves by certain distance, not necessarily to the next position. These assumptions are quite natural if, e.g., the concentration of solid particles is sufficiently small, and if external forces are absent. This situation is typical in many important applications dealing with dilute particle flows. Further in the present work, we laid down some conditions under implementation of which it is possible to carry out limiting process in the built discrete 1D model: as a result we obtain a continuous 1D model as an initial-value boundary problem for certain integro-differential equation. A probabilistic interpretation of the obtained 1D model is provided, and its solvability is studied. We find that unique solution exists at certain sufficient condition. It is shown that the Fokker-Planck equation can be obtained from the integro-differential equation. Finally, a generalization to the 2D case of the investigated problem is performed.

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OPTIMIZATION OF BIOGAS PRODUCTION FROM LIGNOCELULOSIC MATERIALS BY DIFFERENT METHODS OF SUBSTRATE TREATMENT

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Abstract: One of the most used types of biofuels is the biogas, produced during the process of anaerobic digestion of organic waste. The current project aims utilization of plant biomass waste, used to produce energy in the form of biogas, after proper pretreatment, in order to enhance energetic value and yield. Proper resource and method of pretreatment will be chosen, in order to obtain high biogas yields. The chosen technology will be tested in a plug-flow bioreactor to optimize the technical parameters.

Keywords: BIOGAS, ANAEROBIC DIGESTION, BIOMASS, LIGNOCELULOSIC MATERIAL, BIOREACTOR

1. Introduction

Biofuels represent a great share of the energy carriers of the modern developed society. They are considered an alternative to the traditional energy sources such as oil, coal and nature gas. Biofuels stands for ethanol, produced from plants, biodiesel, produced from nature lipids and biogas, produced through anaerobic digestion of plant and animal waste.

Biogas is widely used fuel in economically developed countries, as well as in the countries from 3rd world. It has many applications. Among the most important ones are as fuel for both thermal power plants, national gas grid and as a fuel in various types of vehicles, including passenger cars, trucks, small and midsize boats and aircrafts. The main source to produce biogas is manure. Some of the disadvantage of producing biogas, is the low content of methane (50-60%), as well as the presence of sulfuric compounds. In the current case, our aim is to investigate the possibilities of optimizing the methods and conditions for biogas production from vegetal waste.

Series of periodic experiments on biogas production from vegetal waste have been carried out in the Institute of Chemical Engineering (BAS). In each one of them, coniferous material was mixed with manure. Pretreatment of manure and coniferous material was conducted in some of the experiments. Most commonly, the treatment involved acid hydrolysis of the coniferous material, autoclaving applying electrical field in the reactors containing coniferous material and manure. After both materials were treated in the corresponding way, they were subjected to mesophilic anaerobic digestion in sealed glass vessels. Biogas was collected and stored above water in gas-holders. Biogas yields were checked and samples for analyze were taken daily.

During the experiments, we used a coniferous material from type *Picea excelsa* L. The first part of treatment focused on the lignocellulosic material. The branches and leaves were shredded and then collected in a beaker. After that, their weight was measured. In the next step, the material was mixed with water or acid. Then, the material was autoclaved for 20 min at 121 °C. In the meantime, the second part of the treatment was carried out. A specific amount of organic waste (cow/cattle manure) was taken, and then it was mixed with water. After that, the slightly liquefied manure was treated in various ways. One of them included passing an electrical current through the mixture for some time. After that, the lignocellulosic material and the organic waste were mixed. Then the mixture was poured in air insulated glass vessels. The vessels were installed in water bath, where the temperature was kept at around 35 °C. Each experiment included different ways of treatment, mixing and autoclaved material.

Experiment 1 has no additional treatment of the two materials used (coniferous and manure). It serves as a base experiment.

Experiment 2 Sample A contains cattle manure only. Sample B includes coniferous material mixed with acid and autoclaved. Then it was mixed with cattle manure.

Experiment 3 Sample A contains coniferous material mixed with water and then cattle manure was added. Sample B contains coniferous material treated the same way, but before adding, the cattle manure was treated with electricity for ½ hour.

Experiment 4 Sample A contains coniferous material mixed with acid and autoclaved, then before adding, the manure was treated with electricity for ½ hour. Sample B contains coniferous material mixed with water and then autoclaved. Before adding, the cattle manure was treated with electricity for 1 hour.

Experiment 5 Sample A contains coniferous material which was treated by method called “steam explosion”. Then it was mixed with manure. Sample B has the same treatment, only before adding, the manure was treated with electricity for ½ hour.



Fig. 1 Outlook of the small scale bioreactor

2. Results and Discussion

During the first part of the project, it was investigated the possibility to produce biogas by using different waste materials, which include lignocellulose, pretreated in various ways (including hydrolysis, enzymes, electrochemical processes) and kept in defined conditions (temperature – 35 °C). The materials used were mainly from plant, animal, and/or industrial waste (wasted glycerol from biodiesel production). Their treatment included different schemes of mixing, use of digestion compounds (acid hydrolysis, water autoclave, electrical treatment).

Table 1: Biogas daily yield – Samples A and B. Results from burning test.

	Biogas yield Samples A, mL	Biogas yield Samples B, mL	Total amount of burning biogas, mL
Experiment 1	2285	1691	A-2075; B-1691
Experiment 2	70	325	A-0; B-325
Experiment 3	3345	210	A-0; B-210
Experiment 4	2100	1005	A-0; B-1005
Experiment 5	328	388	A-0; B-303

In the conducted experiments, we have found out that, the treatment of the waste material with electric current leads to improvement in the ingredients of produced biogas, expressed mainly in higher methane content (reaching in some cases 95 – 98 % (vol.) in a comparison with most commonly observed 50 – 75%). It is important, as the higher methane content in the produced biogas, means better fuel properties. Therefore, the accumulated biogas (containing 95 – 98% methane), could be directly used as a

fuel in public transport, or to be supplied into the national gas grid system without additional treatment, as it is in the case with biogas with lower methane content. Then additional treatment is required, when the biogas will be used as fuel in public vehicles or the injection into the national gas grid. The treatment includes compressing, drying the biogas and separating the remaining CO₂ and sulfuric compounds (hydrogen sulfide and mercaptans). This leads to higher energetic and economic expenditure and therefore producing less amount of methane.

In the present case electric current as pretreatment method avoids the necessity of additional treatment of the produced biogas.

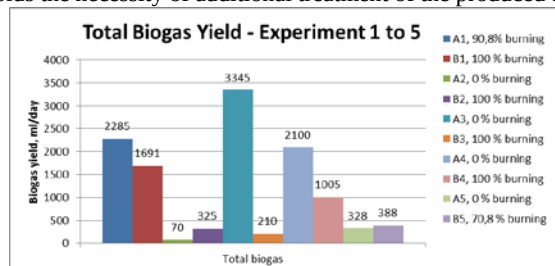


Fig.2 Biogas yield in experiments 1 to 5

Fig. 2 shows the combined results from 5 experiments. Each experiment contains two samples, named A and B. In some of the samples, the burning is 100 %, which means that all the collected for the day biogas is burnt. In others, the percentage is lower, because not all taken samples were burning (when the methane content in the taken sample drops to below 50 %, vol). Sample A3 gave the highest quantity of biogas, but there was no burning, while B3 gave much less biogas quantity, but with 100 % burning.

Fig. 3 to Fig. 6 show the corresponding biogas results for each experiment. It can be noticed that in most of the experiments, Samples A show higher amount of biogas, but has lower content of methane, while Sample B shows lower amount of biogas, but higher methane content.

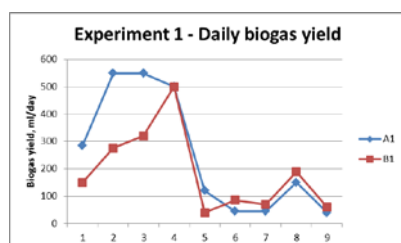


Fig.3 Biogas yield Experiment 1

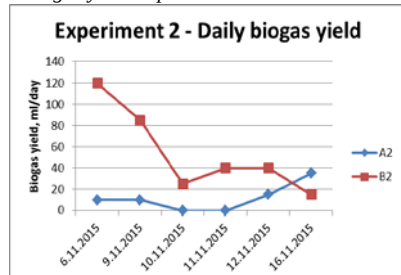


Fig.3 Biogas yield Experiment 2

In Experiment 2, Sample A contains manure only, while Sample B contains acid hydrolyzed (with 1 % H₂SO₄) coniferous material mixed with manure. (Acid treatment was applied to the plant material only).

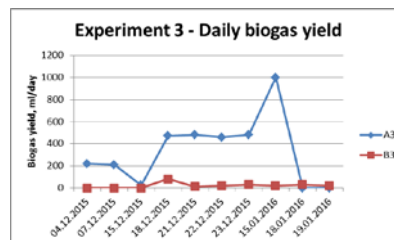


Fig.4 Biogas yield Experiment 3

In Experiment 3, Sample A contains water autoclaved coniferous material, later mixed with manure, and Sample B contains the same way treated coniferous material, plus additional treatment of the manure – charged with electrical current for 30 min.

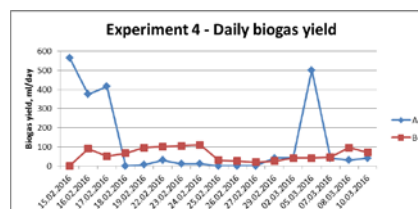


Fig.5 Biogas yield Experiment 4

In Experiment 4, the coniferous material was treated with 1% H₂SO₄ and the manure was treated with electrical current for 30 min (Sample A). Sample B was treated the same way, with the only difference – the manure was treated with electricity for 1 hour.

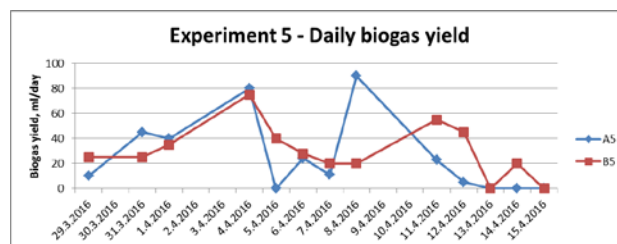


Fig. 6 Biogas yield Experiment 5

In Experiment 5, the coniferous material from Sample A and B was treated by method called steam explosion. It was believed that such treatment would make the organic compounds more accessible for the microorganisms present in the anaerobic digestion process. Then the exploded coniferous material was mixed with untreated manure (Sample A), and a treated with electrical current for 30 min manure.

3. Conclusion

According to the results obtained from our experiments, we have noticed that treatment did improve the quantity and quality of the collected biogas. While some of the treatments gave more biogas quantity with slightly less amount of CH₄, others gave slightly lower amount of biogas, but with higher content of CH₄.

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PROGRAMMING MODULE DESIGN FOR SETTING TECHNOLOGICAL PARAMETERS FOR WORKPIECES

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Abstract: This paper presents an option of formalizing input data in automated design processes for machining. A tabular data model required by the technology technician is designed to develop products for the machining process, namely a workpiece. A script-based approach of human-computer dialogue in the setup of structural and technology parameters of a workpiece is adopted as well as particular algorithms to be submitted into the system.

Keywords: SYSTEM ANALYSIS, COMPUTER AIDED PROCESS PLANNING, TABULAR DATA MODELLING, STRUCTURAL PARAMETERS, LIFECYCLE, LOGIC CONTROL

1. Introduction

Technology Design (DT) process is an idealised creative process of the human brain based on a priori information from the structural design of each item and a posteriori data, providing particular production. This determines the complexity of input data into Computer aided process planning (CAPP) systems containing both output results of structural design and basic data for resource provision of production processes. Practically, formalization of the inputs in CAPP systems and development of an efficient database (DB) schema are the main factors that ensure high quality and efficiency in managing the technology design process and the new product development.

In order to fulfill the task the following terms and clarifications have been adopted, specified in the basic concepts and related to technological design:

- Subject of our scientific research is a machine-building product, namely a workpiece, resulting from machining.
- Objective of technology design is to develop and maintain effectiveness of the product across all phases of its lifecycle from planning, analysis, design and implementation through continuous monitoring and optimization of each intermediate stage.
- Development of algorithms aims at human-computer dialogue, which is a proper combination of user-guided dialogue, system-guided dialogue and scenario-based design.
- Data is entered and selected from tables, being verified by continuous visual, and where possible mathematical and logical control.
- Entry algorithms follow the already chosen approach [4] of maximum unification and modular implementation ensuring updating.

2. Tabular Input Data Model

A source of basic inputs for CAPP system is the structural design results, derived by different means and supplemented with mandatory production and operational requirements for each particular product. Data related to supply (stock of resources, raw materials, etc.), staff (labour force, labour productivity, etc.), distribution (feasibility, cost, etc.) plays an essential role. Marketing data connected with the characteristics and prospects of every detail in the functional and structural analysis of the product at all stages of its lifecycle is also of great significance.

The perspective adopted here regards formalization of input data into technology design process as classification structure represented by functional modules in technological database (TDB):

- Data reference for the workpiece: drawing number, shape, dimensions, material, weight, accuracy, manufacturing program, etc. (Table 1);
- Billet condition data: type, shape, dimensions, etc. (Table 2);

- Additional data requirements: type of product, system, functional, structural requirements, etc. (Table 3).

Table 1: Structural inputs for the workpiece

General Data	Dimensions	Material	Weight	Accuracy Indicators	Additional Prescriptions	Production Program

Table 2: Billet condition data

General Data	Dimensions	Material	Weight	Accuracy Indicators	Surface Roughness	Additional Prescriptions

Table 3: Additional requirements for the product

General Data	Information System Requirements	Functional Requirements	Structural Requirements	Performance Requirements

It is essential for the input stage to ensure authenticity of the inputs, their accuracy and completeness across all stages of the lifecycle. Thus, two main types of data are involved, namely mandatory and recommended.

To determine mandatory data, it requires both a comprehensive systematic analysis of the information flow and definition of the necessary and sufficient conditions for managing all stages of work preparation.

Recommended data should be of the sort that the system analyst, designer and CAD technician could miss to submit, without consequences to incorrect implementation of design and planning processes.

The diversity in the type and application of the inputs in the TDB tables has to be organized into groups of products and of workpiece structure.

For instance, the structural input table, apart from the serial product numbers, includes the following groups:

- General data: drawing number, name and shape of the workpiece;
- Dimensions: maximum linear and angular dimensions of the workpiece;
- Material: type and brand name material selected by the designer;
- Workpiece weight;
- Accuracy and precision: required level of accuracy of linear measurements and angular measurements, accuracy of shape, position and orientation accuracy, beating and surface roughness.
- Additional prescriptions: requirements for hardness, additional treatments to achieve it, coating, etc.
- Production program: annual program for the production of the workpiece, batch size, etc. [1, 2, 3].

Mandatory data can include dimensions of the workpieces, such as length and diameter for rotational symmetrical workpieces; length, width and height for prismatic workpieces and so on.

Incomplete data dimensions are a prerequisite for the uncertainty of the type and dimensions of the working area of the machine and the impossibility of applying design technology, respectively.

Billet condition data is grouped in the same way as described above concerning structural input data for workpieces. The difference is in the parameters reflecting surface quality: depth of the surface deformed layer, spatial variation and relative workpiece distortion.

3. Algorithms and software to setup structural and technological parameters of workpieces

Due to the large number of structural and technological parameters of the workpieces and their complex interrelationships the task of formalizing input data needs to be decomposed into multiple subtasks so as to create a hierarchy. This suggests implementation of decision on a modular basis as each module performs a particular subtask and represents a relatively autonomous decision.

3.1. General framework for algorithms to setup structural and technological parameters of workpiece (Figure 1)

In automated design processes for machining there are two main options for entering structural and technological parameters of the workpiece: manual – from pen or pencil drawings and automated – from CAD systems. Setting parameters for workpieces from CAD systems can be done in two ways by means of reading data from the CAD model, which has been recorded in a neutral file format

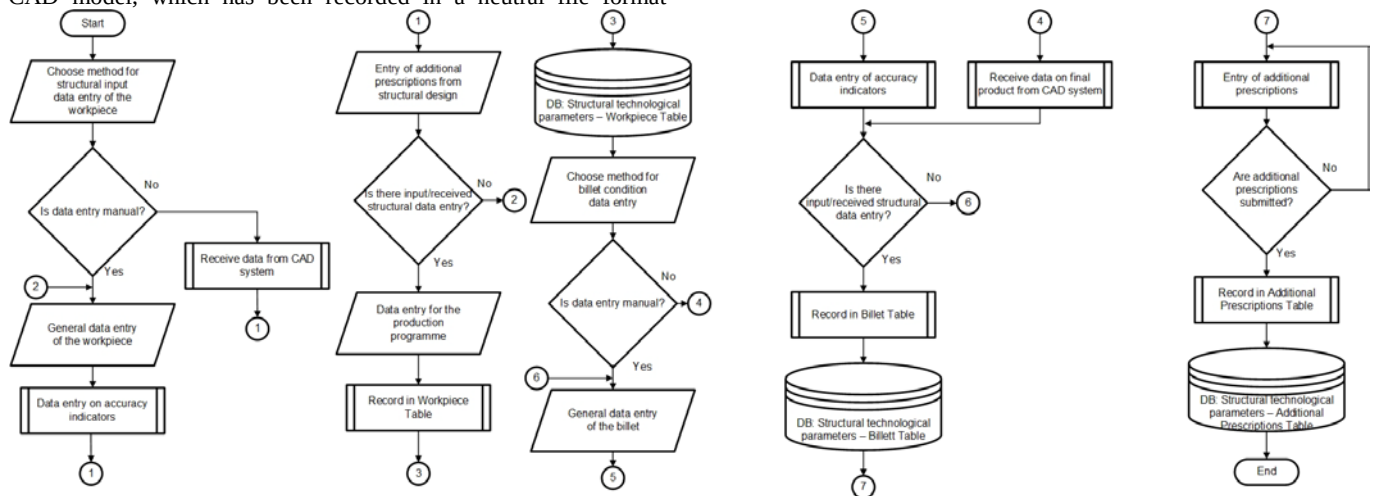


Figure 1. General framework for algorithms to setup structural and technological parameters of workpieces

3.2. Algorithm for accuracy indicators entry (Figure 2)

Normative documents (standards, norms, etc.) determine different ways to refer to accuracy indicators in design documentation. For example, the lack of a prescription for a minimum tolerance of linear measurements in drawings does not mean there have not been any intentions to do so. This calls for the design of CAPP system be defined a function with prescribed tolerance in accordance with the normalized by the designer maximum degree of accuracy.

In non-machine technology design it is the technician who does this prescription in the design process. Therefore, accuracy parameters entry begins with initializing made by the designer prescriptions. The step is significant for user-guided dialogue in submitting each of the indicators. The dialogue is mixed, providing full control of input (visual, logical and mathematical).

(STEP, DXF, etc.) or as a result of exchange of information between graphics rendering and CAD systems. In the last two cases the CAPP system must include a module for unified access, obtaining and control of input data by the design technician.

The dialogue requires an appropriate entry methodology as the result determines system's mode of operation: manual or automated. If submitting data is manually selected, human-computer interaction (HCI) follows the user-guided model. In the automatic mode, task execution continues with the inclusion of a special module for obtaining data from CAD systems. Taking into consideration the wide variety of CAD systems and especially data completeness at data set level, the algorithm provides for mixed mode of data submission. It is realized by checks for input completeness and/or for data obtained by returning execution to General Data Entry Block for the workpiece.

Control is both logical and visual and in the absence of mandatory values for structural parameters of the workpiece the cycle of iterations closes for entering missing data. Cycle exit and data record in Structural Parameters Database (Table 1) occur when all required mandatory parameters have been entered.

The process of finishing condition data submission takes place in a similar way, however under complete supervision: visual, mathematical and logical.

Additional prescriptions are entered directly by the technologist and are visually controlled while the process of TD is repeated and indirectly controlled so it frequently involves multiple-criteria optimization. The nature of information in this table is often subjected to entering catalog data from reference tables stored in system libraries in CAPP system.

The complicated relationship between accuracy indicators requires mathematical, logical and other data processing from libraries in CAPP system. Therefore, the algorithm for accuracy parameters entry is based on modular approach. The algorithm structure is divided into fundamentally identical groups of blocks for various accuracy indicators. Indicators entry takes place consecutively, starting with possible tolerances for linear dimensions. Using control prescription and visualization help limit deviations in the absence of data from this structural design. Similarly, if there is lack of evidence of deviations from angular dimensions, values according to the ones normalized by the designer for maximum accuracy are assigned. Entering each of the following indicators for form accuracy, precision orientation and location as well as beating is carried out in case there is data for each one in the design documentation. Visual control and/or control with mathematical and logical relationships is realized between inputs and values of linear dimensions. Entering prescriptions for

surface roughness and tolerances for linear and angular dimensions is managed by an interim control for entering values based on normalized by the designer maximum roughness.

4. Conclusion

The proposed table model is based on the formalization of input data and provides systematic approach to technology design.

The developed algorithms define human-computer dialogue by means of visual, logical and mathematical control so as to achieve authenticity, accuracy and completeness of the process for entry input of the workpiece and the billet.

