tribology in industry

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contents

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Project "Energy Savings Through Tribology"

Within the new cycle of fundamental research for the period of 1996 till 2000., the Ministry for science and technology of Republic of Serbia has accepted to financially support the multidisciplinary project entitled "Savings of energy through tribology. In its realization are included investigators from Faculty of Mechanical Engineering in Kragujevac (the principal investigator), from Faculty of Mechanical Engineering in Belgrade, Faculty of Electrotechnics in Belgrade and Faculty of Technical Sciences in Novi Sad.

Goal and expected results

The proposed project was conceived about the main goal to, through improvement and application of tribological knowledge, significantly contribute to realization of strategic social program for rational managing the energy.

It is expected that the Project results in research and scientifically valid "weapon", motivation and strategy for leading the organized fight against friction and wear, as a road to achieve significant savings at the level of national economy.

The obtained results ought to satisfy the needed successfulness indicators, both during the realization of the Project phases and in the final score. In that, it is especially important that, by realization of this Project, the conditions will be created for realization of several Ph. D. theses submitted by young researchers, as well as 3 M. Sc. theses of assistants-probationers.

State of the art of the research in the world and in our country

The quickly developing discord between the present exponential growth of energy consumption and limited resources of the primary energy carriers, generates the global problem of today and the future development of the humanity. The degree of systematic dealing with this problem is directly related to the degree of the countries' development.

In the highly developed countries (England, Germany, USA, Japan, Canada, China) the significant funds were and are being invested into the long term research strategic programs that have as their objective to identify the areas of the largest tribological sinks, to economically express losses and potential savings, and to define the main research-developing and educational ways of obtaining the estimated savings. Considering the world experiences in this area, it can be expected that paying the appropriate attention to tribology can result in savings (of energetic character) of up to 2 % of the gross national product. Up to 20 % of these effects can be achieved without any significant investments of funds.

The consciousness about tribology as a strategic subject and a cause that may lead to retardation of the modern technological development has caused the expansion of tribological research in the world. As an example can serve the data that by the end of the eighties tribological research in USA was done in about 90 institutions with financial support of over 50 million US $ per year. In financing the tribological programs in this country takes part about twenty government organizations.

Generally, all present tribological research can be grouped into four basic areas with significant mutual overlapping: materials, mechanical systems, lubrication and lubricants and others.

In comparison to industrially developed countries we are characterized, before all, by the following:

- Far larger energy consumption per national product unit;
- Insufficient education in the area of tribology;
- Lower level of application of the existing tribological knowledge; and
- Lack of seriously organized, strategically founded and financially supported research programs of savings through tribology.

Such an undesired gap concerning the developed world promises more convincing potential (relatively expressed) effects at the account of improvement and application of the tribological knowledge.

Program and plan of the project realization work

The program of the project realization is based on the idea that it is necessary to cover the logical order of mutually caused fields:

1. Identification of basic tribological sinks,
2. Fundamental experimental research of tribological mechanisms and possibilities for tribological improvement of elements of the tribomechanical systems structure,
3. Tribodesign based on research from the previous group,
4. Diagnostics according to the state of the technical systems, which contributes to decreasing the negative tribological effects and which represents the source of the return information that are relevant for fields 2 and 3, and
5. Estimation of the possible tribological savings and strategies for their achievements.

The work on the enumerated areas would be organized according to the series of the corresponding activities:

1. Identification of the parts of tribology that are significant for the energy savings (as a basis for directing the tribometric research) and determination of main areas in which the energy is lost due to tribological causes;
2. Investigation of the fundamental mechanisms of tribological phenomena with special emphasis on friction without the presence of lubricant and abrasive wear;
3. Investigation of the machining processes tribology in metal cutting (tribologically advanced tools and cutting fluids);
4. Investigation of machining processes tribology in metal forming (machining at extremely high pressures, drawing of stainless sheet metal);
5. Investigations of the new tribological materials and lubricants;
6. Investigations of modified contact surfaces (hard lubricant coatings, multicomponent coatings, coatings obtained by the so called cold PVD procedures);
7. Definition of tribological influential factors, initial data and phases in the design process of technological systems;
8. Tribological optimization in technical systems design;
9. Investigation and choice of diagnostic parameters of technical systems;
10. Development of technical systems maintenance systems according to state;
11. Estimation of the possible tribological savings in corresponding areas and proposition of strategy for their realization.

Possible users of results

In estimating the potential users it is necessary to start from the worldwide accepted fact that tribology, as a multidisciplinary science and technology, has the generic character, i.e., that it enhances many areas. Due to that, the gain realized by improvement of tribology, even when it is insignificant in one segment (e.g. in the company, and even in the whole industrial branch), has the large significance at the national level. This is why in the world programs as these have a sound of the national campaign, with the aim to transfer the tribological knowledge to the large scope of users that is immanent to this area. Keeping ourselves on that general level, we consider that results of realization of this project would be a valuable help to the Program for rational managing of energy (Program RGE) of the Government of Serbia.

Investigations in 1996.

