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INOCULATION OF IRON USING AN INOCULATING AGENT THAT CONTAINS SILICON, IRON AND MAGNESIUM, WHICH ALSO APPEARS AS CIRCULAR DROPS AT THE INOCULATION TEMPERATURE

BY

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Abstract: Chemical elements silicon and iron are used, currently, as accompanying chemical elements for inoculating agent chemical elements. Silicon increases the inoculating agent density and thermodynamic activity of carbon around the inoculating agent drops. Iron increases inoculating agent density, significantly, so, leading to the increasing of the inoculating efficiency. Experimentally, it is confirmed the silicon particles around the inoculating agent drops.

Keywords: silicon and iron in inoculating agent; inoculating mechanism; inoculating efficiency.

1. Introduction

Inoculation is interesting through features that give birth in cast iron.

This paper analyses inoculation of iron, taking into consideration the inoculating theory that considers tendency to chemical equilibrium between two thermodynamic phases in contact (Cojocaru-Filipiuc, 2011).

On researches improvement of the inoculating efficiency by increasing

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of the inoculating agent density and increasing of the carbon thermodynamic activity around the inoculating agent drops.

From the point of view of the maximum degree of compactness, nodular shape, ideal aggregation state of the inoculating agent, in liquid iron, is gaseous one. But, gaseous state corresponds to a very low density. This situation causes evacuation of the inoculating agent bubbles from metallic bath by a high speed, and, so a small inoculating efficiency. Here is why the state of aggregation of the inoculating agent to be liquid. The density of the liquid state is much smaller than for gaseous one. When the inoculating agent state of aggregation is liquid, inoculating agent losses by evacuating from the metallic bath are lower.

If the inoculating agent density is of the same order of magnitude as that of liquid iron, practically, there is no loss of inoculating agent by evacuating from the metallic bath.

The presence of iron and silicon in inoculating agent increases its density.

If reference is done for magnesium, it is in gaseous state at the inoculating temperature of iron.

Magnesium vapors density is in the 0.002 g/cm^3 range, which is very small.

Because there are iron and silicon in the inoculating agent, the aggregation state of the inoculating agent, at the inoculating temperature of iron, is changed. So, the gaseous state is changed in liquid state.

The aim of the experiment is to demonstrate that the silicon particles are found in larger quantity at the boundary between the metallic matrix and the graphite nodules, *i.e.*, where appropriate to increase the thermodynamic activity of carbon.

Discussion have in mind that graphite nodules are formed outside of thermodynamic equilibrium, in liquid iron (Loper & Heine, 1961, 1962; Lux *et al*.,1975; Pohl *et al*., 1960).

2. Drawing of Cast Iron Inoculation

Fig. 1 shows the drawing of iron inoculation using an inoculating agent that contains silicon, iron and magnesium and which also appears as circular drops.

The inoculating agent is in the liquid state at the cast iron inoculation temperature, appearing as circular drops.

The 1st sequence shows the inoculating agent drop immediately after the insertion of the inoculating agent (FeSiMg) in the liquid iron and its melting.

The 2nd sequence illustrates the triggering of the diffusion processes of the carbon particles from the metallic matrix towards the inoculating agent drops, as well as of the silicon particles from the drops towards the metallic matrix.

One may notice, in the 3rd sequence, how the silicon and carbon particles start gathering around the drops in the metallic matrix.

The 4th sequence shows the carbon particle agglomerations (6) in the metallic matrix.

The hexagonal graphite nuclei are shown in the 5th sequence.

The 6th sequence tackles the growing graphite single crystals, (7), in the inoculating agent drops. While the graphite single crystals grow, the magnesium and iron particles in the inoculating agent drops start to be released from the drops in the metallic matrix, more precisely in the immediate vicinity of the drops.

The first layer of graphite single crystals (2), formed on the inner surface of the drops, is shown in the 7th sequence.

The continuous diffusion process of the carbon particles from the metallic matrix towards the drops leads to the formation of new graphite nuclei in the interstices (8) between the graphite single crystals in the first single crystal layer, 8th sequence.

The graphite single crystals formed from the graphite nuclei shown in the 8th sequence start growing and their impact with the graphite single crystals in the first layer cause the dislocation of the graphite single crystals from the first layer and their movement towards the inside of the drops, 9th sequence.

One may notice, in the 10th sequence, the second graphite single crystal layer.

This phenomenon is repeated until the drops are completely “filled” with graphite single crystals and all the silicon, iron and magnesium particles either diffused (silicon) in the metallic matrix, in the immediate vicinity of the drops, or they were released (iron) in the metallic matrix, in the immediate vicinity of the drops, or they were released (magnesium) outside de drops adsorbed on the graphite single crystals, which are found outside phase 3. The 11th sequence shows the crystalline body of graphite (5), on which magnesium particles are adsorbed; silicon and iron particles are found around it, in the metallic matrix.

The metallic matrix subsequently becomes either homogeneous or quasi-homogeneous as concerns the silicon and iron contents, 12th sequence.

The Si, Fe and Mg particles “leave” the drops while the latter are filled with graphite single crystals, mostly due to the mechanical equilibrium tendency, which occurs between the now forming phase 3 and the liquid metallic matrix.

For example, if the inoculating agent drops need to be compacted, the inoculating agent should also contain, in addition to Si, Fe and Mg, one or several surface-active element(s) able to decrease the interfacial surface tension between the metallic matrix and the drops and to be adsorbed on graphite, when there is not enough magnesium.

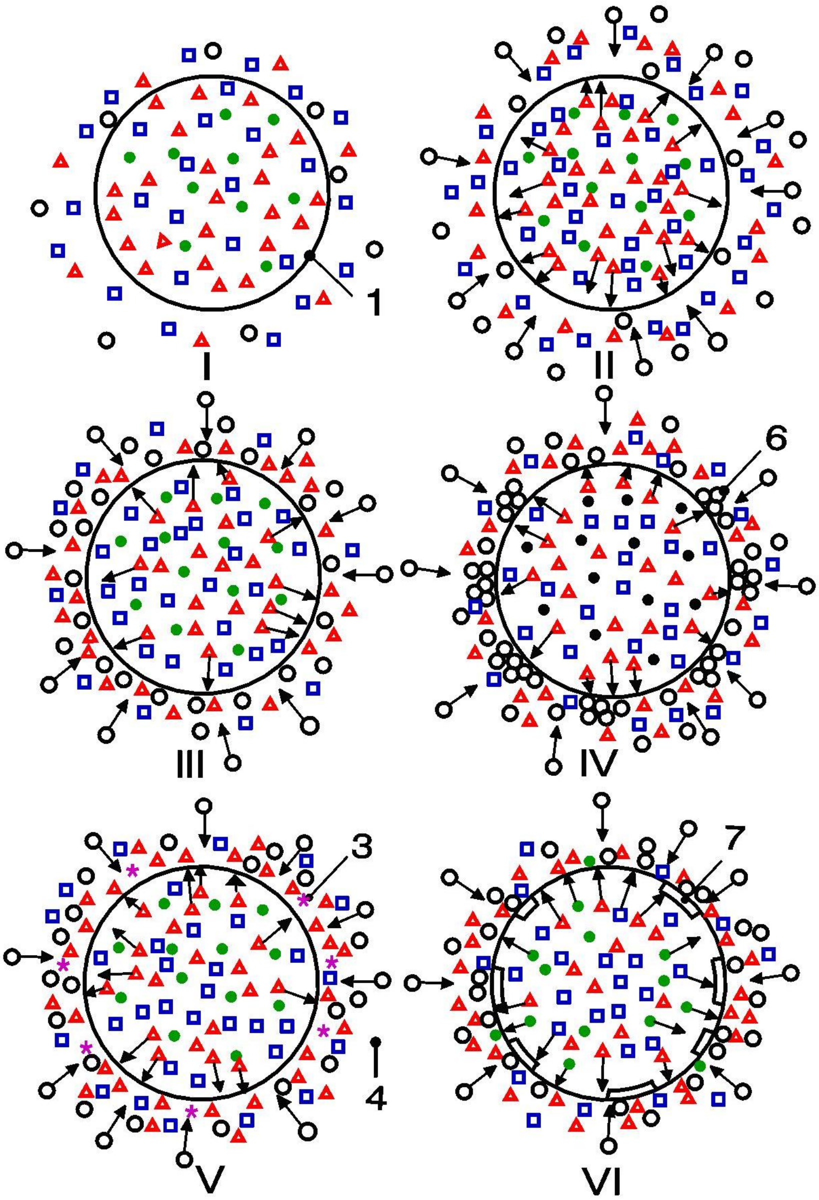

Fig.1 – Drawing of iron inoculation using an inoculating agent that contains silicon, iron and magnesium and which also appears as circular drops. ○ – carbon particles; Δ – silicon particles; □ – iron particles; ● – magnesium particles; 1 – drop (phase 2); 2 – graphite single crystals; 3 – graphite nuclei; 4 – liquid metallic matrix; 5 – crystalline body of graphite (graphite nodule) – phase 3; 6 – carbon particle agglomerations; 7 – growing graphite single crystals; 8 – interstices; * – hexagonal graphite nuclei.

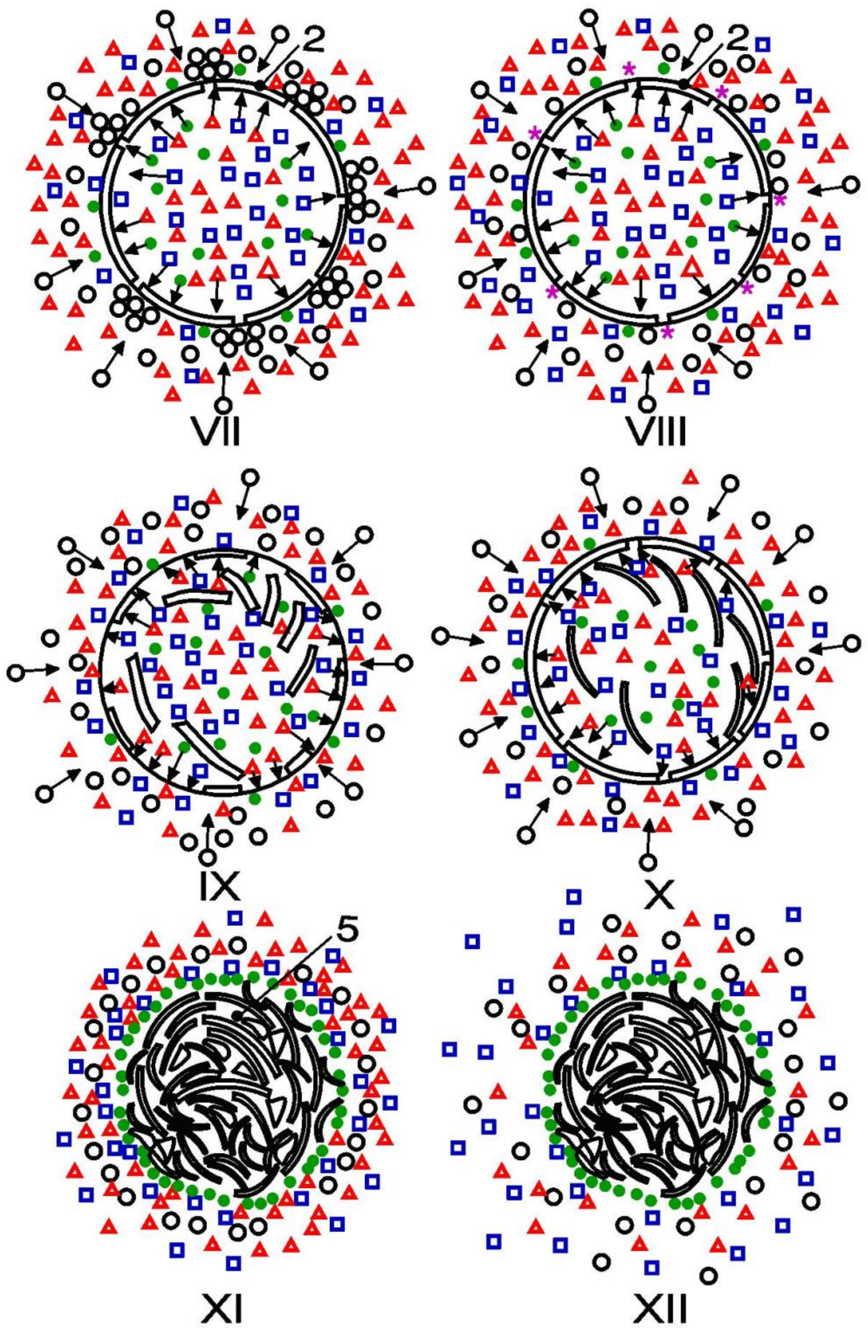

Fig. 1 – Sequel

3. Experiment and Results

6 kg of liquid iron were processed.

Iron which was inoculated had the following chemical composition: C = 4.2%; Si = 3%; Mn = 0.8%; P = 0.12%; S = 0.06%; Fe = balance.

Inoculating agent had the following chemical composition: Mg = 9.5%; Si = 45%; Ca = 1.5%; Fe = balance.

It was used for the modification 2% of inoculating agent.

Fig. 2 shows the structure of the inoculated iron – nodular graphite cast iron (unprocessed chemically).

Fig. 3 represents section line made trough a graphite nodule in view of achievement of chemical elements distribution.

Variations of C, Al, Si, Mg and Ca contents in section made in a graphite nodule according to Fig. 3 are presented in Fig. 4. Variation of silicon content is represented by curve bolded.

Distribution of silicon particles is represented in Fig. 5, both in the graphite nodule and in the metallic matrix around the graphite nodule.

4. Discussion

All the inoculating agents where the inoculating chemical elements are accompanied by matrix elements such as Fe, Si, Cu, Ni, etc. have a disadvantage that cannot be prevented and that is related to the dissolution of some of the matrix elements in the metallic matrix, that is there are chances that the drops dissolve in the metallic matrix. On the other hand, there is the advantage brought about by the iron in the inoculating agent, which, according to the tendency to chemical equilibrium, does not diffuse from the drops towards the metallic matrix, as iron activity in the metallic matrix is more intense than iron activity in the drops. As concerns the silicon present in the inoculating agents, its role is very important in nodular graphite formation in a short period of time. Thus, unlike iron, silicon must dissolve in the metallic matrix in order to achieve the highest possible thermodynamic carbon activity around the drop, in other words, in order to maintain the highest possible carbon activity gradient around the drops, designed to reach the highest possible carbon diffusion rate. It is therefore very important that the chemical composition of the inoculating agent should include, for instance, 50% of Si. Silicon diffuses from the drops into the metallic matrix due to the tendency to chemical equilibrium between the metallic matrix and inoculating agent drop phases. The silicon activity gradient should be high in order for the silicon diffusion rate from the drops towards the metallic matrix to be high. This is achieved by very large amounts of silicon in the inoculating agent (there are inoculating agents that contain up to 75% silicon) and small amounts of silicon in the metallic matrix (1.6%…3.0%); they should not however drop below 1.6%, since this decreases carbon activity in the metallic matrix very much, or exceed 3%, as this diminishes some characteristics of nodular graphite cast iron (silicon increases ferrite microhardness and resistance and, at the same time, it embrittles ferrite). Silicon dissolution from the drops in the metallic matrix is relatively uniform, occurring from all directions, which means that the drops become smaller. Since silicon has low density, 2.33 g/cm^3, the use of large amounts of it in the chemical composition of the inoculating agent significantly decreases the density of the inoculating agent as compared to the density of the metallic matrix. Hence, there are considerable drop losses due to the high ascension rate of the drops through the metallic matrix. The consequences of this shortcoming may be reduces by using iron in the chemical composition of the inoculating agent (iron density is 7.874 g/cm^3). Moreover, as it does not dissolve in the metallic matrix, iron ensures the quasi-immiscibility of the inoculating agent as a metallic matrix, meaning that it ensures the existence of inoculating agent, that is the existence of drops.

Graphite nuclei formation is only possible if carbon activity is one, and if it is as close to one as possible towards the metallic matrix, before inserting the inoculating agent in the metallic matrix. If, as it is the case with unalloyed cast iron, for example, the silicon content cannot exceed 3%, the amount of silicon present in the metallic matrix may be nonetheless increased but only around the inoculating agent drops, that is precisely where the carbon activity should be as high as possible (as close to one as possible). The higher temperature, the higher the thermal agitation of the chemical element particles in the chemical composition of the inoculating agent. The higher the temperature, the more chaotic the motion of the particles in the inoculating agent drops. Thus, high temperature is the factor causing heavy silicon particle diffusion from the drops towards the metallic matrix, more precisely, in the vicinity of the drops. A large amount of silicon diffuses towards the outside of the drops during graphite nodule growth, which enhances carbon activity precisely in the area where the carbon particle concentration is low and precisely towards the end of the graphite nodule formation process, when the amount of carbon, and hence the thermodynamic activity of carbon, decreased considerably. Large amounts of silicon in the inoculating agent are compulsory.

After graphite nodule formation, the large amounts of silicon particles around the graphite nodules will diffuse in the metallic matrix, farther away from the graphite nodules, as long as the metallic matrix is in the liquid state. The silicon content in the metallic matrix thus becomes homogeneous as well. After graphite nodule completion, most of the iron particles are in the metallic matrix, close to the graphite nodules. As concerns silicon particles and other matrix particles, the iron and other similar chemical element in the metallic matrix are also homogenized.

The most frequently used in industrial practice are the inoculating agents that contain mainly big amounts of silicon and, secondly, iron, and that are in the liquid state at the cast iron inoculation temperature. The role played by silicon in the inoculating agent is essential to the inoculation process. Therefore, big amounts of silicon in the inoculating agent render possible the inoculation of low carbon irons and even of steels. For instance, reference (Kozac, 2011) deals with the manufacture of nodular graphite hypereutectoid steel; after inoculation and solidification, the steel contains 1.4%...1.6%C, 2.3%...2.7%Si, 0.15%...0.25%Mn, 0.012%...0.014%S, 0.015%...0.020%P and 0.025%...0.04%Mg. The inoculating agent contains 50%...60% silicon and 10%...30% iron.

The role played by the big amounts of silicon in the inoculating agent may also be taken over by other chemical elements able to enhance carbon activity in the cast iron bath, like, for instance, nickel (Kozac, 2011). Nickel increases inoculating agent density considerably, which is a great advantage, as it reduces inoculating agent losses significantly.

Fig. 4 shows that silicon is located in metallic matrix relatively uniform. In left part of the Fig. 4 one notices a larger amount of silicon particles. In zones from metallic matrix further of graphite nodule silicon content is constant. One appreciates that the larger content of silicon near the graphite nodule is due to the absence of time for silicon particles diffusion inside metallic matrix.

Previous conclusions results from Fig. 5, too, where one notices a homogeneous distribution of Si particles, and metallic matrix and interfaces zone between graphite nodule and metallic matrix. Fig. 5 shows presence of Si particles in graphite nodule, too, as little amount. Diverse shape of graphite monocrystals like foils makes possible presence of silicon particles (as clusters) among those graphite foils.

One appreciates that continuous diffusion of carbon particles to filling up of spherical drops of inoculating agent do that silicon particles coming from inoculating agent drop to get away from inoculating agent drops, that is from there, from their provenance.

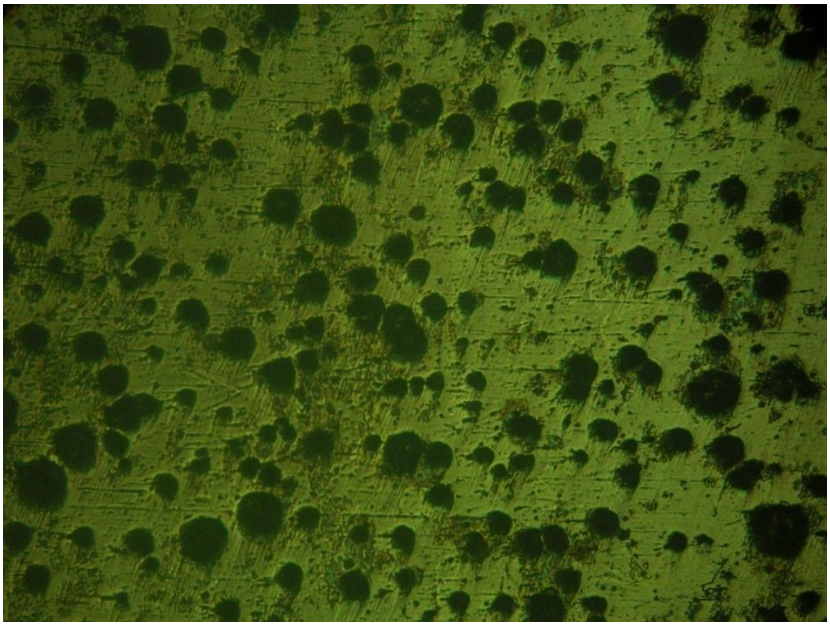

Fig. 2 – Structure of inoculated iron – nodular graphite cast iron. X 48.8.

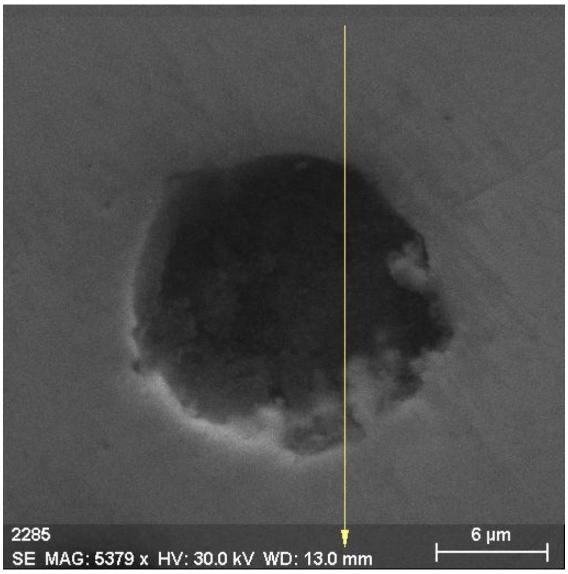

Fig. 3 – Section line through a graphite nodule in view of making of chemical elements distribution.

Structure from Figs. 4 and 5 shows that silicon particles have not had sufficient time to diffuse inside the metallic matrix.

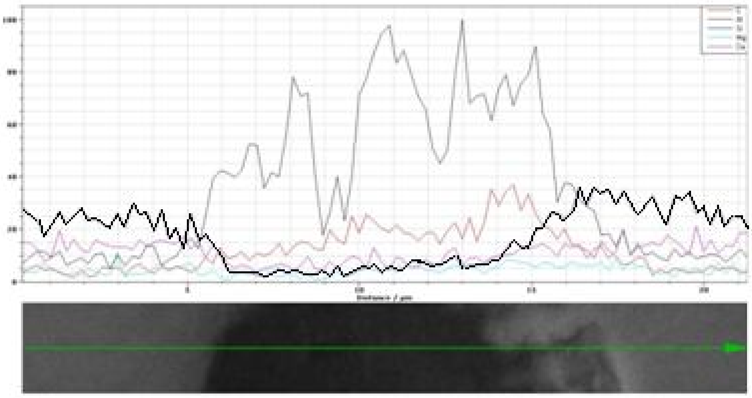

Fig. 4 – Variation of C, Al, Si, Mg and Ca chemical elements in a section through a graphite nodule according to 3 figure.

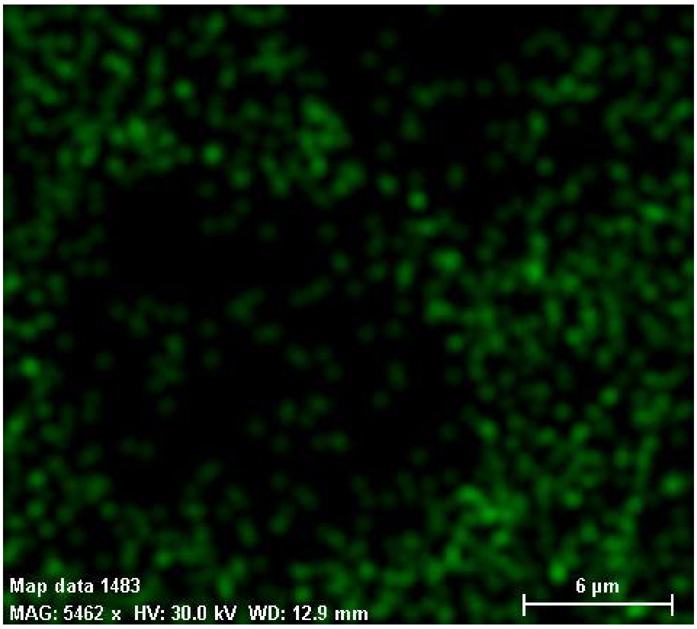

Fig. 5 – Distribution of Si particles inside graphite nodule and in metallic matrix.

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MODIFICAREA FONTEI CU MODIFICATOR CE CONȚINE SILICIU, FIER ŞI MAGNEZIU ŞI CARE ESTE SUB FORMĂ DE PICĂTURI CIRCULARE LA TEMPERATURA DE MODIFICARE

(Rezumat)

Elementele chimice siliciu şi fier se utilizează în mod current ca elemente însoțitoare pentru elementele chimice modificatoare. Siliciul măreşte densitatea modificatorului şi determină, în mare măsură, mărirea activității termodinamice a carbonului în jurul picăturilor de modificator. Fierul măreşte semnificativ densitatea modificatorului, astfel, conducând la mărirea randamentului de modificare. Experimental, se confirm distribuirea particulelor de siliciu în jurul picăturilor de modificator.

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A NEW LOOK ON THE GRAPHITIZANT INOCULATING MECHANISM FOR IRON

BY

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Abstract: A new direction about the graphitizant inoculating for grey irons is presented in this paper. So, there is a focus on the role of the carbon thermodymanic activity for forming of the graphite nuclei, outside the thermodynamic equilibrium, in liquid iron, for temperatures larger than the temperature of the liquidus line. Practically, it is increased the carbon thermodynamic activity around one new phase created in liquid iron. The new phase is formed from ferro-silicon whose composition is eutectic and whose content of silicon is large. Silicon atoms diffuse from ferro-silicon drops to the interface between the metallic matrix and the ferro-silicon drops, increase the carbon thermodynamic activity to 1 value. This one leads to the formation of the graphite nuclei. These nuclei lead to the iron crystallization by the stable system.

Keywords: graphitizant inoculating agent; thermodynamic activity; graphite nuclei; chemical equilibrium.

1. Introduction

The inappropriate chemical composition of the iron and the high cooling rate lead to iron undercooling during the eutectic transformation and to the occurrence of cementite in the structure, from the liquid, either in eutectic colonies (in all cast iron categories), or as free cementite (primary cementite in hypereutectic cast irons).

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According to figure 1, if the carbon activity in the eutectic liquid found in the hypoeutectic and eutectic cast irons is not 1 during the eutectic

transformation, no graphite nuclei are formed, during the cooling, the carbon atoms chemically interact with the iron atoms and thus form cementite (Fe_3C), the cast iron produced is white. The same happens if the carbon activity along the C'D' curve in the Fe-C stable binary diagram is not 1.

Graphitizing inoculation is performed in order to prevent cast iron crystallization in the Fe-C metastable system.

Graphitizing inoculation is performed using graphitizing inoculating agents that contain chemical elements able to increase carbon activity significantly. However, these chemical elements must also be compatible with the type of iron to be treated. Concretely speaking, highly graphitizing elements such as Cu and Al cannot be used in unalloyed irons (Cojocaru-Filipiuc, 2011).