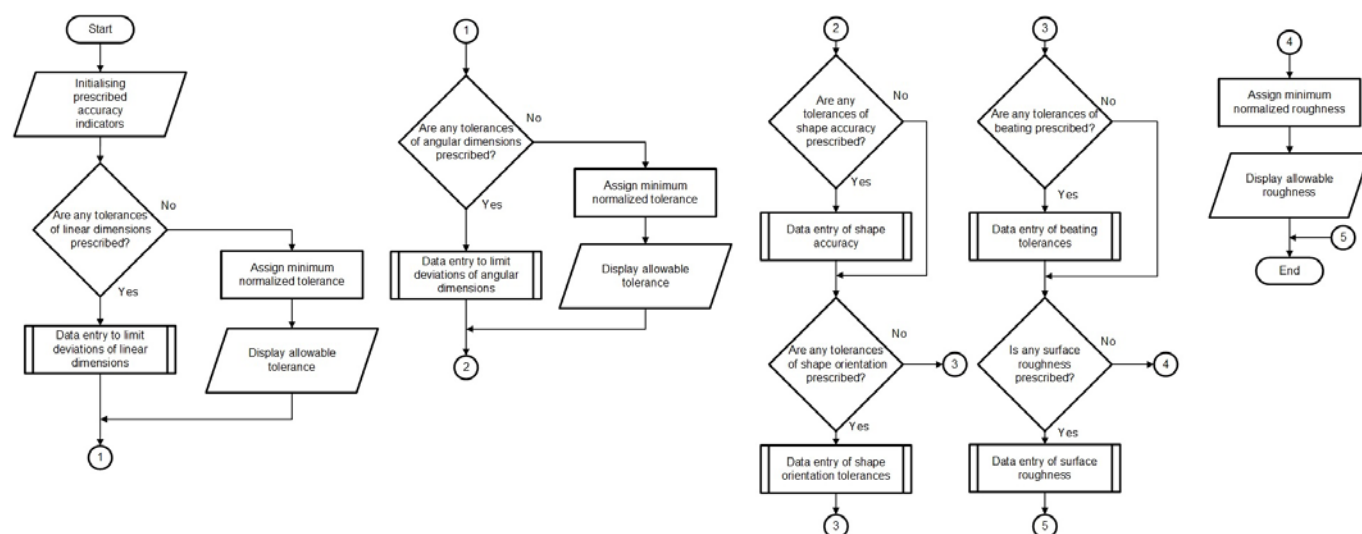


Figure 2. A node-positioning algorithm of accuracy indicators entry

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TECHNOLOGICAL SUPPORT OF PERFORMANCE CHARACTERISTICS OF MACHINE COMPONENTS

ТЕХНОЛОГИЧЕСКОЕ ОБЕСПЕЧЕНИЕ ЭКСПЛУАТАЦИОННЫХ СВОЙСТВ ДЕТАЛЕЙ МАШИН

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The relationship between the layer quality parameters of the machined surface and the technological conditions of cutting has been presented, as well as the calculative estimation of the performance characteristics of machine components: fatigue life, wear life, and compression joints' strength.

KEYWORDS: CUTTING CONDITIONS, PROPERTIES OF MATERIALS OF MACHINE COMPONENTS, QUALITY OF THE SURFACE LAYER, PERFORMANCE CHARACTERISTICS.

1. Introduction.

Managing the surface layer quality in order to provide the performance characteristics for machine components makes feasible calculating correlations between the parameters which characterize the surface layer quality and the cutting conditions. In this regard, the functional relation has been defined between the cutting condi-

tions, the tool geometry and the surface layer quality parameters as well as the cutting accuracy based on the properties of the machined and the tool materials and the stiffness of the machine-attachment-tool-work piece technological system:

$$(t, S, v, r, \varphi) = f \left(\sigma_{\text{oct}}, h_h, Rz, T_p, \sigma_T, E_d, \tau_p, \mu, \beta_d, \beta_n, \lambda_{\text{ct}}, a, \lambda_d, \lambda_p, \right. \\ \left. c\rho, \theta_{\text{m}}, \gamma, \alpha, \varphi_1, \rho_1, j_{\text{снст}}, B_1, H_1, L_p, H, \alpha_1, \alpha_p \right),$$

where T_p is the size tolerance provided when cutting; β_d and β_n are the coefficients of the linear expansion of the machined and the tool materials; E_d and τ_p are the elasticity modulus and the flow shear strength of the machined material, respectively; λ_d and λ_p are the heat conductivity coefficients of the machined and the tool materials; θ_{m} is the melting point of the machined material; α and γ are the face and the end tool edge angles; φ and φ_1 are the main and the auxiliary cutting edge angles in the plane; ρ_1 is the rounded cutting edge radius; B_1 and H_1 are the width and the height of the tool holder cross section; L_p is the length of the cutter part projecting from the tool head; H is the size of the work piece; λ_{ct} is the heat conductivity of the cutter holder material; α_1 and α_p are the conductivity coefficients of the machined material and cutter holder material; $j_{\text{снст}}$ is the stiffness of the machine-attachment-tool-work piece system; $c\rho$ is the volumetric specific heat of the machined material; S is the feed (the tool displacement rate); t and v are the cutting depth and rate; r is the tip radius in the plane; σ_{oct} is the value of residual stresses on the set level from the work piece surface; h_h is the degree of cold working of the surface layer material; Rz is the peak-to-valley deviation on the work piece surface; δ is the wear flat height

on the tool point back face; a is the thermal diffusivity of the machined material; σ_T is the tensile yield strength of the work piece material.

Thus, the cutting conditions and the tool geometry are the function of the characteristics of the work piece surface layer, cutting accuracy, properties of the machined and the tool materials, work piece and the cutter dimensions, rigidity of the technological system.

2. Findings of the study.

To manage forming the work piece surface layer the calculative dependencies were obtained to define residual stresses in the surface layer σ_{oct} , those of degree N and depth h_h of cold working, and parameters of surface roughness Rz etc. Some examples are given below.

For instance, axial residual stresses $\sigma_{\text{o.oct}}$ in the surface layer caused by the thermal effect, at $r > r_{\text{oh}}$ and $\sigma_{\text{o.o}} \max < 2\sigma_T$ are determined by the following formula:

$$\sigma_{\text{o.oct}} = -\sigma_T + \\ + \left\{ \left(\frac{r_h - r + a_1}{a_1} \right)^{X_2} + \frac{2}{a_1^{X_2} (r_h^2 - r_b^2)} \left[\frac{r_h + a_1}{1 + X_2} \left[a_1^{1+X_2} - (r_h - r_b + a_1)^{1+X_2} \right] - \frac{1}{2 + X_2} \left[a_1^{2+X_2} - (r_h - r_b + a_1)^{2+X_2} \right] \right] \right\} \left\{ \frac{\beta_d A_1 E_d}{1 - \mu} \right\},$$

where r is the work piece radius from the center in which the values of the residual stresses are determined; r_h and r_b are the outer and the inner radii of the work piece; μ is the Poisson's ratio of the work

piece material; A_1 and X_2 are the values defined by the technological cutting conditions [1].

$$A_1 = C_0 \theta_A (EB)^{X_1} \left(\frac{\rho_1}{a_1} \right)^{X_3 - d} \sin \alpha^{0,05 - 0,042 X_4} \sin \gamma^{-0,021 X_4},$$

where $B = \frac{va_1}{a}$ is the cutting process dimensionless group characterizing the impact of cutting conditions on the temperature in the surface layer comparing to the impact of heat-transfer properties of the machined material [2]; $B = \frac{1}{\text{tg} \beta_1}$ is the dimensionless group characterizing the plastic yield degree of the removed stock material and the material of the work piece surface layer; β_1 is the relative

shear plane inclination; C_0, X_1, X_3, X_4 and d are the values depending on the cutting conditions [1].

The depth of cold working in the surface layer is determined based on the condition of equality:

$$\sigma_y + \sigma_H = -\sigma_T,$$

where σ_y is the stress conditioned by the force impact on the surface layer; σ_H are the stresses caused by the heat impact on the surface layer.

$$\begin{aligned} \sigma_y &= \left[\frac{\tau_p}{2\pi} \cdot \psi \left(B; \frac{y}{h}; \frac{h}{a_1} \right) - \frac{\tau_p b}{2\pi b_1 \cos \alpha} E \left(\frac{y}{h}; B; \frac{\Delta}{\Delta_1}; \gamma \right) \right] \cdot \frac{1}{1 - \mu^2}; \\ \sigma_H &= \frac{\beta_d A_1 E_d}{a_1^{X_2} (1 - \mu)} \left\{ - (r_H - r + a_1)^{X_2} + \frac{1}{0,5(r_{OH}^2 - r_B^2) E_d} \times \right. \\ &\times \left[E_d (r_H - r_{OH} + a_1)^{1+X_2} \left(\frac{r_H - r_{OH} + a_1}{2 + X_2} - \frac{r_H + a_1}{1 + X_2} \right) + (r_H - r_B + a_1)^{1+X_2} \times \right. \\ &\times \left. \left(\frac{r_H + a_1}{1 + X_2} - \frac{r_H - r_B + a_1}{2 + X_2} \right) E_d \right] - \frac{0,5 a_1^{X_2} \sigma_T}{\beta_d A_1} (r_H^2 - r_{OH}^2) \left. \right\}, \end{aligned}$$

where τ_p is the flow shear strength of the machined material; h, Δ, Δ_1 are the dimensions of the area of the plastic material in the surface layer; y is the depth of the layer under consideration from the surface; r_{OH} is the radius corresponding to the boundary of elastic and plastic flow in the surface layer under heating, $r_{OH} = r_H - r = y$.

The degree of the cold working on the work piece surface is defined by the formula:

$$N = \frac{h_H}{1,25(\sigma_B / \sigma_{B3})^{0,8}},$$

$$Rz = \frac{1}{8r} \left\{ \frac{1}{t\tau_p \left[1 + \frac{1}{B} + \text{tg}(\arctg B - \gamma) \right]} \left[\frac{a_1^{0,125} b_1^{0,7} c\rho\theta\rho_1^{0,1} a^{0,43}}{v\lambda \sin^{0,165} \alpha} \times \right. \right. \\ \times \left[2,85 \sin^{0,115} \alpha v^{0,57} a_1^{0,345} \lambda b^{0,3} + 0,6625 \lambda_p \beta \varepsilon a_1^{0,57} \rho_1^{0,075} \right] - \left. \left[-0,5 \tau_p \rho_1 b \left(\frac{\arccos \left(1 - a_2 B^{-b_2 (1 - \sin \gamma)^{-X}} \right)}{+ \frac{a_2 B^{1-b_2 (1 - \sin \gamma)^{-X}}}{\sin \alpha (\cos \gamma + B \sin \gamma)} + \frac{\delta}{\rho_1}} \right) \times \cos \alpha \right] \right\}^2.$$

Using the above dependencies to determine the surface layer quality parameters the dependences were obtained to define the indices of performance characteristics of machine components. So, the endurance limit of the work piece material machined with the edge tool is determined as follows:

– when turning

$$\sigma_{-1} = m \cdot (\sigma_B / \sigma_{B3})^K \cdot Rz^{-0,05} \cdot h_H^{0,147} \cdot \sigma_{OCT}^{-0,09};$$

– when milling

$$\sigma_{-1} = n \cdot (\sigma_B / \sigma_{B3})^L \cdot Rz^{-0,067} \cdot h_H^{0,139} \cdot \sigma_{OCT}^{-0,063},$$

where m, n, K, L are the values depending on the cutting type [1]; σ_B and σ_{B3} is the ration between the yield value of the machined material and the yield value of the electrical steel taken as a standard.

The wear rate of the machined surface is defined by the formula:

$$J_h = 0,0316 \cdot 3,7^{v+1} \alpha_2^{0,5} b \times \left\{ \frac{1}{8r} \times \left[\frac{0,6625 a_1^{0,125} c p \theta_0 \times \left(4,3 \sin^{0,115} \alpha v^{0,57} a_1^{0,345} \lambda \left(\frac{t}{m} \right)^{0,3} + \lambda_p \beta \varepsilon a^{0,57} \rho_1^{0,075} \right)}{\tau_p a^{-0,43} \sin^{0,05} \alpha v_0 t^{0,25} c_0 m^{0,74-n_0} \times b^{0,04} \rho_1^{n_0-0,1} (1-0,45 \sin \gamma)} \right]^{\frac{2}{1-n_0}} \right\}^{0,719-0,2(v+1)+5,2t_y} \times \frac{1}{(v+1) \left(\frac{34,64 \sigma_0}{k f_m} \right)^{t_y} \left(\frac{N}{A_c} \right)^{-0,323(v+1)+0,161-0,16t_y} \left(\frac{1-\mu^2}{E} \right)^{0,161+0,84t_y-0,323(v+1)}}.$$

where R_z is the peak-to-valley ratio of the contact surface profile, mm; v and b are the bearing surface approximation curve parameters; σ_0 is the acting stress in the contact area of mating surfaces, MPa; N is the load acting on the contact, H; A_c is the nominal area outlined by the dimensions of the adjoining solids, mm²; μ is the Poisson's ratio of the work piece material; E is the elasticity modulus of the material which wears out faster, Pa; t_y is the friction fatigue curve parameter [3]; K is the coefficient characterizing the stress condition on the contact (for brittle materials $K = 5$, for high-plasticity materials $K = 3$); f_m is the value of the molecule-based component of the friction ratio.

Thus, the surface wear rate is the function of its cutting conditions, as well as the properties of the work piece material.

When making pressure couplings the values of axial force P_0 and torque M_{kp} , which provide the strength of such connections, are determined by the formulas:

- when manufacturing joinable parts made of the same material:

$$P_0 = \pi \cdot l \cdot f_{oc} \cdot \frac{2(1+\mu) \cdot \sigma_{0,2}^2}{\alpha^2} \cdot \frac{\delta_H - 1,2(R_{z1} + R_{z2})}{\frac{C_1 W_1}{N_1^2} + \frac{C_2 W_2}{N_2^2}},$$

$$M_{kp} = \pi \cdot d \cdot l \cdot f_{kp} \cdot \frac{(1+\mu) \cdot \sigma_{0,2}^2}{\alpha^2} \cdot \frac{\delta_H - 1,2(R_{z1} + R_{z2})}{\frac{C_1 W_1}{N_1^2} + \frac{C_2 W_2}{N_2^2}},$$

where l is the length of the contact area of the mating parts; d is the nominal mating diameter; f_{oc} and f_{kp} are the friction coefficients

under the press fitting and press fitting with twisting; δ is the value of the nominal tension; R_{z1} and R_{z2} is the peak-to-valley ratio on the contacting surfaces; N_1 and N_2 are the cold working degrees on the surface of mating parts; $\sigma'_{0,2}$ and $\sigma''_{0,2}$ are the conventional yield stress for the materials of the mating parts; W_1 and W_2 are the values of the stored power in the surface layer of the materials of the first and the second mating parts; μ_1 and μ_2 are the Poisson's ratio of the mating part materials [3]; C_1 and C_2 are the factors depending on the part dimensions and the Poisson's ratios of the materials of the mating parts.

3. Conclusion.

Thus, the methods was presented to calculate the cutting mode, providing the predetermined performance characteristics of work pieces and allowing to control the cutting process thereby ensuring manufacture of reliable and durable products and making the manufacturing process be science-intensive and cost-effective.

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КОМПЛЕКСНО РЕШЕНИЕ ЗА МЕХАНИЧНО ОБРАБОТВАНЕ НА ТЪНКОСТЕННИ, КУТИЕОБРАЗНИ ЕДРОГАБАРИТНИ ДЕТАЙЛИ В УСЛОВИЯТА НА ШИРОКО НОМЕНКЛАТУРНО ДРЕБНОСЕРИЙНО ПРОИЗВОДСТВО

COMPLEX SOLUTION FOR MACHINING OF THIN-WALLED, BOX-SHAPED LARGE PARTS IN A WIDE RANGE OF SMALL BATCH PRODUCTION

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Abstract: The mechanical processing at low stability of parts is a major challenge in a wide variety of products and small series. Achieving efficiency requirements for technology and universality of the equipment is very difficult. This problem is particularly pronounced when it comes to expensive bulky and unstable details. The publication examines a complex solution for achieving these objectives in a particular proceeding.

Keywords MECHANICAL PROCESSING, LARGE-SIZED PARTS

1. Въведение

Механичното обработване на скъпи едрогабаритни тънкостенни детайли в условията на голямо разнообразие на изделията и дребни серии е сериозно предизвикателство. Постигането на изискванията за ефективност на технологиите и универсалност на оборудването е силно затруднено. В публикацията се разглежда едно комплексно решение за постигане на тези цели в условията на конкретно производство.

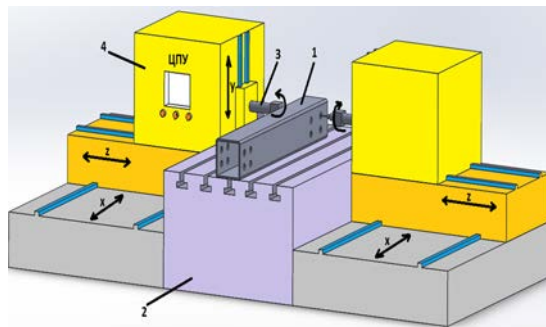
Едрогабаритните кутиеобразни тънкостенни детайли са съставен елемент на редица изделия. В повечето случаи те изпълняват ролята на корпусни детайли, основи, носещи конструкции и т.н. Заготовките за тях са с призматична, цилиндрична или друга форма и се получават от стандартни профили или чрез разкрой, огъване и заваряване. Във връзка със служебното им предназначение за част от тях се налага механично обработване чрез рязане на определени повърхнини. Това са равнинни и ротационни повърхнини, канали, ребра и различни видове отвори, включително и такива с високи изисквания към качеството. В тези случаи възникват проблеми при обработването им, дължащи се на неблагоприятното съотношение на размерите на обработваните повърхнини и на изделията - дължина/сечение/дебелина на стената, т.е. на ниската им стабилност. Анализът на възможностите на наличното технологично оборудване за обработване на едрогабаритни тънкостенни детайли, напр. стрели за автокранове, при условията на широка номенклатура в СПАРКИ – Русе АД доказва, че е налице необходимостта от разработване на специално конструирана машина - обработващ център с две срещуположни вретена, притежаващи възможността да осъществяват движения в пространството, независимо едно от друго [1].

2. Комплексно решение

Металорежеща машина. В резултат на направения анализ в [1] и в [2] за производствените условия на СПАРКИ – Русе се препоръчва специална конструкция на металорежеща машина - двуколонен, двувретенен обработващ център (ОЦ) с обща система за ЦПУ и управление на 2х3, 2х4 или 2х5 оси. - Разгледаните в [2] два варианта отговарят и удовлетворяват изискванията за осигуряване на точност, универсалност и гъвкавост на технологичната система. Вариант 2 (фиг.1) [2] (с една система за ЦПУ и един оператор) е за предпочитане.

Дори вариантът на машина с 2х3 линейни оси (без въртяща маса или завъртане на вретеното), осигуряващ възможност за едновременно или последователно двустранно обработване има редица предимства спрямо едностраниното обработване.

Съществено предимство е, че при обработване на напречни двустранни отвори може да се използват до два пъти по-къси (с



Фиг.1 Двувретенен ОЦ с една система за ЦПУ

по-малък излет) и съответно по-стабилни режещи инструменти, което намалява вероятността от възникване на вибрации.

Отпадането на необходимостта от преустановяване на стрелата елиминира опасността от възникване на грешки от преустановяване, които биха компрометирали осигуряването на изискванията за взаимно разположение на обработените повърхнини.

На лице са големи възможности точността да се контролира и управлява и автоматично (базира се на използване на трокоординатна измервателна глава - ТИГ);

Очаквани предимства при използване на такава машина са:

- По-висока производителност в сравнение с варианта на двувретенен портален обработващ център заради възможността за непрекъсната едновременна работа на двете вретена с оптимални условия и режими на работа;
 - По-висока производителност за варианти с 2х4 оси (осигурява обработване на 4 страни на стрелата) или 2х5 оси (осигурява обработване от всички страни) в сравнение с вар. 1;
 - По-ниска цена и разходи в сравнение с вариант 1, тъй като се вгражда само една система за ЦПУ, която се обслужва от само един оператор;
 - По-висока надеждност в сравнение с вариант 1 (Надеждността зависи от само една система за ЦПУ, една програма, един оператор).
 - Възможности за постигната гъвкавост и универсалност.
- Недостатъци:
- Висока цена на технологичната система;
 - Наличие на критични работни зони, възникващи при паралелна концентрация на преходите (Движения и позициониране при синхронизация на двете вретена)

Следователно може да се приеме, че с използването на специален двувретенен обработващ център се постигат редица предимства и се получава едно комплексно решение за обработване на едрогабаритни кутиеобразни тънкостенни детайли в условията на дребно- и средносерино широкономеклатурно производство. В таблица 1 са представени основните поставени цели (проблеми), отнасящи се до обработването на такъв тип детайли при посочените технологични условия, за които се получава съответното решение и средство, благодарение на специалния ОЦ.

Таблица 1: Цели и проблеми, решения и средства за решаването им с помощта на двувретенен обработващ център.

Цел (проблем)	Решение	Средство
Точност	Чрез висока точност на позициониране на супортите	Използване на следящи преводи
	Обработване без грешки от преустановяване на изделието.	Двустранно обработване на една установка с две вретена и голяма работна зона
	Прилагане на координатни измервания за: 1)Технологичен контрол, 2)Настройване и поднастройване на технологичната система 3)Контрол на геометричната точност на машината	Трикоординатна измервателна глава
		Калибри
Производителност	Обработване с оптимални или близки до тях режими на рязане	Използване на безстепенни преводи
	Прилагане на паралелна концентрация на преходите	Едновременно обработване с две независими вретена
	Висока скорост на позиционирането	Подавателни преводи с подходящи характеристики
	Бърза автоматична смяна на инструмента	Устройство за бърза смяна на инструмента
	Без загуби за преустановяване на изделието	Голяма работна зона и двустранно обработване с две вретена
Себестойност	Оптимални режими на рязане	Безстепенни преводи с голям обхват на регулиране
Надеждност	Автоматичен цикъл на обработването по програма	Система за ЦПУ и NC – програми
	Без преустановяване на изделието	Работа с две вретена голяма работна зона
Гъвкавост	Лесно и бързо пренастройване	Трикоординатна измервателна глава. Екипировка
Универсалност	Различни по вид и размери детайли	Голяма работна маса и работни ходове на супортите
	Различни по вид и размери повърхнини	Система за ЦПУ, NC - програми, режещи инструменти
	Голямо разнообразие от технологични преходи	Система за ЦПУ, NC - програми, режещи инструменти

Осигуряването на точността на обработване е задължително условие за всяка технология, което важи в най-

голяма степен, когато става дума за обработване на заготовки с по-висока себестойност. В случая освен общите и типичните задачи възникват и специфични, които произтичат от конструктивните особености на детайла.