Investigations within the first year were dedicated to activities aimed to identify those tribological areas that are of the primary importance from the energetic aspect in the broader sense. Considering them, the segments can be separated which in the summary amounts represent the basic tribological sinks. The basis for analyses, besides the existing available data, will represent the experimental measurements of the ratio of the spent electrical energy and mechanical work, as well as the losses of the tribological nature. Also, the preliminary fundamental investigations were performed of the tribological mechanisms that are the most important from the aspect of tribological losses, as well as the certain actions in the area of the knowledge transfer towards the users.

UDK 621.9.025.7.003

RESEARCH

B. IVKOVIĆ

Tribological Approach to Productivity Problems of Industrial Systems

The problem of industrial systems productivity can be solved in several ways by application of knowledge from numerous areas of science and technology. One of possible, very effective approaches, is based on application of the existing, and continuous development of the new tribological knowledge. Tribology is, for the long time now, being considered, in the industrially developed world, as one of the kinds of new technologies, whose application does not require great investments into the new computerized equipment, but on the other hand, it enables significant increase of productivity and reliability of production and transportation systems.

Keywords: *tribology, productivity, reliability, industrial system.*

1. INTRODUCTION

Productivity, reliability and production costs in industrial systems depend, largely, on intensity of development of tribological processes in the contact zones of numerous tribo-mechanical systems, that are contained in production equipment on which the manufacturing processes are being realized.

Tribology is, in industrially developed countries, being grouped into the category of the new types of technologies, by which the increase of production systems productivity is ensured, as well as the significant increase of production processes reliability.

Introduction of the new technologies into industrial systems requires, as a rule, investment of large financial resources, that are being returned in the relatively short or longer time periods. However, the application of tribology as a science and as a type of the new technology makes possible for the increase of production efficiency of the industrial systems without larger investments into the production and other equipment.

By application of the tribological knowledge in practice, and by continuous research to acquire new knowledge of this type, the national gross product is increased in industrially developed countries for *1.3* to *1.6%* annually (between *300* and *500* dollars per capita per year).

Increase of industrial systems productivity and production processes reliability is basically possible to realize, by lowering the friction in the contact zones of numerous tribo-mechanical systems and by slowing down the wear process on their critical elements. From the total energy that is spent in the production processes in industry, for overcoming the friction forces in tribo-mechanical systems is spent from *30* to *50%*, depending on the type of production. The phenomenon of critical wear of tribo-mechanical systems elements is the main cause of stops in production processes and replacements of worn elements of the production equipment by the new ones.

The structure of the possible savings through application of tribological knowledge in industrial systems is shown in Figure 1.

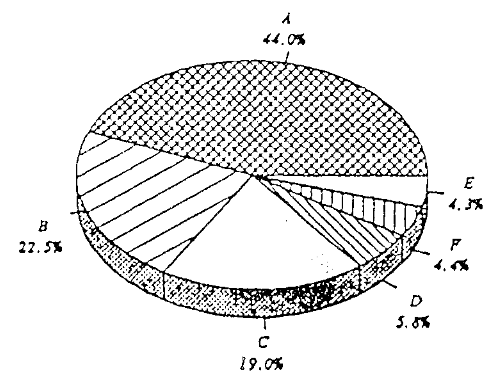

Figure 1. The structure of possible savings in industry through application of tribology

By slowing down the wear process through application of the modern procedures for improvement the wear resistance of the contact surfaces of tribo-mechanical systems elements, and by use of the optimal lubricants, the costs of maintenance and replacements of the worn elements by the new ones, are greatly reduced (*44%*), as well as the costs of production processes stops (*22.5%*), and

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costs of investments into the new equipment (*19%*), due to increase of the working life of the existing equipment.

Through application of the tribological knowledge the energy costs are significantly reduced (*5.85%*), as well as the lubrication costs (*4.3%*) and live labor costs (*4.3%*).

Productivity of industrial systems increases with decrease of production costs. Decrease of stops in the production processes, due to increase of the production equipment working life, also affects their reliability. The tribological approach to proctuwity problems based on these grounds.

2. TRIBOLOGICAL PROCESSES IN INDUSTRIAL SYSTEMS

Production processes in industrial systems are realized on production and other equipment with consumption of material, energy and human labor. The production equipment consists of machining systems in which the machining processes are realized through some kind of existing machining processes (cutting, drawing, unconventional procedures, welding, mounting, etc.). In machining systems are realized all the necessary movements of tools and material in order to realize the machining process, namely to manufacture the basic material into semi finished and finished products. Machining systems are functioning through numerous tribo-mechanical systems (TMS), which can, in one machining center, be as many as several hundreds (classical machine tools) or several thousands (complex CNC systems). In tribo-mechanical systems, in which occur the power and motion transmissions, guiding of machine elements along certain trajectories and the information transmission, and in which are realized the machining processes (cutting, drawing, etc.), there exist and are developing, during the manufacturing processes, also the tribological processes (the processes of friction and wear).

Tribological processes are developing in the contact zones of tribo-mechanical systems elements, depending on the conditions of the contact realization, as well as on the nature of the contact layers of both elements in contact. Regardless of the complexity of the machining system (e.g. machine tools) their working life and reliability of its work depend on intensity of the wear process development and magnitude of the friction force in the contact zones of the numerous tribo-mechanical systems through which the machining system is functioning.