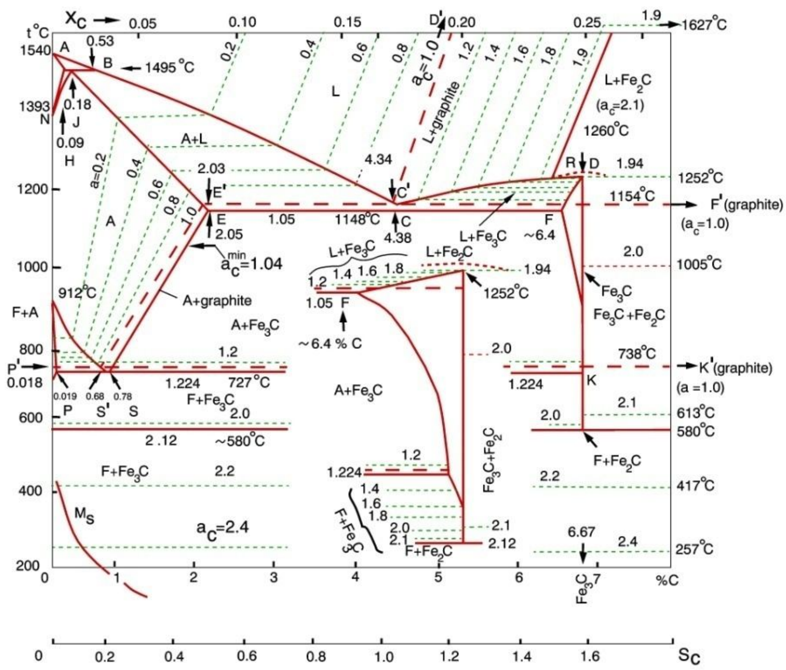

Fig. 1 – Carbon isoactivity curves on the detail of the Fe-C binary thermodynamic equilibrium diagram. S_c – degree of saturation in carbon; A – austenite; F – ferrite; a_C – carbon activity; L – liquid; X_C – carbon molar fraction; C – cementite (Jukov, 1992).

Silicon may also be used for unalloyed cast irons, as silicon is a basic chemical element that accompanies iron and carbon.

If silicon were inserted as such, it would be assimilated to a lesser extent because of the low density (2.33 g/cm^3), while the ascension rate of the silicon granules or drops through the metallic matrix would be high. Moreover, the silicon melting temperature is about 1,410^{o}C, which means that it is a hardly fusible element. If the temperature of the metallic matrix is lower than the silicon melting temperature, silicon dissolution is more difficult as silicon is in the solid state (as granules).

If silicon is used as ferrosilicon, the density increases, which also means that it is better assimilated. In the Fe-Si equilibrium diagram, silicon forms the FeSi chemical compound at a 50% Si concentration, when its melting temperature is about 1,422^{o}C.

The lowest temperature of the liquidus line in the Fe-Si binary system is 1,207^{o}C and it corresponds to the 67%...73% silicon range. Therefore, ferrosilicon containing 67%...73% silicon is the most suitable graphitizing inoculating agent, since it is in the superheated liquid state at the iron graphitizing inoculation temperature, when the silicon atoms undergo a chaotic motion and they diffuse in the metallic matrix at high rates (the Fe-Si diagram was processed in the SGTE alloy databases (Fig. 2).

The temperature of the liquidus line for ferrosilicon with 75% Si, which is highly common in industrial practice, is about 1,257^{o}C, while the temperature of the solidus curve is about 1,207^{o}C.

The ferrosilicon with the highest silicon content used in practice is FeSi85 (Sofroni *et al.*, 1978), the liquidus line temperature of which is about 1,327^{o}C, while the ferrosilicon with the lowest silicon content used in practice is FeSi60, the liquidus line temperature of which is about 1,337^{o}C. The solidus line temperature of all the FeSi60-FeSi85 compositions is 1,207^{o}C, which means that they have high diffusion capacity in the metallic matrix.

If silicon were inserted as such, it would dissolve evenly in the metallic matrix and it would not do anything but alloy it, acting mainly on the secondary structure.

If silicon were inserted as ferrosilicon, the latter would form a phase in the metallic matrix, given the tendency towards chemical equilibrium, and the silicon atoms would diffuse from the ferrosilicon drop towards the metallic matrix, due to a high silicon activity gradient between the metallic matrix and the ferrosilicon drops. The carbon particles also diffuse from the metallic matrix towards the ferrosilicon drops, and some of the carbon atoms are also thought to diffuse in the ferrosilicon drops. Micro-volumes are thus created around the ferrosilicon drops, where carbon activity reaches 1, when graphite nuclei are formed. In the areas that are more remote from the ferrosilicon drops, the silicon content in the metallic matrix is more or less similar to that of the initial metallic matrix (for instance, 1%...2.5% in a grey unalloyed cast iron).

As concerns ferrosilicon with 27%...37% silicon, the solidus line temperature is also about 1,207^{o}C, while the maximum liquidus line temperature is 1,220^{o}C; however, given its low silicon content, it is not recommended for inoculation.

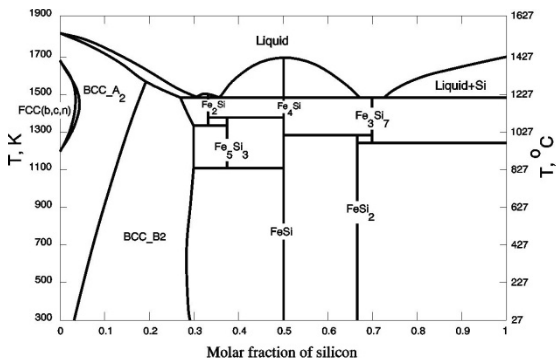

Fig. 2 – Fe-Si binary diagram.

Silicon dissolves more easily in the metallic matrix if the graphitizing inoculating agent is in the liquid state at the inoculation temperature.

The ferrosilicon drops finally disappear. If silicon is associated with calcium in the graphitizing inoculating agent, both the density of the graphitizing inoculating agent and the melting temperature decrease. If this is the case, calcium manifests its reactivity to certain chemical elements in the iron, such as oxygen and sulphur, for instance, and it does not dissolve in the iron. If silico-calcium is inserted in the iron through the runner of the manufacture aggregate or in the iron jet that is poured in the ladle, that is when the temperature decreases, calcium plays its role of highly deoxidizing agent, while silicon dissolves in the metallic matrix, thus creating micro-volumes with higher silicon content and higher carbon activity. The consequence is that at eutectic temperature, for instance, additional crystallization nuclei occur and a higher number of eutectic cells is achieved.

If ferrosilicon is in the solid state, if ferrosilicon is inserted as granules in the pouring ladle during the pouring of the iron, at the bottom of the pouring ladle before the pouring of the iron in it, and also in the pouring basin of the moulds or in the iron jet during mould pouring, silicon dissolves in the metallic matrix and, hence, the carbon activity in the micro-volumes around the ferrosilicon granules increases.

Consequently, new graphite nuclei occur on the eutectic transformation.

The general consequence is that micro-volumes with higher silicon contents also enjoy higher carbon activity, which leads to a higher number of homogeneous graphite nuclei, which are caused by carbon activity enhancement. The number of eutectic cells is also increased, the graphite becomes finer and the cast iron produced has better mechanical resistance features.

Graphitizing inoculation is very important for thin wall castings, the undercooling of which is more marked due to the higher cooling rate, and, therefore, there is a higher risk for the cast iron to solidify as mottled or even white cast iron, which renders its mechanical processing more difficult. The carbon activity increase by silicon cancels the negative influence of the undercooling increase on the eutectic transformation and hence it determines cast iron solidification in the Fe-C stable system and in the thin walls. Graphitizing inoculation thus prevents cast iron whitening.

In practice, the iron is manufactured using less silicon content, and the adequate amount of silicon needed by the cast iron to be manufactured will be reached by graphitizing inoculation.

2. Experiment. Results

Iron was manufactured in an electric induction furnace with capacity of about 25 kg and equipped with a melting pot of SiC with capacity of about 15 kg.

Pig iron had the following chemical composition: C = 4.2%; Si = 2.6%; Mn = 0.8%; P = 0.12%; S = 0.06%; Fe = balance.

Metallic charge mass was of 6.3 kg.

After melting and overheating a sample of graphitizing uninoculation iron whose structure is presented in Fig. 3 (SEM image).

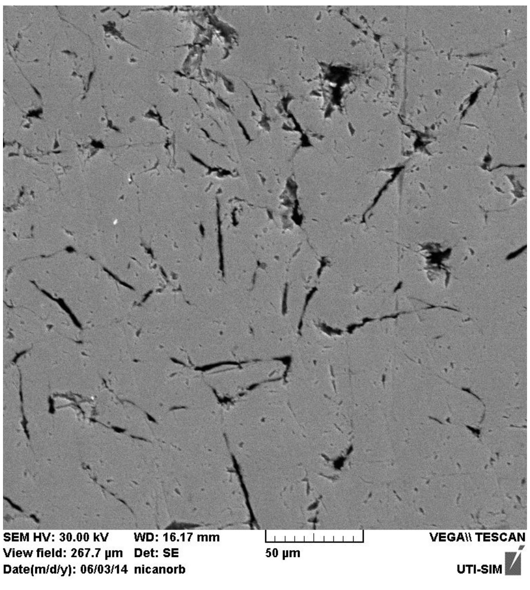

Fig. 3 – Structure of graphitizing uninoculation iron (SEM image).

Graphitizing inoculation was done with FeSi75, with amount of 0.1% and with granulation size of 2-5 mm. Structure of graphitization inoculated iron is presented in Fig. 4 (SEM image).

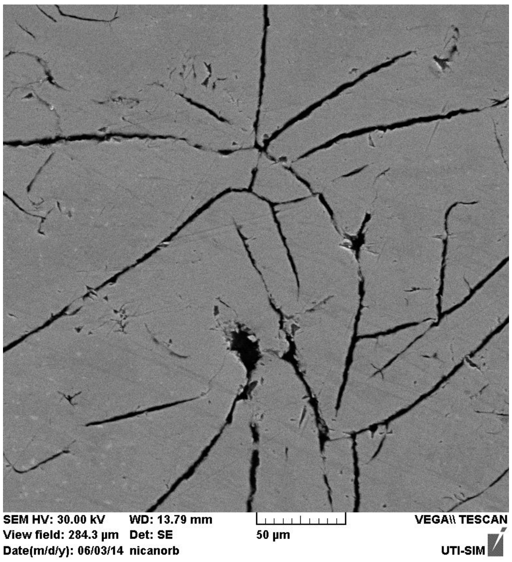

Fig. 4 – Structure of graphitizing inoculated iron (SEM image).

In Fig. 5 it is presented edax chemical analysis for Fe, Si and C chemical elements, for a sample of graphitizing uninoculated iron.

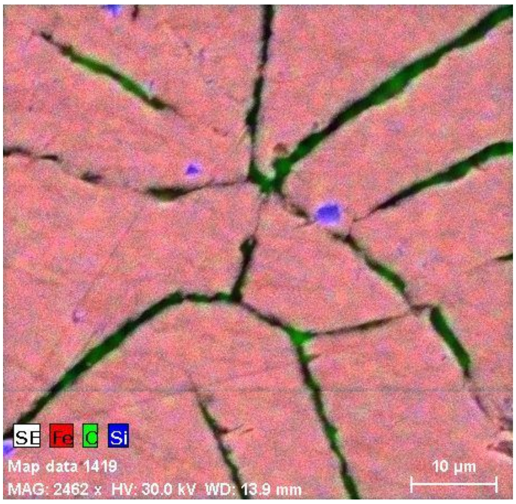

Fig. 5 – Edax chemical analysis for Fe, Si and C chemical elements, for graphitizing uninoculated iron.

In Fig. 6 edax chemical analysis is presented and C and Si edax chemical analysis is presented in Fig. 7, both analyzes are for graphitizing inoculated iron with FeSi75.

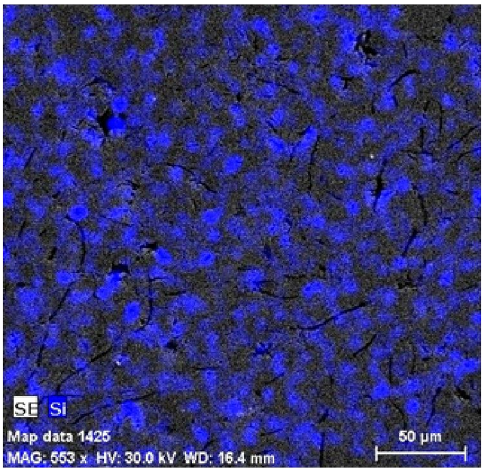

Fig. 6 – Edax chemical analysis for Si, for graphitizing inoculated iron with FeSi75.

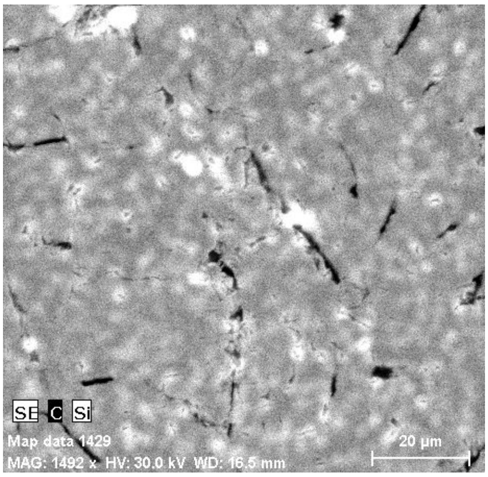

Fig. 7 – Edax Chemical analysis for Si and C, for graphitizing inoculated iron with FeSi75.

3. Discussion

Doing a comparison between iron structures graphitizing uninoculated (Fig. 3) and graphitizing inoculated (Fig. 4), one observes inoculating effect by shape of graphite inclusions that is more fine for graphitizing inoculated iron than graphitizing uninoculated iron.

Fig. 5 shows that there are very few silicon particles clusters in graphitizing uninoculated – these have dark colour and one notices 3 clusters namely 2 pieces at the top – centre and one at the bottom – left. It is certain that these Si clusters are part of a chemical compound on the basis of silicon.

Fig. 6 shows a large number of Si particles clusters, respectively these that are derived from FeSi75 drops. Fig. 7 confirms what is shown by Fig. 6, here, one observes fine graphite inclusions in the centre of Si clusters.

4. Conclusions

By graphitizing inoculating with FeSi75, carbon thermodynamic activity increase around the FeSi75 drops is occurred, what determines appearance of graphite nuclei. These ones lead to obtaining of fine graphite inclusions, in addition to eutectic graphite inclusions.

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O NOUĂ PRIVIRE ASUPRA MECANISMULUI DE MODIFICARE GRAFITIZANTĂ A FONTEI

(Rezumat)

Se urmăreşte în această lucrare o nouă orientare privind modificarea grafitizantă a fontei cenuşii. Astfel, se pune accentul pe rolul activității termodinamice a carbonului asupra formării de noi germeni de grafit în afara echilibrului termodinamic, în fonta lichidă, la temperaturi superioare liniei lichidus. Practic, se măreşte activitatea termodinamică a carbonului în jurul unei faze nou create în fonta lichidă. Faza nouă este constituită din ferosiliciu de compoziție eutectică, cu un conținut mare de siliciu. Atomii de siliciu, ce difuzează în picăturile de ferosiliciu la interfața matrice metalică – picături de ferosiliciu, măresc activitatea termodinamică a carbonului până la lucrarea 1, ceea ce determină formarea de germeni de grafit. Aceşti germeni determină cristalizarea fontei în sistemul stabil.

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NOISE LEVEL WARNING SYSTEM

BY

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Abstract: This paper shows some motives and a basic scketch for a warning system designed to noise level exhibiting.

Keywords: safety and health at work; noise.

1. Introduction

"Noise-induced hearing loss is insidious, permanent, and irreparable. In a developed country, exposure to excessive noise is at least partially the cause in more than one-third of those in the population who have hearing loss. Noise-induced hearing loss is the most prevalent irreversible industrial disease, and noise is the biggest compensable occupational hazard." (Henderson, 2005)

Despite being a well-known hazard, noise is still a risk to workers at the start of the 21st century. It is difficult to estimate how many people may be harmed by noise, but with 20% of workers in Europe being exposed to loud noise (EWSC, 2000) (about 40 million workers) the human and economic cost of this hazard is very great.

"Noise can cause hearing impairment, interfere with communication, disturb sleep, cause cardiovascular and psycho-physiological effects, reduce performance, and provoke annoyance response and changes in social behaviour" (Factsheet 258, 2005). In short, noise is a problem.

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A set of European Directives protect workers from harm caused by exposure to noise such as the "Framework Directive" (Directive 89/391/EEC, 2005), Noise Directive 2003 giving the greater detail, the "PPE Directive" (Directive 89/656/EEC, 2005) and others.

Because of the importance of noise exposure the European Agency for Safety and Health at Work, with the occasion of European Week of Safety and Health at Work, released in 2005 a collection of good practice works made in European countries, Prevention of Risks From Occupational Noise in Practice.

2. Theoretical Considerations

The harm caused by noise is largely acknowledged by specialists but apparently not enough taken into consideration by the personnel exposed to this kind of risk. Starting from stress, and fatigue, temporary hearing loss, dizziness and headaches, continuing with hearing damages, noise-induced occupational diseases and finishing by tinnitus or becoming death, the effects are as important as can be for the activity itself and for the personal life of the worker. Loosing hearing is one of the conditions that can ruin, in time, someone social life and professional career.

Many studies confirm that the effects of noise are usually neglected but also, when realized, by self experimenting it can be too late, as irreversible damages on hearing are installed.

Also in the most cases of workers exposed to severe noise, hearing problems are known and the workers have a very receptive attitude in what concerns the methods of reduction and fight against noise.

Unfortunately there are many situation when the efforts to reduce noise are not so efficient as someone would desire and prevention is the way to deal with this kind of situations but this needs awareness.

In my opinion, awareness of the noise level danger is not so easy to get and implementation of methods to do it can improve the situation significantly, as some reports confirm it (European Agency for Safety…, 2005, pp.19-23).

3. Rough Desingn for a Noise Level Warning System

Taking into account the existing methods to improve awareness about noise levels I consider that a supplementary one can be useful.

Describing the sketch of a “noise level warning system” is the purpose of this paper.

Signal issue

Warning systems use signals. When noise level is high and because of it, the first most sensible human receptor, the ear, is not available. The second liable and available sense is sight and this is why the warning signal shall address to it.

Using a red light for signaling danger in traffic for cars and trains is well known and has the advantage that is easy to be recognized by anyone without any supplementary training.

So using a red light at the door of the facility where noise overcomes a certain limit can be used as a solution, or why not, “a sort of traffic light”.

System operation

When designing the system operation we must decide when the signal to light is on or off. For noise signaling this can be a major problem because of the noise parameters themselves.

Sound intensity and duration can vary very rapidly. High level of noise can last for less than a second but also can last for minutes. The frequency of noise is subject to the same appreciation.

In conclusion a simple sensor (microphone) “coupled with the bulb” is not enough to do the job. Using something like this the light signal will be on/off for to short periods in time so not effective for one person who needs to pass through the dangerous zone.

For solving the problem there can be implemented many solutions.

I shall present the functioning of one of them in short without giving too much technical details.

The sensors to collect noise must be placed at the hearing level of the average person about 165cm and close enough of the exposure zone. The data from the sensors will be collected in time, during a shift or on a longer period using a data acquisition system. All the characteristics of noise can be collected for further analysis and use (intensity, frequency, duration, predictability a.s.o.).

Analyzing the collected data will be the basis of designing of a neural network software for predicting and signaling the dangerous noise levels. After training, such a software can give a useful signal – long enough for being a consistent warning for “the traffic light”.

Of course this system is designed only for awareness but the data collected can be used also for superior analysis.

4. Conclusions

The idea proposed for the noise level warning system can be build starting from available devices as sound meters, sound dosage devices, the integration of all of them to a computer interface and software needs further considerations which are not the subject of this paper.

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SISTEM DE AVERTIZARE PENTRU NIVELUL DE ZGOMOT

(Rezumat)

Se prezintă câteva motive şi o schiță generală de proiect de sistem destinat evidențierii nivelului de zgomot.

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THE IMPLEMENTATION OF THE CONFORMITY AUDIT USING FILES TO CHECK LEGAL REQUIREMENTS

BY

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Abstract: The audit for Health and Security at the Workplace is a process of examination that can be used by employers and employees within a company in order to determine the way in which the specific requirements of health and security at the workplace are respected and to create a viable organizing framework according to the company’s specific activity.

The results of performing the activity of H.S.W audit can include: identification of weak points of audit’s target, emphasizing the potential risk or security areas (according to audit’s purpose), the lack of conformity with legal tasks mentioned in the specific legislation.

The effects of realising an objective audit process and specifically finding some optimum solutions for the established irregularities or lack of conformity will cause the increase of the preventive activities’ effectiveness, the decrease of final costs by a coherent policy in the security at the workplace domain, the increase of the parteners’ trust level and the improvement of the company’s market image.

Thus, to realise an audit that complies with the present day legislation’s provisions (in this case, from the Health and Security at the workplace domain), with the purpose of checking the way the present day legal provision is applied at the workplace, including the layout of activity and making of documents, which follows a qualitative evaluation by transposing into pointers with the same

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importance (Yes, No or It is not the case) testing sheets of legal requirements have been made.

Keywords: security at the workplace; audit; legal forecasts.

1. Introduction

The audit for health and security at the workplace is a process of examination that can be used by employers and employees within a company in order to determine the way in which the specific requirements of health and security at the workplace are respected and to create a viable organizing framework according to the company's specific activity.

The audit's criteria are represented by the entirety of legal provisions, standards and requirements specific to the organization, from which the audience compares the collected audit evidence and which refer to the audited objective (unit/activity performed).

The results of performing the activity of H.S.W audit can include: identification of weak points of audit's target, emphasizing the potential risk or security areas (according to audit's purpose), the lack of conformity with legal tasks mentioned in the specific legislation.

The effects of realising an objective audit process and specifically finding some optimum solutions for the established irregularities or lack of conformity will cause the increase of the preventive activities' effectiveness, the decrease of final costs by a coherent policy in the security at the workplace domain, the increase of the parteners' trust level and the improvement of the company's market image.

2. Theoretical Considerations

Based on their object, H.S.W audits can be:

1º Audits of H.S.W management system:

a) pre-evaluation audit (preaudit or 1st stage audit, effected before the audit of certification of the H.S.W management system;

b) audit of certification (2nd stage audit), effected with the purpose of certificating the H.S.W management system by an accredited external organism;

c) surveillance audit effected periodically , after the certification of the H.S.W management system .

2º Audits accordant with the legislation's provisions in the H.S.W. domain:

a) audits regarding the workplaces' conformity with security and health towards workplace requirements provided with the domain regulations (Law nr.

319/2006, Methodological requirements of applying the Law nr.319/2006 approved by H.G nr. 1425/2006, H.Gs specific to H.S.W., inherent instructions);

b) audits for the conformity of the organisation's ensemble on security and health at workplace requirements (Law nr 319/2006, H.G. nr. 1425/2006);

c) audits for the conformity of technological processes and technical equipments provisioned in the legislation (Law nr 319/2006, H.Gs'in the domain of H.S.W , the standards of security at the workplace) and with other requirements (technic books, good practice guides , projects, etc.);

d) audits for products' conformity with H.S.W requirements, . provisioned in the standards of security at the workplace.

Based on the notation system used, audits can be:

a) audit which follows a qualitative evaluation, in which the pointers have the same importance and are appreciated by: YES, No or It is not the case.

b) audit which follows a quantitative evaluation, in which the pointers could have different importance grades marked by weighting factors, and the assessment are being made by giving a score or a percentage point.

3. Surveillance Lists

No matter what is wanted to be audited and the chosen methodology that is used, it will be necessary for the auditor to know the imposed conditions, the rules that need to be accomplised by the employer , the system, the process or even the content of the elaborated documents. .

Thus , to realise an audit that complies with the present day legislation's provisions (in this case, from the Health and Security at the workplace domain), with the purpose of checking the way the present day legal provision is applied at the workplace, including the layout of activity and making of documents, which follows a qualitative evaluation by transposing into pointers with the same importance (Yes, No or It is not the case) testing sheets of legal requirements have been made.

Furthermore, to highlight some lacunas within complex requirements (organizational, which involve responsibilities or the content of some documents) a column has been introduced: **''partly accomplished (How, What)''**.

The document that has been created can be a handy tool for every person (employee, employers, auditor) which, without them knowing the content of legal provisions , can check the way of application , the fulfillment of its requirements and the creation of new documents, their content, precision and the way of accomplishing the legal obligations prefigured in the transposed legislative measure.

Table 1
Checking List for Highlighting the Applicable Legal Provisions at the Audited Workplace (example)

Crt. Nr.	Pointer	Legal provision (article, paragraph, letter)	YES	NO
1.	Manual crowds have been manipulated at the workplace? (manipulating the manual crowds means any kind of transport or sustenance of a crowd by one or more workers, including lifting, setting, pushing, pulling, carrying or displacing a crowd)	Chp. I, art. 1(acc. to Art. 3)		
2.	The activities that have been displayed at the workplace imply activities in the industry of extracting the drilling? (It will not be applied to the activities of prime material processing)	Art. 1, paragrph.1		
3.	The activities that have been displayed at the workplace contain constructions or civil engineering projects provisioned in the 1st annexe – H.G. 300/2006?	Art. 4, lett. a		
	➢ Excavations	Annexe Nr. 1		
	➢ Embankments			
	➢ Constructions			
	➢ Assembling and dismantling the prefabricated elements			
	➢ Arrangements or instalation			
	➢ Transformations			
	➢ Renewals			
	➢ Reparations			
	➢ Demolitions			
	➢ Deconstructions			
	➢ Services			
	➢ Maintenance – painting and cleaning projects			
	➢ Innings			
	➢ Consolidations			
	➢ Modernizations			
	➢ Rehabilitations			
	➢ Increases			
	➢ Restorations			
	➢ Dismantling			

Table 2
Specific Checking List for Complying with Legal Requirements that are Included in Judgement nr. 1.028 from the 9th of August 2006 which Involve the Minimum Requirements of Security and Health at the Workplace with Reference to the Usage of Equipments with Visualization Display (partly)

Crt. Nr.	Pointer	Legal provision (article, paragraph, letter)	YES	NO	It is not the case	It is partly accom plished (how, what)
1.	Has an analysis of workplaces been made to evaluate the security and health conditions offered to the employees, especially when it comes to the eventual risks forseeing, physical problems and mental request?	Art.5				
2.	Have tasks been planned for the employee so that daily usage of a display can be periodically interrupted by pauses or activity changes , which can reduce the overexertion resulting from sitting in front of the display?	Art.8				
3.	Is each employee instructed how to use the workplace before starting this type of activity and any time the workplace's organisation is significantly changed?	Art.10				

4. Conclusions

A detailed analysis before the beginning of the activity allows the implicated parts a correct understanding of measures that must be taken, the risk that may appear, the simple awareness of these factors being a precursor of the increasing of the security level and decreasing of the level of risk. The use of checking files of the legal requirements the comply with the provisions of a legislative measure allows:

a) highlighting the main legal provisions that can be applied to the workplace/audited unit;

b) checking the way legal requirements are applied and respected even if the person does not have knowledge in the security and health at workplace domain;

c) checking the application of the imposed measures by the legal provisions, if they are not applied or partly accomplished, the requirements for a certain aspect, activity or specific requirement of a performed activity;

d) highlighting the way that the editing of the content of some documents has been respected, who must execute them, keep them or fill them in;

e) respecting the tasks and obligations that come by law to some persons and the way they accomplish them;

f) highlighting and respecting the accomplishing terms and depositing of some documents, as much internally as at various units of the states (I.T.M., I.S.C.I.R., C.N.C.I.R., I.S.U.).

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REALIZAREA AUDITULUI DE CONFORMITATE UTILIZÂND FIŞE DE VERIFICARE A CERINȚELOR LEGALE

(Rezumat)

Auditul securității şi sănătății în muncă reprezintă un proces de examinare aflat la dispoziția angajatorilor şi angajaților, la nivelul unei companii, pentru determinarea modului în care sunt respectate cerințele specifice în domeniul securității şi sănătății în muncă şi crearea unui cadru organizatoric viabil, în concordanță cu specificul activității din unitatea respectivă.

Rezultatele efectuării activității de audit S.S.M. pot include: identificarea punctelor slabe ale obiectivului auditului, evidențierea zonelor cu potential de risc sau de securitate (în funcție de scopul auditului), neconformitățile cu cerințele legale precizate în legislația specifică.

Efectele realizării unui process de auditare obiectiv şi mai ales găsirea unor soluții optime pentru neregulile ori neconformitățile constatate va determina creşterea eficienței activităților preventive, scăderea costurilor finale printr-o politică coerentă în domeniul securității în muncă, creşterea nivelului de încredere a partenerilor şi îmbunătățirea imaginii de piață a companiei.