Настройване на технологичната система, технологичен контрол и поднастройване. Специфична задача на настройването на системата машина – приспособление – инструмент - детайл, освен автоматичното осигуряване на номиналите и допуските на размерите на обработваните повърхнини е и осигуряване на разположението на обработваните повърхнини по детайла, а също и равномерност, разпределяне или поне минимални стойности на прибавките за рязане, останали от предварителното обработване и разкроя. Технологичният контрол има за основна цел типична планирана проверка за настроеността на технологичните преходи. Поднастройването трябва да компенсира влиянието на евентуалните смущаващи систематични, а също и на някои случайни въздействия, на планирани прекъсвания на операцията (напр. приключване на работната смяна преди завършване на обработването) и непланирани такива в резултат на счупване на режещ инструмент, прекъсване на електрозахранването и др.

Окончателен контрол е необходим за проверка на изискванията по отношение на точността на размерите на някои повърхнини, както и за допустими отклонения във формата и разположението им.

Контрол на елементи от геометричната точност на машината. Това е специфична задача, налагаща се от особеностите в технологичността на обработвания детайл и конструктивните особености на обработващия център, предназначен за неговото обработване.

Избор на параметри за контрол. Съгласно практиката и утвърдените стандарти съществуват различни норми, методи и средства за оценка на геометричната точност (ГТ) на металорежещите машини и в частност на обработващите центри. С оглед особеностите на конструкцията на машината, нейното предназначение и технически характеристики, както и на изискванията към получаваното качество при обработване на специфичните в случая детайли (стрели) в условията на ежедневна нормална експлоатация на машината е достатъчно и възможно да се осъществява контрол на определена част от параметрите на геометричната ѝ точност:

1) Грешка в стъпката на винта. Това е параметър, имащ отношение към точността на позициониране, което е с основно значение както при получаване на някои размери, така и за осигуряване на положението и взаимното разположение на обработваните повърхнини.

2) Отклонение от успоредност на осите на вретената спрямо равнината на масата.

3) Отклонение от перпендикулярност на осите на вретената спрямо надлъжната ос (канал) на масата.

Вторият и третият параметър имат отношение към осигуряването на разположение и взаимно разположение на симетрично обработваните повърхнини.

4) Отклонение от съосност на вретената.

Четвъртият параметър е свързан и зависим от първия, втория и третия параметър. Той има голямо значение в случаите при обработване на симетрични повърхнини от двете страни на детайла. Това е особено важно за осигуряване на изискване за съосност на двата входа (края) на отвор, разположен напречно спрямо надлъжната ос в две срещуположни стени (плочи/планки) на стрелата.

Метод и средства за контрол.

Използването на лабораторните методи, утвърдени от стандартите ISO и БДС изисква сложни и скъпи специални или специализирани технически средства и квалифициран персонал, което е непрактично и неприемливо за ежедневната практика. Голяма част от другите известни разработки [5] са неподходящи в случая поради високата си цена, недостатъчен обхват (габаритите и работната зона на ОЦ са големи) и

невъзможността да бъдат използвани, когато на работната маса е установена стрела.

Редно е да се отчете фактът, че вече наложила се практика е обработващите центри да могат да работят и като координатно измервателни машини с помощта на контактна трикоординатна измервателна глава (ТИГ). Поради това наличието на ТИГ се счита за стандартна част от окомплектовката с екипировка на всеки нов ОЦ, а и вече съществува достатъчен практически опит в прилагането на измервания с ТИГ на ОЦ.

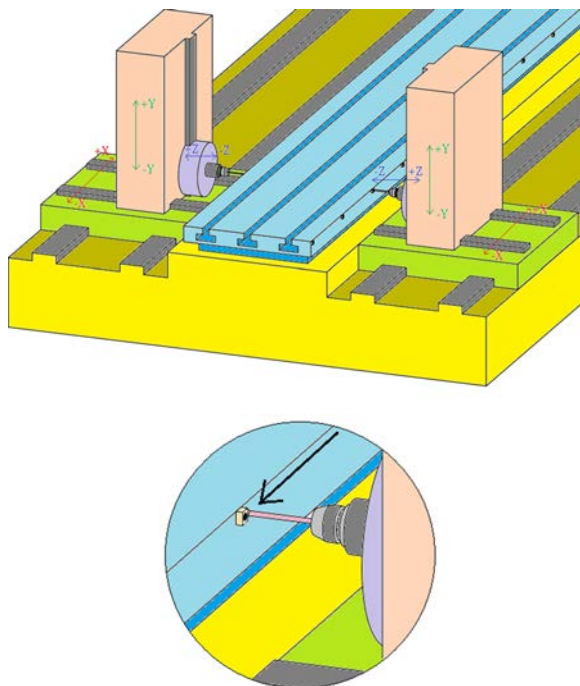
Следователно е естествено и целесъобразно да се анализира възможността за осъществяване на размерен контрол с помощта на координатни измервания и ТИГ.

Положителни страни при прилагането на тази възможност са: достатъчно висока точност и универсалност, удовлетворяваща производителност и себестойност, а също и възможността за автоматизиране. Последното е изключително важно, защото има отношение към точността, производителността, универсалността и надеждността на метода. За достоверността и точността на получаваните резултати по този метод на контрол може да се разчита след анализ и определяне на всички смущаващи фактори (особено на тези със случаен характер), водещи до формиране на неопределеност на резултата [3,4]. Числено това се изразява чрез сумарната неопределеност.

Съставните ѝ са полетата на разсейване на редица случайни грешки. Основните сред тях са на ТИГ, на регулируемия превод, на системата за ЦПУ, на грешката при установяване на ТИГ във вретеното на машината и др. [3,4]. Следва да се отбележи, че с осъществяването на поне две повторения на измерванията във всяка точка и подходящо калибриране влиянието им се ограничава. Недостатък е необходимостта от допълнителни приспособления (калибри) в зависимост от конкретните измервателни задачи. Тези калибри следва да бъдат налични в работната зона на машина с всички произтичащи от това проблеми, свързани както с тяхното надеждно и точно определяне и определено временно или постоянно установяване, така и със защитата им от замърсяване и опазване от повреда.

С оглед резултатите от анализа [2] на конструктивните особености на обработваните детайли (стрели) осигуряването на изискванията за разположение на обработваните отвори по тях е свързано с големи премествания на супорта по работна ос X на машината. Следователно по тази ос е най-необходим контрол за определяне на грешката и промяната в стъпката на винта.

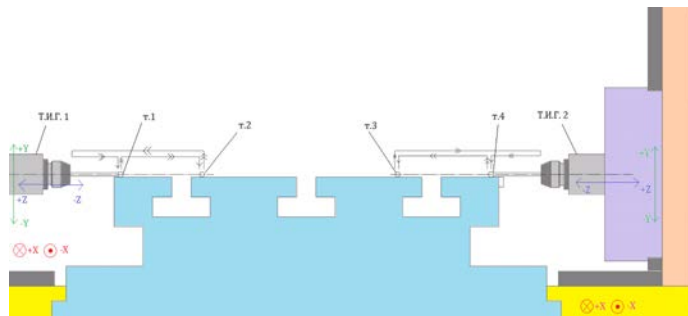
За целта е предвидено по страничните повърхнини на масата да се монтират призми, както е показано на фиг.2.



Фиг.2 Определяне на грешката на стъпката на винта по „X“

След като предварително и възможно най-точно е определено взаимното положение на контролните им повърхнини, впоследствие установената чрез координатни измервания промяна би била индикация за промяна в стъпката на винта, напр. от топлинни деформации при експлоатация на машината. Същите призми са подходящи и за измерване на евентуално възникнали хлабини в превода.

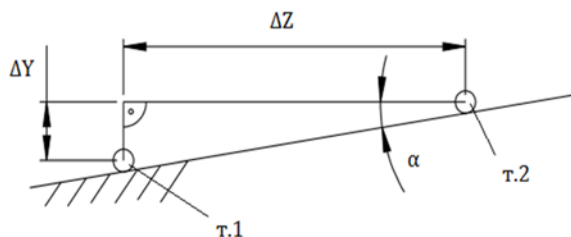
На фиг.3 е показана принципната схема на координатните измервания, с помощта на които може да се установят отклонения от успоредност на оста на всяко от вретената в едно сечение (YZ по дължина на масата) спрямо равнината на масата.



Фиг.3 Определяне на отклонението от успоредност на вретената спрямо работната маса

За да е възможно това измерване е необходимо повърхността на масата да е почистена и ненаранена, а дължината на измервателния накрайник на ТИГ да е възможно по-голяма, или да е с форма, позволяваща измерване "по-навътре" по масата.

От получените, в резултат на измерванията с ТИГ, координати по съответните оси могат с помощта на подходящ математически апарат да се пресметнат отклоненията в контролираните параметри. При измервания в повече такива сечения е възможно да се установи евентуалната промяна на този параметър по дължината на работния ход на ос X.



Фиг.4 Схема за пресмятане на неуспоредността

На фиг. 4 е показана схема за пресмятане на ъгъла на неуспоредност α , а по-долу са тригонометричните изрази, които могат да бъдат използвани за целта. Координатите, които са необходими са по оси Y и Z във всяка от контролните точки. В контролните T.1 и T.2 чрез измервателно движение по ос Y се получават съответно координатите Y1 и Y2 и могат да се пресметнат разликите ΔY и базовото разстояние ΔZ :

- (1) $\Delta Y = Y1 - Y2$
- (2) $\Delta Z = Z1 - Z2$

От тук следва че:

$$(3) \operatorname{tg} \alpha = \frac{\Delta Y}{\Delta Z} \rightarrow \alpha = \arctg \frac{\Delta Y}{\Delta Z}$$

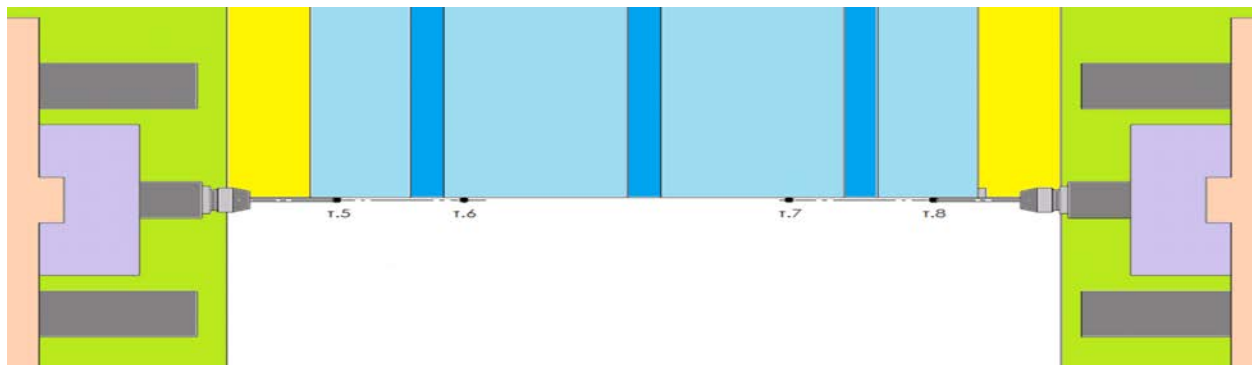
като условието машината да е годна за експлоатация е:

$$(3) \alpha_{\text{изм}} \leq \alpha_{\text{доп}}$$

Схемата (фиг.5) за определяне на отклонение от перпендикулярност на оста на вретеното спрямо надлъжната ос на масата е аналогична. Контролът е индиректен, тъй като за целта се проверява отклонението от

успоредност на вретената спрямо страничната (челна) повърхност на работната маса на машината.

влиянието на радиалното биене на контролираното вретено във всяко сечение се предвиждат измервания при две симетрични



Фиг.5 Схема на измерванията за определяне на перпендикулярността на вретената спрямо оста на масата

В случая трябва да се определят разликите Δx на базово разстояние Δz , а отношението им, чрез обратна тригонометрична функция би извело съответното ъглово отклонение.

Съосността на вретената е много важен показател, който трябва да се постигне при двустранно обработване на напречно разположен отвор в корпуса на стрелите. Най-подходящо, с оглед точността при обработване, би било този показател да се проверява непосредствено преди осъществяване на двустранно обработване на отвор в позиция с координати в равнината XY, съвпадащи с оста на бъдещия отвор, т.е да се постигне съосност чрез поднастройване с т.нар. центротърсене. Последното обаче по принцип е неосъществимо тъй като заговката би попречила със стените си. Компромисното решение е тази процедура да се изпълни в непосредствена близост над/под мястото (осите) за направа на отворите. Така се избягва позиционирането впоследствие по ос X, която, както е известно, е с най-голяма дължина и може да бъде източник на

ъглови положения на вретеното, отстоящи на ъгъл 180° . Резултатите от двете измервания за всяко сечение се усредняват.

Получените стойности ΔX и ΔY при необходимост се въвеждат като стойности за компенсация на несъосността.

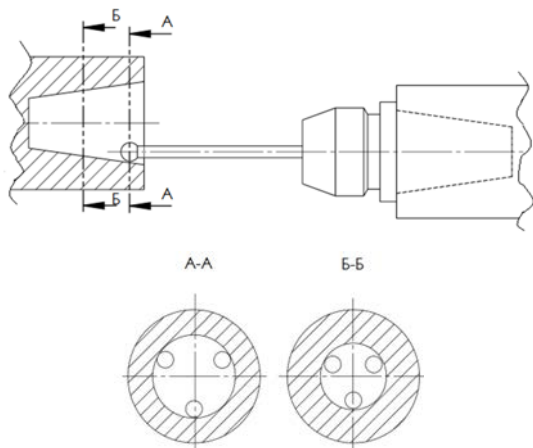
3. Заключение

Използването на специално конструиран ОЦ с две независимо работещи хоризонтални вретена и обща неподвижна маса е предпоставка за постигане на удовлетворяващи резултати относно основните поставени цели при обработване на едрогабаритни тънкостенни кутиеобразни детайли в условията на широка номенклатура и малки производствени серии.

Осигуряването и управлението на точността на обработване в конкретните технологични условия е практически възможно чрез използване на координатни измервания върху машината с помощта на измервателна глава.

4. Литература

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Фиг.6 Измервания за определяне на съществуващи грешки.

На фиг. 6 е показана принципната схема за установяване на несъосността между двете вретена в дадена позиция от работната зона на машината. За целта в едното от вретената се установява ТИГ, с помощта на която се осъществяват координатни измервания на отвора на другото вретено. Прилага се стандартен цикъл на измерване на окръжност с цел определяне координатите на центъра ѝ по ос X и ос Y. Той може да се изпълни по четириточковата или триточковата схема, както е показано на фиг. 6. Ако измерването се изпълни в две сечения A-A и B-B, които са възможно най-отдалечени едно от друго ще може да се определи евентуална кръстосаност или неуспоредност на осите на вретената. За да се намали

ГРУПОВ ПОДХОД ЗА ЕКСПРЕСНО ОФЕРТНО ОПРЕДЕЛЯНЕ НА СЕБЕСТОЙНОСТТА НА МАШИНОСТРОИТЕЛНО ИЗДЕЛИЕ В УСЛОВИЯТА НА ДРЕБНОСЕРИЙНО ПРОИЗВОДСТВО

GROUP APPROACH FOR FAST DETERMINATION OF THE COST OF THE PRODUCT INSIDE THE TERMS OF THE SMALL-SERIES PRODUCTION IN THE FIELD OF MECHANICAL ENGINEERING

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Abstract: *Determining the cost of the product is the foundation of any offer. It is expensive and responsible activity performed by highly qualified specialists. There is an increased risk of large inaccuracies when the deadlines are small. The publication examines approach to quickly calculate the cost based on the application of group technology processes.*

Keywords MECHANICAL ENGINEERING, TECHNOLOGY COST, OFFER

1. Въведение

Възможно най-точното пресмятане на технологичната себестойност за дадено машиностроително изделие (детайл) е основно изискване с цел осигуряване на минимален риск от допускане на груба грешка при разработването на оферта по задание на възложител за това изделие. Следователно това е една изключително отговорна дейност. Познатите методики за пресмятане на себестойността се базират на цялостно разработена за целта технология за изработване на изделието, а това е доста трудоемко и ангажиращо висококвалифицирани специалисти. Когато пресмятането на технологичната себестойност трябва да се изпълни в малки срокове за условията на широко номенклатурно дребно- и средносериенно производство задачата е още по-трудна.

2. Изложение

Система за пресмятане на себестойността

Същественото в предлагания чрез настоящата публикация подход е да се използва натрупания технологичен опит в условията на конкретно машиностроително производство и производствени условия. За целта е необходимо чрез унификация и систематизация на вече разработените технологични процеси, да се приложи т.нар. групов подход. Последователността от дейности в този процес всъщност представлява един алгоритъм, който включва следните основни стъпки:

1. Анализ на конструктивните особености на изделията. Източник е архивът с конструктивна документация.
2. Прилагане на систематизация. Анализ на технологичните особености на изделията и на известните въведени технологии в предприятието
3. (производството). Източник е технологичната документация за разработени технологични процеси.
4. Класификация и групиране на изделията (детайлите) по елементарни повърхнини, а от там по елементарни процеси (преходи) и избиране представител, който да

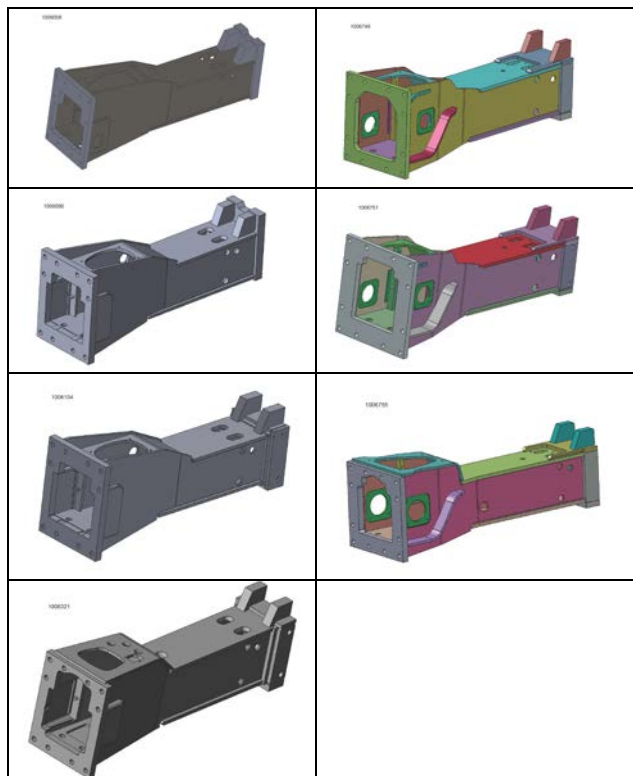
играе ролята на т.нар. комплексно изделие или създаване на въображаемо (условно) такова.

5. Разработване на групов технологичен процес за комплексното изделие.
6. Пресмятане на технологичната себестойност на комплексното изделие.
7. Създаване на математичен модел. Привеждане на себестойността към безразмерна величина (единица). Определяне на относителния дял (чрез коефициенти) и значимост на отделните компоненти, формиращи себестойността.
8. Пресмятане на себестойността на конкретно изделие с помощта на модела и с корекции на коефициентите на относителните дялове на отделните компоненти за отчитане на конкретните му особености при установени съществени конструктивни и количествени разлики спрямо комплексното.

Важна особеност в предлагания подход е възможността част от стъпките да бъдат автоматизирани, което е съществена предпоставка за увеличаване на производителността и надеждността на получения резултат, поради ограничаване значимостта на субективното влияние. На този етап за целта е подходящо и достатъчно използването на WordExel.

Разработеният подход и алгоритъм може да се поясни с разглеждането на конкретен пример, базиран на производствената програма на фирма СПАРКИ – Русе АД.

Въз основа на анализите и изпълняването на инструкциите в точки 1 и 2 от алгоритъма, описан по-горе значителна част от изделията, изработвани във фирмата могат да се обединят в различни групи. Някои от тях (стрели на автокранове, колони и рами) са представени в [1,3]. За разглеждания пример вниманието е насочено към друга група изделия. Това са т.нар. „Кутии“, включващи седем представителя от тип „Среден размер“ (фиг.1). С цел улесняване визуалния анализ на изделията от групата при избирането (съставянето) на комплексно изделие с помощта на SolidWorks е направено „разглобяване“ на всеки представител на съставните му детайли по начин, аналогичен на показания на фиг.3, който може да се приеме и за монтажна схема.



Фиг.1 Кутии среден размер (триизмерен вид)

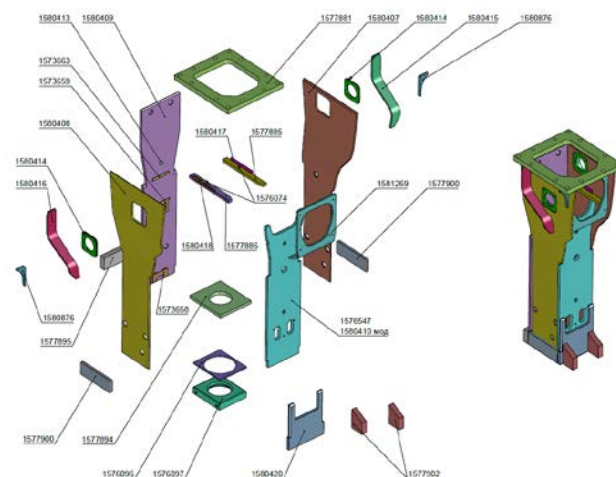
Списъкът (колона А) на всички възможни конструктивни елементи (детайли) от всичките седем изделия (колони С,...,I) може да се види в специално съставената таблица с WordExel (фиг.2), която е разновидност на т.нар. матрица на групиране [2]. В таблицата с червен цвят са маркирани някои от клетките. Това са всъщност елементите, които следва да се „вградят“ в комплексното изделие. Така създаденото комплексно изделие (фиг.3) съдържа в себе си детайли, които могат да бъдат открити в поне един представител на групата.