Tribo-mechanical systems contained in manufacturing and other equipment in industrial systems are various and they differ by form and size of elements that make them, as well as by function that they realize in the production process. However, tribological processes (processes of friction and wear) are developing in basic tribo-mechanical systems always with the same structure and way of functioning.

In Figure 2 are shown three tribo-mechanical systems that are present in machining systems in which the metal cutting is performed, and which differ both by function and by size of contact elements.

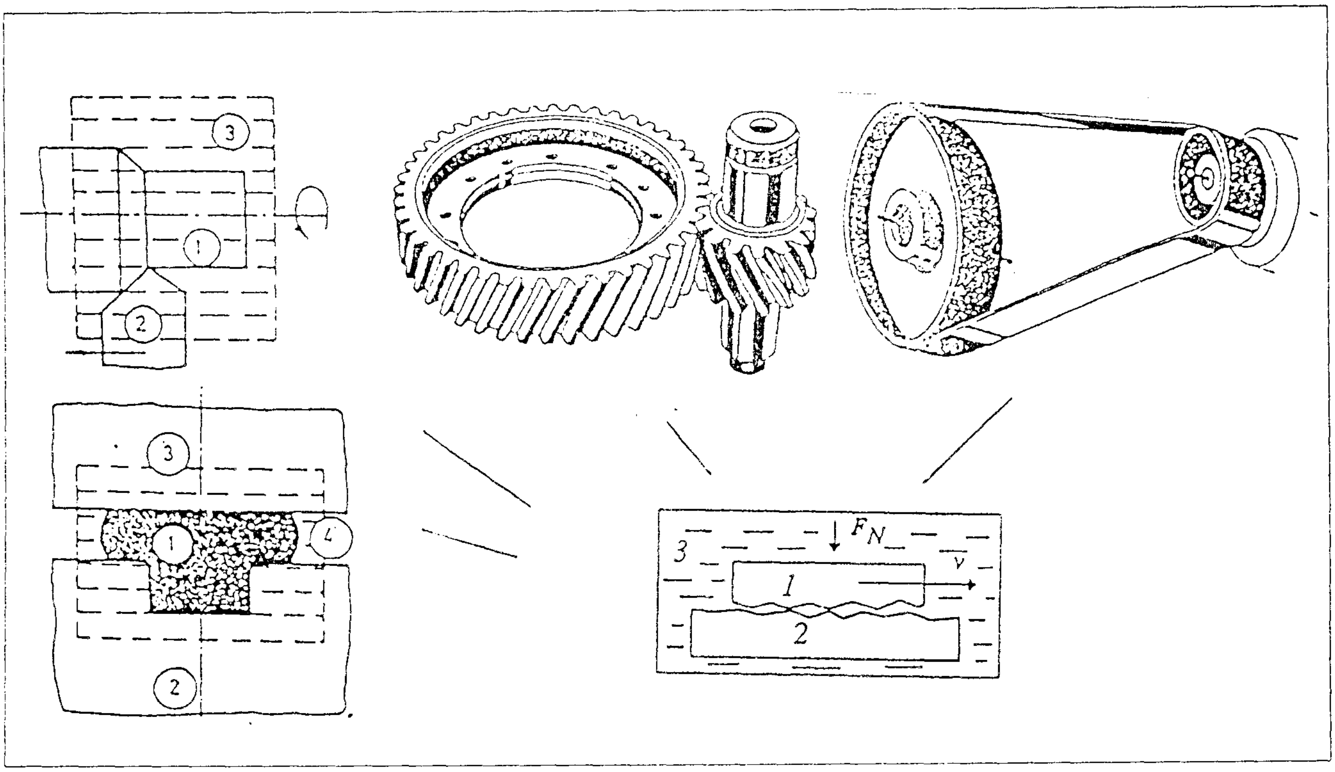

Figure 2. Examples of the tribo-mechanical systems

The basic tribo-mechanical systems differ by conditions of contact realization (outside loading, sliding velocity, contact zone temperatures, contact surfaces roughness), nature of material of solid elements in contact and lubricants.

The need for maintaining the production and other equipment (existing of the maintaining service) and stops in production processes due to failures of production equipment, or due to necessity for substitution of worn tools by the new ones, are the consequence of the wear processes that are developing, during the production processes, in the contact zones of the basic tribo-mechanical systems. The application of lubricants of various kinds in industrial systems is the consequence of the need to reduce the friction (to reduce the energy consumption per product unit) and to slow down the wear process in the basic tribo-mechanical systems.

It can be concluded that, by control of tribological processes that are developing in the contact zones of the basic tribo-mechanical systems, one can control the great deal of the production costs in the industrial systems.

3. PRODUCTIVITY OF INDUSTRIAL SYSTEMS

Productivity of industrial systems is defined, as it is well known, as the ratio between of the realized added value and costs that are realized during the same time period:

$$P = \frac{OUTPUT}{INPUT} = \frac{DV}{UTP}$$

where: *OUTPUT* and *INPUT* are the output and the input value into the industrial system, respectively, and
DV and *UTP* are the added value and the total production costs realized in the industrial system in the observed time period.