Astfel, pentru realizarea unui audit de punerea în conformitate cu prevederile legislației în vigoare (în cazul de față, din domeniul Securității şi Sănătății în Muncă), având ca obiect verificarea modului în care se aplică prevederile legale în vigoare la locul de muncă, inclusiv modul de organizare a activității şi întocmire a documentelor, care urmăreşte o evaluare calitativă prin transpunerea în indicatori cu aceeaşi importanță (*Da, Nu* sau *Nu e cazul*) au fost realizate fişe de verificare a cerințelor legale.

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REMEDIATION AND NATURAL ATTENUATION OF URANIUM IN GROUNDWATER

BY

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Abstract: A mining research and development complex that operated for 75 years resulted in uranium contamination of soil and groundwater within the original banks of an adjacent river. The contaminated fill created a low terrace or bench with an elevation of approximately one meter above the average river water level. Oxygen-rich surface water entering the terrace from the river dissolved and mobilized uranium from both background and contaminated soils. A wetland that later developed on the terrace created a groundwater zone with low levels of available oxygen. The uranium that had been mobilized a few meters upstream was then precipitated into the soils within the wetland zone. Groundwater returning to the river from the downstream end of the terrace was demonstrated to have low concentrations of uranium. Confirmation of the mechanism of uranium mobilization was confirmed through monitoring of groundwater, conditions and events.

Keywords: uranium; wetland; groundwater; roll-front; oxygen potential.

1. Introduction

A mining industry research and development facility was operated at Golden, Colorado USA between 1912 and 1987. The Colorado School of Mines

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Research Institute (CSMRI) operated the facility at the time of its closure in 1987. During the 75 year operating history thousands of samples of ores, minerals and concentrates were brought to the facility.

Depending on the type and origin of the ores and materials, the samples had varying amounts of naturally occurring radionuclides such as uranium and radium.

2. Development of a Wetland Area with Elevated Concentrations of Uranium

Before the construction of the facility in 1912 a river, (Clear Creek) flowed through the City of Golden in a wide bed with numerous braided channels as can be seen in Fig. 1. Many of the ore and mineral samples were disposed of on the grounds of the CSMRI facility or used as fill including within the banks of Clear Creek. In addition to the sample material, natural soil from the area was often used in the same area as fill.

Fig. 1 – Clear Creek at Golden, Colorado looking east from Mount Zion, 1888. Arrow indicates approximate area of future Lower Terrace and wetlands area.

By 1950, artificial fill had resulted in the restriction of the river to a narrow channel through much of the valley. Adjacent to the CSMRI facility on the south side of the river, the fill created a low-lying terrace or bench (Lower Terrace) one meter or less in elevation above the average water level. Around 1950, a tailings pond for use by the CSMRI facility was created on the Lower Terrace as can be seen in Fig. 2.

After the facility was closed in 1987, environmental evaluation and cleanup started and the facility became known as the CSMRI Site ("Site"). In 1993 cleanup had been completed on the tailings pond portion of the Lower Terrace. Following that cleanup, a wetlands area developed naturally where the tailing pond had been located.

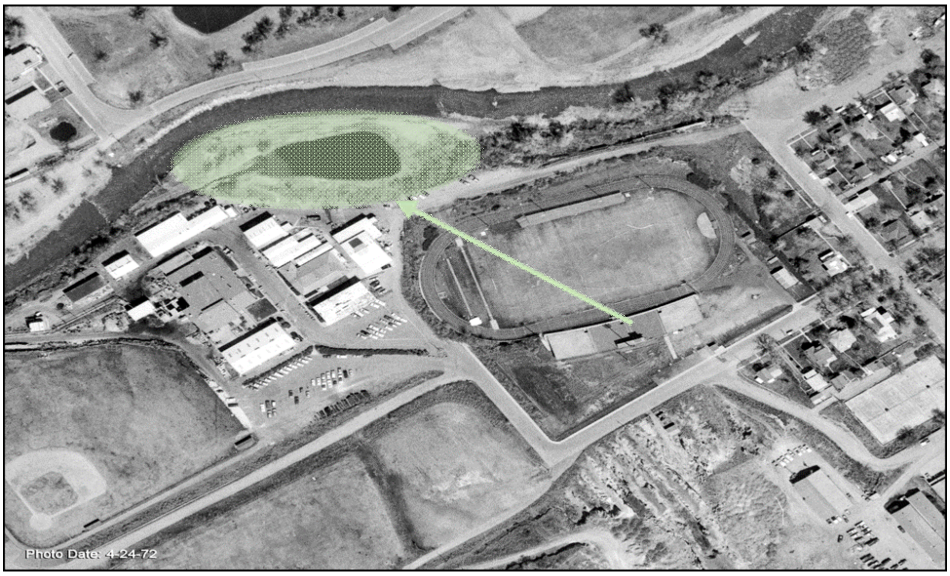

Fig. 2 – The Lower Terrace area had developed to its final outline by 1950. That year, a tailings pond was constructed on the Lower Terrace. Arrow indicates approximate Lower Terrace area. The buildings below and to the left of the Lower Terrace area include the developed area of the CSMRI complex. In this image, water flow in Clear Creek is left to right; north is at the top of the image.

3. Uranium Mobility and Transport through the Lower Terrace

The fill, river, and groundwater resulted in the development of a human-created wetlands on the Lower Terrace after the 1993 cleanup. The modern Lower Terrace contained original soil and alluvium from the original structure of Clear Creek, clean fill, and sample and waste material from CSMRI operations. Due to the high and varied metals content of the samples, portions of the material that had been used in the filled area contained uranium at concentrations above local background.

The solubility of uranium in water is related to oxygen potential. Oxygenated surface water from Clear Creek flowed into the Lower Terrace groundwater at the west end of the Lower Terrace. This oxygenated water dissolved and mobilized uranium into the Lower Terrace groundwater. As the groundwater moved further downstream through the Lower Terrace into the wetland area, the subsurface environment changed to more reducing conditions causing dissolved uranium to precipitate and become immobilized. Thus a stable roll-front system was created that resulted in uranium dissolution then capture without significant amounts of uranium leaving the system. This roll-front system operated largely within the western, upstream side of the Lower Terrace.

Monitoring and testing of the groundwater at the Lower Terrace indicated that the distribution of uranium was consistent with a roll-front model. As water that contained dissolved uranium moved west to east through the Lower Terrace, it encountered the wetlands area. Wetland soils typically have low oxygen content due to the degradation of organic matter in the soils.

The rapid fall-off in uranium concentration across the wetlands area was consistent with precipitation of the uranium under the relative reducing groundwater conditions. The monitoring wells at the east (downstream) end of the Lower Terrace showed that uranium levels in groundwater had been reduced to low levels and was not contaminating the Creek.

4. Verification of Water Oxidation Potential and Uranium Concentration in Groundwater

An inadvertent experiment in 2007 confirmed the uranium-dissolving power of oxygenated water at the Site. In 2007, construction of a new stormwater drainage system fed large quantities of oxygenated runoff onto the eastern (downstream) end of the Lower Terrace. Immediately uranium concentrations in the downstream wells began to rise. After a year of dramatically increasing uranium levels in the wells, the stormwater drainage system outfall was moved away from the Lower Terrace. This eliminated the outside source of oxygenated water from the surface of the wetland area. Immediate the uranium levels in the downstream wells began a rapid drop in concentration. The solubility of uranium at the conditions existing at the Lower Terrace was thus demonstrated to be closely related to the oxygen content of the water.

5. Site Geology and Uranium Concentration in Groundwater

The geology of the Site influenced the system as well. The Site is located at the eastern edge of the Rocky Mountains. The formation of the Rocky Mountains resulted in uplift of geologic strata to the near vertical in the area of the Site. Thus several types of bedrock are found underneath the Site.

Different types of strata can result in different groundwater chemistries. The strata underlying the eastern portion of the Lower Terrace included a coal seam that provided reducing conditions for the groundwater flowing across the Lower Terrace. A different bedrock type known as the Fox Hills Sandstone formation is found under the center of the Lower Terrace. The Fox Hills Sandstone was determined to be a source of upwelling groundwater that contributed to flow across the Lower Terrace. The groundwater upwelling from the Fox Hill Sandstone had a low oxygen content. The coal seam, upwelling groundwater and the wetland area all ensured a reduction of the oxygen potential across the Lower Terrace from west to east. These all contributed to low uranium solubility conditions at the eastern end of the Lower Terrace.

6. Completion of Lower Terrace Cleanup and Conclusion

In 2007 it was discovered that some sample material or contaminated soil with elevated uranium remained at the west (upstream) end of the Lower Terrace. Removal of all of this contaminated soil and material from the upstream portion of the Lower Terrace and replacement with clean soils with background concentrations of uranium was completed in 2010. This resulted in dropping concentrations of uranium in upstream wells. However, the remaining uranium concentration profile remained consistent with the roll-front model of the system.

The 2010 removal of contaminated materials and subsequent groundwater monitoring and modeling demonstrated that the Site was effectively cleaned up. All of the Site areas were returned to productive use by 2012.

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REMEDIERE ŞI ATENUARE NATURALĂ DE URANIU ÎN APELE SUBTERANE

(Rezumat)

Un complex de cercetare şi dezvoltare minieră, care a funcționa 75 de ani a dus la contaminarea cu uraniu a solului şi a apelor subterane în zona albiei minore adiacentă râului. Materialul de umplere contaminat a creat o terasă joasă sau un mal cu o altitudine de aproximativ un metru peste nivelul mediu de apă din râu. Apa de suprafață bogată în oxigen ce intro în zonă a dizolvat şi a mobilizat uraniul atât din fundal cât şi din solurile contaminate. O zonă de mlaştină care s-a dezvoltat ulterior pe terasă a creat o zonă de ape subterane cu nivele ale oxigenului disponibil scăzut. Uraniul care a fost mobilizat cu câțiva metri mai la deal s-a precipitat în aceste soluri din zona mlăştinoasă. Apa subterană ce se întoarce în râu din aval de terasă a avut o concentrație scăzută de uraniu. Confirmarea mecanismului de mobilizare a uraniului a fost certificată prin monitorizarea apei subterane, a condițiilor şi a evenimentelor.

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ABRASIVE WEAR OF AL ALLOYS BASED COMPOSITES REINFORCED WITH PARTICLES

BY

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Abstract: The objective of this paper is threefold, first to review and synthesize the results obtained from prior composites wear investigations, second to identify relevant parameter interactions and finally to propose a general framework for assessing the parameter influences on composite and counterpart wear performance.

Keywords: composites; reinforced aluminium alloy matrix; sliding wear; wear resistance.

1. Introduction

Composites are "new" materials that offer promising perspectives in assisting automotive engineers to achieve improvement in vehicle fuel efficiency. Their distinctive properties of high stiffness, high strength and low density have promoted an increasing number of applications for these materials. Several of these applications require enhanced friction and wear performances, for example brake rotors, engine blocks and cylinder liners, connecting rod and piston, gears, valves, pulleys, suspension components, etc. (Noguchi *et al.*,

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2003).

The principal tribological parameters that control the friction and wear performance of reinforced aluminum alloys composites can be classified into two categories (Vingsbo 2008; Suh *et al.*, 2001; Hutchings, 2003):

1. mechanical and physical factors (extrinsic to the material undergoing surface interaction), *e.g.* the effect of load normal to the tribo-contact (Florea *et al.*, 2013) the sliding velocity, the sliding distance (transient and steady state period), the reinforcement orientation for no equated particulates, the environment and temperature, the surface finish and the counterpart

2. material factors (intrinsic to the material undergoing surface interaction), *e.g.* the reinforcement type, the reinforcement size and size distribution, the reinforcement shape, the matrix microstructure (Peter *et al.*, 2014), and finally the reinforcement volume fraction.

2. Review

2.1 Extrinsic factors

An initial unstable non-linear period followed by a steady state period, during which the wear rate increased linearly with increasing sliding distance, was observed by Wang and Rack (Wang *et al.*, 2001), Table 1, in agreement with other studies, *e.g.* (Lee *et al.*, 2002; Sannino *et al.*, 2009). Wear mechanisms changed as sliding distance increased; it was found that abrasion was the predominant wear mechanism for both composite pin and steel counterpart during the initial run-in period. While abrasion was still the wear mechanism for the steel counterpart, adhesion-induced tribofracture occurred in the 2124 AI-SiC, during steady-state sliding. Alpas and Embury (Alpas *et al*., 2000), Table 1, noted a very short initial run-in period with the friction coefficient increasing from 0.35 during the run-in to 0.6 for the steady-state period after only a sliding distance of 10 m. They attributed this to generation of loose debris that transformed wear into a three-body abrasive wear during the first ten meters. They also reported that the predominant wear mechanism for the composite was delamination of subsurface layers generating loose debris and giving turbulent friction behavior, in agreement with Sannino and Rack, (2009), Fig. 1. Alpas and Embury, (2000), finally concluded that subsurface cracks nucleated at interfaces between SiC particulates and Al matrix, and the size of the debris were related to size of the SiC particulates.

In contrast to the previous observations, (Pan *et al.*, 2002) did not identify any run-in stage for higher normal load. However, they did not performed wear loss measurements below 300 m and a possible run-in period ending at lower sliding distance may not have been identified.

Table 1
Sliding Wear Investigations Considering the Influence of Sliding Distance

References	Wang and Rack, 2001	Lee *et al.*, 2002	Alpas & Embury, 2000	Pan *et al.*, 2002
Apparatus	Pin-on-disc	Spindle type wear tester	Block-on-ring	Block-on-ring
Reinforcement type	$SiC_{p,\,w}$	SiC_w, Al_2O_3, fiber 13-20 vol.%	SiC $_{p,\,w}$ 20 vol.%	Sic,, 20 vol.%
Reinforcement orientation	Whiskers normal and parallel	Normal, 2-D random oriented	–	Longitudinal, transverse and normal
Reinforcement size µm	Particulate: 2-10; Whiskers: diameter, 0.5; length, 3	Diameter:0.1-l; length: 30-300	14	–
Matrix type	7091	6061	2014	2124
Heat treatment	ss h.t. 475°C, 2 h water quenched 25°C, 6 days 125°C, 24 days	–	–	ss ht. 530 °C, 1 h 25 °C, 6 days 175°C, 6h
MMC surface finish	–	–	–	–
Fabrication	PM	Direct squeeze infiltration	–	PM
Counterpart type	17-4 PH steel 35 Rc	SCM 4 (550 Hv) 304 SS (160Hv)	52100 steel 63 Rc	52100 steel 63 Rc
Sliding speed $m.s^{-1}$	0.36-3.6	0.061.98	0.16	1
Normal load, [N]	14.2	32	9.35	52

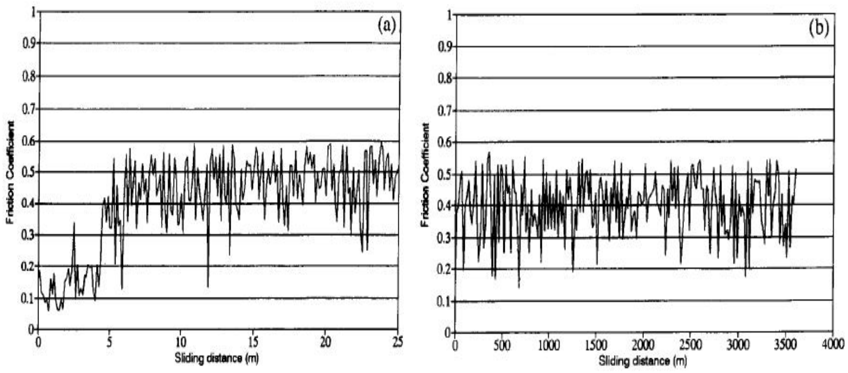

Fig. 1 – Typical friction coefficient against sliding distance for 2009 Al-SiC_p,/ 17-4 PH: *a* – incubation period; *b* – overall testing (Sannino *et. al.*, 2009).

2.2. Intrinsic Factors

Composites containing hard SiC, TiC, Si_3N_4, Al_2O_3, and SiO_2 exhibited lower (four to ten times lower, depending on the velocity and the reinforcement type combination) wear rate than the unreinforced matrix alloy (Sato *et al.*, 2006), Table 2. No obvious superiority among these reinforcement types was detected throughout the velocity range under investigation.

In contrast, composites containing soft particulates, MgO and BN, displayed wear rate four to five times higher than the unreinforced matrix alloy. However, (Hosking *et al.*, 2002) reported that, at low load (0.5 N) and other experimental conditions, (see Table 2), SiC particulate are more effective than Al_2O_3 particulates in resisting wear. They attributed this discrepancy to the difference in wear performance and hardness (1,800 *vs*. 2,600 VHN for Al_2O_3 and SiC, respectively) of the reinforcements themselves.

Long *et al.*, (2008), reported that, at a given reinforcement volume fraction, the best improvement in wear resistance was obtained by an hybrid composition of SiC whiskers and $A1_20_3$ fibers followed by SiC whiskers, the least efficient being Al_2O_3, fibers. This phenomenon was attributed to the barrier effect of the SIC whiskers against the slip of Al_2O_3 fibers during the flow of the matrix. Optimization by combining two reinforcement types (alumina/alumino silicate) was also observed in lubricated sliding, Table 2.

Table 2
Sliding Wear Investigations Considering the Influence of Reinforcement Type

References	Sato *et al.*, 2006	Hosking *et al.*, 2002	Long *et al.*, 2008
Apparatus	Pin-on-disc	Pin-on-disc	Pin-on-disc
Reinforcement particulate	$A1_2O_3$, SiC, MgO TiC, S_3N_4. BN, SiO_2 glass	SiC, Al_2O_3	SiC, Al_2O_3, SiC and Al_2O_3 hybrid
Reinforcement shape	Particulate	-	SiC whiskers; Al_2O_3 fibers; “Saffil”
Reinforcement size (μm)	0.06-840	-	SiC: diameter 0.05-1.5; length 200; Al_2O_3: diameter 3; length 500
Matrix type	Al-4%Cu-0.75%Mg	2014, 2024	6061
Heat treatment	-	-	ss heat. tr. 520°C, 4 h, w.q., 170°C, 8h
Fabrication	Casting	PM	PM
Counterpart type	52100 steel 63 Rc	52100 steel 63 Rc	SKH 5166 Rc
Sliding speed (m s^{-1})	0.05-0.46	1	0.93
Normal load (N)	3	0.5-10	200-500
Volume fraction (vol.%)	0-30	2-30	15.20

3. Application of the Wear Precursors Approach to Composites Reinforced with Particles on Dry Sliding Wear Behavior

Alpas *et al.*, (2003), observed that increasing the applied load increased the wear severity by changing the wear mechanism from abrasion to delamination (Fig. 2). This transition was attributed to reinforcement cracking which is a phenomenon included in subsurface behavior. (Sannino *et al.*, 2009) observed a similar phenomenon for other investigated parameters and experimental conditions. They reported that, while adhesion was a common wear mechanism for all tribo-systems, increasing the reinforcement size resulted in higher MMC wear rate. This increase was due to transition from micro-cutting, plowing and wedge formation to particulate cracking-induced delamination. Indeed the probability of reinforcement cracking, Fig. 3 (Lin *et al.*, 2002), is related to subsurface strain accumulation, which, in turn, is related to the shear stress induced by (i) normal load, friction and sliding distance, and (ii) reinforcement size, shape and spatial distribution. In this case, prediction of reinforcement cracking occurrence will help in designing MMC reinforcement and matrix characteristics to avoid delamination and enhance wear resistance as a function of the most predominant mechanical parameters (applied load, matrix and reinforcement characteristics, in this application).

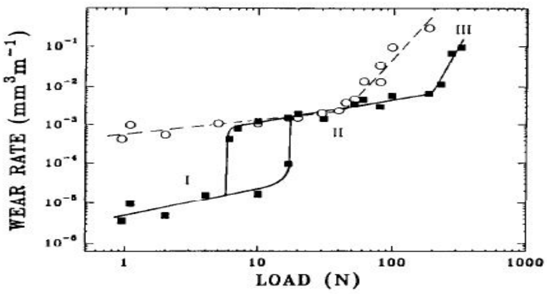

Fig. 2 – Wear rate *vs.* applied load diagram for 6061-20 vol.% Al_2O_3 (○) and 6061Al (■) (Alpas *et al.*, 2003).

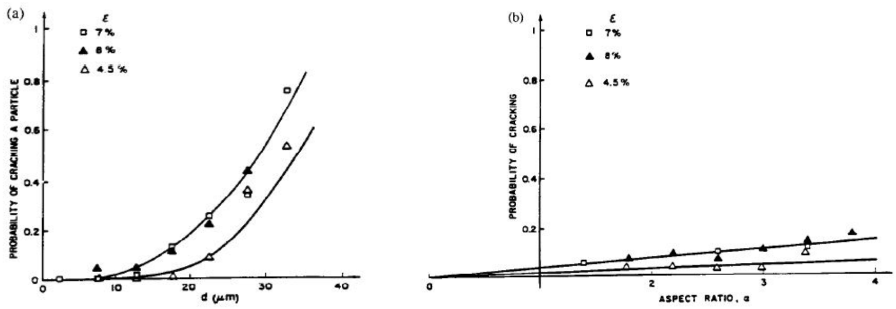

Fig. 3 – The probability of cracking as a function of (*a*) particulate size and (*b*) aspect ratio

4. Conclusions

This review and discussion about wear performance of hard ceramic reinforced MMC depicts an overall panorama and a synthesis of past investigations and suggests a general framework to investigate the tribological performances of MMC-metal couples.

The beneficial effect of reinforcement incorporation in aluminum matrix has been observed when first body abrasion, oxidation, adhesion or thermally activated (high energy involved in surface interactions, *e.g.* at high contact load and/or speed) sever wear are operative in both unreinforced alloy-metal and MMC-metal tribosystems. When third body abrasion (*e.g.* at low speed where friction is enhanced) or subsurface delamination (*e.g.* at medium load where the reinforcement is not sufficiently tough to bear the load) is operative to use a MMC for tribocontact with respect to unreinforced alloys is no longer justified unless the MMC's properties are optimized to minimize the contribution of these wear mechanisms.

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UZURA ABRAZIVĂ ÎN CAZUL COMPOZITELOR PE BAZĂ DE ALIAJE DE AL RANFORSATE CU PARTICULE

(Rezumat)

Obiectivul acestei lucrări este, în primul rând, să revizuiască şi să sintetizeze rezultatele obținute de la unele compozite ranforsate cu particule. Articolul identifică paramentrii relevanți în interacțiunile matrice-ranfort şi în cele din urmă propune un cadru general pentru evaluarea influențelor parametrilor asupra performanței la uzură a compozitelor.

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THE INFLUENCE OF VIBRATION ON AN ALUMINUM ALLOY

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Abstract: This paper is the result of a series of researches regarding the influence of vibrations on cast alloys. Determinations of mechanic properties, structure and segregations have been established by comparing the cast in static and dynamic conditions.

Keywords: circular vibration; aluminum-silicon alloy; hardness distribution.

1. General Considerations

When the vibrations are being applied, a series of physical processes appear, like the action of count forces, the mass macroscopic transfer, cavitations phenomenon’s, the amplification of the overcooling degree and the changing of the conditions of solid-fluid equilibrium.

From the existing researches it has been determined that the realization of cast pieces under the influence of vibrations presents a series of advantages in comparison with static cast.

First of all, the structure of pieces cast in dynamic conditions is more homogenous from a chemical point of view and present a higher degree if

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finesse due to the increase of cooling speed but also due to the fragmentation of dendrites in course of solidification.

2. Experimental Results

To study the effects of vibration of the alloys have conducted a series of experiments using a patented plant in Romania (1). On the table vibrator can cast small and medium pieces.

We used an containing 95%; 4.5% Cu; 0.14% Fe; 0.28% Si, realizing development in an electric furnace with resistance, using pure metals, master alloys and alloys previously obtained liquid bath is protected with a layer of fondant.

The casting temperature was 700ºC, and the forms have been preheated to a temperature of approx. 100ºC.

Size and shape of the specimens are shown in Fig. 1.

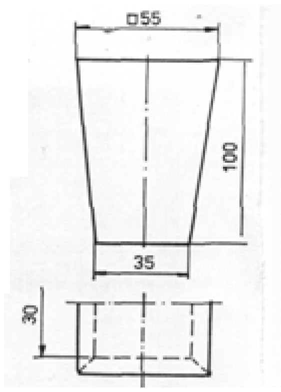


Fig. 1 – Types of specimens.

Castings samples were noted as follows:

a) sample 1 specimen cast in static conditions;

b) sample 2 molded specimen under dynamic conditions (vibrated).

Specimens were sectioned and sampled undergoing a spectrometer EDAX study type maping. The EDAX analysis identified a uniform distribution of the aluminum silicon copper in the alloy composition, respectively, as shown in Fig. 2.

The spectrum of the samples 1 and 2 are shown in Fig. 3.

We have taken samples which were subjected to breaking, have been studied by electron microscopy shape and dimensions of the fracture. Tears form shows a ductile fracture, the present cups and cones areas and areas where traces of slip structures. Also, due to the demands of the material intercrystalline can see small cracks. Rupture occurred transgranular and intergranular. The structures are shown in Fig. 4.