	A	B	C	D	E	F	G	H	I
1		3100 dust		MB 1000	MB 1500	MB 1500B	MB 1700S	MB 2000	MB 4100
2	Наименование	Позиция	Идент.№	Идент.№	Идент.№	Идент.№	Идент.№	Идент.№	Идент.№
3	Плоча	1	1576068	1573608	1574714	1574714	1573648	1578881	1577881
4	Страница дясна	2	1580440	1573810	1574715	1574715	1573649	1580506	1580407
5	Страница лява	3	1580441	1573609	1574716	1574716	1573650	1580507	1580408
6	Капак	4	1580442	1573611	1574722	1574916	1576549	1580508	1580409
7	Плоча	5	1580443	1573612	1574719	1574915	1576547	1580509	1580410
8	Плоча	6	1580875	1573613	1574713	1574713	1573657	1580510	1581269
9	Плоча лява	7	1580444		1574729		1573653		1577885
10	Плоча дясна	8	1570445		1574725		1573653		1577885
11	Шифт	9	1576074		1579079		1573795		1578885
12	Плоча	11	1580446		1573653		1573653		1580411
13	Плоча	12	1580412		1573658		1573654		1580412
14	Плоча	15	1580447		1573659		1573659		1580413
15	Шифт	13	1580447		1579078				1580413
16	Плоча	15	1580414		1574728		1573654		1580414
17	Огъвка дясна	20	1580448						1580415
18	Огъвка лява	21	1580449						1580416
19	Ребро	23	1580876						1577892
20	Плоча	24	1576084						1580417
21	Плоча лява	25	1580450						1580418
22	Плоча 2	30	1573609	1573622	1574717	1574717	1576550	1578899	1577894
23	Носач заден	31	1576092				1576556		1577895
24	Носач страничен	32	1576093				1576552		1577900
25	Носач	33	1580451				1576551		1580420
26	Ограничител	34	1576095		1574718		1576555		1577902
27	Носач защитен	35	1576096				1576554		

Фиг.2 Матрица на детайлите

Самото комплексно изделие е показано на фиг.3 в разглобен вид на всичките му съставни детайли под формата на монтажна схема, а също и в триизмерно изображение. С помощта на WordExel се създава група таблици (страници) в един общ документ. Те имат следното съдържание: За всеки от детайлите, който е елемент на комплексното изделие се

разработва съответен технологичен маршрут до операция сглобяване. Тук се пресмятат, въз основа на фирмени нормативи, времената на всяка операция, включващи машинното и подготвително – заключителното време.



Фиг.3 Комплексно изделие на група кутии среден размер

На отделна страница се изчисляват основните разходи, включващи следните компоненти: Материали; Труд, включващ и амортизациите, Разходи за електроенергия.

При получаване от евентуален клиент на заявка - искане за оферта на изделие (или още офертирано изделие – ОИ), попадащо в групата на изделия тип „Кутии среден размер“, се използва комплексното изделие (КИ), създадено предварително и онагледено с монтажната схема на фиг.3.

Монтажната схема е предвидено и следва да се използва за да подпомогне по-лесното определяне на приликите и разликите между изделието в заданието и КИ, т.е. на аналогичните детайли и на т.нар. подборки от изделието в заданието и КИ. Степента на съответствие, при тези обстоятелства, се налага да бъде определяна субективно (експертно) процентно спрямо аналогичния елемент от комплексното изделие. Това се отразява числено със съответен процент на специално подготвената за целта страница в колона „Процент на аналогия“ от таблицата (фиг.4) на същия документ.

	A	B	C	D	E	F	G	H	I
1		3100 dust		MB 1000	MB 1500	MB 1500B	MB 1700S	MB 2000	MB 4100
2	Наименование	Позиция	Идент.№	Идент.№	Идент.№	Идент.№	Идент.№	Идент.№	Идент.№
3	Плоча	1	1576068	1573608	1574714	1574714	1573648	1578881	1577881
4	Страница дясна	2	1580440	1573810	1574715	1574715	1573649	1580506	1580407
5	Страница лява	3	1580441	1573609	1574716	1574716	1573650	1580507	1580408
6	Капак	4	1580442	1573611	1574722	1574916	1576549	1580508	1580409
7	Плоча	5	1580443	1573612	1574719	1574915	1576547	1580509	1580410
8	Плоча	6	1580875	1573613	1574713	1574713	1573657	1580510	1581269
9	Плоча лява	7	1580444		1574729		1573653		1577885
10	Плоча дясна	8	1570445		1574725		1573653		1577885
11	Шифт	9	1576074		1579079		1573795		1578885
12	Плоча	11	1580446		1573653		1573653		1580411
13	Плоча	12	1580412		1573658		1573654		1580412
14	Плоча	15	1580447		1573659		1573659		1580413
15	Шифт	13	1580447		1579078				1580413
16	Плоча	15	1580414		1574728		1573654		1580414
17	Огъвка дясна	20	1580448						1580415
18	Огъвка лява	21	1580449						1580416
19	Ребро	23	1580876						1577892
20	Плоча	24	1576084						1580417
21	Плоча лява	25	1580450						1580418
22	Плоча 2	30	1573609	1573622	1574717	1574717	1576550	1578899	1577894
23	Носач заден	31	1576092				1576556		1577895
24	Носач страничен	32	1576093				1576552		1577900
25	Носач	33	1580451				1576551		1580420
26	Ограничител	34	1576095		1574718		1576555		1577902
27	Носач защитен	35	1576096				1576554		

Фиг.4. Задаване процента на аналогия спрямо КИ и броя на детайлите, участващи в ОИ

Разбираемо е, че в случая точността, с която се определя степента на съответствие зависи силно от нивото (квалификацията) на експерта и от моментните субективни и обективни обстоятелства, свързани с неговото психо-емоционално и физическо състояние и концентрация.

Използването на монтажната схема цели да се облекчи именно този етап и намаля тази зависимост. Визуалният анализ и оценка на сложността на даден детайл, елемент на изделието така става по-лесен, защото той се състои от много по-малък брой повърхнини в сравнение с цялостното изделие, на което е съставна част. В тази колона се записва 0% тогава, когато детайлът от комплексното изделие няма аналог в оферираното изделие. В отделна колона е предвидено да се отразява количеството (бройката), с която участва в изделието всеки разглеждан детайл. В същата таблица се записва и серията на ОИ при евентуални поръчки.

След попълване на двете предвидени колони за брой на детайлите и степен на аналогия следващите етапи се изпълняват автоматично. Това се отнася и за технологичния маршрут, част от който за конкретно изделие може да се види на фиг.5.

Фиг.5 Работен технологичен маршрут на ОИ

На тази страница се получава и резултатът от изчисляването на основни съставни на сумарното време.

Получените времена се използват за остойностяване при пресмятане на разходите за електроенергия, амортизации на технологичното оборудване и работна заплата.

Фиг.6 Пресмятане на основни разходи за ОИ

Обобщените разходи за труд и ток са показани в таблица на страницата „Труд и ток за оферираното изделие“ (фиг.6). Възможността за попълване на данни в тази таблица са в колони „Цена на електроенергията лв/kW“ и „Средна часова ставка лв/час“. Крайните разходи за труд и ток са на последният ред от таблицата

3. Заключение

При определени производствени условия, когато е възможно прилагането на групиране и въвеждане на комплексно изделие става възможно, на базата на разработения за него групов технологичен маршрут да се осъществи частично автоматизирано пресмятане с цел определяне на елементи от технологичната себестойност на конкретно изделие.

Използването на монтажните схеми на комплексното изделие и на оферираното позволява по-лесното и точно определяне на степента на аналогия между тях.

Прилагането на групов подход е предпоставка за намаляване на времето, което е необходимо за пресмятане на технологичната себестойност.

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МАТЕМАТИЧЕН МОДЕЛ ЗА ОПРЕДЕЛЯНЕ НА НЕПЕРПЕНДИКУЛЯРНОСТТА НА ЛИНЕЙНИТЕ ОСИ НА ОБРАБОТВАЩ ЦЕНТЪР С ПОМОЩТА НА ПРИЗМАТИЧЕН КАЛИБЪР

MATHEMATICAL MODEL FOR DETERMINING OF THE NON PERPENDICULARITY OF LINEAR AXES OF MACHINING CENTER USING A PRISMATIC CALIBER

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Abstract: When processing a workpiece geometrical inaccuracies of the machine is copied in a certain manner on the resulting surfaces. There are a number of methods and practical solutions to control the geometric precision of machines and in particular machining centers (MC) and milling machines (CNC). Among these are those that are based on the measurement of specific suitable caliber. For this purpose, the machine should work in measurement mode, most often using 3D touch trigger probe. The publication presented deduced mathematical relationships necessary to determine the deviations from the perpendicularity between the linear axes of the machine by self-diagnosis. The results were obtained using prismatic caliber who is established disoriented on the workbench of a controlled machine.

Keywords CNC MACHINES, GEOMETRIC ACCURACY, SELF-DIAGNOSIS

1. Въведение

При обработване на детайл геометричните неточности на машината се копират по определен начин върху получените повърхнини. Известни са редица методи и практически решения за контрол на геометричната точност на машините и в частност на обработващите центри (ОЦ) и фрезите с ЦПУ. Сред тях са и такива, които се основават на измерването на подходящ специален калибър. За целта машината трябва да работи в измервателен режим, най-често с помощта на контактна трикоординатна измервателна глава (ТИГ) [4]. В публикацията са представени изведените математически зависимости, необходими за определяне на отклоненията от перпендикулярност между линейните оси на машината чрез самодиагностика с ТИГ. Зависимостите са изведени при използване на призматичен калибър, за който при установяването му върху работната маса на контролираната машина не е необходимо положението му да бъде напълно ориентирано.

2. Изложение

Един широко използван метод за оценка на геометричната точност на машината се основава на сравняването на програмираните и получени контури. За целта се обработва детайл-образец, изграден от характерни повърхнини, подбрани така, че при обработване да могат да проявят и впоследствие лесно да се измерят и анализират геометричните неточности на машината.

Недостатъци на метода са:

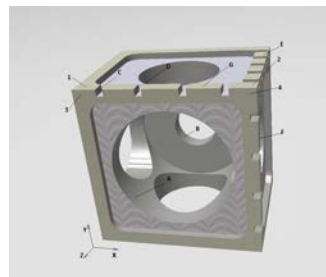
1. За постигане на необходимата точност на измерване е необходимо получаване на повърхнини с ниска грапавост;
2. За да могат достатъчно отчетливо да се отразят грешките от геометрична неточност на машината е желателно обработваните повърхнини да са с достатъчни размери, съизмерими с работната зона на машината;
3. За измерване на обработения детайл е необходима измервателна машина.

Обработването на детайл, покриващ изискванията по точките 1 и 2, е свързано с доста разходи на материали и време. Заедно с необходимостта от измервателна машина, тези недостатъци ограничават масовото приложение на този метод.

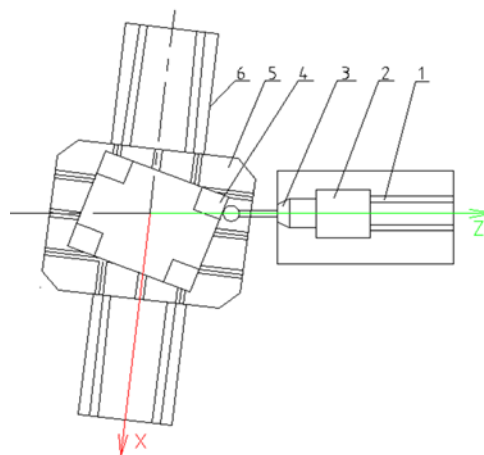
В публикацията се разглеждат възможностите на метод, основаващ се на обратен подход. Специално конструиран и изработен детайл-калибър (фиг.1,а) предварително и

еднократно се измерва възможно най-точно върху измервателна машина. Получават се т.нар. действителни размери и стойности за калибъра. След това същият се измерва и върху контролираната металорежеща машина, като за целта тя се въвежда в режим на измервателна машина. Сравнявайки резултатите от измерването с действителните размери на калибъра се прави оценка за състоянието на машината.

На фиг.1,б) са показани основните елементи в получаващата се измервателна система. С 1 и 6 са означени направляващите по Z и X с видима неперпендикулярност между тях. С 2 е означено вретеното на машината, а с 3 – контактна трикоординатна измервателна глава (ТИГ), С 5 е



а)



б)

Фиг.1 Призматичен калибър - а) и контрол на геометричната точност на ОЦ с негова помощ - б)

означена работната маса на машината, върху която приблизително ориентирано е базирано специалното приспособление - призматичен калибър 4 [3].

При МРМ с ЦПУ почти винаги се използва дясноориентирана правоъгълна координатна система, осите на която са успоредни на съответните направляващи, а началото ѝ се избира според всеки конкретен случай и няма отношение към точността на обработването. Неуспоредността на направляващите спрямо осите на тази теоретична координатна система са в основата на геометричните грешки на машината.

За да може данните от измерването да дадат максимална информация за източниците на грешка е необходимо да се направи предварителен анализ за влиянието им първо самостоятелно, а след това и комбинирано. За целта първо се разглеждат геометричните грешки и тяхното измерване в трите равнини – XOY, XOZ и YOZ, а след това и комбинираното им влияние.

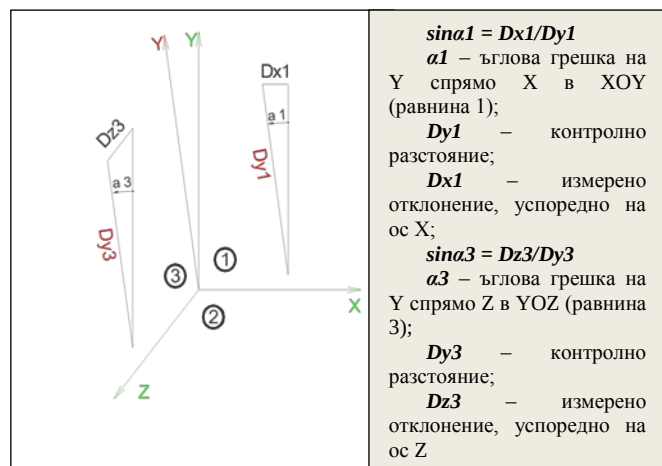
2. Измерване на перпендикулярност на осите X, Y и Z

Неперпендикулярността на осите в трите равнини XOY, XOZ и YOZ се извършва по идентичен начин. Във всяка равнина се избира една от осите да бъде базова и спрямо нея се определя отклонението от перпендикулярност на другата. Резултатът се изразява като отношение ($\sin$ или $\tan$, които при ъгли, по-малки от 1° са практически еднакви) на измереното отклонение Dx по базовата ос (в случая X) спрямо избраното предварително контролно разстояние Dy по другата ос, (фиг.2):

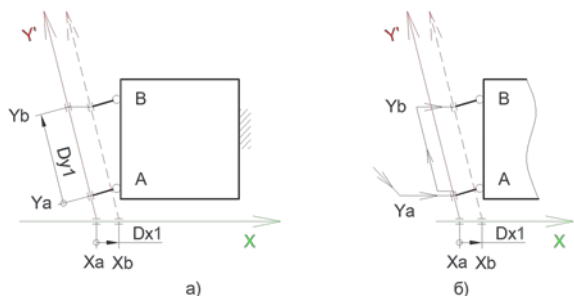
$$(1) \sin \alpha = Dx/Dy \sin \alpha$$

Когато неуспоредността на установяване на ръба на калибъра е сравнително малка (до 2° - 5°) може да се приеме, че при измерване положението на точката на контакт по сферичния осезател на ТИГ оказва пренебрежимо влияние.

Тъй като всяка ос участва в две съседни равнини, резултатите от измерванията в равнината XOY в по-нататъшните анализи са с индекс 1, XOZ – 2 и YOZ – 3.



Фиг.2 Означения на измерваните елементи в 3-те равнини



Фиг.3 Измерване на грешката на ос Y спрямо X в равнина XOY

Със зелено са показани теоретичните положения на осите, а с червено действителните.

В зависимост от конструктивния подход, съществуват машини, при които част от движенията се извършват от детайла, а друга част – от инструмента. Това се взема под внимание при комплектуване на машината със системата за ЦПУ, така че програмирането да не зависи от конструкцията на машината.

На фиг. 3.а е показана схема на измерване на неперпендикулярност на оста Y спрямо X чрез използване на правоъгълен калибър. За целта върху масата на машината се поставя калибър (показан с дебела линия), така че едната му страна да е успоредна на една от осите (в случая ос X). Приема се че детайлът е неподвижен, а движенията се извършват от инструмента, в случая – трикоординатна измервателна глава (ТИГ). На фигурата условно е показан само измервателният накрайник.

Траекторията на ТИГ при измерване е показана на фиг. 3.б. Първото измерване се извършва в т. А, като по Y ТИГ се позиционира в координата Ya. След това започва измервателно преместване по X, при което се очаква съприкосновение на измервателния накрайник с калибъра. При докосване се получава измервателен сигнал и чрез обратната връзка на системата за позициониране координатата Xa се запомня.

Второто измерване става по аналогичен начин, но предварително ТИГ се премества по Y на позиция Yb. Ако оста Y е перпендикулярна на X, измервателният сигнал би трябвало да се получи в същата позиция Xa. При наличие на неперпендикулярност обаче, сигналът от ТИГ ще се получи при ново положение на супорта, носещ направляващата по ос Y, означено като Xb.

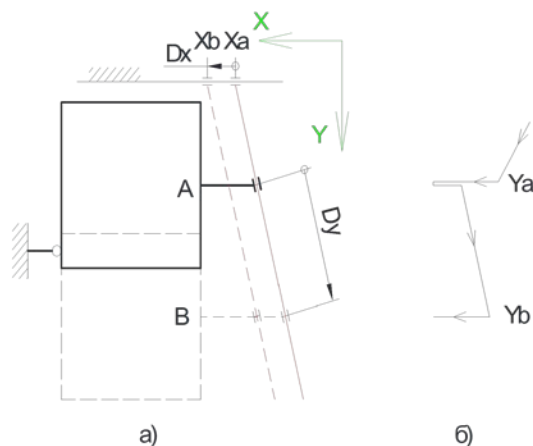
Грешката α_1 в разположението на ос Y1 спрямо X1 (неперпендикулярност на Y1 спрямо X1) в равнината XOY може да се пресметне по зависимостта:

$$(2) \alpha_1 = \arcsin\left(\frac{Dx_1}{Dy_1}\right),$$

където α_1 е отклонението от перпендикулярност, Dy_1 – базата на измерването, Dx_1 – разлика между координатите по X, получени при измерване в т. А и т. В (фиг. 3.б).

За постигане на максимална точност на измерването, базата Dy се избира възможно най-голяма и се ограничава от размерите на калибъра. На фиг. 4.а е показан вариант, при който вретеното с ТИГ е неподвижно, а движенията по координатните оси се извършват от детайла.

И тук калибърът се разполага така, че едната му страна да е успоредна на една от осите (ос X). Вляво схематично е показана ТИГ, неподвижно свързана с корпуса на машината. Траекторията, свързана с измервателните движения на калибъра е показана на фиг. 4.б.



Фиг.4 Измерване на грешката на ос Y при неподвижна ТИГ

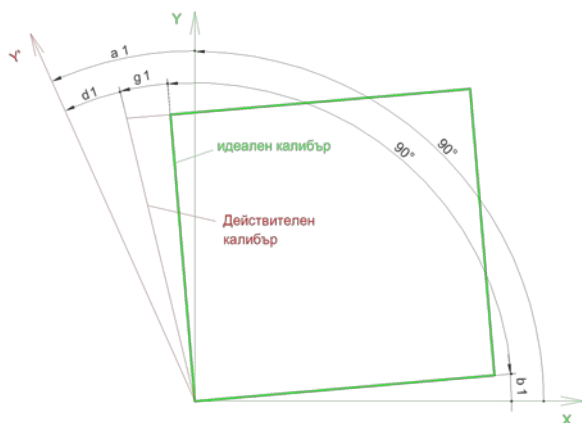
В началото супортът, носещ калибъра се придвижва до координата по Y – Ya, след което започва измервателно движение по X докато калибърът докосне измервателния крайник и съответно в системата за ЦПУ се запамятава координатата Xa. След това калибърът се препозиционира в т. Yb и следва второ измервателно движение по X докато се получи сигнал за докосване, при което се запомня координатата Xb. Положението на калибъра и направляващата Y при това положение са показани с прекъсната линия. Както и в предния случай разстоянието Dx зависи от неперпендикулярността на ос Y спрямо X.

С разглеждания пример се доказва, че резултатът от измерването на грешката не зависи от това, дали се движи ТИГ или калибър. Това се отнася и за проявата на тази грешка при обработването на детайли и за програмирането на движенията при машините с ЦПУ. С други думи, разглежданите схеми на измерване са общо приложими, въпреки многообразието на конструкциите на обработващи центри. Поради това, по-нататъшните анализи ще са на базата на неподвижен калибър и подвижна ТИГ, като по-нагледна и съответстваща на общоприетите принципи за програмиране на машини с ЦПУ.

Извършените до тук разсъждения са верни при условие, че калибърът е с идеални геометрични характеристики. При изработването му обаче, винаги се допускат известни грешки. Свеждането им под определени стойности рязко увеличава цената му. Във връзка с това е приет подход, при който калибърът се обработва с икономически целесъобразна точност, след което той се измерва на измервателна машина. По-нататък измерените отклонения се включват чрез съответни корекции към резултатите от измерването на геометричната точност на ОЦ.