Productivity of industrial systems is considered, as a rule, by application of the reicprocal value of the productivity indicator, i.e.,

$$\frac{1}{P} = \frac{UTP}{DV}$$

due to the possibility of identification of partial indicators that are related to individual types of production costs reduced to the added value unit. If, for instance, in the analysis of the realized production process productivity, in certain time period, one wants to notice the possibility for its increase in the next period, the reciprocal value of productivity is defined as the sum of the partial indicators, i.e.,

$$\frac{1}{P} = \frac{UTP}{DV} = \frac{TM}{DV} + \frac{TR}{DV} + \frac{TA}{DV} + \frac{TPO}{DV} + \frac{TE}{DV} + \frac{OT}{DV}$$

where: *TM* are the material costs,
TR are the labor costs (the gross workers wages),
TA are the tool costs,
TPO are the production equipment costs (amortization),
TE are the energy costs, and
TO are the other costs, which can also be divided into their elements.

By this approach to identification of the industrial systems productivity structure in 1988. was performed the comparison of individual types of realized production costs reduced to the added value unit, namely reduced to one dollar of added value in automobile industry of USA and Yugoslavia. The energy costs were in the USA automobile industry twice smaller than in the domestic automobile industry. The labor costs (direct and indirect) were approximately equal in both countries with average gross wages in USA being 6 to 8 greater than in Yugoslavia.

4. PRODUCTIVITY AND TRIBOLOGY

By analysis of partial productivity indicators of industrial systems and structure of possible savings in realization of production processes, by application of existing tribological knowledge, one can come up to the conclusion that the productivity of processes depends greatly on intensity of the tribological processes development, in the contact zones of the tribo-mechanical systems, through which the production and other equipment are functioning.

The cutting process, for instance, is being realized in the tribo-mechanical system that consists of the tool, the machined piece, and the coolant and lubricant. The tool costs, the part of the machine, labor and energy costs, depend on the intensity of the tribological processes that are developing during the machining period in the two basic tribo-mechanical systems, Figure 3.

The value of consumed energy in the machining process, the generated heat in the cutting zone and intensity of the tool wear, depend on the magnitude of the friction force in the contact zones between shavings and the tool front surface, and the tool rake surface and the machined surface of the working piece.

The tool wear intensity affects the tool working life, the part of the labor and production equipment costs, and total tool costs.

This means that the solution of the productivity problems in industrial systems, in which the production process is being realized, is reduced, partly, to the problem of reducing the friction force and the wear intensity in the main tribo-mechanical systems.

Partial productivity indicators of industrial system, that are related to productivity (costs) of the production equipment, labor and energy, are the function of tribological

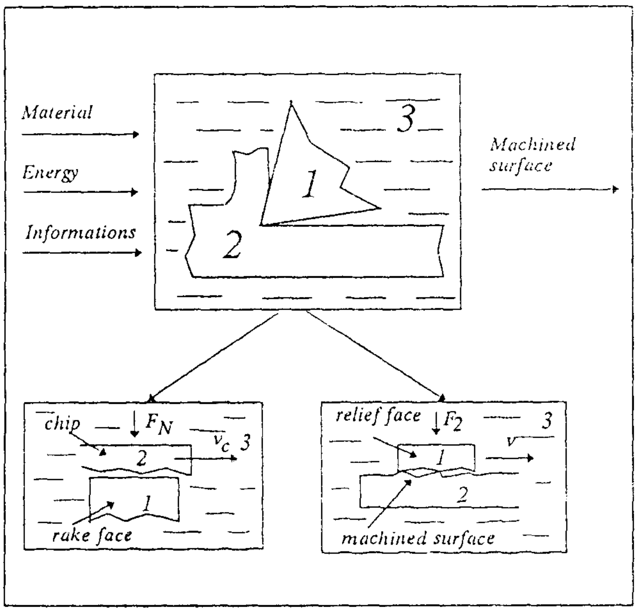

Figure 3. Tribo-mechanical system in the metal cutting

processes in the basic tribo-mechanical systems in which the contact is being realized between the two solid elements in the presence of lubricant.

$$\frac{1}{P} = \frac{TR + TPO + TA + TE}{DV} = F(Ft_J t) =$$
$$= F(\textit{tribological characteristics TMS})$$

In industrial systems, in which the production process is realized by other types of metal machining (forging, metal sheet forming, welding, etc.), the productivity also depends on the character of the tribological processes in the contact zones of the corresponding tribo-mechanical elements. The magnitude of the friction force and the wear intensity in the contact zones of the basic elements of tribo-mechanical systems depends on:

- adhesive,
- abrasive,
- fatigue, and
- tribo-chemical processes in the contact layers of elements in contact.

The knowledge of the friction and wear theories, by which are these processes analyzed, can contribute, to a great extent, to creating the conditions for increasing the productivity of industrial systems. The correct application of these theories in industrial practice enables the reduction of the energy consumption in the production processes, reduction of production costs, and increase of the productivity of the system as a whole.

The tribological approach to problems of increasing the productivity of industrial systems is based on the following:

- application of existing and development of the new methods for data acquisition on tribological characteristics of tribo-mechanical systems elements and forming of the tribological data bases,
- choice of optimal tribological coatings on tools and other elements of the tribo-mechanical systems,
- choice of optimal coolants and lubricants of all kinds,
- application of existing tribological knowledge in all the phases of the production process.