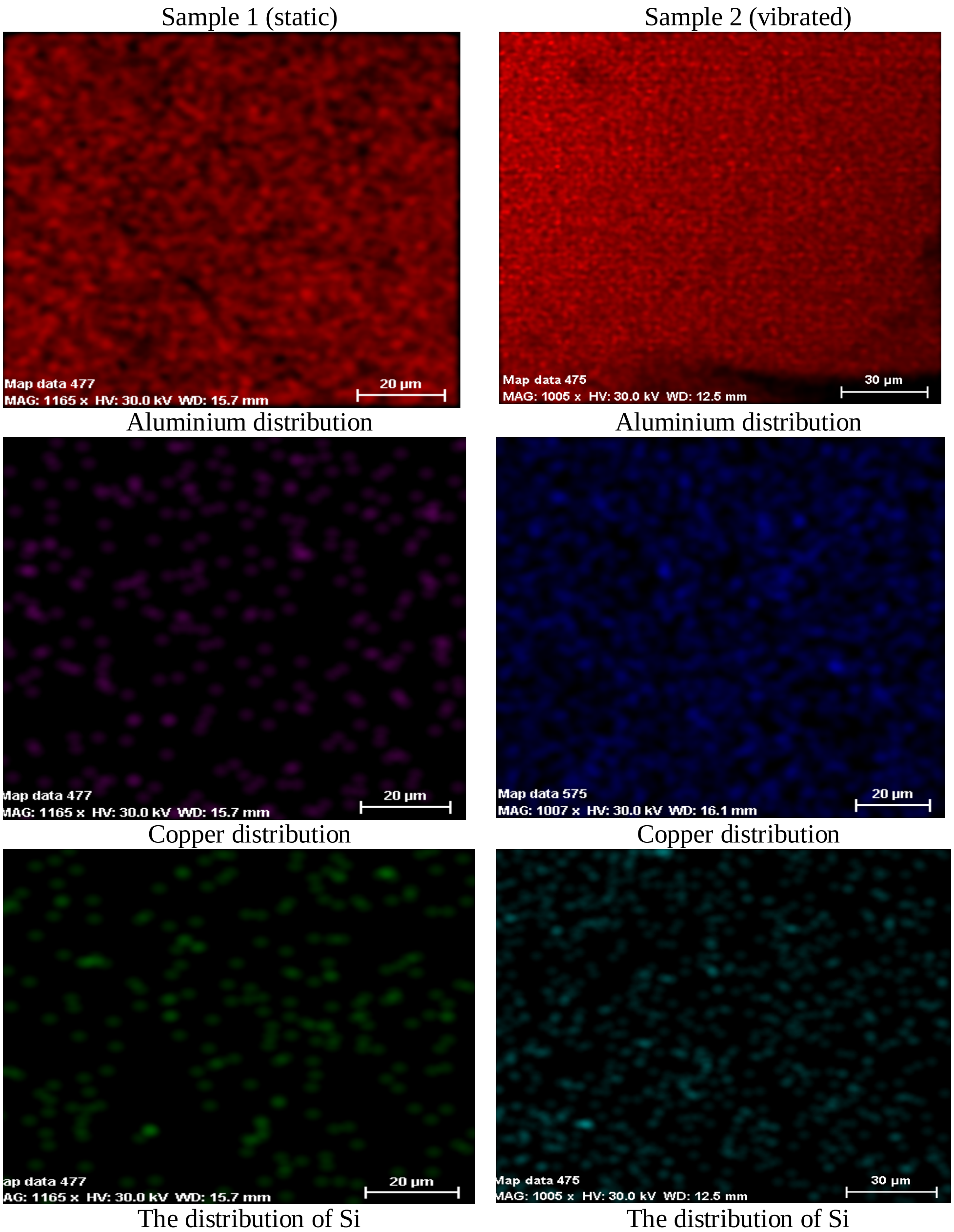
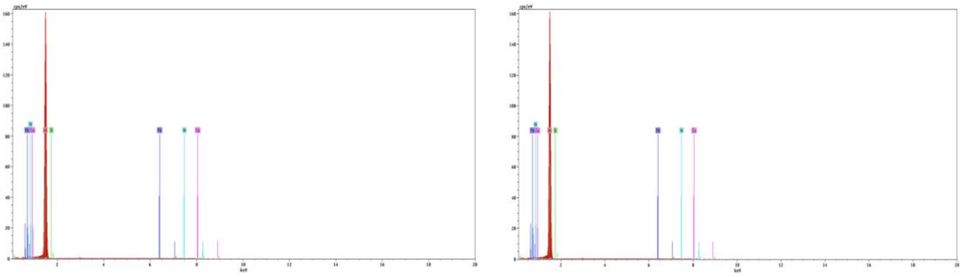
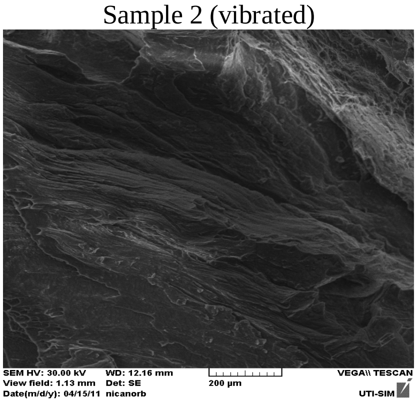
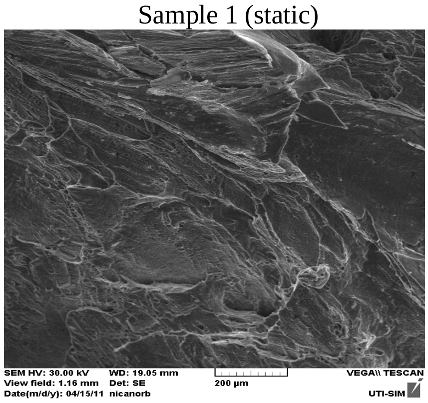
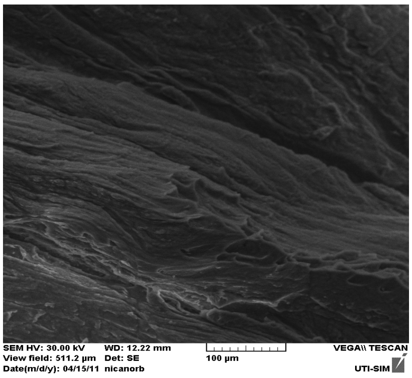
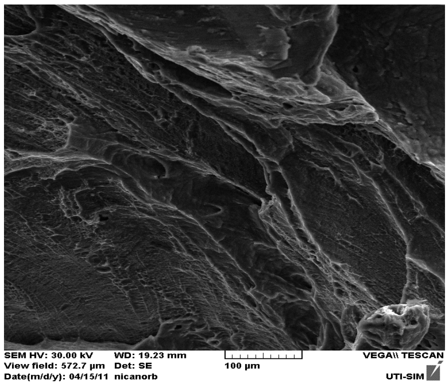


Fig. 2 – The distribution of alloy elements for samples 1 and 2.



Sample 1 (static) Sample 2 (vibrated)

Fig. 3 – Samples 1 and 2 3 - Spectrum

Sample 2 (vibrated)	Sample 1 (static)
	
250X	250X
	
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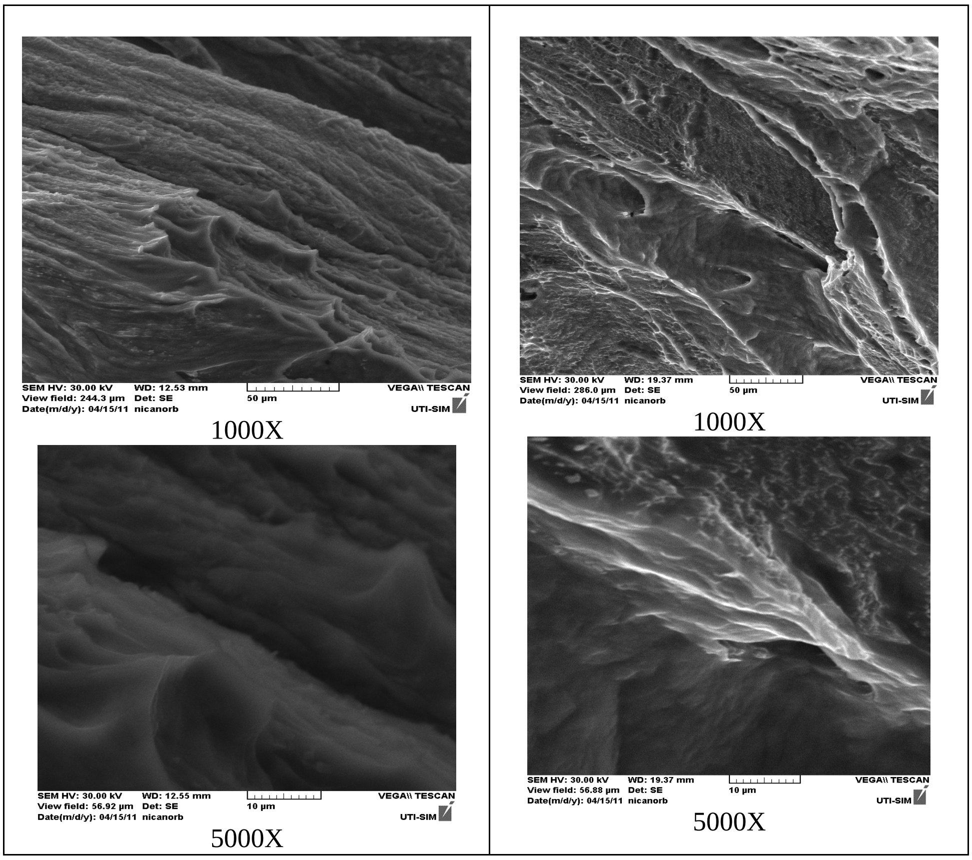


Fig. 4 – Samples 1 and 2 – SEM.

Table 1
Hardness Test 1

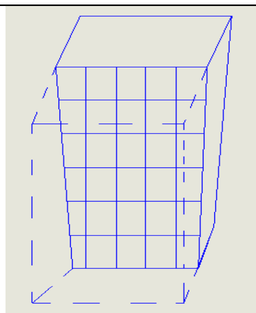
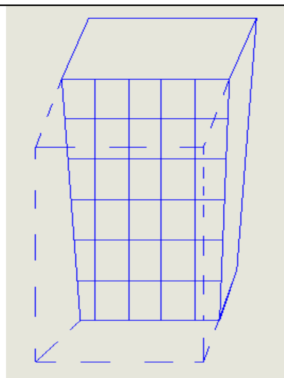
Static cast hardness test 1 [HB]					
30.36	36.31	31.5	33.35		32.88
26.8	36.99	33.1	35.86		33.19
27.22	31.08	35.92	40.29		33.63
27.91	29.54	33.65	34.63		31.43
	31.55	31.53	31.91		31.66
		30.32	29.89		30.11
28.07	33.09	32.67	29.42		Medie

Table 2

Hardness Sample 2

Hardness molded vibrating sample 2 [HB]					
29	26.41	27.17	28.16		27.69
26.06	26.41	28.22	26.93		26.91
26.05	26.69	30.21	26.99		27.49
	28.41	30.53	27.77		28.90
	26.73	29.16	28.24		28.04
	25.97	27.92	24.36		26.08
27.04	26.77	28.87	27.08		Medie

In Figs. 5 and 6 are shown graphically variations in the hardness of the vertically and horizontally in the two samples.

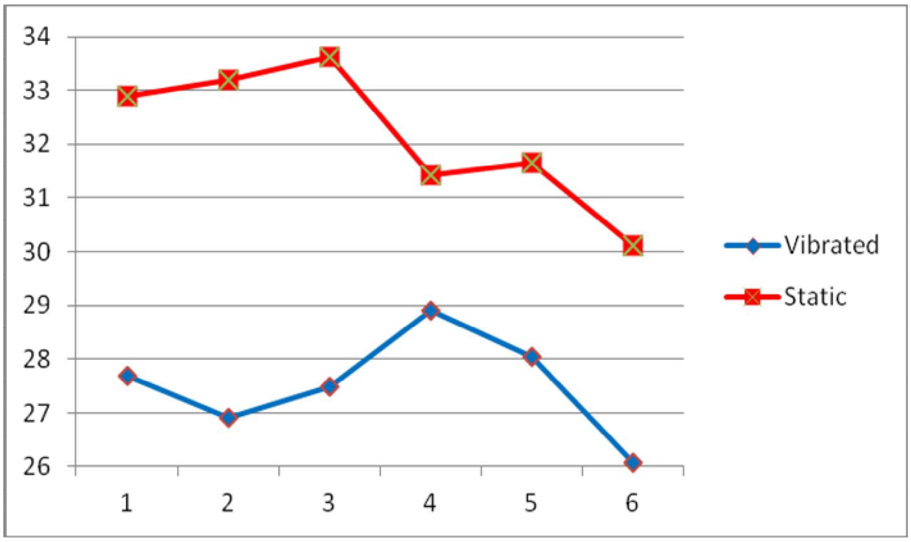


Fig. 5 – Diagram hardness for samples with square.

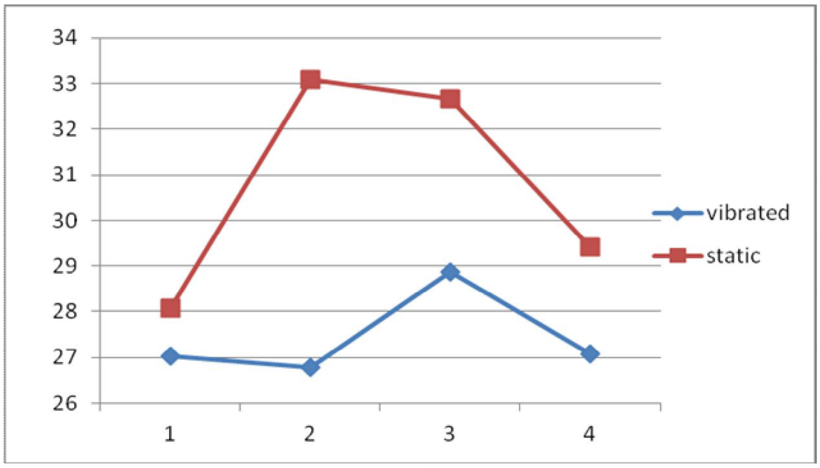
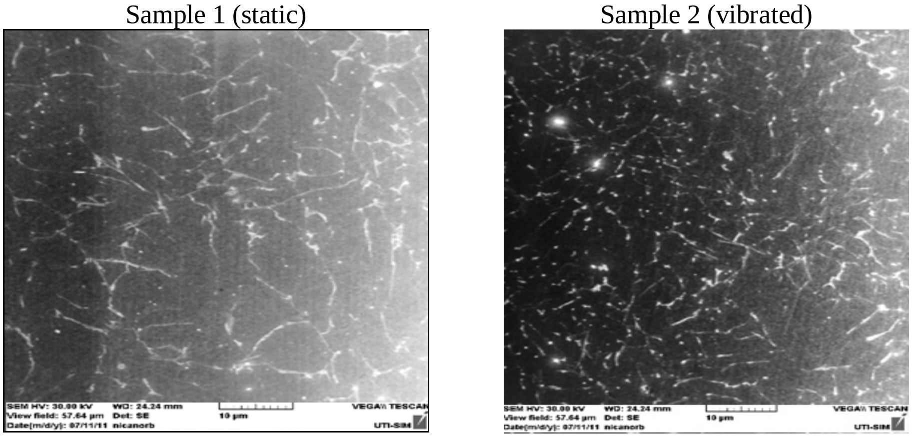


Fig. 6 – Diagram hardness for samples with square.

Pure aluminum and its alloys-phase (consisting of aluminum-rich solid solution) have a very strong tendency to form pouring coarse structure and also to develop pronounced. For this reason the use of the vibration of great practical importance for these alloys, allowing the ingots and castings of a fine-grained microstructure and a uniform macrostructures. To highlight grained alloy was prepared samples were prepared to undergo a chemical attack normally. Reagent used in chemical attack has the following composition: 0.5 ml HF, 1.5 ml HCl, 2.5 ml NH_3, 95.5ml distilled water. Following the attack samples were studied using electron microscopy, the structures are visible grain boundaries seeing a finer structure for samples and hence vibrate a uniformity of material properties (Fig. 7).

Sample 1 (static) Sample 2 (vibrated)



300X 300X

Fig. 7 – Structures samples.

3. Conclusions

We identified a uniform distribution of alloying elements for specimens molded circular vibrating horizontally.

It can be seen in most of the fine structural failure in the test specimens being subjected to vibration during solidification, which demonstrates the beneficial effect on the grain structure.

Tears form shows a ductile fracture, the present cups and cones areas and areas where traces of slip structures. Also, due to the demands of the material intercrystalline can see small cracks. Rupture occurred transgranular and intergranular.

If specimens square, horizontal circular motion leads to the creation of swirl in the corners of the specimen.

From microscopy done on samples chemically attacked grain boundaries are observed in the structure. If there is a vibrating sample finer structure and hence uniformity of material properties.

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INFLUENŢA VIBRAŢIILOR ASUPRA UNUI ALIAJ DE ALUMINIU

(Rezumat)

Această lucrare este rezultatul unei serii de cercetări privind influenţa vibraţiilor pe aliaje turnate. Determinările proprietăţilor mecanice, structura şi segregarea au fost stabilite prin compararea datelor obţinute pe piese turnate în condiţii statice şi dinamice.

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METALLIC MATERIALS BASED ON IRON FOR NUCLEAR PLANT

BY

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Abstract: In this paper we analyze the usage of fe-based metallic alloys for power plants construction. After a short description of power reactors by type, worldwide, we focus on the main metallic elements used in primary and secondary circuits of a power plant. Pressurized water (15.5 MPa) in the primary circuit enters the reactor core at 275ºC, picks up heat from the reactor core with a core exit temperature of 325ºC, and transfers the heat across the u-tubes in the steam generator to water at a lower pressure. This water turns to steam that powers the turbine, and is condensed and recirculated. In order to foresee new materials and new applications we establish some metallic materials challenges in future fission reactor concepts.

Keywords: nuclear plant; austenitic steels; high strength.

1. Introduction

Obtaining sustainable and affordable energy is viewed as crucial to worldwide economic prosperity and stability (Chu & Majumdar, 2012; Arunachalam & Fleischer, 2008). Nuclear fission energy has emerged over the

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past 40 years to become a reliable base-load source of clean and economical electrical energy. As of 2011, there were 435 nuclear reactors in operation worldwide, producing 370 GWe of electricity (World List of Nuclear…, 2012). Another 108 units or 8 GWe are forthcoming (under construction or on order), for a total of 543 units and 478 GWe of electrical capacity.

The largest producer of power from nuclear energy is the USA, with 104 commercial reactors licensed to operate at 65 sites, producing a total of 103 GWe of electricity. These provided just fewer than 20% of the nation's total electric energy generation and more than 30% of worldwide nuclear generating capacity. Worldwide, nuclear energy provides about 13% of the electrical demand (Chu & Majumdar, 2012). Given that nuclear power has very low carbon emission (Arunachalam & Fleischer, 2008) and that energy generation currently accounts for 66% of worldwide greenhouse gas emissions (World Energy Outlook, 2008), nuclear energy is considered an important resource in managing atmospheric greenhouse gases and associated climate change (Chu & Majumdar, 2012).

The core of a nuclear reactor presents an exceptionally harsh environment for materials due to the combination of high temperature, high stresses, a chemically aggressive coolant and intense radiation fluxes. Many of the features that make reactors attractive from a physics perspective (*e.g.* high specific power, self-sustaining reaction) exert high operational burdens on structural materials.

2. Types of Nuclear Fission Reactors

The predominant reactor design worldwide is the pressurized water reactor (PWR), accounting for two-thirds of the installed capacity, followed by boiling water reactors (BWRs) at 21% and heavy-water reactors at 14% of installed capacity, respectively (Table 1) (World List of Nuclear…, 2012). All of these water-cooled reactors use ceramic fuel pellets consisting of UO_2 or other fissile actinide oxides to generate heat.

The ceramic pellets are stacked inside of long zirconium alloy tubes (fuel cladding) that transfer the nuclear heat to flowing water coolant and serve as the primary barrier containing the volatile radioactive fission byproducts. The remaining 5% of installed nuclear energy comes from gas-cooled reactors, graphite-moderated reactors and liquid metal cooled reactors (Table 1). The vast majority of the reactors listed in Table 1 are classier as Generation II reactors (Marcus, 2000), which were designed in the 1960s and predominantly achieved initial commercial operation from the 1970s through the 1990s. These reactors are distinguished from Generation I designs (1950s-60s), which were early commercial prototype and demonstration reactors, and Generation III reactors, designed in the 1990s to incorporate significant advances in safety and economics (Marcus, 2000). Generation III reactor construction for the past decade has been centered in Asia, with a few units recently built in Europe. The current generation of light-water reactors (LWRs), Generation III+, include still further advancement in economics and safety, such as passive heat removal systems. There are a total of 108 Generation III and Generation III+ reactors on order or under construction around the world, and of those, 89 are PWRs.

Table 1
Power Reactors by Type, Worldwide (World List of Nuclear…, 2012)

Reactor type	Units Net (in operation)	Mw_e net	Units Net (forthcoming)	Mw_e net	Units Net (total)	Mw_e net
Pressurized light-water reactors (PWR)	267	246,555.1	89	93,014	356	339,569.1
Boiling light-water reactors (BWR)	84	78,320.6	6	8,056	90	86,376.6
Gas-cooled reactors, all models	17	8,732.0	1	200	18	8,932.0
Heavy-water reactors, all models	51	25,610.0	8	5,112	59	30,722.0
Graphite-moderated	15	10,219.0	0	0	15	10,219.0
Liquid-metal-cooled reactors, all models	1	560.0	4	1,016	5	2,076.0
Totals i	435	369,996.7	108	107.896	543	477,894.7

Given the high representation of PWRs and BWRs in the world's fleet, materials issues in these two types of reactors are of greatest interest. And of the many materials in a reactor, those that experience the most extreme conditions (stress, corrosion and radiation) are most important for maintaining plant safety and reliability. Fig. 1 shows a schematic of the major components in the primary and secondary circuits of a PWR (Staehle). Pressurized water (15.5 MPa) in the primary circuit enters the reactor core at 275ºC, picks up heat from the reactor core with a core exit temperature of 325ºC, and transfers the heat across the U-tubes in the steam generator to water at a lower pressure. This water turns to steam that powers the turbine, and is condensed and recirculated.

Fig. 1 also lists the alloys used throughout the primary and secondary circuits, all of which are in contact with high-temperature water and are subject to significant mechanical stress. Alloys inside (and including) the reactor vessel are also subject to varying levels of radiation, which produces displacement damage and radiolysis decomposition of the coolant water.

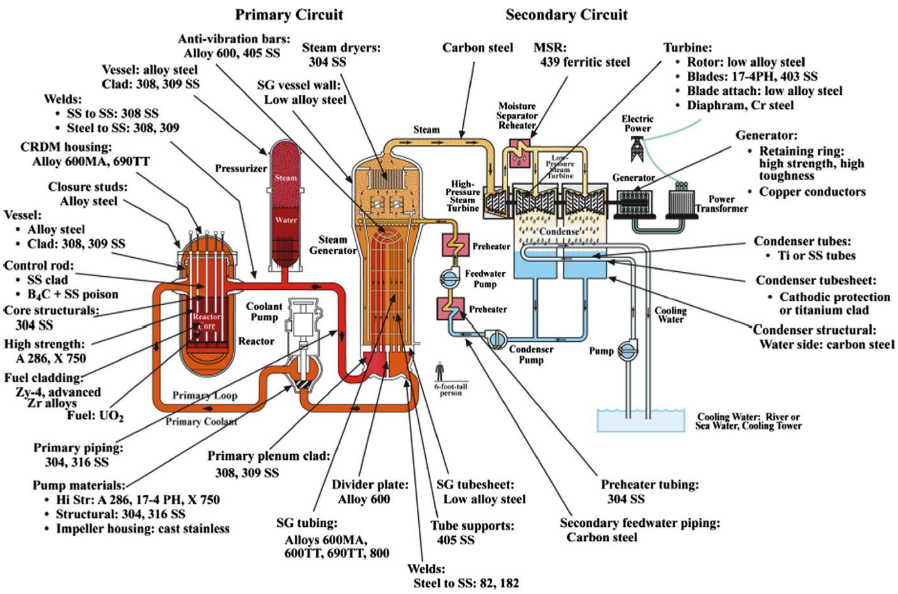

Fig. 1 – Schematic of the primary and secondary circuits of a pressurized water reactor and materials of construction (Staehle).

Major pressure boundary components (reactor pressure vessel, pressurizer, steam generator, steam lines, turbine and condenser) are made of either low carbon or low alloy steel. Austenitic stainless steels (Types 304, 304L, 316, 316L, 321, 347) dominate the core structural materials, as well as serving for cladding (308SS and 309SS) on the inside surface of the reactor pressure vessel and pressurize. Higher strength components such as springs and fasteners are made of nickel-base alloys. Vessel penetrations and steam generator tubes are made of nickel-base alloy 690 (previously alloy 600, which were found to provide insufficient resistance to stress corrosion cracking). Condenser tubes are generally made of titanium or stainless steel. The selection of nickel-base alloys and austenitic stainless steels for core internals and the steam generator tubes is driven by the need for good aqueous corrosion resistance at high temperatures. These alloys have low corrosion rates due to the formation of Cr – bearing spinels that form adherent, high-density protective surface layers that grow very slowly at operating temperatures.

3. Materials Challenges in Future Fission Reactor Concepts

Construction is currently in progress worldwide on several so-called Generation III and Generation III+ LWR power plants that are designed for improved efficiency, passive safety and economics. To a large extent, these reactors represent an evolutionary design change utilizing materials systems that are similar to current (Generation II) LWRs, and therefore the materials challenges facing the new reactors will be comparable to those faced in existing reactors. Another class of light-water-cooled reactors under consideration would utilize in factory construction techniques and new designs with high emphasis on passive safety to construct small (50…300 MWe) nuclear power plants; some of the materials challenges with these small modular reactors (SMRs) are discussed in the following section. Finally, a brief discussion on the materials challenges for Generation IV reactor concepts will be provided. Over the past 10 years, the United States Department of Energy and the Generation IV International Forum have explored six particularly appealing advanced reactor concepts as potential next-generation (Generation IV) nuclear power systems (Nuclear Power Reactors …, 2012; Garner *et* al., 2000).

These concepts were selected from hundreds of ideas submitted to the US DOE by scientists and engineers worldwide, during a broad canvassing operation as part of the first phase of the collaborative Generation IV program in 2002 (Was, 2007). The objective was to identify concepts that had one or more of the following attributes: increased efficiency, generation of process heat to drive chemical processes such as the production of hydrogen, increased safety and reduction in waste generation. The concepts finally selected were the supercritical- water-cooled reactor (SCWR), the sodium fast reactor (SFR), the lead fast reactor (LFR), the very-high temperature reactor (VHTR), the gas fast reactor (GFR) and the molten salt reactor (MSR) (Zinkle, 2005). To allow operation at much higher temperatures, advanced Generation IV reactor concepts utilize different coolants, including water in the supercritical state, liquid metals such as Na and Pb–Bi, molten salts and high-pressure He gas.

The materials challenges for the Generation IV reactor concepts come about because of the very high fuel temperatures, the intense radiation flux and coolant compatibility issues. Thus, the fuel, the cladding, the structural materials, the reactor vessel and the interaction of these materials with the coolants present the greatest challenges to new, more robust nuclear reactor concepts for the XXI century. Structural materials used in the cores of advanced reactors will face unprecedented combinations of temperature, radiation dose and stress (Schilling & Ullmaier, 1994; Zinkle, 2012; Danko, 1987; Feron & Olive , 2007).

As shown in Fig. 2 a common feature of all advanced designs is a high operating temperature com- pared to current LWRs. Another unique feature is the simultaneous presence of intense knock-on displacement damage by the fission neutrons. Almost all of the Generation IV concepts call for radiation damage levels that exceed those of LWR experience (Kilian & Roth, 2002; LeCalvar & DeCurieres, 2012; Was & Andresen, 2012).

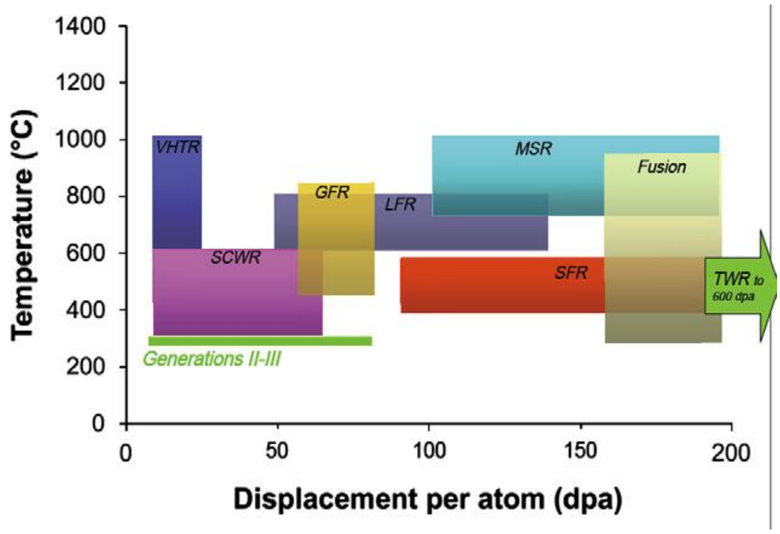

Fig. 2 – Temperature and requirements for in-core structural metallic materials for the operation of the six proposed Generation IV advanced reactor concepts, the traveling wave reactor and fusion reactor concepts; the dimensions of the colored rectangles represent the ranges of temperature and displacement damage for each reactor concept (Zinkle, 2005).

4. Conclusion

The continued utilization of nuclear energy systems for worldwide base-load electricity offers a number of materials research challenges. The high reliability of current light-water fission reactors (*e.g*. 90% average capacity factor by US reactors for the past decade) demonstrates the high reliability of this energy source under normal operating conditions. Planned extensions in the operating lifetime for reactors are being supported by accompanying materials to investigate corrosion and neutron-induced materials degradation phenomena.

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MATERIALE METALICE PE BAZĂ DE FIER PENTRU CENTRALE NUCLEARE

(Rezumat)

Se analizează utilizarea aliajelor metalice pe bază de fier pentru construire centralelor nucleare. După o scurtă descriere a principalelor tipuri de reactoare, la nivel mondial, sunt prezentate cele mai importante elemente metalice folosite pentru circuitele primar şi secundar ale unui central nucleare. Apa sub presiune (15.5 MPa) din circuitul primar ajunge în central reactorului la 275ºC preia căldură din central reactorului cu o temperatură de eliminare de 325ºC şi transport căldura de-a lungul tuburilor de formă U în generatoarele de aburi la o presiune mai joasă. Această apă este transformată în aburii care alimentează turbina şi este condensată şi apoi recirculată. Pentru a propune materiale noi în acest domeniu cu aplicații speciale am stabilit câteva cerințe necesare a acestora pentru aplicațiile în cadrul conceptelor de viitor a reactoarelor de fiziune.