Друг проблем при измерването на геометричната точност на ОЦ е правилното разполагане на калибъра върху масата на машината. В разглежданите схеми се налага едната страна на калибъра да е успоредна на избраната за база ос. Като се обърне внимание, че желаната точност на измерване е от порядъка на стотни и хилядни от mm, правилното установяване на калибъра се оказва доста трудоемко. За да се опрости тази част от работата се приема калибърът да се установи с относително ниска точност (примерно 0.2-0.3 mm), като при измерванията се отчете действителното му положение и при изчисленията автоматично се включват съответни корекции.

На фиг.5 е показан общ случай, при който ръбът на калибъра, показан с дебела зелена линия, сключва с базовата ос ъгъл β_1 . Самият калибър също е с определена грешка γ_1 , представляваща неперпендикулярност на втория ръб спрямо базовия. Ъгълът δ_1 е резултатът от измерването на геометричната точност на машината. Интересуващата ни грешка е α_1 , представляваща неперпендикулярността на Y спрямо X в равнината XY.



Фиг.5 Влияние на допълнителните грешки при измерване

От построението на фиг.5. може да се изведе следното равенство:

$$\beta_1 + 90^\circ + \gamma_1 + \delta_1 - \alpha_1 - 90^\circ = 0,$$

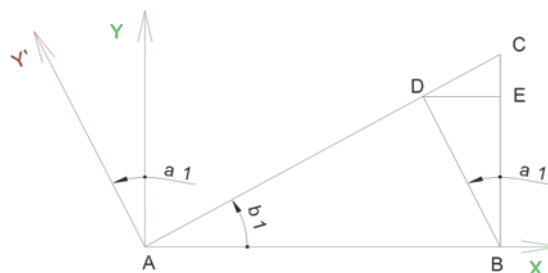
което след съкращаване и опростяване придобива окончателно вида:

$$(3) \quad \alpha_1 = \beta_1 + \gamma_1 + \delta_1$$

За да се изчисли грешката α_1 по формулата (3) е необходимо предварително да бъде измерена грешката γ_1 . Това трябва да стане на измервателна машина и резултатите да се използват като константи при използване на калибъра.

Ъгълът β_1 се изчислява на базата на измервания, направени на самата атестирана машина – фиг.6.

Отсечката AC е част от ръба на калибъра, който трябва да е успореден на оста X. Грешката на установяване β_1 се изчислява от правоъгълния триъгълник ABC.



Фиг.6. Определяне на грешката β_1 на установяване на калибъра

$$(4) \quad \beta_1 = \arctan BC/AB$$

AB е контролното разстояние за измерването, аналогично на разстоянието Dy от фиг.3. Измерената линейна грешка BD е успоредна на оста Y', по която става преместването на ТИГ и е аналогична на Dx от фиг.3. Отсечката BC се изчислява от правоъгълните триъгълници BDE и EDC:

$$BC = BE + EC$$

$$BE = BD * \cos \alpha_1$$

$$DE = BD * \sin \alpha_1$$

$$EC = DE * \tan \beta_1 = BD * \sin \alpha_1 * \tan \beta_1$$

$$(5) \quad BC = BE + EC = BD * (\cos \alpha_1 + \sin \alpha_1 * \tan \beta_1)$$

От (5) се вижда, че за изчисляване на BC са необходими α_1 и β_1 , които за момента са неизвестни. От друга страна разликата BC-BD за малки ъгли е пренебрежимо малка. Например, при контролно разстояние AB=200mm, $\beta_1=2^\circ$, $\alpha_1=0.5^\circ$, за BC-BD=0,00186mm. Същевременно отклонението на Y' спрямо Y на разстояние 200 mm при ъгъл $\alpha_1=0.5^\circ$ е 1.745 mm. Вижда се, че грешката в отклонението на оста е около 1000 пъти по-голяма от разлика BC-BD. Това ни дава основание в по-нататъшните анализи при изчисляване на β_1 да използваме измерената стойност BD вместо необходимата BC.

Следва да се отбележи, че направените до тук анализи имат за цел определянето на номиналните стойности на евентуалните геометрични отклонения на машината. Естествено е, че в случая трябва да се имат предвид и възможните грешки (особено случайните), които биха могли да възникнат и формират неопределеност при прилагането на този подход. Този аспект е подробно анализиран в [1,2], а направените заключения потвърждават перспективността и приложимостта на подхода в практиката.

3.3. Заключение

Осъществяването на контрол чрез този подход осигурява достатъчна точност на измерване и е лесно приложим в условията на малки предприятия.

Не е необходима специална квалификация, допълнителна екипировка и специална подготовка.

Конструкцията на необходимия работен калибър е достатъчна технологична и изработването му е във възможностите на повечето фирми.

Зависимостите, които се използват не представляват голяма сложност за трансформиране в MACRO за NC програма.

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PRECONDITIONS OF SEPARATION IN STR WITH INTEGRATED MEMBRANE FOR ENERGY-SAVING BY RECOVERY OF VALUE-ADDED MATERIALS

УСЛОВИЯ НА СЕПАРАЦИЯ В РЕАКТОР С РАЗБЪРКВАНЕ ИНТЕГРИРАН С ПОТОПЕНА МЕМБРАНА ЗА ЕНЕРГОСПЕСТЯВАНЕ ПРИ УЛАВЯНЕ НА КОМПОНЕНТИ С ДОБАВЕНА СТОЙНОСТ

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Abstract: Energy-saving by recovery of value-added materials from complex dispersions by using semi-permeable membranes has been proved world-wide. The effect is related to fundamental knowledge of fluid flow and mass transfer in complex fluids close to membrane interfaces. Innovative biotechnologies for value-added products such as exopolysaccharides or antioxidants benefit by such explorations in preserving the biological activity of the target components. The paper presents a solution of theoretical model of a stirred tank reactor (STR) Biostat equipped with membrane immersed in a non-Newtonian model solution of exopolysaccharide, e.g. glucomannan and biomass. CFD methodology is employed to reveal original data on shear deformation rates and shear stress at the membrane interface, as well as to predict the average mass transfer coefficient related to the boundary layer at the membrane surface based on the flow information obtained. The results are compared with similar data reported for conventional systems with different impeller and systems with external membranes.

KEYWORDS: ENERGY-SAVING, DESIGN WITH INTEGRATED MEMBRANE, STR, SHEAR STRESS, MASS TRANSFER

1. Introduction

Recent developments in membrane separation technology and increased implementation of various membrane techniques for water purification and recovery of value added products brings attention to the lack of data on the performance of membranes designed as immersed modular systems in stirred tanks [1]. The recent advances of the science of mixing reactors and membranes allowed the superposition of information on fluid flow in STR with data on separation dynamics of immersed membranes, thus generating combined knowledge on the performance of integrated systems. This combined knowledge would allow further exploration of integrated designs for recovery of value-added products possessing complex non-Newtonian physical properties otherwise important for their application in material practice.

Overlooking another aspect, recent advances in process design introduce single-use bioreactors and show them to be amenable for scale-up of data collected from traditional bench-scale fermenters [2]. Related to single-use bioreactors, modeling and characterization of bioreactor environments from mixing and shear perspectives at both small and large scales demonstrated high level of interest [3]. The trend increased the importance of performance data of traditional bioreactors, such as conventional bench-scale Biostats, and suggests further analyses on integrated designs to be performed in such starting vessels. In other words, the performance data of integrated immersed membranes should be related to conventional Biostat STR vessels, in order to ensure further scale-up analysis.

The aim of this study of preliminary research is to reveal two characteristics - shear and mass transfer rates - as important parameters for separations focusing on a design of traditional bench-scale reactor Biostat in original integrated set-up with in-line tubular membrane module immersed in non-Newtonian fermentation fluid for recovery of components of highly viscous biofluids, for example, separation of emulsion stabilizer exopolysaccharide and biomass containing prebiotics, both important for practice. The idea of using combined impeller and membrane designs has been considered as prospective in so far as such designs allow application to separations in highly viscous and complex production fluids where both interface and transport problems occur.

2. Experimental design and simulation details

Fig. 1 shows the experimental system, the corresponding computational domain and its discretization pattern.

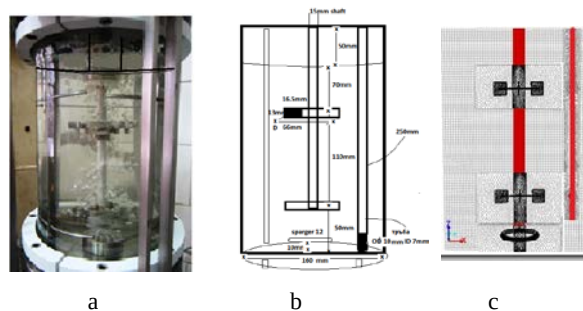


Fig. 1 Experimental reactor and simulation grid.

The vessel (Sartorius Biostat Aplus) was $T=0.16\text{m}$ in diameter equipped with two impellers sized 0.066m . The tubular membrane module was ID 7mm and OD 10mm with 250mm length positioned as shown in the figure.

The design has proved successful for production of exopolysaccharides, e.g. glucomannan that was implemented as viscosity promoter and emulsion stabilizer in cosmetic creams [4]. The optimal operating conditions of this production, namely, mixing impeller speed of 400rpm and relative volumetric gas flow rate of 1vvm ($4.5\text{dm}^3/\text{min}$ related to 4.5dm^3 fluid volume), were considered as primary for the assessment of a membrane operating in simultaneous separation with the productive bioreaction. The biofluid containing EPS showed non-Newtonian properties and was classified as a power law fluid with consistency coefficient $K=0.02\text{Pa}\cdot\text{s}^n$ and flow index $n=0.78$. Considering the impeller speed of 400rpm , these physical parameters revealed average apparent viscosity μ of the material of $6.7\text{mPa}\cdot\text{s}$ causing flow pattern of complex nature in the targeted stirred volume.

The study was carried out by computational fluid dynamics (CFD) analysis and a mathematical model based on the Reynolds-averaged Navier-Stokes (RANS) momentum equation (1) with

added two equations (4 and 5) to account for turbulent kinetic energy (k) and turbulent energy dissipation (ε) as additional parameters for closure. The set of equations conformed to the standard (k - ε) model [5, 6]. The model was extended to account for the non-Newtonian flow property of the studied biofluid by introducing the above power law parameters K and n (eq. (3)). The computed components of the stress tensor were used to determine the shear rate $\dot{\gamma}$ using eq. (6) and to transform it to shear stress τ using eq. (7):

$$(1) \frac{\partial V_j}{\partial t} + V_j \frac{\partial V_i}{\partial x_j} = -\frac{\partial}{\partial x_j} \left(\frac{p}{\rho} + \frac{2}{3}k \right) + \frac{\partial}{\partial x_j} \left(\frac{\mu}{\rho} \left(\frac{\partial V_j}{\partial x_i} + \frac{\partial V_i}{\partial x_j} \right) \right)$$

$$(2) \mu = \mu_a + \mu_t; \mu_t = \rho C_\mu \frac{k^2}{\varepsilon}$$

$$(3) \mu_a = K \left(\frac{\partial V_j}{\partial x_i} + \frac{\partial V_i}{\partial x_j} \right)^n$$

$$(4) \frac{\partial k}{\partial t} + V_i \frac{\partial k}{\partial x_i} = \frac{1}{\rho} \frac{\partial}{\partial x_i} \left(\mu_a + \frac{\mu_t}{\sigma_k} \frac{\partial k}{\partial x_i} \right) + \Pi - \varepsilon$$

$$(5) \frac{\partial \varepsilon}{\partial t} + V_i \frac{\partial \varepsilon}{\partial x_i} = \frac{1}{\rho} \frac{\partial}{\partial x_i} \left(\mu_a + \frac{\mu_t}{\sigma_\varepsilon} \frac{\partial \varepsilon}{\partial x_i} \right) + C_1 \frac{\varepsilon}{k} \Pi - C_2 \frac{\varepsilon^2}{k}$$

$$\Pi = \frac{\mu_t}{\rho} \left(\frac{\partial V_i}{\partial x_j} + \frac{\partial V_j}{\partial x_i} \right) \frac{\partial V_i}{\partial x_j}$$

$$(6) \dot{\gamma} = \frac{\partial V_j}{\partial x_i} + \frac{\partial V_i}{\partial x_j}$$

$$(7) \tau = K \dot{\gamma}^n$$

In eq. (1)-(7), V is fluid velocity, x indicates the space coordinate, p is pressure, ρ is fluid density, k stands for turbulent kinetic energy, and ε is the rate of kinetic energy dissipation.

The kinetic energy dissipation rate ε was used to outline the zones of active mass transfer close to the membrane interface where an average mass transfer coefficient k_L could be obtained via eq. (8) reported for transitional flow across vertical cylinder [7]:

$$(8) Sh = 0.43 + 0.193 Re^{0.618} Sc^{0.31}$$

where $Sh = k_L T / D$; $Re = Nd^2 \rho / \mu_a$; $Sc = \mu / \rho D$ are Sherwood, Reynolds and Schmidt numbers on the side of the biofluid, T is the hydraulic diameter of the vessel, D is the diffusion coefficient, here assumed to be for diffusion of sucrose molecular weight 342, $D = 0.45 \cdot 10^{-9} \text{ m}^2/\text{s}$; N stands for impeller revolutions at 6.7 s^{-1} , impeller diameter d is 0.066 m , and ρ density of aqueous phase 1018 kg/m^3 .

Referring to the simulation details, the computational domain was represented by structural conformal mesh composed of tetrahedral cells close to the impeller and with refinements in the near-wall regions, the cells numbering ca. million (e.g. $0.9 \cdot 10^6$ (Fig. 1c).

Simulations were carried out by application software ANSYS FLUENT (release 13.0, Ansys, Inc., 2010). The boundary conditions included symmetry for the free fluid surface, pressure outlet for the gas phase with backflow ratio 1 and volume fraction 1 for the outlet, as well for the air inlet where initial velocity of 8 m/s in vertical direction was applied to account for inlet gas flow rate of $4.5 \text{ m}^3/\text{min}$. Stationary wall boundary condition with zero velocity gradients for the vessel walls and moving wall boundary conditions with rotational velocity of 400 rpm to the moving parts. The presence of gas in the two-phase flow case has been modeled by the Euler-Euler multiphase model accounting for the flow properties of the separate phases, as well to the contact between them. The

convergence criterion was set for velocities and turbulence values equally at 1×10^{-5} . Convergence was judged upon by both residuals and target quantities, i.e. linear velocities and strain rate. A reasonable convergence was achieved and realistic logical values were obtained.

Model validity was studied by comparison of parameters, e.g. moment and power input, and separately by comparing experimental shear rates with shear rates predicted by the model in selected points of the bioreactor volume, more specifically at 20 mm off the impeller tip in the upper impeller plane. Data on validation are reported elsewhere [6].

3. Results and discussion

Fig. 2 illustrates the flow field for the stirred tank and the velocity contours generated by the impeller in the reactor cross section including the tube of the membrane in gas presence. The solution of this complex system shows the areas of major interest are the impeller levels $z=0.05 \text{ m}$, and $z=0.16 \text{ m}$, the membrane surface front, side and rear to the impeller and the stagnant zones, with relatively low backflow and transfer rates within the stirred fluid.

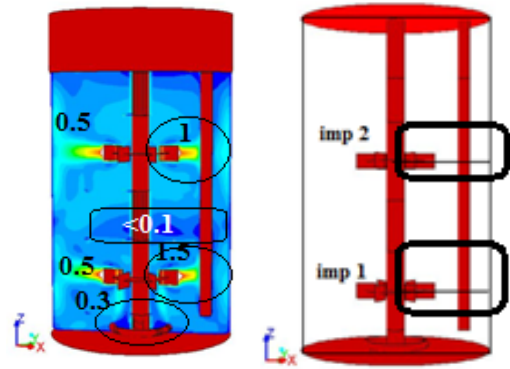


Fig. 2 Velocity (m/s) zones of interest for enhanced trans-membrane wall mass transfer

The variation of shear rate and kinetic energy dissipation rate along the lines across the membrane in the two impeller planes are shown at gas absence in Fig. 3. Referring to Cartesian coordinates with $z=0$ at the vessel bottom, the radial lines of the plots were selected in the $x=y$ plane at off-bottom distance $z=0.05 \text{ m}$ (lower impeller plane) and $z=0.160 \text{ m}$ (at the upper impeller plane) corresponding to the impellers' positions. It is seen that the maximum shear rate $\dot{\gamma}$ and kinetic energy dissipation ε determined in gas absence are seen to be 8 ks^{-1} and $1200 \text{ m}^2/\text{s}^3$, respectively. The corresponding values of shear stress are 17.7 Pa at the maximum and 1.2 at the minimum. It is noteworthy that these values exceed the range of shear stress ($\tau < 10$) reported for membranes with narrow channel with spacers [8].

Contributing to the reported goal, shear distribution along the membrane interface was also of interest. It is illustrated directly by the immersed solid body diagrams in Fig. 4, where also the effect of gas presence is seen clearly. Determining the surface-average values in both cases, i.e. absence versus presence of gas, the effect of the gas shows only slight rise of shear in gas presence in terms of the optimal rate of gas flow registered (e.g. 1 vvm and $4.5 \text{ cub.m. per min}$). The area-averaged shear rate in both cases (i.e. "no gas" vs. "gassed") differs by only 10% , such as 900 vs. 1050 s^{-1} , yet the distribution in gas presence is largely different, being more uniform

in gas presence and increasing the zones of moderate shear in areas where shear is low in gas absence (marked with red).

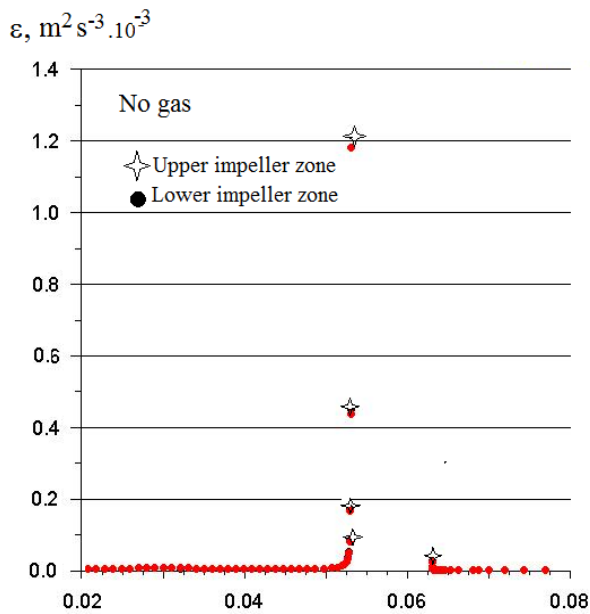
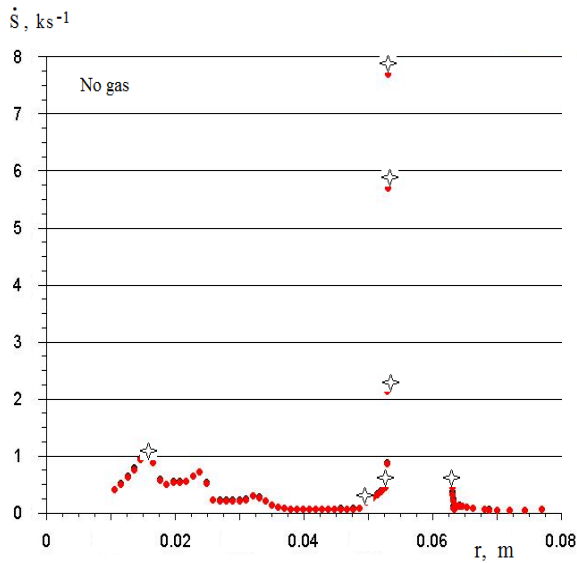


Fig. 3 XY plots of shear and turbulence parameters vs radial coordinate.

The effect can be assessed more clearly by the XY plots along the Z-coordinate adhering to membrane external front shown in Fig. 5, where additional peaks can be observed to correspond to the colored sections in Fig. 4. [The coordinates of the membrane front vertical line has been determined to be x (0.03722, 0.03722), y (0.03722, 0.03722), z (0.035, 0.22)]. The fact proves the positive effect of the gas in achieving more uniform distribution of velocity, shear and viscosity close to the membrane surface accompanied possibly by enhanced mass transfer in the boundary layer. Further analysis of this performance parameter at other gas flow rates seems obligatory to confirm the effect of gas presence on the performance of immersed membranes.

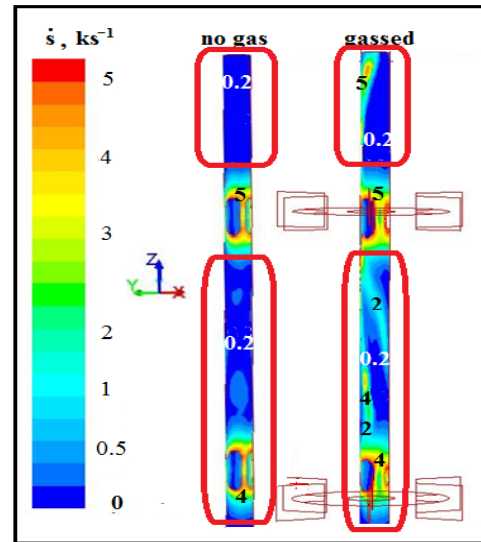


Fig. 4 Membrane contour plots showing the effect of gassing on the distribution of shear rate (in ks^{-1}).