It is very important to always keep in mind that tribological processes and their consequences play an important role in all the phases of production, starting from the product design and production processes preparation, all the way up to their realization.

5. CONCLUSION

The costs of energy, production equipment, tools, lubricants of all kinds and direct labor in industrial systems, can not be reduced without application of existing tribological knowledge and constant development of the new knowledge in this area of science and technology.

Tribology, as a kind of new technology, does not require large investments into the new production equipment, but with application of tribological knowledge the working life of the existing equipment is increased, as well as the efficiency of the production processes, namely the productivity of the industrial system as a whole is being increased.

The tribological approach to productivity of industrial systems is fundamentally, based on studying the processes and phenomena that are developing in the contact zones of the basic tribo-mechanical systems, namely in the contact zones of the two solid elements in the presence of the lubricant as the third element of the system.

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RESEARCH

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Friction and The Development of Technological Processes of Metal Forming by Deformation

Contact friction, due to a series of its specific features and effects in the conditions of plastic deformation of one of the components of the contact couple, has an exceptional influence on the technological process of metal forming by deformation. The paper describes some of the possibilities, bearing in mind all basic features of this type of friction, enabling, by means of transformation of negative (reactive) into positive (active) effects of the friction forces, first of all by change of intensity (increase in particular) and direction, achievement of higher quality of impact-extruded parts, better utilization of blank materials, higher die life, reduced number of operations, higher manufacturing rate etc., in other words significant economic effects.

Keywords: friction, contact, deformation, technological process, machining, active, reactive, effects.

1. INTRODUCTION

Contact (external) friction in the processes of metal forming by deformation essentially differs from the friction in kinematic machine couples. Pressure, temperature, sliding (relative movements) rate, physical/chemical properties of the contact layer etc. in the process of forming by deformation change constantly, some-times very suddenly, both in time and space. Contact friction is one of the main factors determining boundary conditions of technological processes of metal forming by deformation (forging, extrusion etc.). as well as energy and deformation parameters of these processes. Depending on its arrangement, intensity etc., contact friction can significantly increase possibilities of technological processes of metal forming by deformation, but it may also significantly reduce or even completely hinder them. Such effect of the contact friction, as well as significant quantity of energy spent for mastering them etc., imply a need of research into possible new technological processes where the technological limitations will be lessened or gradually eliminated, power consumption reduced, quality of impact-extruded parts and machinability increased etc.

The paper describes some possibilities of solving these problems, primarily by using the so-called active effect of the friction forces in the technological processes of metal forming by deformation.

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2. BASIC NOTIONS AND DEFINITIONS

Differing from the contact friction in machine mechanisms, when the components (parts) of the friction couple are plastically deformed (relatively rigid bodies), the friction in the process of forming by deformation appears between components of the friction couple (impact-extruded part and tool) where one (most frequently) or both components are plastically deformed. Such friction is called deformation friction.

In the processes of forming by deformation the stimulus of the contact friction can be the tool of a part of the impact-extruded piece material. There is a positive influence of the contact friction in these processes, for example at tightening the ends of the sheet metal during the drawing operation...However and regretfully, their negative effect is much more frequent, for example at extrusion on side surfaces of the impact-extruded part etc. Depending on the technological conditions of the process, both active and reactive effects of the friction force can be both positive and negative, i.e. there are four possible cases: positive - active; positive - reactive; negative - active and negative - reactive. Whether the friction forces effect is positive or negative is determined by the content of the technological process, but the activity or reactivity of their effect is conditioned by the diagram of effects of friction forces within limits of the considered part of the contact surface. Very important is also the notion of the degree of performance of activity and reactivity of effect of the friction forces, which depends on intensity of relative speeds at the contact point.

For example, in the case of forging in separate tools, the friction at the rim channel point is reactive, but it is reactive - positive till the filling-up of the tool cavity, while immediately after that it becomes reactive - negative, because it hinders leak of the impact-extruded part material into the rim and increases energy consumption within the process even up to *30-50%* with respect to the total energy required for deformation [1]. To reduce this effect and increase the die life the principle of replacement of the slide friction by the so-called "separation friction" is used, i.e. the tool design is enhanced by widening the rim channel bridge which will provide for the rim separation at the beginning of the final stage of forging, i.e. at the beginning of additional forging. Expansion of the rim channel can be done at one or at both sides by flat or curvilinear surfaces. There are numerous practical solutions.

3. DEVELOPMENT OF TECHNOLOGICAL PROCESSES WITH ACTIVE EFFECT OF FRICTION FORCES

In the conventional technological pr-cesses, the reduction of negative effects of the contact friction, and the said limitations, are achieved mainly by reduction of its intensity by means of lubrication. However, in the development of new technological processes all possibilities of transformation of negative effects of friction forces into positive effects are used, primarily by the change of their direction, intensity (increase in particular) and elimination of use of lubricants. It must be kept in mind that, depending on the technological conditions of the process the effect of the friction forces (both positive and negative one) can be at times active (enhancing the progress of the process) and at another reactive (hindering the progress of the process) or the combination of the two.