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COMBINED TREATMENT OF HARDENING OF METAL PARTS

BY

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Abstract: Technological process presents a degree of novelty and complexity that consists in produce the pieces in three successive phases. In the first phase the micro-alloying of the superficial layers of the auto-vehicles parts is achieved directly in the liquid phase. In the second phase the final hardening heat processing is achieved by induction, two physical-chemical phenomenon taking place simultaneously: martensitic hardening and formation of the hard chemical compounds in the superficial layer. In the third phase the final heat treatment is achieved in several variants depending on the chemical composition of the base material, the composition of the superficial layers and the conditions of stress and service of the vehicles parts. The processing is carried out both in liquid phase and solid phase.

Keywords: hardening; superficial layers; combined processing.

1. Introduction

The process has as objective the achievement of the hard superficial layers at the surface of the vehicles parts and component parts with a view to

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increasing the performances and the reliability of these ones using a new technology (Corăbieru & Corăbieru, 2012a, 2013). Having a strong physical-chemical stability and high mechanical resistance to shocks, the micro-alloyed and hardened superficial layers represent the optimum solution that permits the increase of the durability of the component parts for auto-vehicles (Bey & McAloone, 2006; Edquist, 2005).

Technological process aimed at solving the following problems:

1º Stabilization of the physical-mechanical properties during the first 24 hours of service by diminishing of the hot oxidation phenomenon in the transition area of the superficial layer. This phenomenon influences directly the decrease of the induction of micro-oscillations of level and exfoliations. Diminishing of the oxidation phenomenon is due to the fact that the micro-alloying is achieved directly in the liquid phase and not in the solid phase, concomitantly with the hardening heat treatment.

2º Diminishing of the local accumulation and extending along the transition area of the stresses due to the important difference between the thermo-mechanical properties of the part core and the properties of the superficial layers (Corăbieru & Corăbieru, 2004; Corăbieru *et al.*, 2009).

2. The Principle of Technological Process

Principle consists in obtaining superficial hardened layers of the vehicles parts by the implementation of the proposed technology having the following main phases:

a) Phase 1 – superficial micro-alloying directly in the liquid phase, achieved by the interaction of the liquid steel with the layers deposited on the mould walls. The successive layers deposited on the mould walls have been obtained using a paste having as base the hardening mixture with the composition of 40% metallic powders and 60% carburizing powders (Corăbieru *et al*., 2005).

b) Phase 2 – hardening thermal processing id made in an induction heating installation using treatment cycle-diagrams previously established depending on the base material of the vehicle part and on the composition and structure of the superficial layers obtained following the superficial micro-alloying directly in the liquid.

c) Phase 3 – final heat treatment, using a variant depending on the chemical composition of the base material (vehicle part core), composition and structure of the superficial layers and the real stress and service conditions of the vehicle part.

The technological process consists in the utilization of a hardening granular mixture that in interaction with the liquid steel leads to the forming of superficial layers micro-alloyed with Chrome, Nickel and Vanadium. Quenching by high frequency currents performs the hardening of the superficial layers. The final heat treatment achieves the stress relieving and finishing of the superficial layers structure.

3. The Technological Flow

The main stages of the process flow are (Velicu *et al*., 2009):

a) Preparing the casting mould.

b) Preparing and deposition of the hardening mixture (40% metallic powders + 60% carburizing powders).

Table 1
Chemical Content of the Micro-Alloyage Paste PM

Symbol of micro-alloyed paste	Composition of microalloyed paste, [%]								
	Metal powders 40%			Carburizing powders 60%					
	Ni %	Cr %	V %	Charcoal %	$BaCO_3$ %	Cocs %	$CaCO_3$ %	Na_2CO_3 %	Binder %
PM	14	14	12	35	5	15	2	2	1

c) Micro-alloying directly in liquid phase:

c_1) elaboration of base material (C < 0.3%; S < 0.02% < Si = max.1% < < Mn = max. 0.45%);

c_2) casting of base material ($T_{casting}$ = 1,550...1,600°C).

d) Preliminary machining.

e) Control of the superficial layer (structure, thickness, compactness, adherence).

f) Preparation of the hardening mix AD.

Table 2
Chemical Content of the Hardening Mix AD

Symbol of hardening mixture	Composition of the hardening mix, [%]									
	Metal powders 35%				Elements of carburizing 65%					
	Ni %	Cr %	V %	Mo %	Charcoal %	$BaCO_3$ %	Cocs %	$CaCO_3$ %	Na_2CO_3 %	Binder %
AD	10	10	10	5	30	5	20	4	4	2

g) Deposit of the hardening mix on the surface of the part.

h) Hardening by induction:

h_1) technological parameters: T = 950...1,050°C; $t_{heating}$ = 1...5 s; maintainning time = 1...5 min;

h_2) technical characteristics: part diameter: 25...35 mm; optimum frequency, $f_{optimum}$ = 10 kHz; specific power at the parts surface: Psp = 1 kW/cm^2; generator of useful power: 20 kW; current intensity: 700 A; voltage: 20,...,30V.

i) Final heat treatment – Tempering:

i_1) variant A – direct hardening CD + low tempering RJ (it is applied to the vehicle parts of reduced importance that have to present especially high values of the superficial hardness);

i_2) variant B – accentuated cooling + layer simple hardening CS + low tempering RJ (it is applied in the case of the vehicle parts that have deformations, renouncing at the direct hardening. The parts are accelerated cooled in ventilated air and re-heated at 800°C,...,840°C, in order to achieve the layer simple hardening);

i_3) variant C – accentuated cooling + intermediary sub-critical annealing RcI + layer simple hardening CS + low tempering RJ (it is applied in the case of

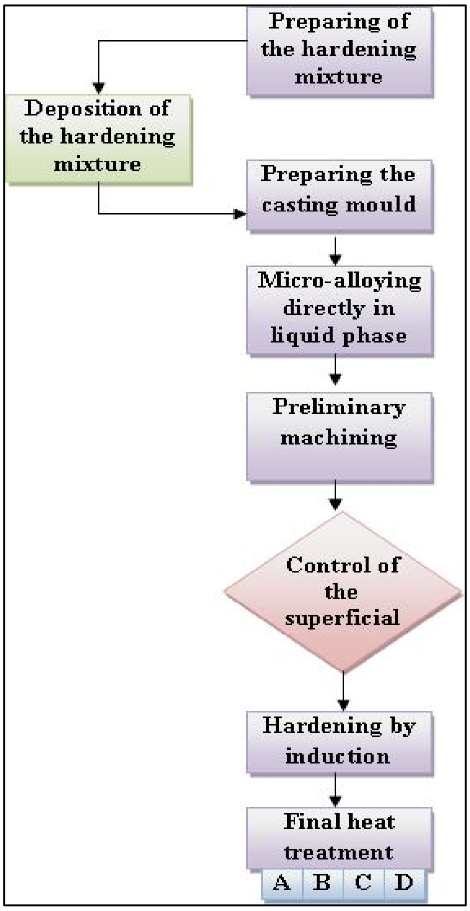

Fig. 1 – The technological flow.

the vehicle parts that need machining by cutting after treatment. Between carburizing and layer simple hardening a sub-critical intermediary annealing is introduced, at 630°C,...,680°C);

i_4) variant D – double hardening with intermediary annealing (it is applied to the vehicles parts manufactured of medium alloyed steels superficially hardened for the improvement of the superficial layer performances).

Control of the layer – characteristics (Corăbieru & Corăbieru, 2012b):

- average of the hardness of the superficial layer: 55,...,60 HRC;
- minimum fragility of the superficial layer: does not present cracks in the proximity of a trace obtained by pressing a pyramidal diamond tip with a force of 100 daN;
- thickness of the superficial layers: min. 50 μm;
- metallographic structure of the layer: preponderantly martensitic + complex carbides;
- fine granulation in the superficial layer; reduced number of inclusions in the superficial layer: p = max. 2;
- specific adherence of the superficial layer: q > 170 N/mm^2 (Corăbieru *et al.,* 2008).

4. The Main Economic Aspects

4.1. Economic Effects at the Manufacturer Economic

1º Reduction of the cost price by 5%...10%.
2º Quality comparable with that of the concurrence.
3º Consolidation of the economic agent by creation of new work places.
4º Increase of the work productivity by 8%.

4.2. Economic Effects at the Beneficiaries Users of the Products

1º Increase of the service time by 20%.
2º Reduction of the service expenses by 5%.
3º Reduction of the maintenance costs by 5%.

5. Conclusions

The technology is distinguished by the technological procedure (micro-alloying directly from the liquid phase+ induction hardening + final heat treatment) and by the composition of the hardening mixture.

Micro-alloying is achieved directly from the liquid phase, by the interaction of the liquid steel with the hardening mixture deposited on the casting mould walls.

Micro-alloying is achieved concomitantly with the process of solidification of the base material.

As casting method the spin casting method is preferred for the high degree of compactness of the superficial micro-alloyed layer.

The average of the hardness of the superficial layer of 55,...,60 HRC as well as the metallographic structure preponderantly martensitic with complex carbides are comparable to the values obtained by the technologies used worldwide.

The fact that the technology implementation does not need important investments imposes the proposed technological solution as a viable and economic variant. The processing is carried out both in liquid phase and solid phase.

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PRELUCRĂRI COMBINATE DE DURIFICARE A PIESELOR METALICE

(Rezumat)

Procedeul tehnologic prezintă un grad de noutate şi complexitate care constă în realizarea pieselor in trei faze succesive. În prima fază se realizează microalierea direct din fază lichidă a straturilor superficiale ale pieselor auto. În faza a doua se realizează prelucrarea termică finală de durificare prin inducție având loc simultan două fenomene fizico-chimice: călirea martensitică şi formarea compuşilor chimici duri în stratul superficial. În faza a treia se realizează tratamentul termic final în mai multe variante în funcție de compoziția chimică a materialului de bază, compoziția straturilor superficiale şi condițiile de solicitare şi exploatare ale pieselor auto. Procesul de prelucrare este efectuat atât în fază lichidă cât şi în fază solidă.

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APPROACH OF INDUSTRIAL COMPETITIVENESS PROBLEMS

BY

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Abstract: The present paper is treating some aspects regarding the innovating process and is analyzing the competitivity of machines' metallurgical and constructive industry of Romania from the angle of price-quality relation. There is pointed out the connection determined between creativeness, innovation and competitivity. Retracing the lines of an industrial firm in the context of a durable development there are pointed out the elements of diagnosis analysis regarding the competitivity. The paper is identifying the causes and the measures that must be taken for the growth of the Romanian products' competitivity of the metallurgical and constructive machines' industry. Increasing competitiveness is the key driver of export growth. Joining the eurozone impose increased competitiveness.

Keywords: increasing competitiveness; industry; eurozone.

1. Innovative Process

The innovation and the creativeness were defined by scientists in a different way oscillating between considering the two terms as synonyms or as fundamentally different terms.

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The definitions formulated by specialists evolved as follows:

- Innovation = the process by which new results are obtained concretized in products, services and organizational structures;
- Innovation = the transformation of creative criterions into useful applications;
- Innovation = the planned and orientated modernization of the existing systems towards the reaching of improved results by the utilization of new ideas and technologies;
- Innovation = the process which includes all stages of modernization from idea into its putting into application.

The experts have a general valid point too regarding the fact that no matter how brilliant and progressive the ideas would be, these don't add a value only if they are converted into applications with practical usefulness, respectively products, services or processes.

The evolution of the society on the whole led to the changing of the innovation's significance too: from the meaning of a new result, respectively a product, an equipment, a process at which it is considered an integrant process of solving the business, technical, cultural and organizational complex problems.

The two approaches of the innovation process are different and their evolution is favourable to the new approach (Table 1) (Ioniță, 2005; Kimura, 2000) .

Table1

Specific Approaches to the Innovating Process

Former approach	New approach
Innovation → result material (research –concept-prototype-product)	Innovation → all the specific aspects of the process of the creative solving of business, technical, cultural complex problems, processes, substructure
Innovation-research	Innovation – Social dialogue with a view to the creation of relation's networks between the involved parts.

The creativeness being the start point of the innovation, there is a big gravity of the creativeness involved into innovation in accordance with the diagram presented in Fig. 1.

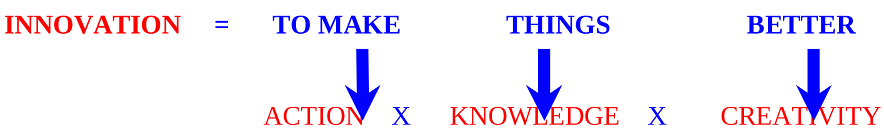

Fig. 1 – Innovation scheme.

2. The Connection Between Creativeness, Innovation and Competitivity

Between creativeness, innovation and competitivity there is a determined connection. The creativeness is a necessary condition for the appearance of innovation representing the start point of the innovation (figure 2).

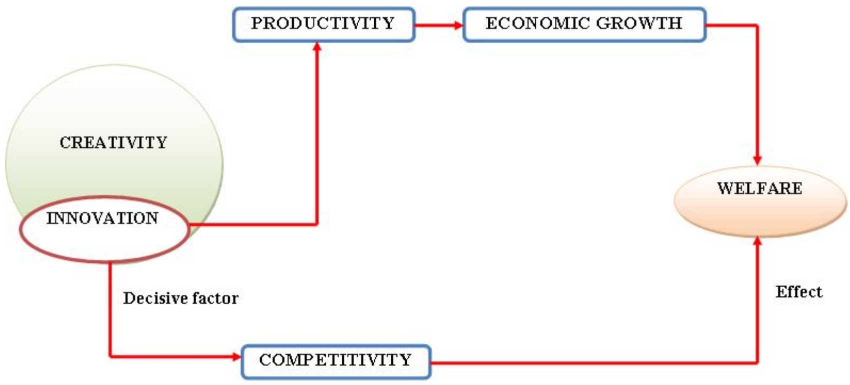

Fig. 2 – The link between creativity - innovation – competitivity.

The innovation is a determining element of the competitivity influencing the productiveness which determines the economical growth. The positive effect of the economical growth is manifesting itself by the significant contribution to the increase of the prosperity which is exactly an effect of a high competitivity (Corăbieru A., Corăbieru, 2012a; Corăbieru *et al.*, 2010).

3. Product Design for Sustainable Development

At international level, considering normally the list of the most important enterprises and corporations, it is had in view to harmonize the points of view of the producer and user regarding the products life cycle (Corăbieru & Corăbieru, 2012a, 2012b; Corăbieru *et al.*, 2010a; Corăbieru *et al.*, 2012; Corăbieru & Corăbieru, 2013). The research of the Fraunhofer Institute identifies the product development as the main paradigm for the next ten years. Three main directions in what concerns the product development have been identified: increase of competitive solutions number, shorting/hurrying the iterative ringlets and self-control organization. From an organizational point of view, a change without precedent is proposed for the organizational structures: passage from a stiffly controlled, hierarchical structure to a self-adjustable and self-governable net structure.

In Germany, by The Digital Auto Project program, the diminishing with 50% of the product development time is proposed. The project is based on three working principles: increase of the simultaneity of the designing charges;

elimination of certain designing charges, as the physical prototype; more rapid completion of the remaining project (Corăbieru & Corăbieru, 2012a, 2013).

In the USA, at the basis of the product development stands the idea that only by the way of choice shortening the designing, building and manufacture processes can be fundamentally changed. Simultaneity designing/study leaded to the reduction of the personnel with 25% and implicitly, to the costs diminution (Corăbieru & Corăbieru, 2012a, 2013).

In France, the accent is put on the methods that lead to the best solutions of materials for the new products, so that a recycling ratio of 95% could be provided, by choosing plastic materials. At the whole world level, the tendency is to utilize the multidiscipline design optimizing, a design technique of the complex systems and of sub-systems exploiting the synergy of mutual interaction of the phenomenon. The methodology offers the possibility of answering the questions: how to decide what to change? What change is amplified when the system is interactive (each of them influences each of them)?

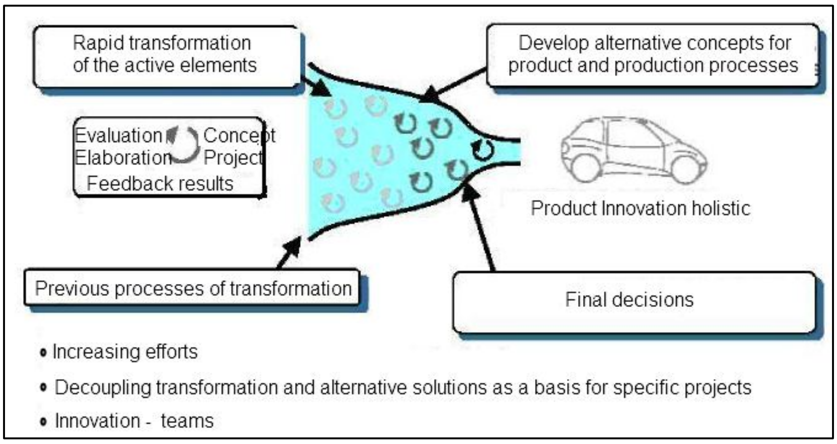

Fig. 3 – Development of iterative development worldwide.

All these are possible due to the possibility of achievement of a very big number of iterations in a very short time, many solutions succeeding to be studied at a relatively low cost, by the implication in the evaluation of all the points of view of the relevant performance attributes.

4. Resizing Industrial Company

In the informational society based on knowledge, the ebb and flow of knowledge transcends the traditional borders of a firm, including the sources of knowledge of the economical-tehnological environment and the socialacademical one, as well as alliances, contractors, distributors, clients and even market competitors (Corăbieru *et al.*, 2010b).

Considering the dynamics of the innovative process, the opportunity appears really when an organization is able to interface itself with the aggregate of the external relations which it can have. The real value is obtained by the fusion of knowledge, which can be effectuated beyond the borders of the organization. The informational technologies and of modern communication allow the creation of a collaborator initiative which includes the whole enterprise, including partners, contractors and clients. The creation of ideas and the storing of knowledge must be found again in innovating products on the market.

The architecture of the firm's systems of management evolved towards an innovating architecture expressed by five interconnected dimensions of an organization: the economic performance, structure, the human resource, the processes and the technology. This multi-disciplinary approach is a mean of integrating the aspects of an economical, technological and environmental nature, within a firm (Lebas, 1995; McAdam & McClelland, 2002).

The transition from data and information focusing on knowledge imposed an innovation in architecture of management, thought as being transnational in objectives, offering the opportunity of the optimizing, the rationalizing and the utilization of the financial, humanistic and technical resources. First of all, there is considered the problem of an economy of knowledge, in the sense of measuring the intangible value of a firm and of estimating the effect of raising the commercial barriers to a total level, with the opening of certain special facilities in the development of big corporations.

Secondly there is considered the problem of passing from the concepts regarding the achievement of strategic business unities, as a possibility of segmenting the business, to manage and to follow the performances, to a perspective of creation of a strategic network in business, as an innovating approach of a dynamic system, in which its elements, the participants in the system, are contributors and beneficiaries at the same time.

5. Approach and Evaluation Problems in the Context of Sustainable Development

The creative problems settlement, including health and safety, can be approached as an adapted, systemic and structured model of contradictions settlement, built on formal-abstract bases and which permits the transcription of the specific problem in a general context, while its instruments offers the possibility of finding and implementation of a general solution, at its turn transposable to the specific problem (Corăbieru & Corăbieru, 2012a, 2013).

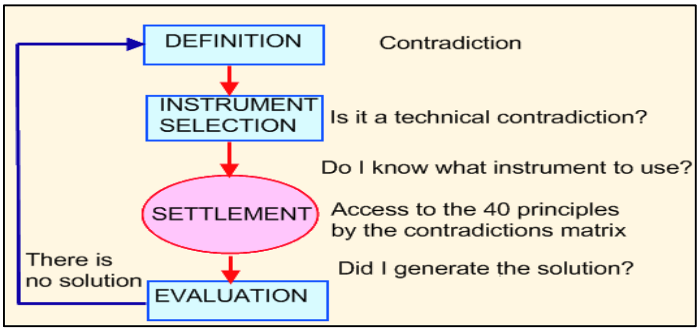

Fig. 4 – Steps of problems systematic settlement.

The most utilized general instrument for the systematic settlement of technical and health and safety, problems is represented by the contradictions matrix. This matrix, by construction, orientates the user toward the most utilized innovation principles for each identified contradiction.

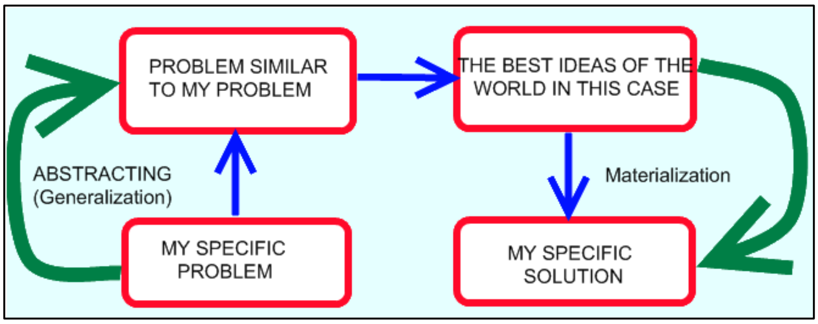

Fig. 5 – Method of problems settlement.

In the context of the awareness regarding the permanent necessity of innovating and intensifying the efforts in the sense of creating new products, the approach of evaluating the problems of occupational safety and health is included in the European method of approaching the innovation as a complex and integrating process of solving the problems.

6. The Competitivity of the Industry of Romania Analyzed from the Angle of Price-Quality Relation

Any economical agent – producer, importer, distributor or provider – wishes to sell as many products and services as possible and to gain as much as possible. The economical agent can achieve this thing when the product or the service is competitive, meaning that when this one has the capacity of imposing itself on a competitive market, it is sold in quantities at least comparable with those in which the competitive products and services were sold. An analysis of competitivity which becomes useful for the taking of strategic decisions, requires a tridimensional diagnosis, which takes into consideration the economical environment as well as the actors of the competition. The three dimensions of this one are (Corăbieru *et al.*, 2008, 2009):

a) the situation of industry or of the industrial branch;

b) the situation of competition in the respective branch;

c) the analysis of the competitional forces and of the key competitors of the industrial analyses firm.

Regarding the situation of the industrial branches, their analysis is taking into consideration the following elements (Dinu *et al*. 2001; Ioniță, 2005):

a) the structure of the industrial branch;

b) the moving forces of the changing in the industrial branch which determines the direction and the dimensions of the changing is;

c) the economical elements and the characteristics of the business environment which lead to success;

d) the strategic problems of the industrial branch;

e) the prognosis of evolution of the industrial branch in the perspective of aggregation.

The detailed analysis of the competition's situation in an industrial branch has in view:

a) the competitive forces and their intensity ;

b) the competitive positions of the main competitors;

c) the possible actions of the main competitors.

The situation of the industrial analyses firms refers to:

i) the valuation of the satisfaction degree for the actual strategy of the firm in relation with the actual situation of the branch and with the perspectives of the competitional environment;

ii) the valuation of the internal force and of external position of the firm by a swot analysis – the establishment of the competitive relative position.

From analysis of the practical reality of the Romania industry there were pointed out much more situations which show that the services and the fabricated products aren't in general competitive, the main causes being (Dinu *et al*. 2001; Ioniță, 2005):

a) the low quality of the products;

b) the price which isn't a stimulating one;

c) the uncertain or the too long term of effectuation;

d) the ineffectual managerial system;

e) the lack of professionalism;

f) the lack of autonomy of the big industrial unities;

g) the lack of support or of an ineffectual support from the government;

h) the fear of social reactions and the taking of the responsibility.

The causes of the marked falling-off of the machines' metallurgical and constructive industry are the following:

1º the maintenance in this domain of a week competitivity of the effectuated products and even of the continuous decrease of the value of this indicator;

2º the shy and ineffectual preoccupations of straighten out partially this industrial field didn't orientated it selves in the direction for the raising of the competitional level;

3º there was erroneously stated that the main problem of this branch is the increase of request of this type of products on internal and external market;

4º the reality is a totally different one meaning that at a total level the request was an ascending one and it is continuously growing;

5º if before 1989, the maintenance on certain markets of the products of the machines' metallurgical and constructive industry was accomplished by protectionist techniques supported by the politic regime, at the same time with the collapse of this system, the mechanism didn't work anymore;

6º the firms which assimilated and applied the new rules of the economy on the market survived;

7º difference between those who sell their products and those who produce them just to be produced is given by competitivity, more exactly by the price/quality relation.

The analysis of the price/quality relation, respectively of the competitivity of the machines' metallurgical and constructive branch points out the following aspects:

i) the costs of the products' obtaining were and were maintained high due to the prices of utilities as well as to the ineffectiveness of the primary sector (Corăbieru & Corăbieru, 2012b; Corăbieru *et al.*, 2012);

ii) the costs were influenced by the effects of a social politics which transferred a series of social costs into costs at the level of the products;

iii) the level of high fiscality influenced the costs and implicitly the prices;

iv) the debts and the penalties of the machines' metallurgical and constructive firms accumulated towards the state budget made impossible their launching once again;

v) the after-privatisation sparings granted to different governments created, by the taking over of the sums to the public duty, big social problems, finally contributing to the population's impoverishment.

7. Elements of Diagnosis Analysis

The diagnosis analysis points out the following elements:

– if a part of the spent sums at the level of some firms in order to stop some social tensions (compensatories salaries, production on stock) had been invested for the re-technology and for the growth of the qualitative level of products and services, the benefits wouldn't hesitate to appear. In some industrial sectors it would have been registered a real growth of the competitive production with certain detachment and whose results were becoming sources of re-launching for other sectors;

– the bank systems, representing another source of financing of qualitative growth of products and services, didn't find viable solutions of solving these problems because of the structural vices and of the lack of trust in the economical climate;

– regarding the quality of products and services, its growth was tried to be done in some domains, but there was taken into view an alignment of this to the mondial level of the'80 years or an improvement of the technical performances by isolated measures;

– the lack of a legislative and organizatorical frame, of a support at a macroeconomical level, of a correlation of measure which regards the quality with fiscality, or of other nature made the efficiency of steps for an improvement of quality to be limited, and the competitivitaty of products and services to remain in continuation a low one;

– the fundamental and applicative request were reduced, and in some domains it was totally gone, although the level of the specialists' training involved in this activity and the obtained results were allowing a continuation of this activity with very good results;

– the import of technology was situated at low levels, the buying of sub-aggregates and its integration in the already existing products;

– the omission of the key domains in the application of the scientific research of the results and in its ulterior generalization in other economical branches too (the defence industry) as well as in the implementation of some important systems in the qualitie's control domain;

– the lack of coherent programmes for the quality insurance at the level of commercial societies and especially, at a macro level the efficiency of some efforts to improve the competitivity of the Romanian products to remain a low one.

8. Perspectives and Conclusions

In the last years appeared a preoccupation with the meaning of a quality's total approach. Thus, the majority of the Romania firms resort to the implementation of some quality systems and of the ISO certification. However, there's necessary the support of these efforts by programmers at a national level, initiated and run by the Government, but who have into account the stage of development and the specific features of the Romanian industry. A large majority of the commercial societies were certified by ISO 9000, but the generating procedures, of maintenance and control of the quality exist only on paper, without being also applied in the spirit in which they were created.

Up to the end of the year 2008 the export intensity of the Romania industry as well as the total capacity of the export has continuously increased. In spite of the phenomenons of economical recession, the export increased in relative terms as well as in its capacity, fact that indicates the following:

a) the growth of competitivity and of the power of reaching the external markets of the Romanian industrial products;

b) the relative growth of resources;

c) the diminution of the phenomenon of producing on stock.

Together with the EU partners' going out of the crisis, the foreign investments in the domain will be stimulated, fact that will lead to the reaffirming of industry's statute as a locomotive of the Romanian economy.

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MOD DE ABORDARE A PROBLEMELOR DE COMPETITIVITATE INDUSTRIALĂ

(Rezumat)

Se tratează aspecte privind procesul inovativ şi analizează competitivitatea industriei metalurgice şi constructoare de maşini din România prin prisma raportului preț – calitate. Este evidențiată legătura determinată între creativitate, inovare şi competitivitate. Retrasând liniile unei firme industriale în contextul dezvoltării durabile sunt punctate elementele analizei diagnostic privind competitivitatea. Se identifică cauzele şi măsurile ce trebuie luate pentru creşterea competitivității produselor româneşti din industria metalurgică şi constructoare de maşini. Creşterea competitivității reprezintă factorul cheie al creşterii exporturilor. Aderarea la zona euro impune obligativitatea creşterii competitivității.