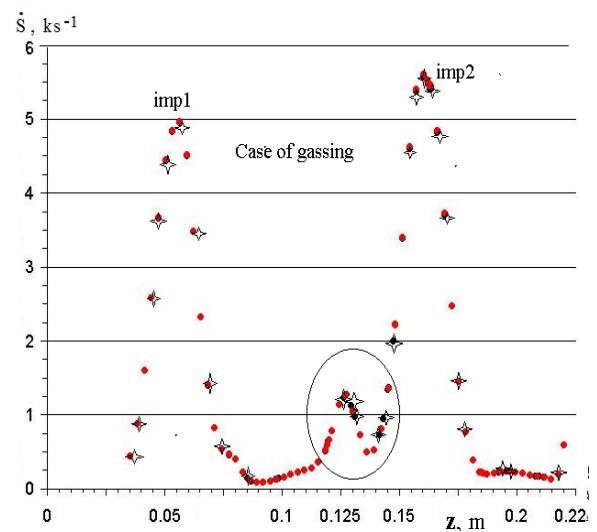
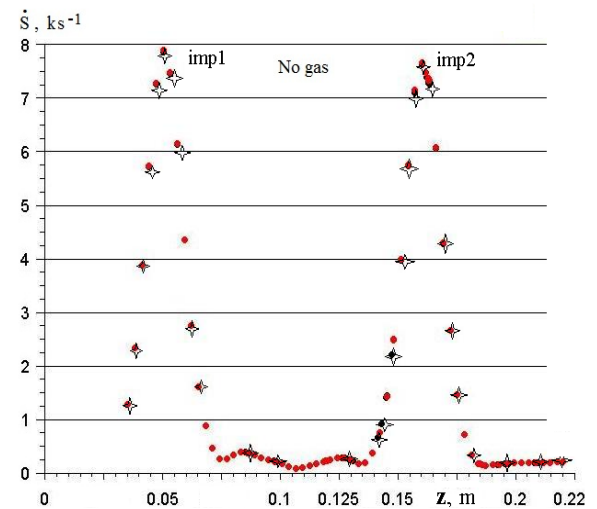


Fig.5 The effect of gassing on the distribution of shear rate (in ks^{-1}).

The values of shear stress and mass transfer rate coefficients obtained in this study are compared with reference data in **Table 1**. The reference data reveal comparable parameters reported for mixing equipment with membranes immersed in fluids with different hydrodynamics, e.g. arc-blade impellers, composite bodies [8], and also membranes operating on different principle as external off-tank designs [9-11]. It is seen that the Biostat with immerse membrane shows characteristics comparable with the reported designs. The mass transfer coefficients vary mainly depending on the size of the diffusing molecule, for the sake of comparison being assumed sucrose (340 Dalton) in aqueous solutions of 6 and 2 mPas in case 1 (this study) and case 3 [8] (with diffusion coefficients $\sim 5 \cdot 10^{-10} \text{ m}^2/\text{s}$), respectively, and dextran (167 kDa) in case 6 [12] (diffusion coefficient of $5 \cdot 10^{-11} \text{ m}^2/\text{s}$).

Table 1: Summary of experimental results on shear stress and mass transfer compared with achievements for various reported membrane systems in diluted aqueous solutions.

Separation system	Reference cConditions	Membrane integrated as	τ , Pa	k_L , $\text{m/s} \cdot 10^4$
STR with flat blades	This study Re=3800, 1m/s $\mu_a=6 \text{ mPa}\cdot\text{s}$, low D	Immersed tubular module	2 (up to 20)	~ 0.1 (Sh ~ 650 , Sc $\sim 12 \cdot 10^3$)
STR with arc blades	This study Re=8200 2.6m/s	Immersed tubular module	2-4	-
Stirred cell	Koutsou [8] Re=8000-10000, 0.3m/s (up to 0.9m/s)	Immersed flat bottom	1-2 (up to 10)	~ 0.5 (Sh $\sim 10^3$, Sc $\sim 5 \cdot 10^3$)
Cross-flow Unit	Dzhonova et al. [9] Re=8500 0.6 m/s	External flat-sheet	5.3 (< 20)	-
Hollow Fiber Unit	Bérubé et al. [10] Re=12000, 0.2m/s (up to 0.4m/s)	External	2.9 (up to 6)	-
UF Unit	Ghosh et al [11] $\sim 0.2\text{m/s}$	External Tubular	-	10^{-3} (Sh $\sim 10^2$)

3. Conclusion

In terms of the theoretical model and CFD simulations employed, the system of STR and immersed membrane explored is comparable with reference membranes, both external and immersed in STR with different circulation pattern in the sense that it allows comparable shear and mass transfer rates close to the membrane interface. The **design of Biostat with immersed membrane** is prospective for further detailed analysis including also other parameters, such as internal mass transfer, as well as wider operating conditions and physical properties of value-added materials.

4. Acknowledgement

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5. Literature

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HOW DOES 10% ETHANOL COMPOSITION OF GASOLINE AFFECT CAR ENGINE PERFORMANCE

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ABSTRACT: *Ethanol is a renewable, domestically produced alcohol fuel made from plant materials, such as corn, sugar cane, or grasses. Using ethanol we can reduce oil dependence and greenhouse gas emissions. Ethanol fuel used in the U.S. has increased dramatically from about 1.7 billion gallons in 2001 to about 13.4 billion in 2014. E10 is now the standard replacement for traditional unleaded. Over 90% of all unleaded sold today contains ethanol.*

In this paper it has been examined the influence of the E10 fuel mixture on some car engine performance.

KEYWORDS: ETHANOL, RENEWABLE FUEL, BIOFUEL, FUEL MIXTURE, BIODIZEL, GREENHOUSE EFFECT.

INTRODUCTION

E10 is now the standard replacement for traditional unleaded [1-4]. E100 (pure ethanol) is widely used as fuel and for this purpose is needed special engine. It can be used as a supplement to regular engine. Over 90% of all unleaded sold today contains ethanol. Ethanol has higher octane than gasoline, and adds 2,5 - 3 points at the 10% level. E10 can be found at all octane levels from 87-93.

Bioethanol is a form of renewable energy that can be produced from agricultural raw materials [5]. It is commonly used maize, sugar beet, potatoes and cereals. According to the International Energy Agency, cellulosic ethanol could allow ethanol fuels to play a much larger role in the future than previously thought.

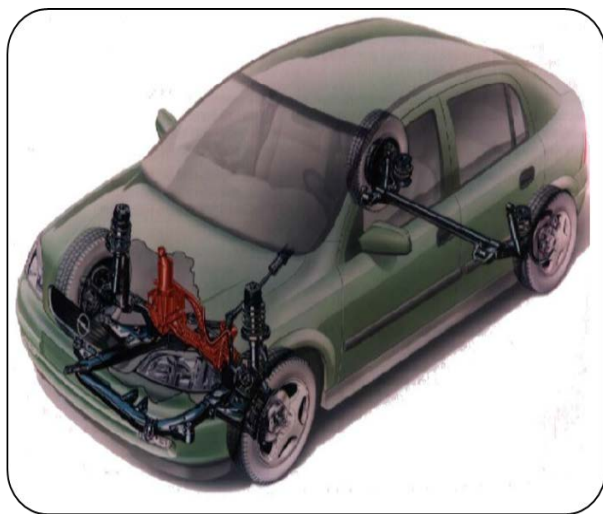
EXPERIMENTAL

General characteristics of the object of our researches

Details for the car: Brand: Opel Astra 1.6G; Engine: X16SZR; Displacement 1598 cm³; Power: 55 (75)/5200 [kW(hp.)/min⁻¹] Torque: 128/2800 [Nm/min⁻¹]; Compression Ratio:1:9.6; Maximum pressure at the end of the compression stroke: 12-15Bar; Ignition system: Multec-Ze; Fuel system: Multec-Ze; MAP (Manifold absolute pressure); Combined control of ignition and fuel system; Axle: Front; Gearbox: manual 5-speed; Fuel consumption (urban): 9,7 L/100 km; Fuel consumption (outside city) 5,6 L /100 km.

Conditions in which the control trips were carried out

In order to ensure comparability of the results during the control test with different fuels was provided: Adjustment of the engine; Regulation of the running part of the car; Thermal state of the engine - the same temperature of the coolant; Engine oil type - Repsol Elite Multivalvulas 10W40; Spark plugs Champion-RC10DMC; Oil filter Champion - G102/606; Air filter Filtron; Fuel OMV - H95; Ethanol is E100.



In order to cover the whole working area of the engine using fuel mixture E10 and to assess its technical and the car's engine performance were carried out the following inspection trips:

- Disassembly and assessment (after 3000 km) of the technical parameters of the engine and technical evaluation of the undercarriage of the car and connected elements of the passenger compartment with it;

- The fuel system is Multec-Mono with fuel pressure 3 bar. The fuel filter was replaced after 1000-1500km running as well as the engine oil 10W40 Repsol. The gearbox F13/5 was in good condition;

Trip distances for the entire period of the car test 25 771 km; 15 793 km with a fuel mixture E10 and 9918 km with H95 fuel;

Assessment of the state of the rubber static seals fuel system of the vehicle

In order to examine and evaluate the influence of the fuel mixture E10 on the rubber elements which are directly in contact with fuel, rubber gaskets samples of the fuel system were taken, as well as rubber "O" rings of this system. Material: NBR(Nitril-butadiene rubber), Hardness Shore A: 40÷90; Temperature range: -30÷ +85°C; tensile strength N/mm²: 5-15; very good scrub resistance.

The examined samples were immersed into gasoline H95, E10 fuel mixture and E100 (pure ethanol). Testing was done according to ISO 1817: 1999 "Vulcanized Rubber-Determination of the effect of liquids [6].

Determination of resistance of different liquids was made of our samples ~3,5mg with thickness 2±0,2mm. The obtained results are shown in the following graphics.

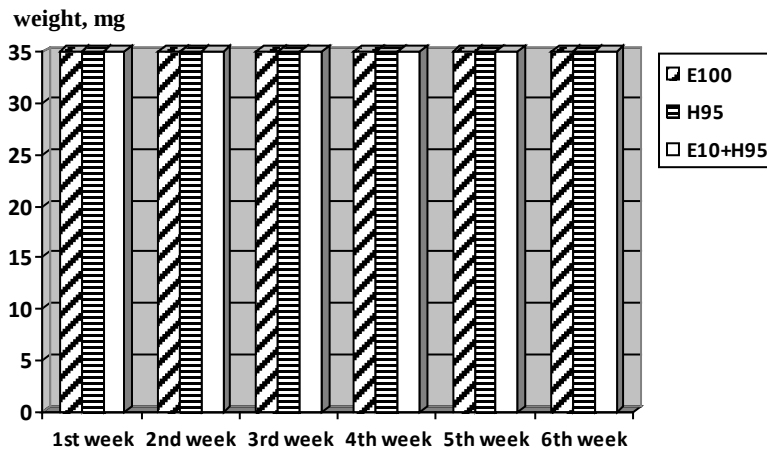


Fig. 1. Weight-time dependence of our samples immersed into different fuels E100, H95 and E10+H95.

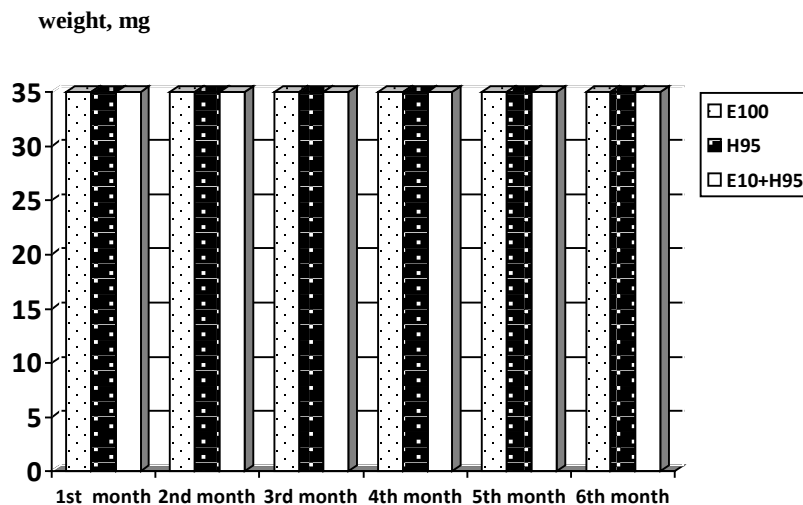


Fig.2. Weight-time dependence of our samples immersed into different fuels E100, H95 and E10+H95 for the next six month.

As a result of our researches was established that the used solvents - gasoline and ethanol do not cause change in mass of test samples. Vulcanizates are resistant to the action of such solvents for the whole period of our testing. There is no change in mass after being immersed into gasoline, pure ethanol and mixture E10+H95.

Ethanol has a lot of benefits - very high octane, which contributes to greater resilience to shock loads and the ability to optimize engine (compression ratio, pre-ignition) and with density close to that of gasoline;

- Presence of oxygen in the composition can provide a homogeneous fuel air mixing and as a result decreasing unburned or partially burned molecular emissions (hydrocarbons and carbon oxides);

- Ethanol has high latent heat of vapourisation allows "cooling effect" of air and thus improves the efficiency of the filling;

- Has a higher lubricant index compared to petro-diesel ones and this could lead to a longer life of the injection system. When

ethanol is blended with conventional gasoline in small amounts (<10%), the improved burn of gasoline due to the oxidation by ethanol compensates for the lower energy content of ethanol itself;

Ethanol is characterized by high octane number RON. The special engine will be less sensitive to detonation combustion and the degree of compression can be increased in order to increase its effectiveness. This property is especially useful for reducing the carbon oxides emissions of spark-ignition engines. One promising approach is the reduction of conventional engines and distribution of gas turbine engines with smaller displacement. Having in mind that these engines can be highly sensitive to shock loads, significant improvement can be done by using of high octane fuels – Table1.

The typical ratio that is used for the compression ratio gives 1 point CR increase in 5 points octane. When ethanol is used for spark ignition engines (CR=RON95), the maximum pressure at the end of compression can reach 13-14 atmospheres and may induce heat for the efficiency increasing.

Table 1. *Calorific values of the fuel oil*

Fuel	RON	Calorific values of 1L, kJ/l	Calorific values of 1kg, kJ/l
Gasoline	91-98	29,00	44,00
Propane	111	23,40	46,10
Butane	103	26,50	45,46
Methane	135		39,82
Ethanol	129	19,59	26,40
Methanol	133	14,57	22,61
Gasohol	93-94	28,06	43,54
Disel		40,90	42,47

CONCLUSION

The results obtained give us information that solvents like gasoline and ethanol do not lead to the change in mass of the test samples. Vulcanizates are resistant to the action of such solvents.

Biodiesel improves engine performance, increases power, does not contain sulfur, reduces fuel consumption. The combustion of this fuel in the engine cylinder is not accompanied by the formation of sludge and the release of soot.

It has a higher octane rating and clean burn, so it supports a higher compression ratio and more aggressive ignition timing. Ethanol is considered also as renewable resource. Replacing gasoline with ethanol is aimed to reduce gasoline consumption for a reduction in greenhouse gases.

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EFFECT OF PLASTIC DEFORMATION ON THE MICROSTRUCTURE AND PLASTICITY OF HIGH FREQUENCY ELECTRIC RESISTANCE WELDING

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Abstract: High frequency electric resistance welding is one of the most extensively used methods for production of longitudinally welded carbon steel pipes suitable for line pipe, casing and tubing. In this pipe production process, the hot rolled steel strip goes into the continuous cold forming process and its edges are continuously joined by a combination of localized high-frequency electric resistance heating and plastic deformation. The heated edges up to the welding temperature squeezed together at the “Vee” apex by the forge pressure rolls, plastically deformed and a forge type weld is formed. The plastic deformation which is realized under the action of the squeezing rolls caused changes of the microstructure constituents in the bond line and in the heat affected zone and plays principal role on the quality of the welded joint. In this paper microstructure and plasticity of the welded joint were investigated by light microscopy and flattening testing. The obtained results shows that plastic deformation plays principal role on the microstructure and plasticity of the welded joint.

KEYWORDS: MICROSTRUCTURE, PLASTIC DEFORMATION, HIGH FREQUENCY WELDING, PLASTICITY.

1. Introduction

High-frequency electric resistance welding (HFERW) process is one of the most extensively methods for production of high quality longitudinal seam welded carbon steel pipes suitable for line pipe, casing and tubing. In this process, hot rolled strip is gradually formed into round shape through roll-forming stands, and its edges are joined by a combination of localized high-frequency electric resistance heating and forge pressure, as schematically illustrated in Figure 1 [1,2,3]. Most of these pipes are produced according to API Standard [4] plus client supplementary requirements. Under this heat input condition and forge pressure it is possible to improve the weld joint quality and productivity of longitudinal seam welded carbon steel pipes.

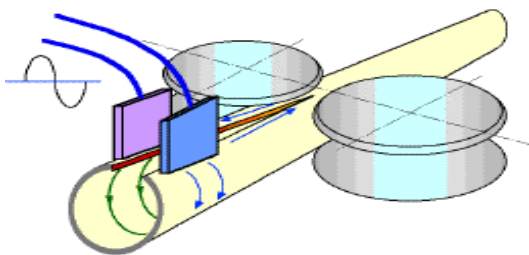


Fig.1 Schematic illustration of HFERW

The high-frequency current applied to the strip edges through sliding contacts, concentrated on the surface layer of the strip edges due to the “skin” and “proximity” effects, generate joule heat and the hot “Vee” converge edges are forged together in the weld squeeze and a forge type weld is achieved [5]. The HF weld is a true forge weld in that no filler metal is added and, if done properly, no molten or oxidized metal is left on the bond line.

One of the most important factor in the high frequency electric resistance welding (HFERW) is plastic deformation which is present in the entire manufacturing process, from the beginning to the end of the manufacturing process. Almost in all manufacturing operations, plastic deformation directly or indirectly participates on the development of these operations at room temperatures or at elevated temperatures. Depending on the intensity of cold plastic deformation and the sizes of pipes (diameter and wall thickness), it can happen changes of mechanical properties, i.e. strength increased due to work hardening or decreased due to Bauschinger effect [6].

Figure 2 shows that during HFERW, all of the molten thin layer and metal oxides and other inclusions are squeezed out of the weld toward the outside and inside surfaces as a result of plastic deformation of the squeezing rolls.

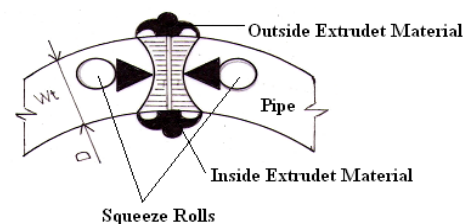


Fig.2 Effect of plastic deformation on the HFERW

The material extruded on the inside and outside weld surfaces, usually removed by scarfing while still hot and forms a typical HFERW weld with narrow bond line (BL) or fusion line (FL) and associated local heat affected zone (HAZ) is formed [5]. The high frequency electric resistance welded seam is subjected to post weld heat treatment in-line such as induction heating and gradually air cooling, the purpose of which is to eliminate zones of excessive hardness from the initial welding process as such zones could be susceptible to various forms of environmental cracking.

The plastic deformation which is realized under the action pressure of the squeezing rolls caused metal flows of the hot rolled coils towards the outside and inside surfaces of the bond line. This flow pattern consists of streaks and striations. The orientation of this pattern, with respect to the new surface, indicates the direction of metal flow lines (fibres), respectively flow angles during plastic deformation [6]. The flow lines, respectively flow angles ($\alpha_1, \alpha_2, \alpha_3, \alpha_4$), Figure 3, are a natural consequence of applied plastic deformation of the squeezing rolls. The orientation of the flow lines indicates the direction of the metal flow during plastic deformation. By the measurement of the flow angles ($\alpha_1, \alpha_2, \alpha_3, \alpha_4$) and especially flow angle ($\alpha_1 + \alpha_3$), it is possible to determine directly whether the squeezing pressure and relevant welding temperature are correct or not.

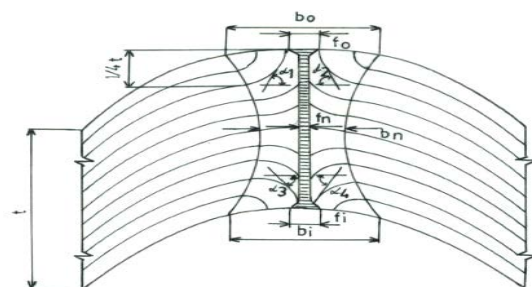


Fig.3 Flow lines (fibres) and flow angles around bond line during plastic deformation

Microstructural changes that takes place during the HFERW covers the properties of the welded pipes, defects associated with welding and the performance of welded pipes in service.

Forge weld area of HFERW may be divided into four zones, Figure 4, [7]: 1-bond line (BL) or fusion line (FL); 2-heat affected zone (HAZ); 3-edge of the heat affected zone and 4-base metal or parent metal (BM). These different zones are normally defined by the peak temperature experienced at certain distance from the fusion line during welding. Each zone in the weld area is characterized by a unique microstructure and hence different mechanical properties. The zones of the weld area are quite narrow and it is difficult to investigate the behavior of specific location without interference from the adjacent zones with different properties.

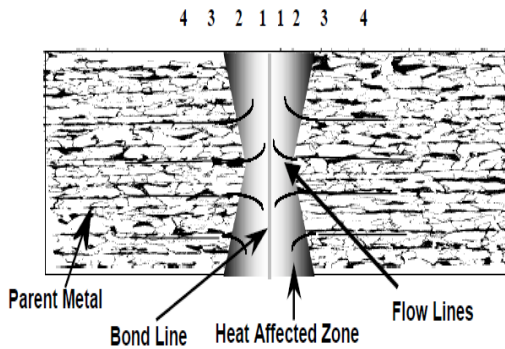


Fig.4 Schematic illustration of constitutive parts of weld area

2. Experimental procedure

High-frequency electric resistance welding was conducted using an L-16 in, pipe mill Newco IMK-Ferizaj, Kosova. Newco IMK-Ferizaj-Kosova produces high frequency electric resistance longitudinal seam welded steel pipes with Ø114.3-406.4mm diameter and 3.2-12.7mm wall thickness. Casing pipes Ø114.3x5.21mm are typical case in the mill production schedule, hence in this paper these pipes were investigated. Pipes Ø114.3x5.21mm were fabricated from high strength steel coils J55 according to API [4] standard, using the pipe mill equipped with a contact type high frequency electric resistance welding machine-Thermatool. The frequency of current was 400kHz.