Complexity of elaboration of new processes is connected with the following major features of deformation friction:

i) There are different friction conditions at various contact surfaces between the impact-extruded part and the tool and consequently there are various conditions for filling the tool cavities etc., as well as changes of numerous process characteristics. For example, during the forming in separate tools until and after the contact of side surfaces of the impact-extruded part and the corresponding surface of the tool holes, appears a significant difference in deformation and filling of tool cavities. So, as shown in the example in Fig. 1, the contact of the impact-extruded part and the side surface of the tool in the point C results, among other things, in a more difficult filling of some recesses in the tool A.

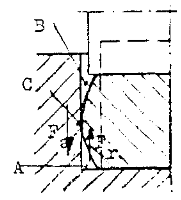

Fig. 1.

ii) In the deformation technological processes there can exist any friction mode: dry, semi-dry and hydro-dynamic. These modes can exist both separately and one at a time, but they can also exist all at the same time, in the same technological process, or can transit one into another in various stages of the same technological process, at the same or at different parts of the impact-extruded part volume. Model of the friction mode and transition from one into another mode is shown at Fig. 2.

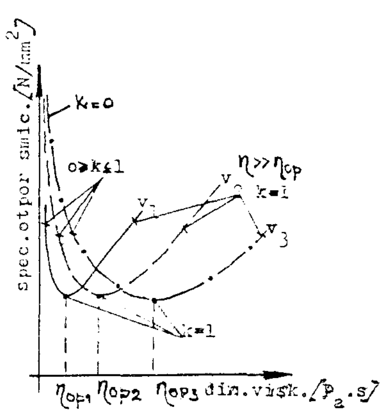

Fig. 2. Diagram of dependence of the specific shear resistance and dynamic viscosity [1]

The figure shows curves in a coordinate system: shear resistance F_{os} - dynamic viscosity η. It is easily noticed that all curves show a steep decline till F_{osmin}, when the viscosity of lubricants is optimal, i.e. corresponds to the transition into hydrostatic friction mode, and then they show growth at viscosity higher then optimal. At infinite viscosity, the specific friction force F_s is determined by the shear resistance of the contact surfaces developed in the mass of one of these contact surfaces, as a result of the fact that one of them has a lower shear resistance. An important parameter, influential on the friction conditions, is the lubrication coefficient of the surface

$$k=Ap/Au,$$

where: Ap - area of the lubricated surface (separated by the third medium);
Au - total friction surface.

Values of the coefficient k for different friction modes are shown in the Fig. 2 and are located within the interval

$0 \leq k \leq 1$, where for $k=0$ it is the dry friction and for $k=1$ hydrodynamic friction.

iii) As the generalizing parameter, characterized by the intensity of contact friction, is considered the specific friction force F_S, i.e. friction forces at the unit of nominal area of contact surfaces, or the shear resistance F_{oS}. It is considered as completely established [1] that the friction coefficient equally depends on: the material of the rubbing bodies and the lubrication mode; shape of friction foci (dimensions of contact surfaces, geometrical shape, mainly, the ratio of contact surfaces and parameters of the third medium); friction conditions (temperature, contact pressure, temperature field in the thin surface layer). Friction coefficient of one contact couple changes within a wide range; thus, for steel rubbing over steel it changes within *0.05 - 0.8* range [1]. The type of material affects the value of the friction coefficient less than the external conditions.

iv) The lubricating layer in forming by deformation is understood not as moving liquid or adsorbing thin layer, but as presence of a third medium between two mutually movable surfaces of solid bodies, one of which is deformable (the impact-extruded part) and the other non-deformable (the tool). The lubricant can be the medium with a viscosity varying from zero (dry friction in the vacuum), dry friction in the gas media (gas lubricant) and liquid, whose viscosity ranges within the boundaries of several Pascalseconds up to infinity. In the last case, the lubricating layer is understood as the third, also solid, body.

4. SOME TECHNOLOGICAL PROCESSES WITH ACTIVE EFFECT OF THE FRICTION FORCES

Successful completion of technological processes of forming by deformation with active effect of friction forces, with respect to all above given comments, can be achieved: by definition of the corresponding technological process diagrams; by design solution of the corresponding tool; by investigation into possibility of achieving these processes on conventional (existing) machines and, if necessary, by definition of technical-technological characteristics of the required machines. Here are some examples:

4.1 Extrusion and active effect of friction forces

Application of the conventional extrusion in cold state has some very important limitations:

i) die life (primarily of the punch) is frequently insufficient for this process to be economically more appropriate compared to the other ones. The principal reason for that are high specific pressures occurring in the process, having the value which in many cases exceeds the value of the impact-extruded part material flow stress. Thus, in the cases of extrusion of impact-extruded parts of medium carbon steels in cold state, the pressure ranges within 2000-25000 MPa which considerably hinders extrusion.

ii) Disruption of continuity of the lubricating layer, having as a consequence sticking of the impact-extruded part material to the punch (when hollow pieces are produced), increase of the friction and extrusion forces and formation of scratches at the internal surface of the impact-extruded part and during its removal from the punch. All that results in the lower quality of the impact-extruded part.

iii) Significant reduction of the impact-extruded part material leak rate, resulting in decline of machinability and cost-efficiency. Leak rates exceeding certain values are, together with friction effect, the principal reason of deficiencies at impact-extruded part surfaces.