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DETERMINATION OF HYDRODYNAMIC FORCE AND IMPROVEMENT OF THE DESIGN OF DIRECTIONAL CONTROL VALVE FOR THE MECHATRONIC DRIVE BASED ON COMPUTER SIMULATION OF HYDRODYNAMIC PROCESSES

BY

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Abstract: A circuit and 3-D model of the hydraulic distributor for the manipulator mechatronic drive is considered. The dependence of the change of hydrodynamic force value on the magnitudes of pressure and spools opening of the pressure relief valve and brake valve of the hydraulic distributor is determined in 3-D model of the hydraulic distributor on the base of approximation of the results of computer simulation of hydrodynamic processes, performed in CAD/CAE system. On the base of the obtained dependences the possibility of hydrodynamic force value decrease as a result of the change of working edge construction of the pressure relief valve spool is determined.

Keywords: manipulator; mechatronic drive; hydraulic distributor; pressure relief valve; brake valve; mathematic model; hydrodynamic process; hydrodynamic force.

1. Introduction

Manipulators, providing the realization of processing operations by means of reproduction of operator’s movements, have been widely used in

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various branches of industry and national economy. Mechatronic systems are applied for the improvement of manipulators control efficiency. Such systems include actuators and mechatronic drives with control system, based on controllers. Synergetics combination of mechanical drives, electronic systems and programming control facilities enables to improve considerably the performance, indices of economic efficiency and operating longevity of manipulators (Christensen, 2000; Harms Hans-Heinrich, 2009; Козлов, 2012; Kozlov, 2013).

Development of mechatronic drive of the manipulator comprises the process of design or improvement of hydraulic components of the drive. The necessity arises to determine the constructive parameters, providing the simplicity of realization, efficient operation and other characteristics of the components. These problems can be solved applying modern CAD/CAE systems, enabling to perform computer simulation of various production processes in 3-D models of the investigated objects.

2. Problem Set-Up

Efficiency of manipulator operation depends or the accuracy of its actuators location above the object, the possibility of proportional control of its components speed etc. Manipulators in such machines perform spatial motion along complex trajectories, which, as a rule, are the combination of several motions, provided by manipulator elements and mechatronic drives. Fig 1 shows the diagram of mechatronic drive, that controls the operation of the manipulator.

The diagram includes constant-delivery pump 1 with servovalve 3 and pressure relief valve 27, variable pump 2 with regulator 4, connected with sectional distributor 5 with spools 6, 7 and relay spools 9,10 equipped with electromagnetic control.

Hydrocylinders of the manipulator are connected to hydrodistributor 5. Hydraulic system comprises controller 12, that receives signals from pressure sensors 13, 14, position sensors 16, 17 and controls relay distributors 9, 10 by means of amplifier 26, servovalve 3 and regulator 4 by means of amplifiers 24, 25. Each section of hydrodistributor 5 includes brake valves 19, 20 correspondingly. The system of mechatronic drives provides simultaneous operation of any two hydraulic cylinders of the manipulator, installed by the operator. Adaptive regulator 12 provides efficient change of pumps commutation with hydraulic cylinders, connected for operation (unit 29), and also formation of feedback signals U_{m1} and U_{m2} (units 8, 11, 30) that enable to control pumps 1 and 2 depending on the change of manipulator operation modes. Adaptive regulator12 is built on the base of neural networks 18, 21 and mathematic units 15, 22, 23, 27, 28, which provide the change of regulator setting in the process of manipulator operation modes change. Application of neural networks 17 and 21gives the possibility to teach the adaptive regulator on data bases, created as a result of the study of operation processes in the system of mechatronic drives in static and dynamic operation modes. Neural network 18 provides the realization of correcting component of adaptive regulator, availability of which decreases the oscillations of mechatronic drive in transient processes (Christensen, 2000).

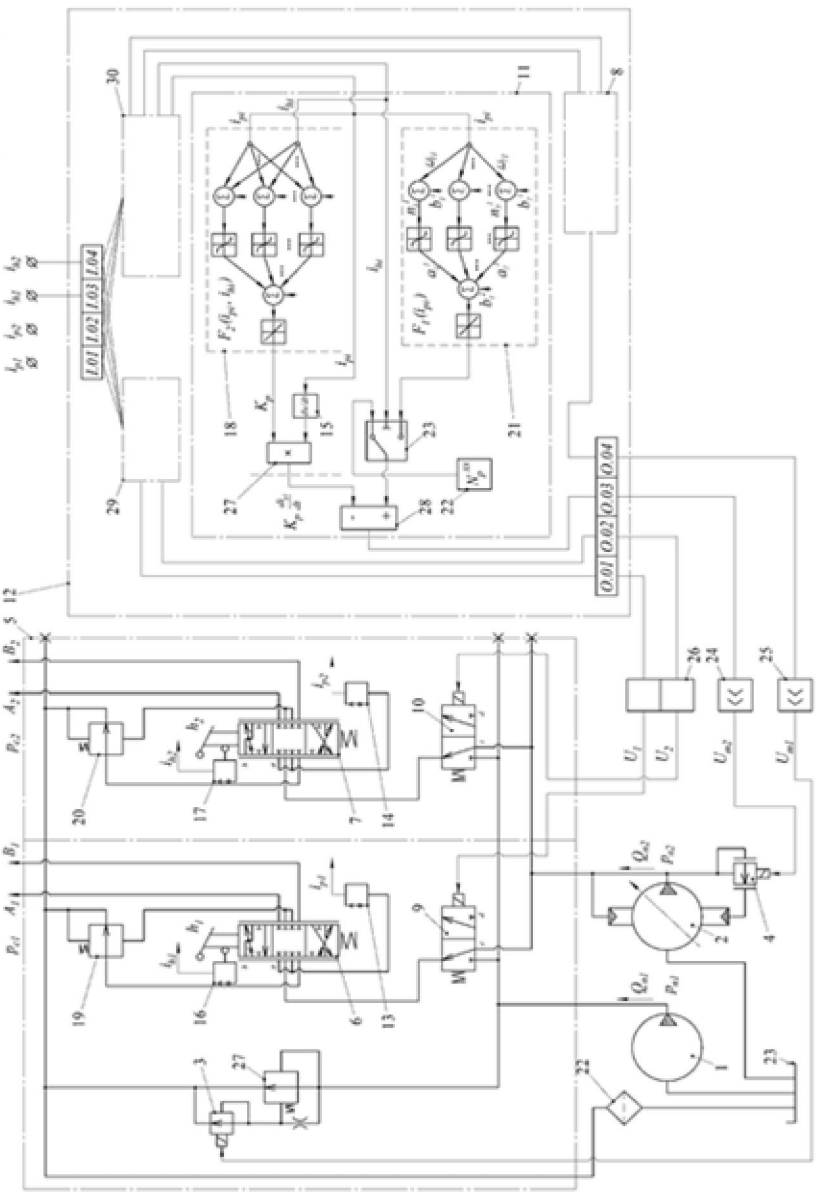


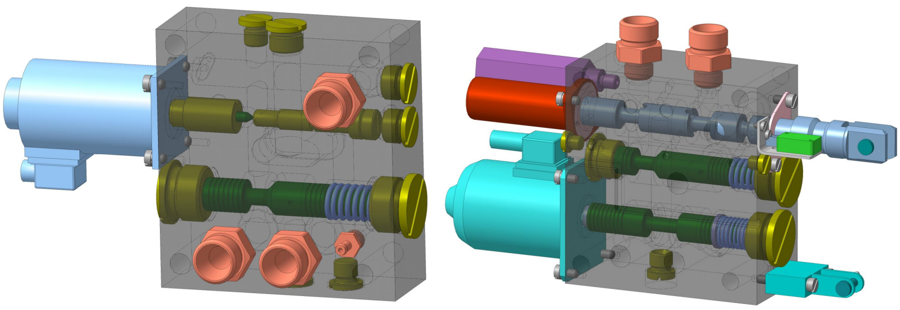
Fig. 1 – Mechatronic drive diagram.

The problems, dealing with the development of optimal construction of manipulators and efficient algorithms of their control, are solved on the basis of mathematic models, describing spatial motion of manipulators. To provide the adequacy of the model of manipulator spatial motion, it is necessary to obtain the dependences of mechatronic drive characteristics on its operation modes. One of such characteristics is the dependence of the value of hydrodynamic force $R_{g,}$ that is generated at the spools of brake and pressure relief valves of the hydraulic distributor, on the pressure value in mechatronic drive and the value of spools opening. The value of hydrodynamic force R_g depends on the peculiarities of valves construction, that is why, its determination requires special studies.

3. Problem Solution

In order to determine the dependence of hydrodynamic force R_g, that emerges at the spools of brake and pressure relief valves of hydraulic distributor, on the parameters of mechatronic drive operation, the computer simulation of hydrodynamic process of fluid flow in brake valve of mechatronic drive was carried out.

Simulation was performed, applying Flow Simulation module of the software package SolidWorks. 3-D models of the pressure relief valve and operation sections of hydrodistributor (Fig. 2) are created. In the relief section a pressure relief valve is studied, and in the operation section – brake valve is studied.



a *b*

Fig. 2 – 3-D models of (*a*) pressure relief valve and (*b*) operation sections of hydraulic control valve

By means of Flow Simulation module computer simulation of hydrodynamic processes is carried out in 3-D model of the brake valve.

Fig. 3 shows the working port of the module and the result of simulation of working fluid flow process under the pressure across the spool of brake valve.

In the process of simulation the initial conditions were set – values of pressure pc2 at the inlet and pressure pT2 at the output of brake valve, as well as spool opening y.

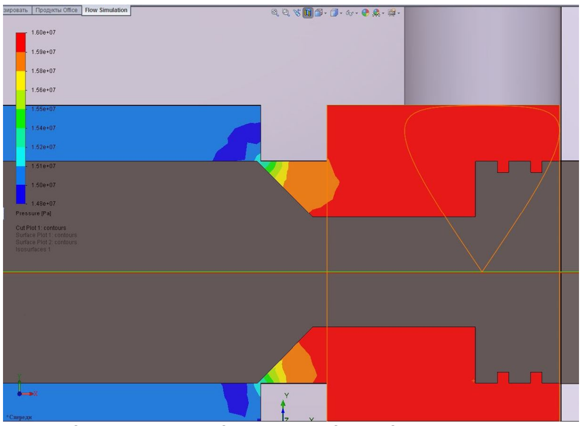


Fig. 3 – Results of simulation of working fluid flow in the brake valve ducts.

As a result of computer simulation pressure distribution by ducts and in operation window of brake valve is obtained. This enables to calculate the value or forces that act on the spool of brake valve. Fig. 4 shows computation scheme for determination of hydrodynamic force values. Cone surface of the spool has inclination angle α = 45º and is divided into a number of sections, having the area $S_1...S_5$. For each section mean value of pressure p_i is determined by the results of computer simulation (Fig. 3). This gives the area S_i of the spool cone surface.

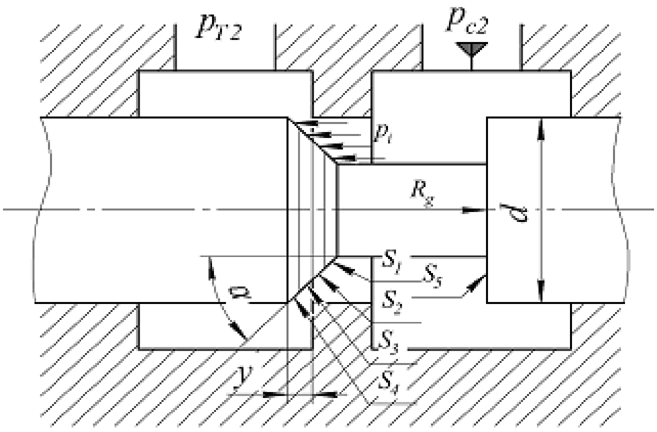


Fig. 4. Calculation scheme for the determination of hydrodynamic force value.

In accordance with the suggested calculation scheme the value of hydrodynamic force will be determined by the formula:

$$R_g = \sum_{i=1}^{4} p_i S_i - p_{c2} S_5 . \quad (1)$$

Value R_g is determined for certain values of opening y of working window of the spool of brake valve and pressure p_{c2} values. Table 1 contains the results of calculation of hydrodynamic force values.

Table 1

Data Array by the Results of R_g Value Calculation

$p_{c2} = 5 \times 10^5$ Pa		$p_{c2} = 50 \times 10^5$ Pa		$p_{c2} = 100 \times 10^5$ Pa	
y, [m]	R_g, [N]	y, [m]	R_g, [N]	y, [m]	R_g, [N]
1.7×10^{-3}	21.82	0.5379×10^{-3}	57.8	0.38×10^{-3}	91.63
1.019×10^{-3}	12.23	0.3221×10^{-3}	42.97	0.2278×10^{-3}	72.39
0.5093×10^{-3}	6.51	0.161×10^{-3}	32.5	0.1139×10^{-3}	59.94
0.1019×10^{-3}	2.99	0.0322×10^{-3}	27.08	0.0228×10^{-3}	53.79

Data array by the results of calculation is approximated by means of Data Fit 8.0 program. Fig. 5 shows graph dependence $R_g = f(p_{c2}, y)$, obtained as a result of approximation.

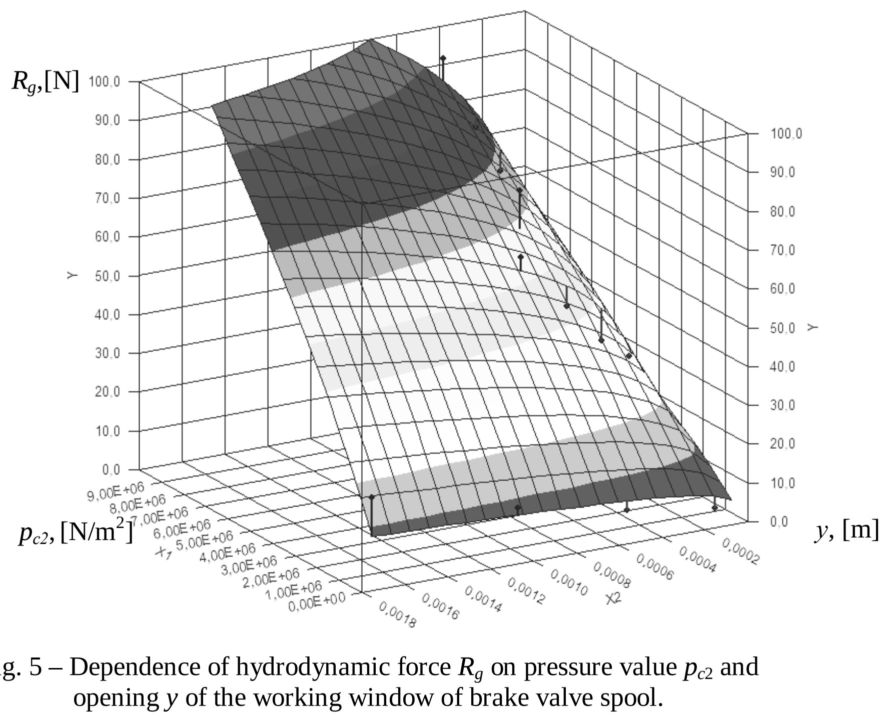
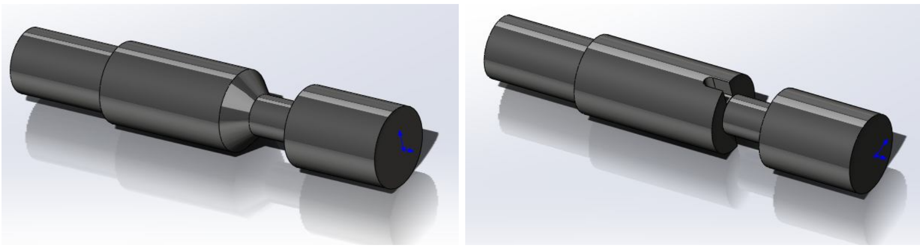


Fig. 5 – Dependence of hydrodynamic force R_g on pressure value p_{c2} and opening y of the working window of brake valve spool.

The dependence is non-linear and is described by the formula:

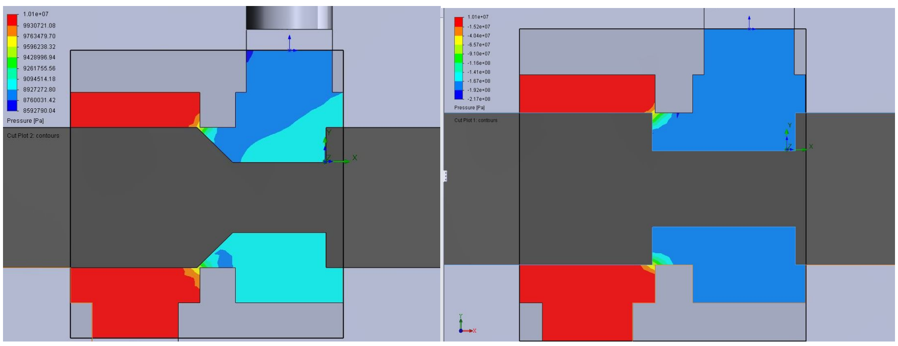
$$R_g = 14.98 + 6.98 \times 10^{-6} p_{c2} - \frac{2 \times 10^{-3}}{y} + \frac{3.15 \times 10^{-8}}{y^2}, \text{ [N]}. \tag{2}$$

Considering the construction of the pressure relief valve, the assumption was made regarding the possibility of reducing the total value of hydrodynamic force at the spool of the valve, changing the construction of the spool. Two variants of the construction of the pressure relief valve spool were considered: with cone working edge with the angle α = 60° (Fig. 6 *a*) and spline working edge (Fig. 6 *b*). Application of spline working edge with two splines provides the reduction of the area of working fluid force action that may lead to reduction of hydraulic force value and the factor of its impact on the spool motion during transient process. For determination of the value of hydraulic force acting on the spool, the computer simulation of hydrodynamic processes in 3-D models of the similar units of the pressure relief valve was made but with two different spools – with cone working edge and spline working edge (Fig. 7). Dependences of the hydraulic force were determined, applying the above-described method.



a *b*

Fig. 6 – Spools of the pressure relief valve.



a *b*

Fig. 7 – The results of simulation of the working fluid flow through the channels of pressure relief valve.

Fig. 7 shows the working window of Flow Simulation module, where the result of the working fluid flow across the pressure relief valve with two variants of spool working edge construction, cone (Fig. 7 *a*) and spline (Fig. 7 *b*) is shown.

As a result of approximation of the values of spool opening and distribution of pressure that act on its surface, the value of hydrodynamic force is determined in the form of dependence. Such dependences are determined for two variants of the spool working edge construction: cone, dependence (3) and spline, dependence (4):

$$f(R_g) = 9.72 + p6.42\times10^{-6} - \frac{6.13\times10^{-4}}{y}, \ \ [\mathrm{N}], \tag{3}$$

$$f(R_g) = 5.5 + p3.7\times10^{-6} - \frac{3.55\times10^{-4}}{y}, \ \ [\mathrm{N}]. \tag{4}$$

The analysis of the results of calculating the hydrodynamic force, that acts on the spool of pressure relief valve, showed that the usage of the spool with spline working edge allows to decrease by 12 – 17% the value of hydrodynamic force as compared with the spool, having cone working edge.

4. Conclusions

Application of Flow Simulation module allows to perform simulation of hydrodynamic processes of fluid flow in the ducts of the hydraulic device blocks and determine the value of hydrodynamic force acting on the elements of the blocks.

The suggested technique of Flow Simulation module application for the calculation of hydrodynamic processes in hydraulic devices can be efficiently used for the development of non-linear mathematic models of complex systems.

On the base of the results of computer simulation of hydrodynamic processes using Flow Simulation module the dependences of hydrodynamic force, emerging on the spools of brake and pressure relief valves of the mechatronic drive hydraulic distributor are determined.

The obtained dependences allowed to make a conclusion that application of the spool with spline working edge in the developed pressure relief valve allows to reduce the value of hydrodynamic force as compared with the spool having cone working edge.

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DETERMINAREA FORŢEI HIDRODINAMICE ŞI ÎMBUNŢIREA DESIGN-ULUI UNEI VALVE DE CONTROL DESTINATE SISTEMELOR MECATRONICE, PRIN SIMULAREA COMPUTERIZATĂ A PROCESELOR HIDRODINAMICE

(Rezumat)

Pornind de la un circuit tipic al unui distribuitor hidraulic destinat unui sistem de manipulare mecatronic şi de la modelul 3-D al acestuia, s-a determinat dependenţa dintre valoarea forţei hidrodinamice şi presiune pentru supapele de frânare şi cele de siguranţă prin utilizarea unui model 3-D al distribuitorului hidraulic, realizat pe baza aproximării rezultatelor simulării cokmputerizate a proceselor hidraulice realizate pe un sistem CAD/CAE. Pe baza dependenţelor obţinute s-a determinat probabilitatea scăderii forţei hidrodinamice ca urmare a modificării construcţiei marginii de lucru a corpului supapei de siguranţă.

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HYDRODYNAMIC FRICTION OF SPHERICAL HINGES WITH WORKING SURFACE, MADE FROM METAL POLYMER COMPOSITES

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Abstract: The design of a spherical joint housing parts, made of metal polymer composites is considered. Composite structure that includes spherical iron particles with the diameter of 1…20 microns has been investigated using the electron microscope. For the microgeometry of metal polymer composite spherical surface that has regular micro protrusions, parameter values were determined. It is shown that the lubricating film on confused areas of micro-protrusions is a system of hydrodynamic wedges. Flow parameters in hydrodynamic wedges were determined. Total carrying capacity and friction torque of the spherical joint, made of metal polymer composite were found.

Keywords: mechanism-hexapod; spherical hinge; angular position of the sphere; regulation; stream system; power support description.

1. Introduction

The development of the effective element base of technological equipment based on spatial mechanism is a vital scientific and technical problem. The problem in general is to develop design and technological production of spherical hinges, which are the main component of element base of spatial mechanisms.

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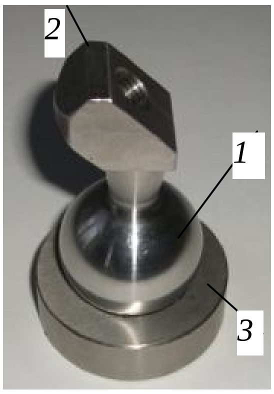
The problem is related with important scientific and practical tasks of a creation the progressive technological equipment, including manipulators, industrial robots, measuring devices, etc. Various spherical hinges of spatial mechanisms are considered in recent studies and publications (Крайнев, 2003). The cardan hinges and hinges with rolling elements are widely used in different structures. Significant part of the publications is devoted to the study of spherical hinges of fluid friction, including hydrostatic and aerostatic (Jachno nov, 2009; Jachno, 2009). From the analysis of publications it follows that the main problems of the hinge design are the provision of required conditions of lubrication and the proper selection of materials (Струтинський, 2010, p 262-270). In some publications it is recommended to use non-metallic materials in the hinge constructions (Струтинський, 2010). The use of metal polymer composites in structures of spherical joints in the literature was not found.

The previously unsolved aspects of the problem include studies of spherical hinges, made of metal polymer composites.

The aim of the research, outlined in this paper, is to establish the characteristics of working processes that take place in a layer of oil. The main objectives of the research are to determine the microgeometry parameters of spherical surfaces, made from metal polymer composites and justification of carrying capacity of hinge to form hydrodynamic wedges in the gap between the spherical surfaces.

2. Researches Concerning Spherical Joint Housing Parts

Spherical hinges, consisting of sphere 1 with shafts 2 and the frame parts are developed, they include metal holder 3 and holes, filled with metal polymer composite 4 (Fig. 1).



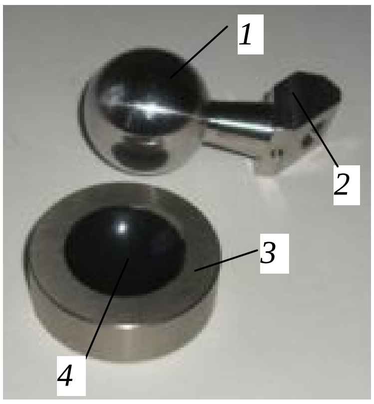


Fig. 1 – Spherical hinge with one-sided spherical contact is made from metal polymer composite: *1* – sphere, *2* – shank, *3* – cage frame part, *4* – spherical surface of the metal polymer composite.

Generally hinges are used with one-way spherical contact. having one frame part. Hinges have also been designed with a two-way spherical contact with two or more frame parts (Fig. 2).

a *b*

Fig. 2 – Hinge with two-way spherical contact.

Spherical hinges of liquid friction which are made of metal polymer composites have high accuracy of working surfaces. This is due to the conditions of formation of the composite over the exact sphere. Metal polymer composite (Ищенко, 2007) includes the iron particles of the accurate spherical diameter 0.5...15 μm. This can be traced on the electronic microphotography of split formed from the composite surface (Fig. 3).

The presence of spherical particles causes the formation of specific surface of the composite when it solidifies. Formed surface has a special microprofile that provides high hydrodynamic characteristics of a pair of fluid friction. Microprofile has quasihomogeneous system of lugs and dents (Fig. 4).

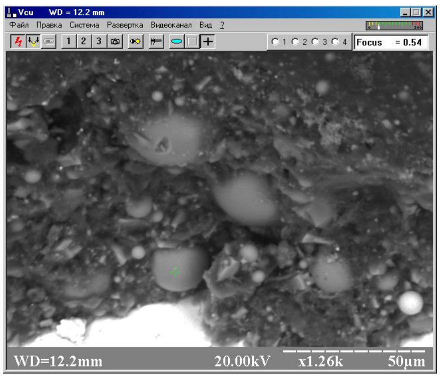


Fig. 3 – Electronic photo of split of spherica.l surface formed of metal polymer composites.

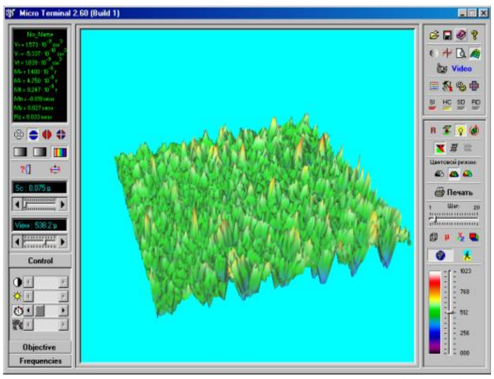
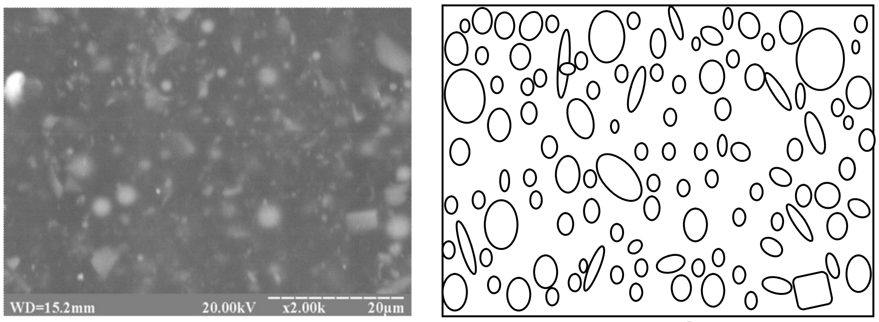


Fig. 4 – Topography of microprofile of surface with a metal polymer made by electron microscope.

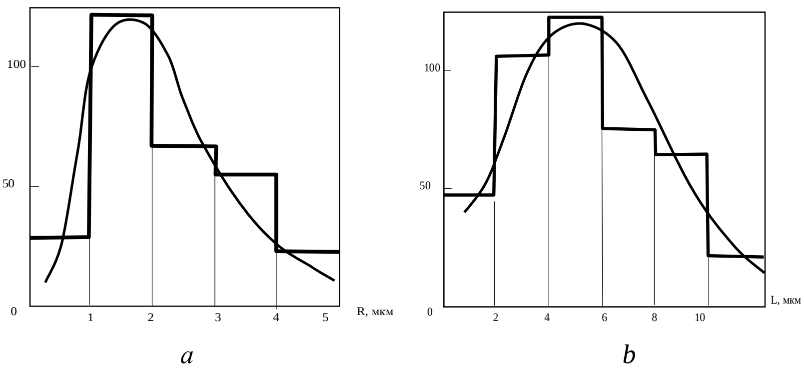
From the analysis of photograph it follows that the lugs on the surface are arranged uniformly over the area and have approximately the same height. Photographs of the surface of the reflected rays are made to determine the patterns of lugs location (Fig. 5).



a *b*

Fig. 5 – Electron microtopography of the surface of reflected rays (*a*) and corresponding photo of size and location of microlugs (*b*).