Chemical composition and mechanical properties of the used steel are given in Table 1 and 2.

Table 1: Chemical composition of used steel coils J55

Steel coils	Chemical composition [wt-%]							
	C	Mn	Si	P	S	Al	Nb	N
API grade J55	0.141	1.11 3	0.22 9	0.01 4	0.00 8	0.04 7	0.01 7	0.0072

Table 2: Mechanical properties of used steel coils J55

Steel coils	Mechanical properties		
	Re	Rm	A ₂ ^o
	[MPa]		[%]
API grade J55	453	557	32.5

The influence of plastic deformation can be observed by examining the flow lines, respectively flow angles around fusion (bond) line.

The flow lines are visible in all metallographic specimens and the degree of upset is different, depending from the intensity of plastic deformation of squeeze weld rolls.

Under the action of plastic deformation, the squeezing amount (Sa), Figure 5 is defined as the difference between the circumference length measured at "Vee" angle in the front of the squeezing rolls and at pipes in the rear of squeezing rolls, which is usually 1-5mm. In this paper squeezing amount ($Sa = C_b - C_a$) varies from 1.7-5.9mm.

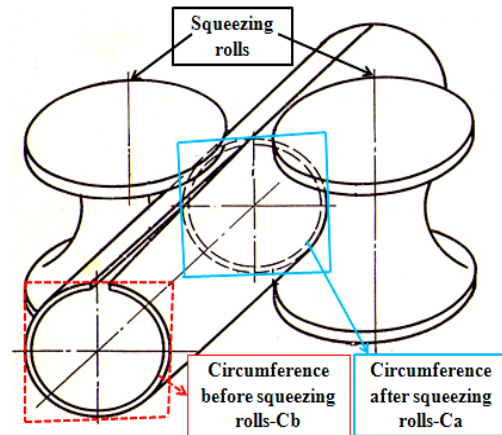


Fig.5 Squeezing amount during HFERW

Plasticity of welded joint was confirmed by conducting flattening testing [4].

In order to determine metallographic macro and micro analysis, the metallographic specimens were prepared by standard metallographic techniques that includes grinding, polishing and etching with suitable etchant (nital and Oberhoffer) to reveal the macro and microstructure.

For the experimental procedure, pipe rings (10-15cm long) were extracted from several pipes for use as the specimens, Figure 6.

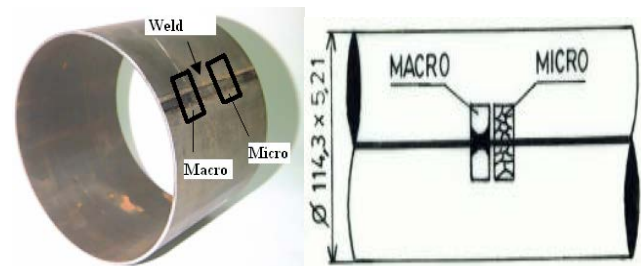


Fig.6 Sketch illustrating the used specimens

3. Results and discussion

Figure 7 shows the effect of plastic deformation on the flow lines and flow angles depending on the squeezing amount ($Sa=1.7-5.9mm$).

The flow lines and flow angles ($\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_1+\alpha_3$ and $\alpha_2+\alpha_4$) were measured separately for each cases of squeezing amount and obtained results were presented in the relevant illustration in Figure 7, together with the values of the squeezing amount at the bottom of the right side of the illustrations. From the presented illustrations in Figure 7 it is clear that increasing of plastic deformation, respectively increasing of the squeezing amount, increased the orientation of flow lines towards the outside and inside of wall thickness. Flow angles also increased with the increasing of plastic deformation and should be noted that for small angles ($\alpha_1+\alpha_3 < 50^\circ$), "Y" flow, Figure 8a, in the outside weld joint were occurred cracks. Cracks or breaks were occurred also for larger angles ($\alpha_1+\alpha_3 > 70^\circ$), "T" flow, figure 8b. Optimal values for ($\alpha_1+\alpha_3$) were $60 \pm 10^\circ$. Plasticity of the welded joint, in this case

measured by the flattening testing is good only for optimal values of ($\alpha_1+\alpha_3=60\pm10^\circ$).

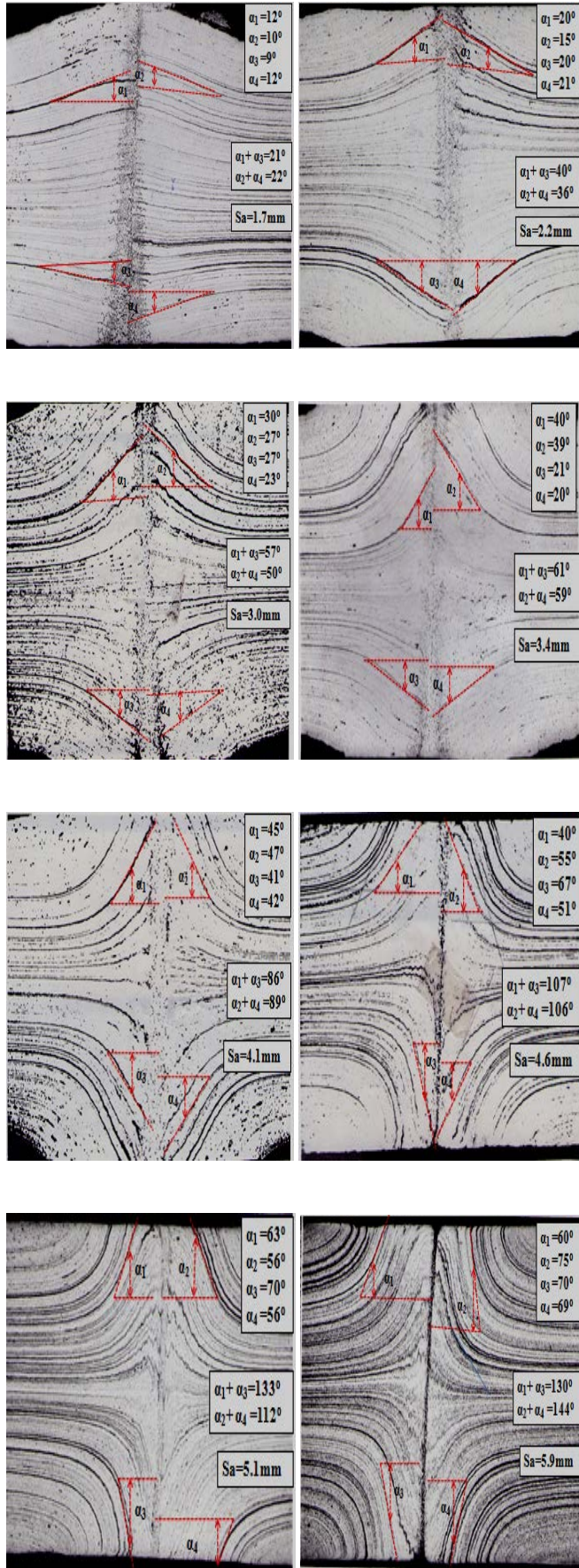


Fig.7 Flow lines and flow angles depending on the squeezing amount

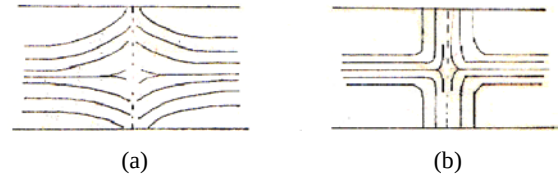


Fig.8 Metal flow during HFERW :a-“Y” flow, b-“T” flow

The test specimens for flattening testing were flattened in a hydraulic press, DIHNAFORIN PS 2043, at room temperature between to parallel plates with the weld line located 90° and 0° to the applied force. The specimens (rings) were flattened to a specified height ($h=2/3D=76.2\text{mm}$) according to API, Figure 9.

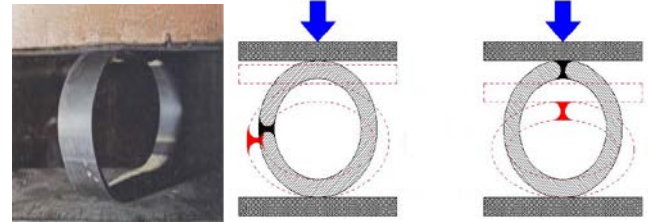


Fig.9 Schematic illustration of flattening test

During flattening testing, in some rings were occurred cracks or breaks in the weld area in the position (90° and 0°) before specified height ($h=76.2\text{mm}$) according to API. Figure 10 shows the results of the flattening testing of all tested specimens.

Correlation between squeezing amount (Sa) and flow angle ($\alpha_1+\alpha_3$), Figure 11 (red rectangle) shows that optimal values of squeezing amount (Sa) are in the range 2.5-3.5mm for manufacturing of HFERW pipes $\varnothing 114.3 \times 5.21\text{mm}$ from high strength steel coils J55 according to API in line L-16, at the pipe mill Newco IMK-Ferizaj, Kosova.

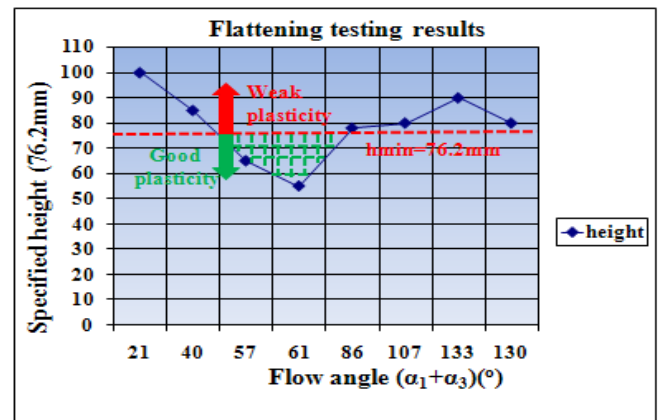


Fig.10 Plasticity of the welded joint

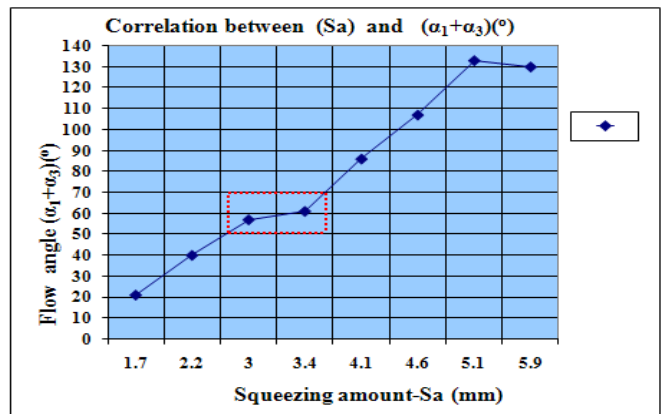


Fig.11 Correlation between Squeezing amount (Sa) and flow angle ($\alpha_1+\alpha_3$)

The shape, width and uniformity of the weld area presented in Figure 12.

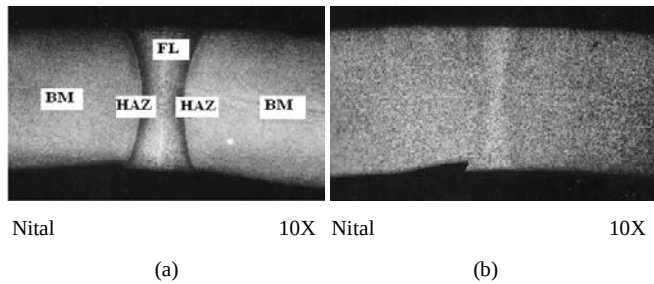


Fig.12 Macrostructure of a cross-section weld area

Macrostructure in Figure 12a shows a cross section of a typical high frequency electric resistance weld of the longitudinal steel pipes in the as welded condition prior to heat treatment. The width of the weld is uniform from top to bottom, indicating that the heat energy input was uniform. The fusion line (FL) or bond line (BL) is vertical to the wall thickness and is usually light colored because it is very low in carbon. Due to high temperature, the carbon amount at the fusion line oxidizes, leaving the iron without carbon to darken it. This part of the weld area called decarbonisation layer or light area [8].

Adjacent to the fusion line (FL) is the heat affected zone (HAZ) where the materials is affected by the heat of the welding process. The heat affected zone (HAZ) is shaped like an hourglass as a result of the heat generated by the high frequency current. Macrostructure in Figure 11b indicates that after normalizing heat treatment, the forge weld areas is indiscernible from the rest of the base metal (BM).

Microstructure of the base metal (BM) and heat affected zone (HAZ) are shown by the photomicrographs in Figure 13. The photomicrograph on the left shows the microstructure of the base metal (BM), whereas the photomicrograph on the right shows the microstructure of the heat affected zone (HAZ) after normalizing heat treatment. The base metal (BM) has fine grained ferrite-pearlite microstructure with some bands in the entire the wall thickness. The heat affected zone (HAZ) has also fine grained ferrite-pearlite microstructure as a result of the proper normalizing heat treatment.

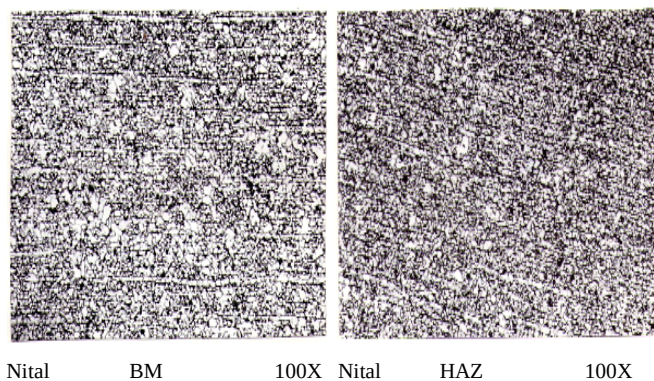


Fig.13 Microstructure of a cross-section weld area

Flow lines and flow angles, Figure 13 illustrates the influence of the forge pressure in the weld area.

The flow lines are visible in all metallographic specimens and the degree of upset is different, depending from the intensity of plastic deformation of squeeze weld rolls. Figure 13 shows flow lines, respectively flow angles from some characteristic metallographic specimens of HFERW pipes $\varnothing 114.3 \times 5.21 \text{ mm}$.

4. Conclusion

Following conclusions can be drawn from the present study:

Plastic deformation during high frequency electric resistance welding (HFERW) plays principal role on the microstructural changes of the welded joint. These microstructural changes affects the mechanical properties of the welded joint, particularly the strength and plasticity.

Cold plastic deformation is present in the entire manufacturing process of high frequency electric resistance welding (HFERW), from the beginning to the end of the manufacturing process, almost in all manufacturing operations, where directly or indirectly participates on the development of these operations at room temperatures and affects the mechanical properties of the base metal (BM) and welded joint.

Hot plastic deformation is present in the welding point, where directly affects the microstructure evolution of high frequency electric resistance welding (HFERW) and the consequent changes in the relationship between the microstructure of the welded joint and mechanical properties, strength and plasticity.

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Advanced Conductor Shape Technology

Оптимизиране формата на секция от правоъгълен меден проводник намираща приложение във статорите на хибридните двигатели

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Abstract: *The aim of the project is to analyze the possible section geometries of stators for starter generators and to select the most effective geometry for use in practice. The experimental results showed the benefits of the "S"-shape conductor compared with "P" or "U"-shape.*

Keywords: CONDUCTORS, HYBRID STATORS, BASKET OF STATOR.

Problem Relevance

The world's leading automotive manufacturers constantly thrive to improve fuel economy. This has taken automobile production in a new direction – the introduction of hybrid vehicle. It has been proven that a hybrid automobile can reduce fuel consumption by up to 50% when compared to conventional engine powered vehicle. The idea is not entirely new however its realizing has seen several major hurdles in the way: very high cost of production for the batteries and the requirement for highly effective (high capacity) starter-alternators. The rapid development of modern technologies managed largely to solve the problem with the batteries. Automotive manufacturers are currently working hard to develop highly efficient starter-generators. In order to increase the starter-generators efficiency, one must first optimize the stator design. This is where the possibilities of increasing efficiency are the greatest.

M3D, a machine manufacturing company, has vast experience in developing machines and technologies that have superior applications in the production of starters and generators. The company has produced machines which operate in some of the world's best automotive producers, such as Bosch and Valeo-Europe, Delco and Prestolite – USA, Denso and Mitsubishi – Japan. By combining the theoretical and experimental experience of the Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre "Acad. A. Balevski" at the Bulgarian Academy of Sciences and with the technological experience of M3D, we have been able to create a setting for ultimate success with these developments.

The thesis of the following research is to create a conductor with new geometry which will improve the stator characteristics.

Problem analysis

The classic generator-stator with coils made of round conductors is technically obsolete, mainly due to the coefficient of filling the stator slot with a round conductor is smaller when compared to a conductor with a rectangular section. This is the reason why all hybrid stators nowadays use only rectangular conductors. Optimizing the conductor geometry of such conductors can indeed help increase the stator efficiency. The purpose of optimizing the geometry of the conductors is for them to form a basket (which is a collection of the conductor heads pointing in the opposite direction of the stator-side outlets/terminals) after being inserted in the stator core (body). The basket should have minimal dimensions, however, the hairpins shoulders should not come into contact with each other. The other condition that must be met is the distance $W1 \leq W3$ (fig. 1). With the upper limits in mind, it is necessary to optimize the shape of the conductors, so that the optimum density of the basket can be achieved, with maximum possible airflow between conductors. This requirement has been formed under one highly important condition – the need for achieving optimal cooling of the stator, for the purpose of reducing heat created in the stator, which can result in over 30% efficiency loss.

The current work process utilizes a 3-dimensional method of shaping the conductor head, i.e., realizing deformation along 3 axes – moving the pin, which allows bending along the X-axis, twisting along the plane of X and Y, as well as controlled positioning of the movable conductor shoulder in the direction of the Z-axis (fig 2.1). Applying deformation in the Z-axis is realized for the first time, but as the following results will show, it is of paramount importance. This deformation helps to control

the shoulders slope in the crown, and thus helps to achieve maximum airflow between the crowns of conductors, in other words the best cooling in the coil.

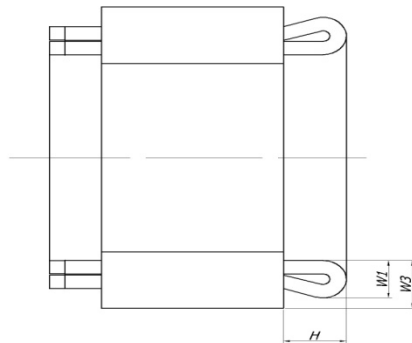


Fig.1

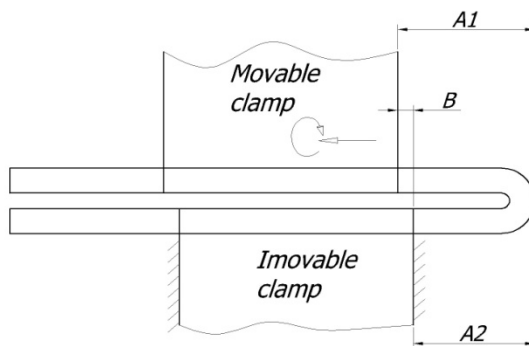


Fig.2.1

Theoretical and experimental methods of solving the problem

A combined approach was used in the experiment optimization – experiments paired with mathematical and computer methods for simulation. The entire forming process can be simulated with the help of specialized software. After which, full analysis of the advantages and disadvantages of each conductor shape can be made. For instance, for “U”-shape of semi-complete conductors, it can be visualized how the final desired form is achieved (fig. 2.2 and fig. 2.3). These results are obtained by experimentation as the mechanical characteristics for copper conductors with precise dimensions were entered in the software. The software also helped in achieving deformations, as well as the spread stress amount in every part of the conductor during the forming process. The

software further permits yet another step, which is inserting the deformed conductor in the stator body and to visualize the basket. This approach enables us to seeing the placement of the conductors in the stator slots, and to also check how they are arranged in the stator basket. This allows us to deduct whether the angle of twist in the last technological step needs to be adjusted and by how much. Following this sequence, the desired geometric parameters of the section are achieved after several iterations.

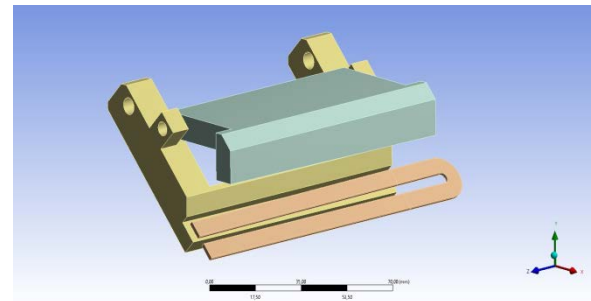


Fig.2.2

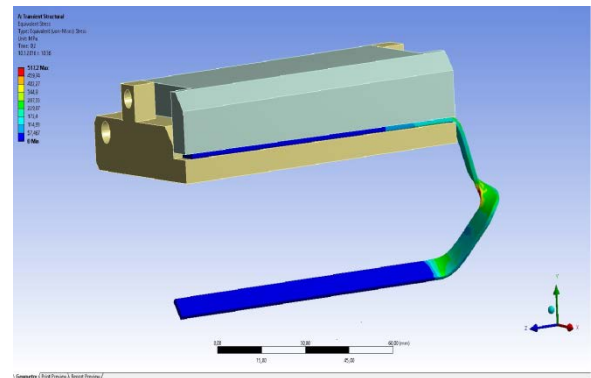


Fig.2.3

Experimental results

Practice shows that three important parameters related to the conductor geometry and forming the stator basket must be taken into consideration during the forming of the conductors.