Some possibilities for utilizing the active effect of the friction forces in technological processes of forming by extrusion are shown in Fig. 3 and 4, i.e. in Fig. 3 for forward extrusion in forming solid pieces and in Fig. 4 for backward extrusion at forming hollow pieces.

Fig. 3a shows the diagram of the conventional forward extrusion process. The process runs in the conditions where the friction forces FT at side surfaces of the contact between impact-extruded part 1 and the tool 2

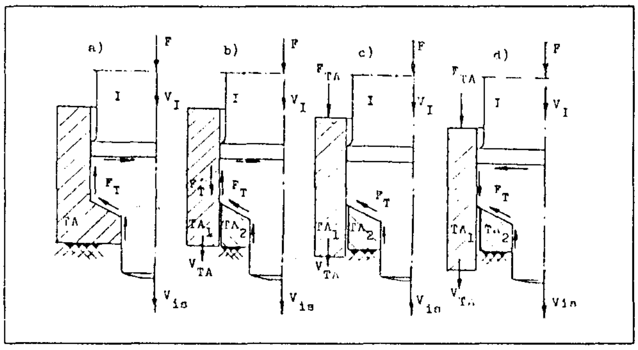

Fig. 3 Diagram of the technological process of extrusion of full pieces

oppose to the process evolution. The same happens at the tapered part of the die, but these friction forces have mutually opposite directions and act radially, i.e. they are directed towards the larger diameter, while at the surface of contact between the front plate of the punch and the impact-extruded part they are also mutually opposite in direction, but oriented towards the smaller diameter, i.e. towards the axis of the impact-extruded part. The last case is particularly interesting, as under the effect of friction forces at that surface and existence of the axial flow of the impact-extruded part material, its separation from the frontal surface of the punch can occur. The main deficiency of the conventional forward extrusion, although the most frequently used in production, is a relatively low limit rate of leak of the impact-extruded part material, primarily due to unfavorable effect of friction forces on the complete contact surface between the impact-extruded part and the tool, and due to very large shift of the impact-extruded part material with respect to the die. The series of impact-extruded part surface deficiencies is the direct consequence.

If the die has two parts, T_{A1} and T_{A2} and if the part T_{A1} is mobile along the direction of effect of the friction forces, the extrusion process will remain the forward type, while forming of the impact-extruded part is achieved with reduced relative movement of the impact-extruded part with respect to the die part T_{A1} which enables an increase in the limit leak rate of the impact-extruded part material. If the external force F_{TA} acts on the part T_{A1} in the direction of the punch motion, then there are two possible outcomes. The first, where the movement of the part T_{A1} is equal to the movement of the punch, due to which the relative movement of the impact-extruded part and the die part will almost completely disappear, and along with it there will be no elimination of the friction force on the contact surface between the impact-extruded part material and the part of die T_{A1} . In that way, in this case, the so called incomplete utilization of the active effect of the friction forces is achieved, but also the increased rate of leak of the impact-extruded part material without the danger of appearance of surface deficiencies. The second outcome, where the full active effect of the friction forces is achieved by the fact that the rate of movement of the T_{A1} part of the die is higher than the rate of the punch, i.e. $V_{TA} > V_I$ (Fig. 3c). At the side contact surfaces of the impact-extruded part material and the die part T_{A1} acts the active friction force, so that a significant increase of the leak rate V_{is} is possible, and accordingly the increase in production rate, too. It was established by experiments that the extrusion process with this process diagram has a characteristic optimum value of kinematic coefficient $K_k=1.4\text{-}1.6$ [2]. The kinematic coefficient for this extrusion is equal to the ratio of rates of movement of the die part T_{A1} - V_{TA} and the rate of punch movement V_I, i.e. $K_k = V_{TA} / V_I$.

Extrusion with the active effect of the friction force and the above described process diagram provides for: increase of the leak rate (for several times) with respect to the conventional process and, accordingly, the corresponding increase in machinability; increase of the coefficient of utilization of impact-extruded part material; reduction of the unevenness of deformations and mechanical properties of the impact-extruded part in longitudinal and transversal direction; elimination of the necessity of use of lubricants; provision of the appropriate directions of the impact-extruded part material flow within the volume to be deformed; formation of required deformation core; intensification of the technological process and, what is particularly important, an increase of the die life and reduction of the deformation resistance. Briefly, the use of active effect of the friction forces can create an efficient replacement of conventional technological processes, with increased techno-economical parameters. The Fig. 4 shows some diagrams of technological extrusion processes in machining the hollow impact-extruded parts. The diagram of the conventional process is shown in the Fig. 4 a). In that case, the die *TA* and lower punch I_d are immobile and only the upper punch I_g is mobile. Other principal diagrams are shown in the Fig. 4 b), c) and d), i.e.: Fig. 4 b) - diagram where the upper punch I_g is immobile, while the lower punch I_d and the die *TA* are mobile; in the Fig. 4 c) the die *TA* is immobile and the lower - I_d and upper - I_g punch are mobile, and, finally, in the Fig. 4 d) the lower punch - I_d is immobile and the upper punch - I_g and the die *TA* are mobile. In all diagrams the directions and vectors of rates, friction forces and respective external forces are shown.