The lugs of surface can be traced on the photo as bright spots. Their shape is close to circles or ellipses. Some lugs combine with each other, forming chains. The analysis of a number of photographs reveals that the size and cross - arrangement of microlugs are subject to statistical laws. Processing of measurement results has been conducted to reveal the statistical characteristics of size and arrangement of microlugs (Корн, 1973). For defined circuits of lugs (Fig. 5 *b*) the histogram of lugs distribution by the size and histogram of values of the distance between adjacent lugs have been constructed (Fig. 6).



a *b*

Fig. 6 – Histograms reflecting the distribution of the number of lugs by the size (*a*) and the distribution of distances between lugs (*b*).

Histograms correspond to the laws of distribution close to unimodal. They are shown in figures by smooth lines. The range of size values close to the average size are observed on the histogram.

As a result, the measurements have revealed that the system of convex lugs close to circular or elliptical is present on the surface, made of metal polymer. Their measurements have been conducted in separate sections to define the quantification of microprofile (Fig. 7).

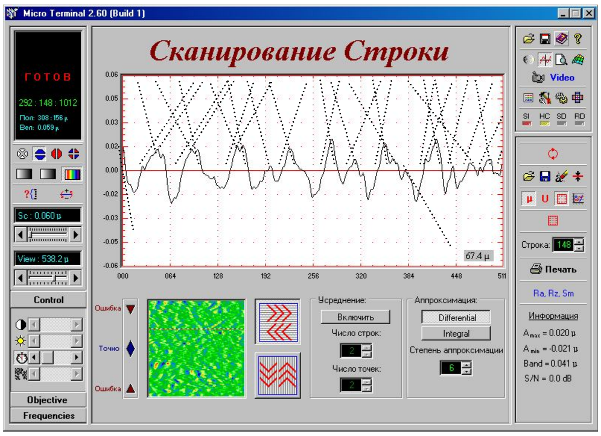
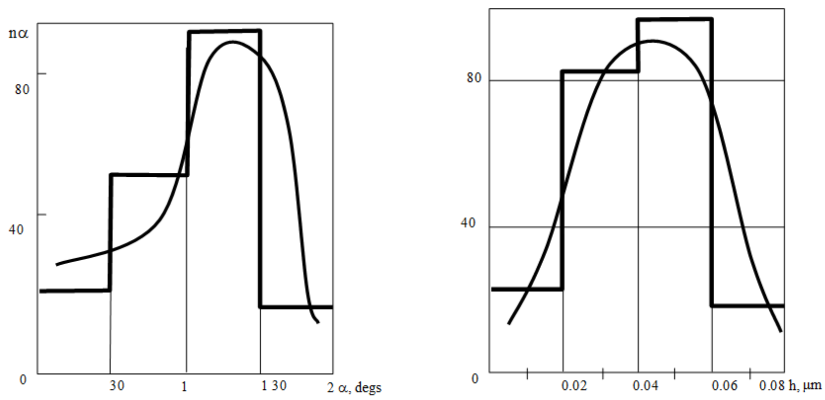


Fig. 7 – Typical experimentally determined profile record of the surface, made from metal polymer where straight lines show averaged values pertaining to microprofile on tops.

From the analysis of profile record it follows that microprofile at the intersection of the surface is similar to a sinusoidal function. Accordingly we can assume that the surface microasperities are similar to regular. It is determined that the amplitude of the lugs – a = 0.015,…,0.020 micron and period T = 5,…,8 microns.

The period value is generally coincides with the defined by the histogram (see Fig. 6 *b*) average distance between microlugs. This confirms the reliability of statistical analysis of shape and location of microlugs.

The spherical surface of metal polymer composites is used in a pair of fluid friction. Between the spherical surface the layer of lubricant is available. So while the hinge is moving, a region of high pressure is formed on the surfaces of microlugs (hydrodynamic wedges). They are localized in the vicinity of vertices in the microlugs direction. Characteristics of hydrodynamic wedge are defined by the angle of surface microlugs. For a number of measured profile records angles at the intersection of tangents of microlugs on top have been defined (see Fig. 7). They are close to the left and right sides of microlugs. Angles between the tangent microlugs on tops are defined to be within laws of accidental nature. Profile records are used to determine the statistical characteristics of the angle values of microprofile lugs slope. In profile records tangents are made (shown by the set of straight lines in Fig. 7). Statistical analysis of tangential angles is conducted (Fig. 8 *a*).



a *b*

Fig. 8 – Histogram of distribution of tangential angles of surface profile microlugs (*a*) and the range of microlugs (*b*).

Mean value of angles microlugs amounts to α_c = 1º10′,…,1º40′. Range of angles of tangent to the tops is 30′…2º.

Statistical processing of the scale h was subjected (lugs double amplitude). Distribution of scale values of microlugs corresponds to unimodal law (Fig. 8 *b*). It has been found that the mean value of scale is h_c = 0.035 microns. The changes in microlugs height can range within 0.02…0.05 microns.

To estimate approximately the microprofile a sinusoidal function of amplitude $a_c \approx h/2$ and period T = 5…8 microns can be used. For this sinusoidal function the estimated values of angles of microprofile are calculated according to the formula: $\alpha \approx 2a_c/T$. As a result of calculations, ranges of microprofile angles are set. Average estimated value of tilt angles is α = 30′…1º30′. This corresponds to the previously defined range of tilt angles of the microprofile tangent that verifies the performed statistical analysis.

As a result of the carried out research calculated geometric scheme of microlugs on the metal polymer surface is substantiated (Fig. 9).

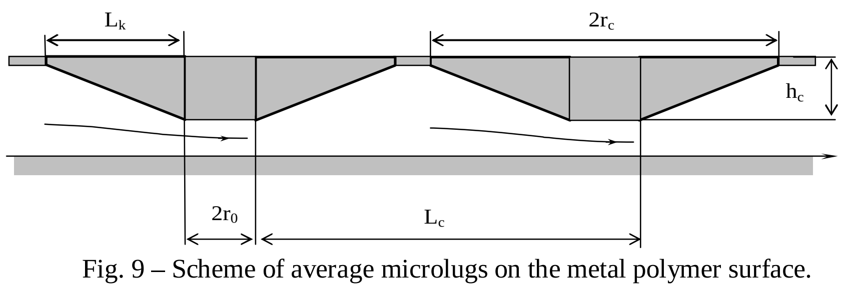


Fig. 9 – Scheme of average microlugs on the metal polymer surface.

Microlugs have the average foundation size $2r_c$ = 4 microns, height h_c = 0.04, located at an average distance of L_c = 5.5 microns. The average angle of microlugs accounts to α_c = 1º30′,…,1º40′. Size of the platform atop of microlugs is determined by the geometric relationships and accounts to $r_0 = r_c - h_c \mathrm{ctg}\alpha_c$ = 0.49 microns. Accordingly, the average length of the wedge is $L_k = r_c = r_0$ microns.

While displacement of sphere relative to the metal polymer surface, that has the regular lugs system, hydrodynamic wedges is formed. The average number of these wedges corresponds to the number of lugs per unit of area and accounts to 20,000 per millimeter square area.

When sphere moves with speed U, a fluid flow appears around microlugs. Hydrodynamic wedge is formed in the central region of microlugs in the direction of motion. Let us concede that in a thin layer fluid flow is close to the flow in the flat hydrodynamic bearing (Fig. 10).

For oil flow in a flat layer of confusion area pressure distribution along the length is defined by the formula (Шлихтинг, 1974)

$$p(x) = p_0 + 6\mu U \frac{l}{h_1^2 - h_2^2} \frac{(h_1 - h)(h - h_2)}{h^2}, \tag{1}$$

where: h_1, h_2 is the values of the gap at the input and the output, μ – the dynamic viscosity of the lubricant, U – circumferential velocity of the sphere, p_0 – constant value.

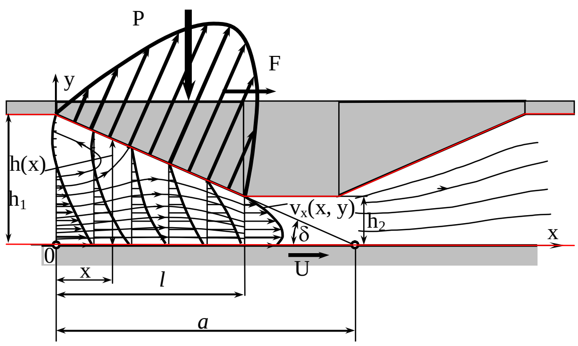


Fig. 10 – Picture of lines flow and epure of hydrodynamic pressure in confusion area of the spherical hinge gap, where hydrodynamic wedge is formed.

Estimated value of the pressure distribution is close to a parabolic dependence. Maximum hydrodynamic pressure is observed at the distance of 1/3 from the top of the microlugs.

Eq. (1) holds for the flow in the plane of hydrodynamic wedge of unit thickness. The received results are generalized for hydrodynamic wedge of finite width b.

The resultant pressure forces in the hydrodynamic wedge of finite width is determined by integrating the formula (1) and will be:

$$P = b\int_0^l p\,\mathrm{d}x = \frac{6\mu UL_2^2}{(k-1)^2 h_2^2}\left[\ln k - \frac{2(k-1)}{k+1}\right]b, \tag{2}$$

where coefficient $k = h_1/h_2$, L – wedge length, b – equivalent width of the carrier layer.

Similarly, the resultant shearing stresses on the wall is found:

$$F = b\int_0^l \mu \frac{\mathrm{d}v_x}{\mathrm{d}y}\bigg|_{y=0} \mathrm{d}x = \frac{\mu UL_k}{(k-1)h_2}\left[4\ln k - \frac{6(k-1)}{k+1}\right]b. \tag{3}$$

The gap at the input of the hydrodynamic wedge accounts to $h_1 = h_2 + h_c$.
Accordingly, the coefficient is $k = 1 + h_c/h_2$.
Combining formulas (2) and (3) we obtain

$$P = \frac{6\mu UL_k}{h_c^2}\left[4\ln\left(1+\frac{h_c}{h_2}\right) - \frac{2h_c}{2h_2+h_c}\right] = P(h_2). \tag{4}$$

Similarly, force of friction can be found:

$$F = \frac{\mu bUL_k}{h_c}\left[4\ln\left(1+\frac{h_c}{h_2}\right) - \frac{6h_c}{2h_2+h_c}\right] = F(h_2)\cdot \tag{5}$$

Equation includes the value of the equivalent width of the hydrodynamic wedge b. It is determined by the shape and size of microlugs. Let us consider microlugs as a truncated pyramid. Because of the spatial motion of the fluid pressure drops in the direction perpendicular to the velocity U. It is assumed that the pressure drop in the transverse direction corresponds to the parabolic law:

$$p_e(z) = p\left[1 - \left(\frac{z}{r_c}\right)^2\right], \tag{6}$$

where p is the pressure in the central part of microlugs.

Eq. (6) assumed that the width of the region of high pressure fits the size of microlugs $2r_c$ (Fig. 11).

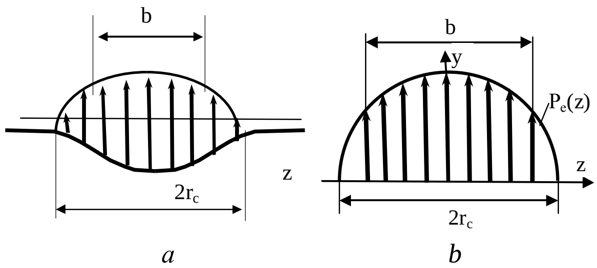


Fig. 11 – Accepted parabolic law of pressure change in the cross section of hydrodynamic wedge: *a* – epure of pressure on curved surfaces of microlug, *b* – determination of the effective width of the hydrodynamic wedge.

The equivalent width of microlugs b is found from the condition of the square equality of rectangular and parabolic pressure diagrams, written in the form

$$pb = 2\int_{0}^{r_C} p_e(z)\mathrm{d}z..$$

Substituting the pressure value of the formula (6) and performing the integration we will find $b = 3r_c/4$.

It is established that the microphopograph of metal polymer surface has two types of microlugs. One of them corresponds to the truncated cone and the other – to the system of extended elliptical microlugs arranged randomly. This leads to the formation of heterogeneous hydrodynamic wedges that are dotted or elongated (Fig. 12).

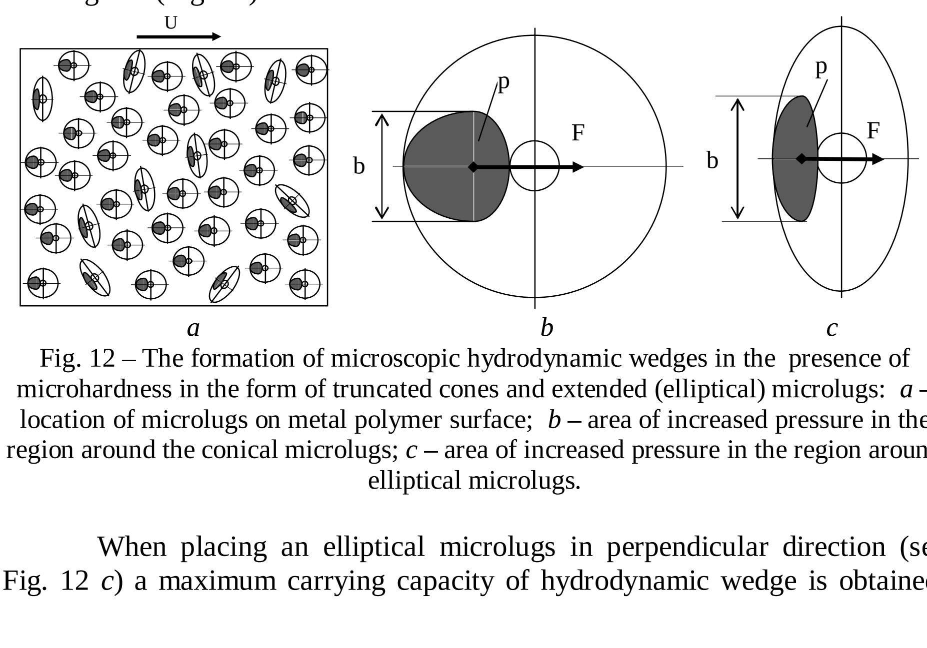


Fig. 12 – The formation of microscopic hydrodynamic wedges in the presence of microhardness in the form of truncated cones and extended (elliptical) microlugs: *a* – location of microlugs on metal polymer surface; *b* – area of increased pressure in the region around the conical microlugs; *c* – area of increased pressure in the region around elliptical microlugs.

When placing an elliptical microlugs in perpendicular direction (see Fig. 12 *c*) a maximum carrying capacity of hydrodynamic wedge is obtained.

When placing an elliptical microlugs at the angle to the direction of the wedge, carrying capacity decreases (Fig. 13).

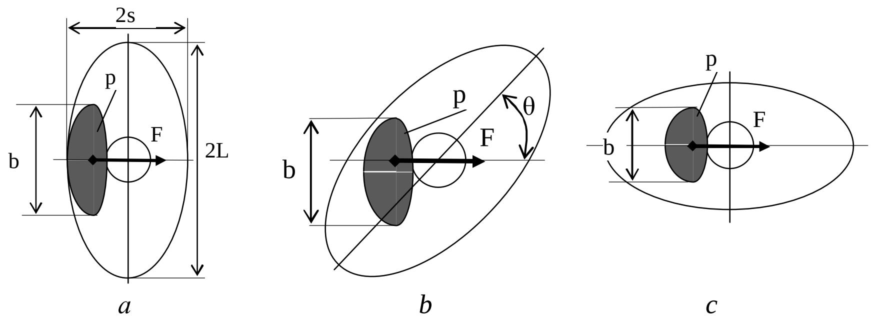


Fig. 13 – Change of carrying capacity of hydrodynamic wedge depending on the orientation of microlugs relative to the direction of mutual displacement of parts in a pair of friction.

To assess changes in the first approximation of carrying capacity of the hydrodynamic wedge, this formula is proposed:

$$P_k = (P_{\max} - P_{\min})\cos\theta + P_{\min}, \tag{7}$$

where: $P_{\max}$ and $P_{\min}$ – the maximum and minimum carrying capacity of hydrodynamic wedge.

Considering the small size of microlugs, it is assumed that the load change is proportional to the ratio of semi-axes

$$\frac{P_{\max}}{P_{\min}} = \frac{s}{L}. \tag{8}$$

Difference of the elliptical presentation from the circular is in increase of its width. So you can accept the link between the carrying capacity of circular and elliptical performances as

$$P_{\max} = \frac{s}{r_c} P, \tag{9}$$

where P is the carrying capacity of wedge defined by the equation (4). Combining formula (7),…,(9) we obtain:

$$\frac{P_k}{P} = \frac{s}{r_c}\left[\left(1 - \frac{r_c}{s}\right)\cos\theta + \frac{r_c}{s}\right].$$

As a result of calculations, it is revealed that the expression on the right side of this formula varies randomly with mean value close to unite. Therefore, for the approximate calculation of the average carrying capacity hydrodynamic wedge on the elliptical lug can be accepted as the carrying capacity of hydrodynamic wedge on a circular lug.

Microscopic hydrodynamic wedges occur on spherical surfaces of the hinge. When shifting spheres of hinge relative to the housing, a regular system of hydrodynamic wedges is forming (Fig. 14).

To determine the total response of the hinge let us take a first approximation

$$\vec{Q} = \sum_{s} \vec{P_i} = P_i n \cdot \frac{\pi D^2}{4},$$

where n is the average number of microlugs per unit of the area.

Herewith the first approximation to the tangent force interaction is:

$$T = \sum_{s} F_i = F_i n \cdot \frac{\pi D^2}{4}.$$

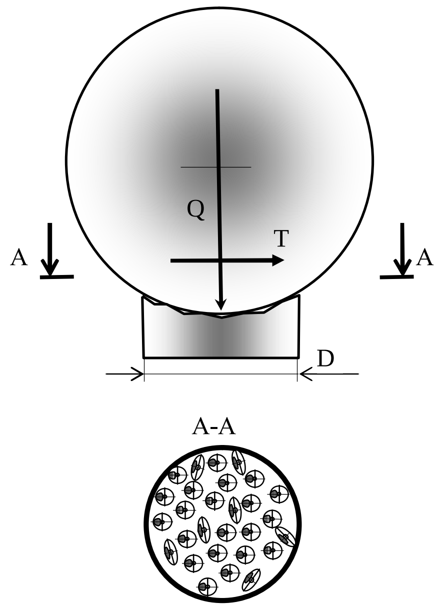


Fig. 14 – Formation of microscopic system of stochastic hydrodynamic wedges in a cleft of the spherical hinge.

As a result of the studies the peculiarities of operational processes that take place in the layer of grease of spherical hinge, made of metal polymer composite are defined. They are of a regular occurrence in the system of hydrodynamic bearing wedges formed on microlugs of the metal polymer surface. The presence of a large number of carrying areas provides high tribological properties of the metal surface of the polymer.

3. Conclusions

1. It is defined that there is a system of regular microlugs that are evenly spaced on the area on the spherical surface of the hinge, made of metal polymer composite. The average height of microlugs is about 0.04 microns, and the average distance between them is 5...8 microns. The surface of lugs forms the confusion slit gaps between spherical surfaces, while the confusion angle averages to 1º30′.

2. In confusion areas the slit of spherical hinge formes a regular system of microscopic hydrodynamic wedges in which there are local areas of high pressure. The number of microscopic hydrodynamic wedges in which there are local areas of high pressure is about 20.000 per square millimeter. Carrying capacity of the hydrodynamic wedge depends on its shape and location. The total carrying capacity of the spherical hinge can be defined by the vector sum of the pressure forces arising in certain hydrodynamic wedges.

3. As a direction for further research it is recommended to determine the parameters of accuracy and wear resistance of surfaces of developed spherical hinges, made of metal polymer composites.

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FRECAREA HIDRODINAMICĂ A ARTICULAŢIILOR SFERICE, REALIZATE DIN COMPOZITE METAL–POLIMER, CU SUPRAFEŢELE DE LUCRU

(Rezumat)

Se studiază design-ul articulaţiilor sferice, realizate din compozite metal–polimer. Structura acestor materiale include particule de fier cu diametrul de 10…20 microni, structura cărora a fost studiată cu ajutorul microscopiei electronice. S-au determinat parametrii microgeometriei suprafeţei sferice. S-a arătat că în zonele de articulare în care există microproeminenţe filmul hidrodinamic este sub forma unui sistem de „pene” hidrodinamice, zone în care s-au determinat şi parametrii de curgere. De asemenea, s-au calculat capacitatea de încărcare şi cuplul de fricţiune din aceste articulaţii sferice.

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IMPROVING THE ACCURACY OF A SPATIAL DRIVE SYSTEM USING A SIX-COORDINATE MICRODISPLACEMENT DRIVE

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Abstract: It has been determined that essential improvement of accuracy of a spatial drive system can be achieved using a special microdisplacement drive. An original design solution of the six-coordinate microdisplacement drive is proposed. A spatial frame with six elastic rods, oriented along the ribs of an octahedron, forms the basis of the drive. Investigation of stress-strain state of the frame has been conducted. Design and technological justification of the microdisplacement drive development is presented. A technology has been developed and the elastic frame of the microdisplacement drive has been manufactured. Jacobian matrix, which describes the relationship between output coordinates of flat springs, has been determined. Microdisplacement drive application has enabled significant improvement of the accuracy of spatial drive systems.

Keywords: drive systems; errors; compensation; microdisplacements; circuit; octahedron; stress; deformations; mock-up; technology; test sample; control; approbation of the drive.

1. Introduction

Spatial drive systems are characterized by insufficient rigidity of the carrying system, which results in accuracy reduction. The improved accuracy of

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the systems could be achieved by application of six-coordinate microdisplacement drives. Therefore, creation of such microdisplacement drives is of current importance.

The problem, in a general form, is as follows: development of technological equipment with high accuracy indicators. This problem is connected with important scientific and practical tasks of designing highly efficient equipment for manipulation of machine-building objects.

The latest studies and publications present technological equipment designs based on spatial drive systems (Кун, 2012).

Low rigidity of the system and kinematic chain errors are shown to be the reason for the equipment accuracy reduction (Рыбак *et al*, 2011). Some publications give recommendations on the equipment accuracy improvement (Павленко, 2007; Merlet, 2006). The authors recommend using periodical control (calibration) of the equipment (Новіков, 2011). All of the above measures do not provide a comprehensive solution to the problem of the equipment accuracy improvement. Compensation of errors by means of six-coordinate microdisplacement drives is a radical method of accuracy improvement.

The literary sources do not give propositions on the equipment accuracy improvement by means of special microdisplacement drives. Therefore, development of special microdisplacement devices, which compensate errors of the spatial drive system, is an unsolved aspect of the general problem.

The aim of the research, presented in this paper, is to improve the accuracy of the spatial drive system through the development of special six-coordinate microdisplacement drives.

To achieve this aim, the following tasks have been set and solved: substantiation of using six-coordinate microdisplacement drives in spatial drive systems; development of an original engineering solution of the six-coordinate microdisplacement drive; studying the stress-strain state of the microdisplacement drive; design and technological justification of the microdisplacement drive development; determining regularities of the microdisplacement drive operation; approbation of the microdisplacement drive as a part of the spatial drive system.

2. Substantification of Using Six-Coordinate Microdisplacement Drives in Spatial Drive Systems

A spatial drive system includes an actuator that moves in space. Position of the actuator as a solid body is characterized by a six-dimensional vector of x-coordinates (Новіков, 2011), the components of which are Cartesian coordinates x, y, z of the actuator pole and angles ψ, θ, φ that determine cross-angular position of the actuator in space. Low rigidity of kinematic chains and drive errors lead to the positioning errors in the adjustment of x-coordinates of the actuator.

A typical spatial drive system is a machine-tool of parallel kinematics, the actuator 1 of which is moved by drives in the form of control rods 2 of a variable length (Fig. 1).

Errors of the actuator spatial position are measured by a special measurement system. It includes stationary assemblies 3, installed on the table, and three movable assemblies 4, installed on the actuator. They create a virtual mechanism – a hexapod with six imaginary rods of variable length, which are the distances between the stationary and the movable assemblies. Precise measurements of distances between the assemblies are made by using optical devices (laser meters). In accordance with the measured values of actual actuator position, errors are determined. Depending on the error value, the required pulses are formed for the control system. The actuator position errors are proposed to be compensated by a specially developed six-coordinate microdisplacement drive. Drive 5 is installed on the machine-tool table. An additional table, where a workpiece is installed, is located on the drive platform. The microdisplacement drive realizes spatial displacements of the workpiece. Displacement of the workpiece in space provides compensation of errors during the machine-tool operation.

Microdisplacement drives are used for different spatial drive systems. In particular, a microdisplacement drive is used as a part of manipulator (Fig. 2).

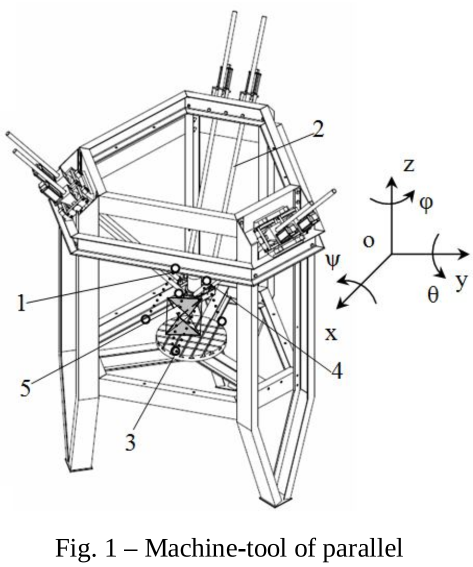


Fig. 1 – Machine-tool of parallel kinematics with a drive of the workpiece microdisplacements.

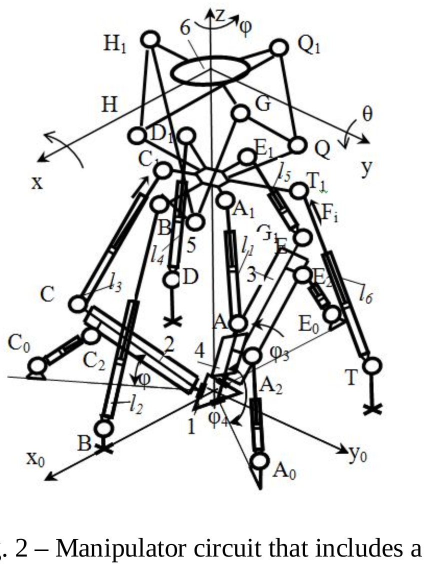


Fig. 2 – Manipulator circuit that includes a microdisplacement drive of the manipulation object.

The manipulator includes discrete pneumatic drives that are built according to the hexapod mechanism circuit with additional degrees of freedom. The drive system has a stationary base 1, rotary bars 2 – 4 and movable actuator 5. Drives in the form of hydraulic cylinders are connected by articulated joints *A*, *B*, *C* with the links of the mechanism. A spatial discrete system of pneumatic drives, built on the modular-assembly principle, is considered. There is a possibility to realize about a hundred of various configurations of the given drive system in accordance with specific problems of object manipulation.

In order to improve the accuracy of positioning platform 6, a micro-displacement drive in the form of frame $HGQQ_1H_1G_1$ is used. The required displacement of platform 6 is provided by varying the length of rods HH_1, QQ_1 and others.

3. Engineering Solution of the Six-Coordinate Microdisplacement Drive

The six-coordinate microdisplacement drive (Fig. 3) includes stationary body 1 and movable platform 2 with 6 degrees of freedom – three Cartesian coordinates *x*, *y*, *z* of translational motion of the platform and three cross-angular coordinates ψ, θ, φ that characterize the platform rotation about axes x, y, z respectively (Струтинський, 2014).