The distance between two adjacent shoulders of conductors forming the basket. Figures 3 and 4 show the shoulder shape in the basket. In this case “P”-shape and “S”-shape can be seen. In the case of “P”-shape, the shoulders are part of the horde, whereas with “S”-shape, the shoulders are rainbow shaped. If the angle of twist of the “P”-shape is large enough, then there is a high possibility that the outside shoulder will touch the inside shoulder. This is the main reason for the high risk of shorting in this area. To avoid this problem, especially with bare conductors,

manufacturers that use “P”-shape sections are usually forced to place an insulating tape between the inside and outside conductor shoulders. This is a highly labour-intensive method and because of that has limited application.



“S”- form

Fig.3

Another way to avoid this problem is by increasing the pin diameter, where a process known as U-bending is applied. This, however, leads to a different problem – increasing the height of the crown ($H_1 > H$) (fig. 5). As of this reason, the idea has limited application, due to the likelihood of insufficient space. As Figure 5 shows, using an “S”-shape conductor is the solution. Several problems that require a solution occur in shaping the basket:

-Contact between two adjacent shoulders in the basket. This is a fairly common problem for conductors with small crown height. After twisting is applied, the

space between two neighbouring shoulders is usually larger in the outside row than on the inside row (fig. 6).



“P”- form

Fig.4

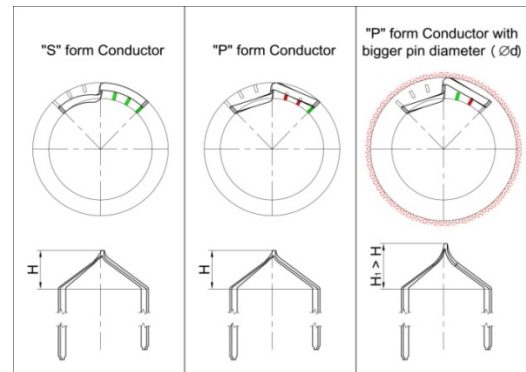


Fig.5

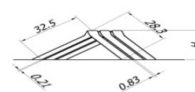


Fig.6

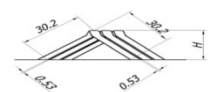


Fig.7

In order to achieve even distances between the adjacent inside and outside shoulders, it is necessary to alter the length of the shoulders in the crown by means of moving in the direction of Z-axis (fig. 2.1). These distances can be made equal by varying the magnitude of movement “B”, if all other parameters remain unchanged. It should be noted that this can be achieved without having to change the height of the crown “H”.

-Controlling the interior and exterior diameter of the stator basket. The possible amount of control is limited for “P” and “U”-shape conductors. It is possible with “S”-shape sections by shifting the section axis of symmetry in the direction of the X-axis (fig. 8).

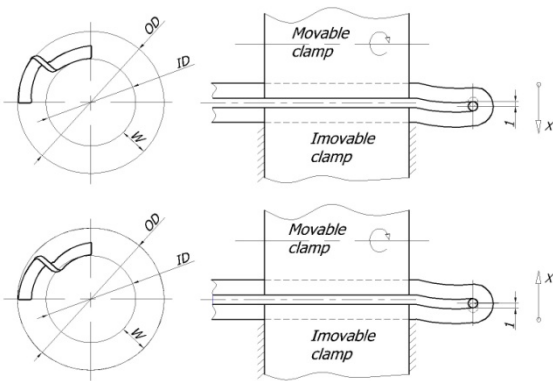


Fig.8

As the figure shows, if during the process of forming the pin around which the twisting occurs, it is positioned in the direction outside the axis of symmetry of the semi-complete conductor (for example, by 1mm as shown in the figure), the interior and exterior diameter of the basket will increase. If the pin is moved in the opposite direction, i.e. towards the axis of symmetry, then the interior and exterior diameter of the basket will decrease. Fine adjustments to the height of the basket can be made using that method. This cannot be applied in the case of “P”-shape, because the axis of symmetry and axis of rotation must coincide.

The production technology of “S”-shape (fig. 9) looks similar to that of “P”-shape, but only seemingly, which is apparent in the big difference in the final shape of the conductor crown. By changing the radii “R” and “r” in step 2, the desired arcs can be set. The above described steps can be visualized with the help of the software. This software can simulate the entire technological process, and thus can analyze the effect of every separate parameter involved in the forming of the conductor. As can be seen in the case of “P”-shape, the distance between the inside shoulders of two adjacent conductors is very small (fig. 10). This is the reason for probably shorting with “P”-shape. As the figure depicts, this effect is increased when the angle of twist grows. If the angle of twist is 20 degrees, the distance between the inside shoulders is sufficient, whereas if the

angle is increased to 45 degrees, the risk of shorting is much higher. The experimental results show that the problem is completely eliminated by utilizing “S”-shape conductors (fig. 11).

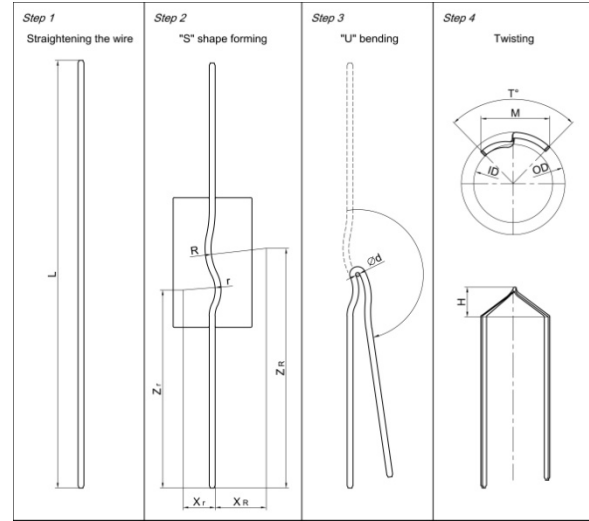


Fig.9

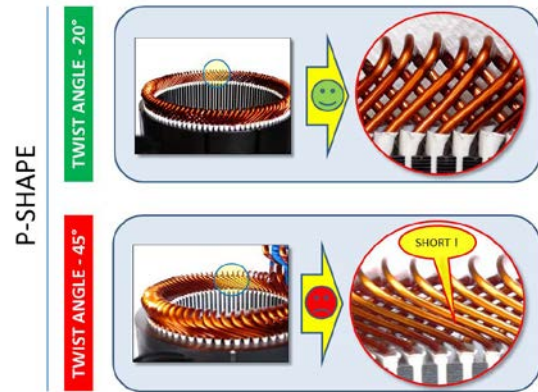


Fig.10

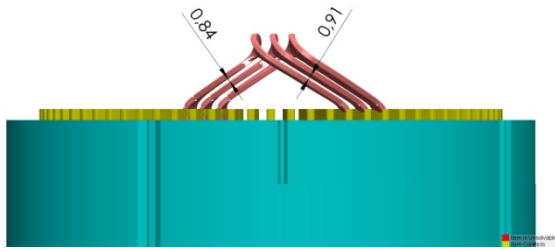
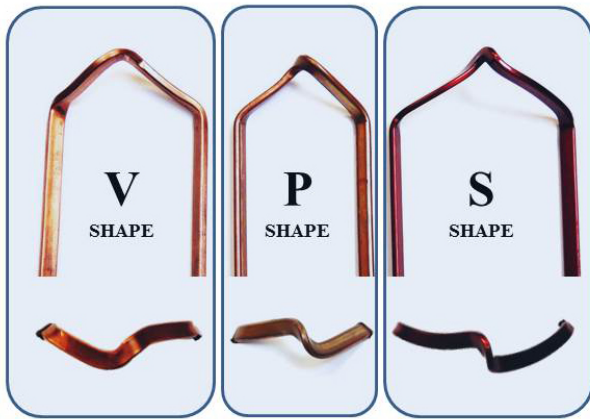


Fig.11



Analysis of the results

We will conduct the experiment to allow us to compare the advantages and disadvantages of the common technologies for conductor forming (table 1).

Productivity: for “V”-shape conductors – it is lowest in comparison with all others, because all production steps are carried out successively in time (score – 1 point). Repeatability of the conductor crown: “S”-shape conductors have high repeatability (score – 3 points), whereas “P”-shape conductors have low repeatability (score – 2 points), because the conductor crown is freely formed during the time twisting process.

Optimal marker dimensions of the conductor crown: only the “S”-shape section allows for fine adjustments of the crown dimensions (score 3 points).

Airflow: minimal airflow in the basket can be observed in the case of “P”-shape section, because the slope of the crown shoulders cannot be controlled (score – 1 negative point). This problem can be solved by applying additional shifting in the direction of the Z-axis.

Practice shows that only “S”-shape can fully optimize the gauged dimensions of the basket and ensure minimal basket width (score – 3 points).

Minimal crown height can be achieved using the “V”-shape conductor (score - 3 points).

“P”-shape has a high risk of shorting in the crown shoulders (score – 1 negative point).

“V”-shape does not allow for any corrections in the crown shape (score – 1 negative point).

“V”-shape is not suitable for varnished conductors because it can easily damage the insulation (score – 1 negative point).

The total scores show the benefits of “S”-shape conductor in comparison with all other section types – 27 points (table 1).

Tabl. 1.

	“V”- SHAPE	“P”-SHAPE “U”- SHAPE	“S”- SHAPE
1. Productivity	+	+++	+++
2. Crown shape consistency	+++	++	+++
3. Optimum overall crown dimensions	++	+	+++
4. Maximum air flow through the winding	+++	-	+++
5. Minimum winding width	++	+	+++
6. Minimum crown height	+++	++	+++
7. Risk of short in the winding	++	-	+++
8. Crown shape adjustment	-	++	+++
9. Enameled wire	-	+++	+++
BALANCE	14 +	12 +	27 +

CONCLUSION

The experimental results show that the proposed “S”-shape has significant benefits when compared to all other conductor types.

We can conclude that the new highly effective “S”-shape conductor and the technology used for its forming can find applications not only in the hybrid, but also in the conventional engines for the automotive industry.

COMPARATIVE RESEARCH ON THE QUALITY OF AUTOMOTIVE STATORS CONDUCTORS WELDING OBTAINED THROUGH BRAZING AND TIG WELDING METHODS

Сравнително изследване качеството на завареното съединение при електросъпротивително и
електродъгово заваряване на статорите на електрогенератори

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Abstract: *The goal of the project is to compare the quality of automotive stators conductors welds produced by means of Brazing and TIG welding. As a result of the performed experiments and microstructural analysis of the welded joints, we have been able to prove the advantages of the brazing method over the TIG method.*

Keywords: CONDUCTORS, HYBRID STATORS, BASKET OF STATOR.

Introduction

It is well known that the quality of the welding process is of critical importance for the quality of the starters armatures and alternators stators. The goal of this research is to study the most popular welding methods applied in welding the stator conductors and the armature commutator.

The most popular welding methods applied for this purpose are the TIG and the brazing welding methods. The laser method has not been under consideration due to information from some users about serious doubt for danger to the operators' health. The TIG method is realised by using a very high temperature (the arc temperature reaches up to 10,000 °C) and an inert gas for protection, usually argon, needs to be used. The brazing method is realized by 720 °C and an additional material - a Sil-Fos band (85% Cu and 15% silver).

Experiments for conductors welding process

The goal of these experiments has been to study the welded joints of the conductors and to compare the resulting strength between the TIG method and the brazing method (copper-silver 15% band). The cooling during the brazing welding is carried out by water or by an air-powered "Vortex Tube cooler". The experiment was to study the strength of the welded seam by using destruction of the welded connection by a test machine. (See Fig.1-2)

- The tensile test results (table 1) have shown that the brazed joint is 30% stronger than the joint realized by TIG welding. The joint obtained by the brazing method is stronger than the base metal. This joint always tears away from the base metal directly to the welded joint. See Fig.3.

Reliability of the welded joint obtained by the brazing method

The metallographic analysis of the welded joint by employing brazing method has shown that it is solid and without pores or hot cracks. The welding layer is without cracks and inclusions. Please refer to Fig.4-5 for the metallographic photos.

Reliability of the welded joint obtained by the TIG method

For the analysis, the metallographic pictures of samples obtained by the TIG method have been studied under an electron microscope. (Fig.6-7). The metallographic analysis of the TIG welded joint has shown:

- coarse crystal structure in the welding zone (Fig.8)
- non-metallic inclusions (Fig.9)

- the welding zone is not solid and has big pores. Please refer to Fig.9-10 for the metallographic photos.

Furthermore, the analysis of the obtained results shows that the TIG welding has many disadvantages compared to the brazing method. The most important are:

- TIG welding method - The high welding temperature makes the copper very aggressive and helps for the formation of pores in the welding area; in brazing method the welding temperature is 720 °C and such pores have not been found. This result explains why the strength of the brazed joint is almost two times stronger compared to TIG.
- TIG welding method – can easily go out of control, while the brazing method can be controlled very precisely.
- TIG welding method - a very expensive method, compared to the brazing method!
- TIG welding method – lack of consistency of the welded joints.

- TIG welding method - very difficult to repair wrong welds compared to the brazing method.
- TIG welding method – there is a safety concern; the high temperatures cause unhealthy emissions, thus are posing higher health risks! Also, it is bad for the environment.

We have made a comparison in the electro resistance of the stator conductors ends welding. The comparison is between two of the most popular welding methods: brazing and TIG. Please see below in the table 2 obtained results. All measurements of the electrical resistance have been made by a precision ohmmeter. The results of the experiments unambiguously indicate that the brazing process has less electrical resistance, respectively less electric and thermal losses. These measurements have been performed at room temperature, but it is known that the losses will increase with increasing the ambient temperature.

The gathered results unambiguously show the advantages of the brazing method compared to the TIG method.



Fig.1 Destruction process of the samples on the test machine to determine the strength of the welded joint.



Fig.2 Recording the extension during the sample demolition for creating a stress-strain diagram.

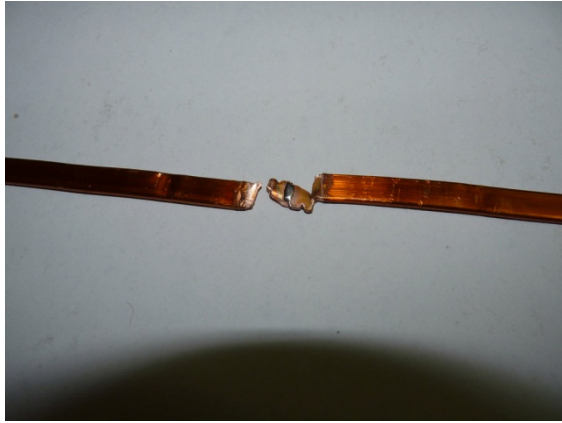


Fig.3 The sample after tearing.

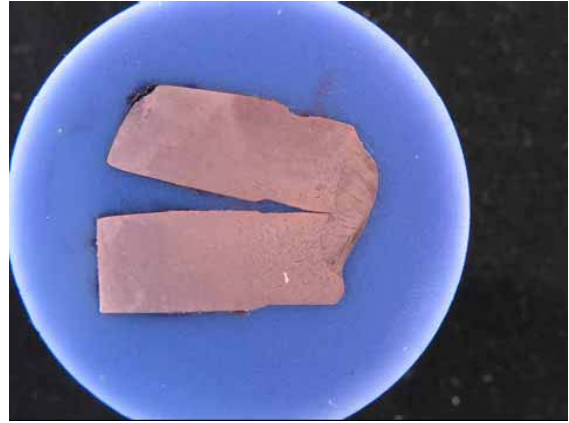


Fig.6 Metallographic sample of weld obtained by TIG welding

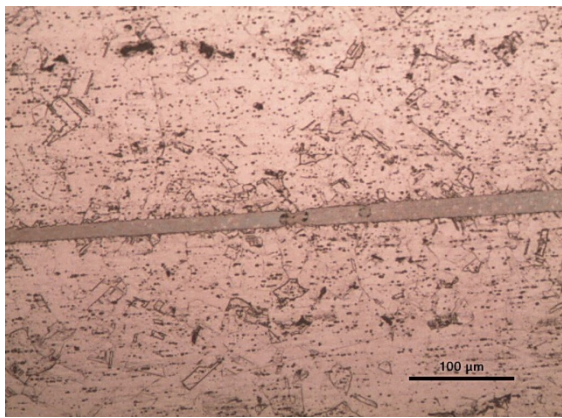


Fig.4 Metallographic structure of welded joint

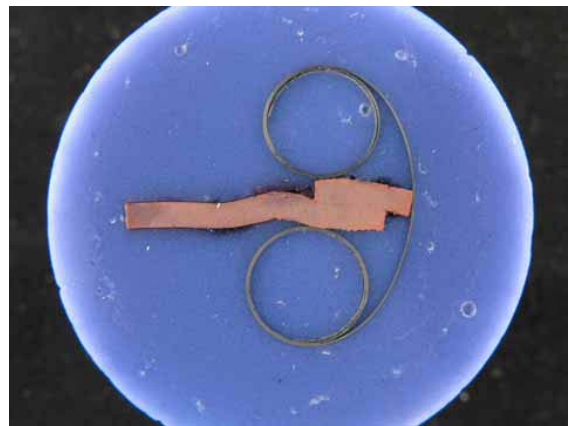


Fig.7 Metallographic sample of welded joint obtained by brazing method

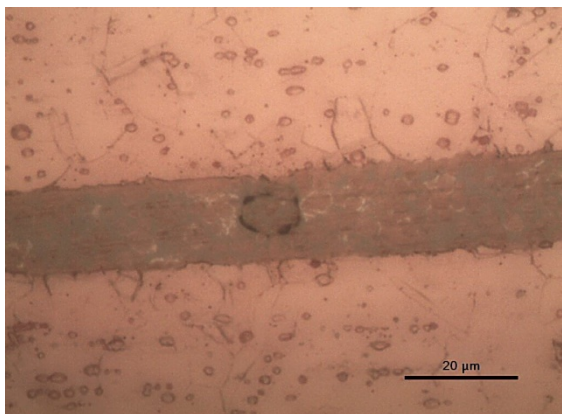


Fig.5 Metallographic structure of welded joint

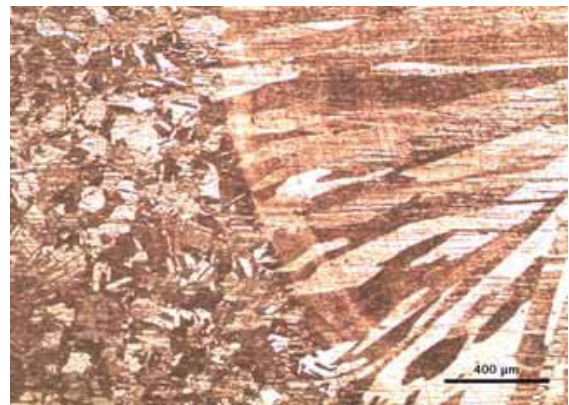


Fig.8 Crystal structure in the welding area

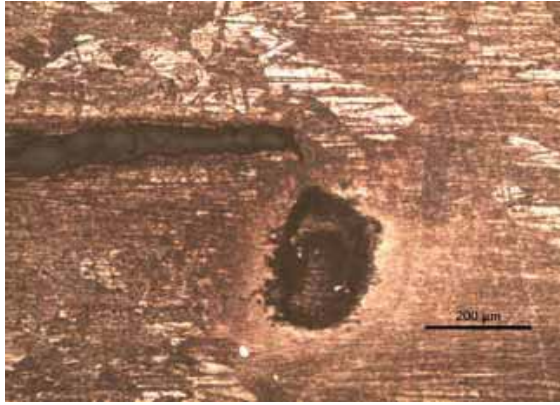


Fig.9 Cracks in the welding area

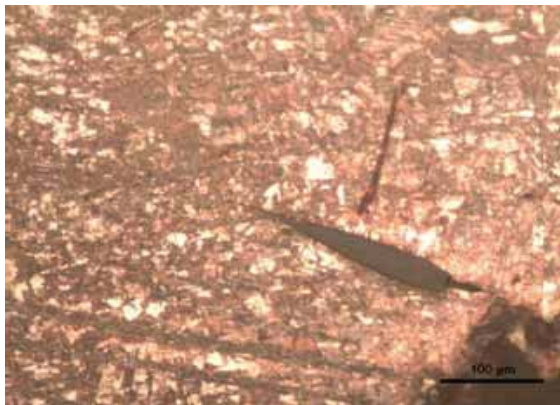


Fig.10 Non-metallic inclusion in the area of welding

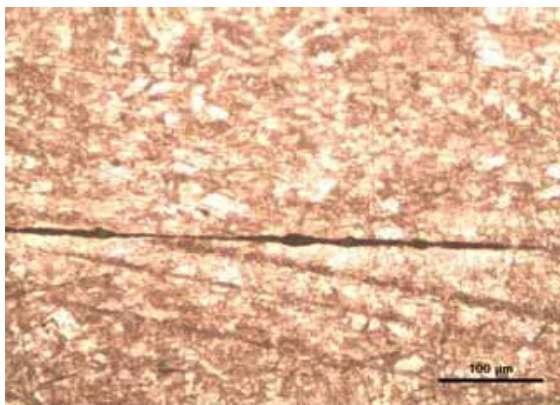


Fig.11 The microstructure of TIG welding layer

Table 1

TENSILE TEST OF WELDED JOINT	
BREAKING FORCE P _{max} (daN)	
TIG WELDING	BRAZING
60	103

Table 2

Sample #	Brazed $\mu\Omega$	TIG $\mu\Omega$
1	102	117
2	105	114
3	100	116
4	97	114
5	102	114
6	105	113
7	98	116
8	99	117
9	98	112
10	102	115
11	106	117
12	99	113
13	102	115
14	106	117
15	107	115
16	99	112
Average	101,6875	114,8125
Range	10	5