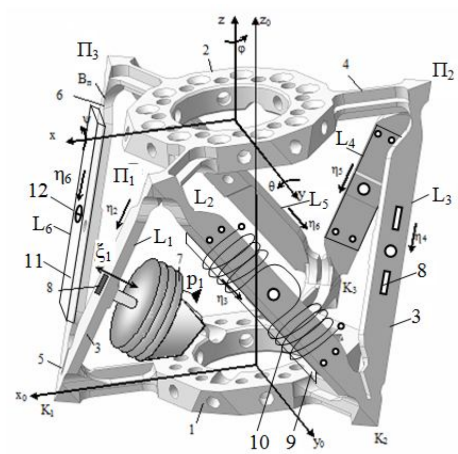


Fig. 3 – Design circuit of the developed six-coordinate microdisplacement drive.

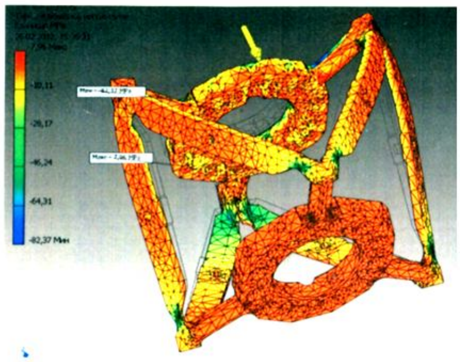


Fig. 4 – Visualization of the results of calculating stress-strain state of the frame of the six-coordinate microdisplacement drive.

The drive includes linear displacement mechanisms, their quantity being equal to the number of the platform degrees of freedom. Linear displacement mechanisms connect three points of the body – K_1, K_2, K_3, which are the vertexes of the equilateral triangle, with three points of the platform Π_1, Π_2, Π_3, which are the vertexes of the same triangle rotated by the angle 60° relative to the triangle of the base. Linear displacement mechanisms are realized in the form of flat springs 3, the areas of which correspond to the faces of octahedron. The vertexes of octahedron are three points K_1, K_2, K_3 of the body and three points Π_1, Π_2, Π_3 of the platform, which are connected by the linear displacement mechanisms. On the body and on the platform there are torsion bars 4 of *X*-shape cross-section, which connect them with fixing points of the linear displacement mechanisms. In places, where the flat springs are connected with the torsion bars, they have elastic joints in the form of shaped beams 5 and 6 which allow for limited displacements of the flat springs in their own planes.

The flat springs are deformed beyond their planes. For this, different spring deformation drives are used, particularly, bellows-type drives, thermomechanical and mechanical drives.

When bellows-type drives are used, deformation of spring 3 is achieved by the force of bellows 7. When pressure p in the bellows is changed, the spring is deformed by value δ and the spring length is deformed by value ΔL_1.

For spring deformation thermomechanical drives are also used. They have brass plates 9 fixed at the springs. Each spring and plate have a separate heater 10 that serves for changing the temperature of the spring and of the plate. When they are heated, difference in thermal deformations of the springs and the plates is observed and, therefore, the required deflection of the spring is provided. Mechanical devices, installed on the springs, serve for additional deformation of the spring. They include cross-arms 11, fixed at the ends of the spring, and screw devices 12 that provide the required deformation of the spring.

The drive of spatial microdisplacements operates in the following way. When pressure p_1 is changed in each of the bellows 7, regulated by the control system, flat spring 3 is deformed beyond its plane in the direction indicated by arrow $\xi 1$. Similarly, the spring is deformed by mechanical device 11, 12. When the drive is heated by heater 10, the spring in the form of a bimetal plate is deformed as well. The required level of the spring deformation is controlled in the mechatronic system on the basis of measurements made by strain gauges 8. When the spring is deformed, its length changes as well as the distance between points K_1, Π_1. The change in the length of all six springs leads to the change in the spatial position of platform 2. The platform has six degrees of freedom and, therefore, depending on the deflection of all of the six springs, the centre of the platform is displaced in directions *x*, *y*, *z* and angular position of the platform, characterized by angles ψ, θ, φ, is also changed.

Displacement takes place within the limits of elastic deformations of flat springs 3 of torsion bars 4 and shaped beams 5 and 6. Design parameters of the manipulator are chosen so that the displacement range of points Π_1, Π_2, Π_3

of the platform will be 0.1…1.0 mm, which is sufficient for providing the required spatial microdisplacement ranges for the platform.

4. Studying the Stress-Strain State of the Microdisplacement Drive

Designing of the complex elastically-deformed frame, which is the basis of the microdisplasement drive, requires substantiation of the choice of its main parameters. For this, a stress-strain state of the spatial frame in the form of octahedron with a rib size of 150 mm was investigated. Standard procedures of the finite element method were used and realized in the computer-aided design system “Inventor”. For calculations, the frame loading was performed by a concentrated force of 3,000 N, applied to different points of the platform. The level of stresses and deformations at each point of the frame has been determined (Fig. 4).

It has been found, that when the platform is loaded by a concentrated force, maximal stresses occur at the periphery of the torsion bars in the places of their connection with the movable platform. The change of the load application point causes changes of maximal stresses. Under different load conditions maximal stresses are in the range of 80…94 MPa. This is considerably less than the elasticity limit of the frame material.

By the level of stresses the load in the frame elements has been determined. Longitudinal compression loads in the flat springs, obtained as a result of calculations, are in the range N = 840…900 N. Testing of the flat spring stability under the action of compression loads has been performed. The value of critical force, under the action of which the spring loses stability, is determined by the formula (Беляев, 1964):

$$N_{KP} = \frac{\pi^2 EI}{(\mu L)^2}, \tag{1}$$

where: E is elasticity modulus of the frame material; I – minimal inertia moment of the flat spring section; L – the flat spring length; μ – coefficient that depends on the boundary conditions of fixing the spring.

The calculated value (formula 1) of the critical compression force, when supporting moments at the spring ends are absent, is 3.3…4.0 KN. This exceeds the calculated working loads on the spring by 3…5 times. Respectively, the flat spring is far from the stability loss limit.

Deformations of the frame elements have different values and nature. Main deformations occur in the flat springs. In order to determine them, elasticity curves of the flat springs have been built for different load conditions. A typical elastic curve of the flat spring (Fig. 5) has maximal deflection $\delta =$ $= 4…6$ mm for spring length $L = 150$ mm.

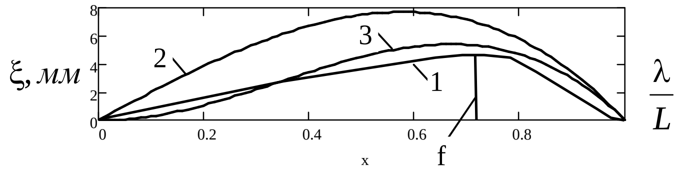


Fig. 5 – Elastic curve of the flat spring included into the frame structure: curve *1* – calculation by the finite element method; curve *2* – calculation by formula (2); curve *3* – calculation by formula (4)

Maximal deflection of the flat spring occurs at the distance of (0.7…0.8)L from the stationary base.

Deformation of the flat spring occurs under the influence of forces acting on the spring in the assembly of its conjugation with the movable platform. The most influential factor is moment M that deforms the flat spring perpendicular to its plane. This moment acts on the spring and causes its deflection that is calculated using the following dependence:

$$\xi_M = \frac{ML\lambda}{6EI}\left(1-\frac{\lambda^2}{L^2}\right), \tag{2}$$

where: λ is distance that is measured along the flat spring length starting from the point of its conjugation with the stationary base. Deflection values, calculated by formula (2), are much higher than those obtained from the frame structure calculation by the finite element method (see Fig.5). This is explained by the presence of reactive moments in the shaped beams.

The spring is connected with the stationary base by shaped elastic beams that have a certain cross-angular stiffness C_n. When the spring is deformed, its angular position relative to the stationary base is changed. The rotation angle of the spring section is determined by differentiation of dependence (2):

$$\theta_M = \frac{\mathrm{d}\,\xi_M}{\mathrm{d}\,\lambda} = -\frac{ML}{6EI}\left(1-3\frac{\lambda^2}{L^2}\right)$$

By substitution of λ=0 into this formula we obtain:

$$\theta_0 = \frac{ML}{EL}$$

Respectively, at the place, where the spring is fixed, a resistance moment occurs:

$$M_0 = C_\Pi \theta_0 = \frac{C_\Pi ML}{EL}.$$

This moment will cause deformation of the spring in accordance with dependence (Струтинський , 2013):

$$\xi_0 = \frac{M_0 L(L-\lambda)}{6EL}\left[1-\frac{(L-\lambda)^2}{L^2}\right]. \qquad (3)$$

The resulting deflection of the spring under the influence of the disturbance moment and the resistance moment is determined by the difference between the values calculated by formulas (2) and (3):

$$\xi = \xi_M - \xi_0 = \frac{ML}{6EI}\left\{\lambda\left(1-\frac{\lambda^2}{L^2}\right)-\frac{C_П}{EL}(L-\lambda)\times\left[1-\frac{(1-\lambda)^2}{L^2}\right]\right\} \qquad (4)$$

Calculation by formula (4) corresponds quite accurately to the finite element method calculation (see Fig.5). Therefore, expression (4) could be used for approximate description of the flat spring elastic curve for its deformation under the action of useful load.

For small transverse displacements of the spring, convergence of its ends is determined by integral (Струтинський , 2013):

$$\delta L = \frac{1}{2}\int_0^L \left(\frac{\mathrm{d}\xi}{\mathrm{d}\lambda}\right)^2 \mathrm{d}\lambda\,. \qquad (5)$$

Formulas (4) and (5) served as a basis for finding the relationship between the maximal deflection of the spring and the change of its length (Fig. 6).

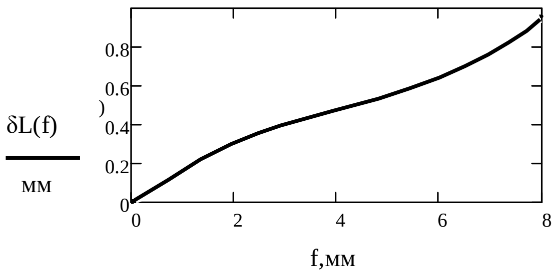


Fig. 6 – Dependence of the spring length change on its maximal flexure.

The dependence, that is close to a linear one, is described approximately by the formula:

$$\delta L_i = K\delta f_i,\ (i = 1,2,\ldots,6) \qquad (6)$$

where δf_i is maximal deflection of the i-spring; K – a constant coefficient.

5. Design and Technological Justification of the Microdisplacement Drive Development

The six-coordinate microdisplasement drive is a principally new device. Therefore, validation tests have been performed as to the possibility of its implementation and operability of the developed device.

Manufacture of the frame for the six-coordinate drive is a complex design and technological problem. In the process of this research engineering documentation was elaborated and the system mocking-up was performed. For this, the drive mock-up was manufactured by the method of laser stereolithography using a solid-body model (Fig.7).

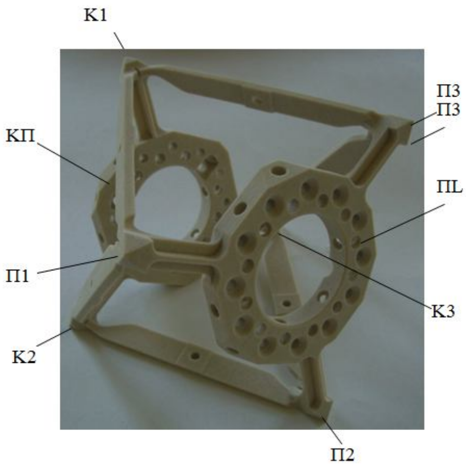


Fig.7 – Mock-up of the drive frame realized by laser stereolithography.

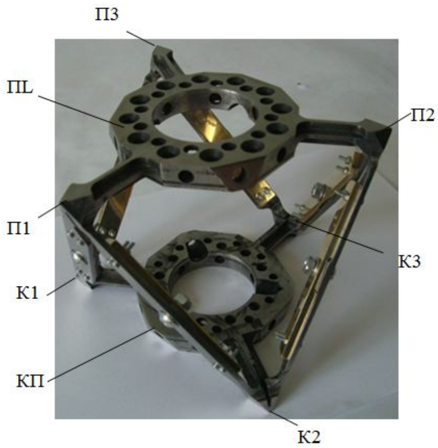


Fig. 8 – Photo of the manufactured frame with brass plates for the microdisplacment drive.

Mocking-up of the drive has made it possible to optimize its geometric dimensions, to choose the necessary datum surfaces and rational tools for manufacturing the drive from metal. Faces of the geometrical figure – a regular octahedron – were taken as datum surfaces. It has 8 faces in the form of equilateral triangles, the sides of which are the octahedron ribs. Six vertexes of octahedron correspond nominally to the vertexes of four-face pyramids – Π_1, Π_2, Π_3 and K_1, K_2, K_3 that are formed at the frame ends. In the nominal position all the external surfaces of the frame correspond to the octahedron faces. Two opposite faces of the octahedron correspond to the external surfaces of the platform ΠL and of the base *K*Π. Vertexes Π_1, Π_2, Π_3 and K_1, K_2, K_3 correspond to these faces. The rest of the octahedron faces correspond to the external surfaces of the flat springs, *e.g.* K_1, Π_1 and K_1, K_2.

Using the mock-up, a procedure for monitoring the workpiece geometry during technological operation has been developed. The technological process of manufacturing the frame has been designed as well as the necessary tooling.

The microdisplacement drive is manufactured from spring steel 65 Г with respective thermal treatment. In order to prevent warping of the spatial frame, its thermal treatment was performed using special fixing devices.

Finishing operation of the drive frame machining were grinding the surfaces of flat springs of the platform and of the base as well as refining operation (lapping on a plate) with control of parallelism of the octahedron faces. During the operations measurements of the actual geometry of the frame were performed, its main geometric parameters were determined. The necessary elements were installed on the frame, brass plates in particular (Fig. 8).

6. Regularities of the Six-Coordinate Microdisplacement Drive Operation

A six-coordinate microdisplacement drive has complex geometry and kinematics. Geometrical and kinematic characteristics of the drive have been investigated.

Flat springs of the drive form six variable-length links $L_1,..L_6$ of the mechanism. Assume that the length of the mechanism links is equal to the distances between the octahedron vertexes:

$$L_1 = K_1\Pi_1,\ L_2 = K_2\Pi_1,\ L_3 = K_2\Pi_2,\ L_4 = K_3\Pi_2,\ L_5 = K_3\Pi_3,\ L_6 = K_3\Pi_3.$$

In order to determine geometric relationships of the spatial frame, we use a circuit of the equivalent link mechanism corresponding to the elastically deformed frame (Fig. 9)

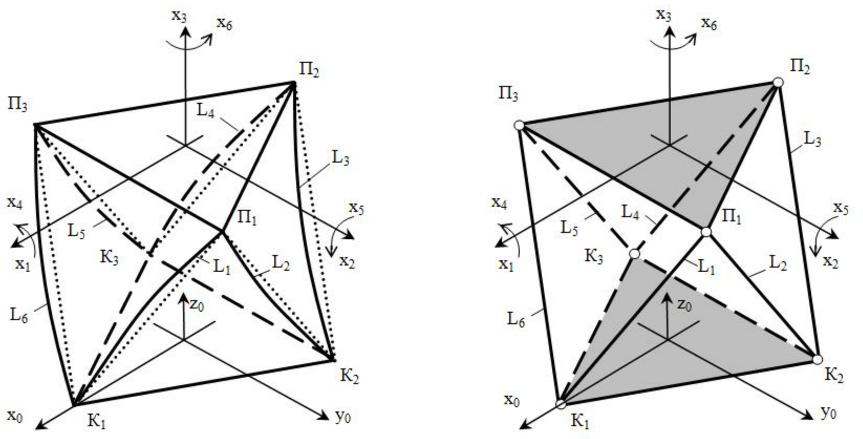
The actuator position in space is characterized by the vector of x-coordinates $X = [x_1, x_2,..x_6]^T$. Three of the vector components x_1, x_2, x_3 are Cartesian coordinates of displacement of the characteristic point (the pole) at the platform $x_1 = x$, $x_2 = y$, $x_3 = z$. Three coordinates x_1, x_5, x_6 correspond to the angles of the platform rotation about the axes of the coordinate system.

To reduce the vector of the x-coordinates to a homogeneous form, it was assumed that:

$$x_4 = a\psi, \qquad x_5 = a\theta, \qquad x_6 = a\varphi,$$

where a is a characteristic size of the mechanism, equal to the length of the octahedron rib.

There exists the following functional relationship between the coordinates that determine the actuator position (x-coordinates) and the lengths of the springs (L-coordinates): $x_i = x_i(L_j)$, ($i, j = 1,2,..6$).



a *b*

Fig. 9 – Circuit of the elastically-deformed pivotless mechanism in the form of spatial frame (*a*) and a simplified circuit of the frame in the form of an equivalent link mechanism (*b*).

For small changes of *x*-coordinates, δx functional relationship will be a linear one:

$$\delta x_i = \sum_{j=1}^{6} \frac{\partial x_i}{\partial L_j} \delta L_j ,\ [\delta x] = M \cdot [\delta L] \tag{7}$$

where $\delta L_j, \delta x_i$ are the gains of respective coordinates; M – Jacobian Matrix that includes the respective partial derivatives.

Components of Jacobian Matrix *M* of the equivalent link mechanism (Fig. 9 b) were found theoretically by respective changes of the link mechanism geometry on the basis of the principle of possible (virtual) displacements (Струтинський , 2013).

Jacobian matrix *M*, determined theoretically, was compared with Jacobian Matrix *Me*, determined experimentally for the manufactured elastic frame (Fig. 10):

$M =$

−3.5	1.7	−3.5	−3.5	1.7	−3.5
1.2	0	−1.2	1.2	0	−1.2
0.8	1.2	1.2	1.2	1.2	0.8
2.4	2.4	0	0	−2.4	−2.4
−4.2	−4.2	1.2	1.2	−4.2	−4.2
1	−3.5	2	−2	3.5	1

$M_e =$

−2.8	1.6	−3.2	−2.9	1.5	−3.0
1.0	−0.6	−0.9	1.1	0.7	−0.8
0.6	1.1	1.0	0.9	1.1	0.7
2.2	2.1	0.8	−0.7	−2.3	−2.1
−3.8	−3.5	1.1	1.2	−3.7	−3.7
0.8	−2.7	1.4	−1.4	2.5	0.7

a *b*

Fig.10 – Comparison of the components of Jacobian Matrix *M* for the link mechanism (*a*) with the Jacobian Matrix *Me* of the elastically deformed frame (*b*)

For the equivalent link mechanism, changes in the length of one spring do not lead to changes of the lengths of other springs. Therefore, in Jacobian matrix there are zero components that correspond to the absence of relationship between the geometrical parameters along separate coordinates.

For the elastically-deformed pivotless mechanism in the form of a frame changes in the length of one spring lead to changes of the lengths of other springs. Respectively, an elastic mechanism in the form of a frame differs from the link mechanism and has a different Jacobian matrix. This matrix *Me* was determined experimentally.

In order to determine Jacobian matrix of the elastically deformed frame, a special procedure was elaborated and implemented (Струтинський, 2013, 492p). In accordance with this procedure, a sequential deformation of each spring by screw drives was performed. Deformation was set by the spring length reduction by 100 mcm from its initial value. At the same time the lengths of the other five springs were measured. Actual length of each of the five springs was measured by a micrometer. Measurements were performed with the accuracy of ±5mcm. The spring deflection was measured by a micrometering device.

As a result of measurements, it was determined that spring deflection f and the change of spring length ΔL are connected by a relationship, close to a linear one. Spring flexure by 1 mm leads to the changes in lengths of the springs by the value of about 0.15 mm. A linear relationship is observed when the spring length changes by 0.2…0.4 mm. This corresponds to the results of theoretical studies presented above (Fig. 6).

The results of experimental measurements were subjected to computer processing. To determine respective changes of x-coordinates, computer simulation of the frame was performed using changes of the ribs determined experimentally. For this, one column of the experimental Jacobian matrix *Me* was determined. It includes translational and cross-angular displacements of the platform: x, y, z, ψ, θ, φ. As a result, a general Jacobian matrix *Me* has been formed (Fig. 10 *b*).

From the comparison of Jacobian matrix *M* of the equivalent link mechanism with Jacobian matrix *Me* of the elastic frame, determined experimentally, it was found that, in general, matrices of the link mechanism and of the elastic frame have similar components. Therefore, for an approximate analysis the elastic frame could be assumed to be close to a link mechanism.

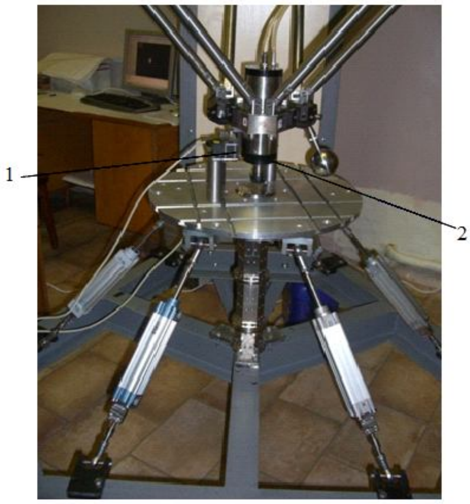
The determined Jacobian matrix *Me* makes it possible to find the dependence of the displacement of the microdisplacement drive platform on the deflections of separate flat springs.

Substitution of dependence (6) into formula (7) gives the relationship between the input parameters of the drive system (the deflection vectors of flat springs f_j) and the output parameters in the form of the vector of changes of the (x_i) coordinates of the movable platform:

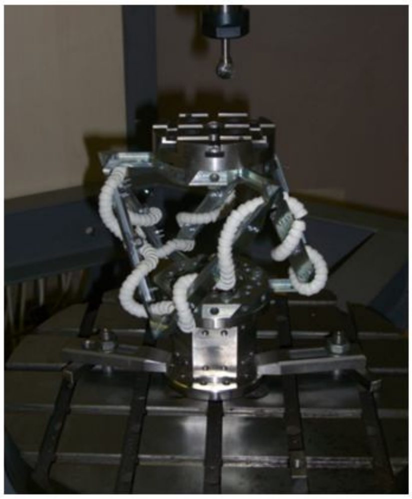
$$(\delta x_i) = KM_e(\delta f_j).$$

7. Test Approbation of the Microdisplacement Drive as a Part of Spatial Drive Systems

For approbation of the microdisplacement drive it was used in a number of advanced drive systems. In particular, the drive was adapted for operation as a part of the technological complex based on the machine-tool of parallel kinematics (Fig.11).



a



b

Fig.11 – Technological complex based on the machine-tool of parallel kinematics (a) and installation of the six-coordinate microdisplacement drive on the machine-tool table (*b*)

Technological complex (Gurzhiy, 2013) is designed for performing various cutting operations. The complex is intended for small mobile enterprises with wide fast-changing product range. The complex provides realization of technological operations under different conditions.

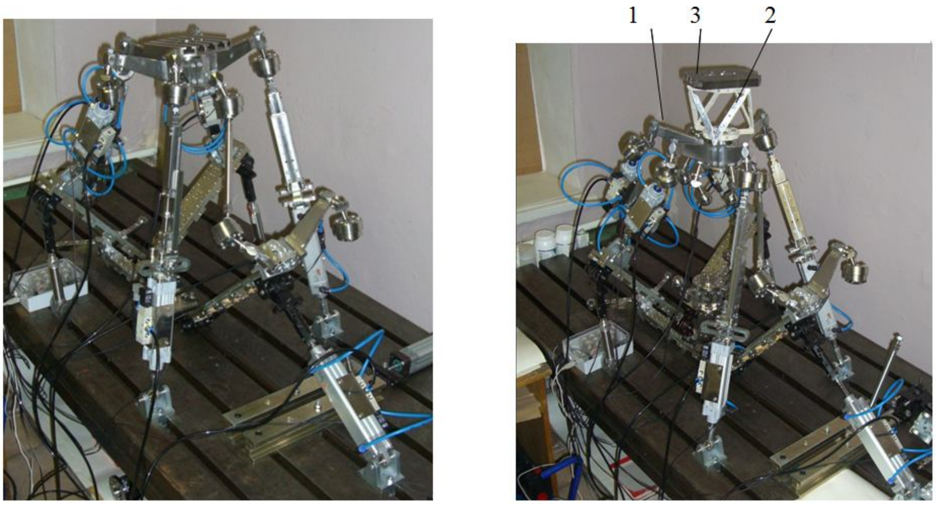
The proposed technological complex has a specific material consumption that is by 10…20 times lower as compared with traditional technological equipment. It does not require special operation conditions (the type of shop at an industrial enterprise). It is distinguished by low energy consumption. The complex does not use special control systems and is controlled from a PC with free software that does not require a commercial license. The complex does not also require highly qualified personnel for its operation.

Application of the microdisplacement drive enables significant improvement of the technological complex accuracy. Due to the use of a special mechatronic control system, accuracy of machining the parts is 10 mcm.

Another variant of the six-coordinate microdisplacement drive application is a manipulator based on a spatial system of discrete pneumatic drives (Fig. 12).

The manipulator includes a movable table where the manipulation object is installed.

In order to improve the manipulator positioning accuracy, the six-coordinate microdisplacement drive is used. Drive 2 is installed on the manipulator table (Fig.12 *b*). A manipulation object is placed on platform 3 of the microdisplacement drive.



a *b*

Fig.12 – A prototype of the spatial drive system for manipulation of objects (*a*) and installation of the microdisplacement drive on the manipulator table (*b*)

The microdisplacement drive application provides the object positioning accuracy of minimum 0.005 mm.

Experimental results have confirmed high efficiency of the developed manipulator.

8. Conclusions

1. The paper substantiates the possibility of implementation of six-coordinate microdisplacement drives based on octahedron-type frame structures. Such drives provide displacement of the object characteristic point in space in the range of 0.2…1.0 mm with simultaneous object rotation about three coordinate axes in the angular range of about 1.25 degrees (75'). This makes it

possible to use the microdisplacement drive in spatial drive systems with significant improvement of their accuracy.

2. The six-coordinate microdisplacement drive is expedient to be implemented in the form of an elastic frame composed of six flat springs. The frame is rational to be made from spring steel (*e.g.*, 651 Г) with respective thermal treatment. In their nominal non-deformed position, external surfaces of flat springs should correspond to the faces of a regular polyhedron – the octahedron.

3. The stress-strain state of the drive frame is characterized by a level of stresses within 100 MPa for different directions and points of applying loads with the value of 3,000 N. In this case displacement of separate points of the frame structure (excluding flat springs) does not exceed 1.25 mm. Stability conditions of flat springs are ensured under different load conditions.

4. Controllability of the six-coordinate microdisplacement drive is close to uniform along all the coordinates. Jacobian matrix of the microdisplacement drive in the form of a frame has components with the absolute value that is by 20%...40% lower than that of Jacobian matrix components for the equivalent link mechanism with respective dimensions.

5. As a result of the six-coordinate microdisplacement drive application in machine-tools of parallel kinematics and in manipulators, the accuracy of such equipment increases by 10…20 times and reaches 5…10 mcm.

6. As further research direction, it is recommended to determine durability (the resource) of the developed spatial microdisplacement drive and new spheres of its application.

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ÎMBUNĂTĂŢIREA PRECIZIEI UNUI SISTEM DE ACŢIONARE SPAŢIALĂ FOLOSIND UN SISTEM DE MICRODEPLASARE ÎN ŞASE COORDONATE

(Rezumat)

Se arată că s-a putut realiza o îmbunătățire semnificativă a preciziei unui sistem spațial de acționare prin folosirea unui sistem special de microdeplasare, fiind prezentată şi soluția de proiectare a acestuia. Baza mecanismului este formată dintr-un cadru spațial cu şase tije elastice, orientate de-a lungul muchiilor unui octaedru. Se prezintă calculul de rezistență al cadrului, dar şi design-ul şi justificarea tehnologică a soluției propuse. S-a determinat matricea jakobiană, care descrie relația dintre coordonatele de ieşire ale arcurilor plate. Utilizarea sistemului de microdeplasare a determinat creşterea preciziei sistemelor de acționare spațială.