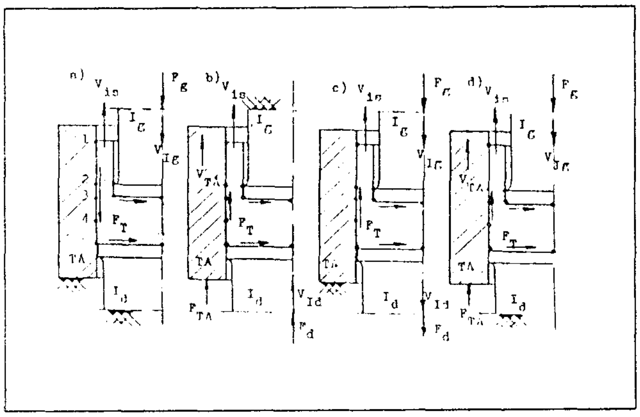

Fig. 4 Diagram of the technological process of extrusion of hollow impact-extruded parts

Besides the presented ones, the possible alternatives are:

1) the die moves - *TA* only under the action of friction forces, i.e. there is no effect of external forces on the die, that is when $F_{TA}=0$.
2) die moves under the action of external forces on F_{TA}.

The simple conclusion is that there can be several technological process diagrams for the forming of the same impact-extruded part. At the free motion of the die only partial reduction of the friction forces on the tool-impact-extruded part contact surface can be achieved, i.e. the incomplete active effect of friction forces can be obtained. The full active effect of the friction forces can be achieved either by a forced movement of the die in the direction of leak of impact-extruded part material, at the rate $V_{TA} > V_{is}$ (Fig. 4 b) or by simultaneous movement of both the upper and the lower punch in the direction opposite to the direction of leak of impact-extruded part material, where the rate of the lower punch - V_{Id} is lower than the rate of the upper punch - V_{Ig} (Fig. 4 c). If the rates V_{TA} or V_{Id} are higher than the rate of leak of the impact-extruded part material - V_{is} then there is an active effect of friction forces at the part of surface 1-5. However, if the said rates are equal, the active effect of the friction forces will exist only at the part of the surface 3-5, and they decline up to zero at the part of the surface 3-4, while at the surface 6-7 and the frontal surface 7-8 the friction forces have reactive character (friction forces and leak rate vectors do not coincide).

Results of the extrusion are, basically, defined by their boundary conditions: kinematic coefficient $K_k = V_{to}/V_{is}$ and specific friction force at the contact surface of the die and impact-extruded part material F_s where

$$0.2 \cdot F_g \leq F_{fs} \leq F_s,$$

and : V_{to} is the relative rate of movement of the die and the impact-extruded part,
V_{is} - the rate of leak of the impact-extruded part material;
$V_{is} = V/(1 - \varepsilon)$,
V - extrusion rate,
ε - degree of deformation;
F_g - limit value of the force determined by the limit value of the shear stress of the impact-extruded part material.

The optimum value of the kinematic coefficient is within the interval $1.05 \leq K_k \leq 1.3$ [3].

Extrusions with the active effect of the friction forces (Fig. 4) are recommended for the formation both in the cold and hot state of the impact-extruded part material, and also both with and without the lubrication. Extrusion in the hot state without the lubrication, although it enables achieving of the full active effect of the friction forces, should be avoided because of difficulties at removing the impact-extruded part from the tool. It should be emphasized that some research results indicate that the reduction of deformation resistance of up to *30%*, as well as an increase of the die life for 2-3 times, and significant economic effects can be obtained 3.

4.2 Several special cases of utilization of the active effect of the friction forces

Utilization of technological processes with the so called moving die offers very wide possibilities. In many cases they provide for the reduction of the number of forming operations.

For example, the process shown at the diagramint Fig. 5 a) provides for the forming to be achieved during forging operation on horizontal forging presses and at the ratio of l/d of even up to 4 (the conventional process can achieve 2-3, l - is the length of the blank portion which is formed and d is its diameter). The diagram of the process shown in Fig. 5 b) enables holding and centering of the blank without prior compression made in order to eliminate tapering of transversal surfaces with respect to the blank axis, occurred at its cutting, i.e. it enables elimination of one operation. It is particularly appropriate in forming rather complex parts, for example the ones with variable longitudinal diameter, when several operations, turning of the impact-extruded part etc. can be eliminated.

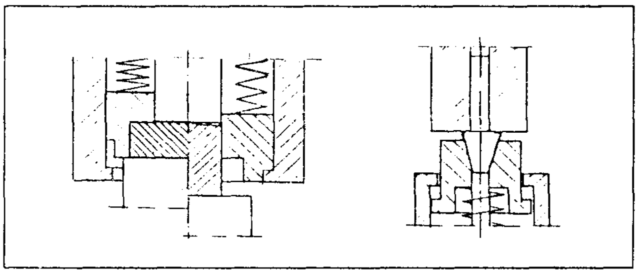

Fig. 5 Diagram of some technological processes with the moving die

Specific and at the same time very important possibilities are offered by the application of moving dies in forming in closed tools. Namely, the complexity of the construction of closed tools is caused by the necessity of existence of an excess blank volume compensator in the final forming stage from the semi-finished part with positive tolerances of diameter and length. Non-existence or unfavorable solution of the compensator in such tools results in the formation of rims on the frontal surfaces of the forging, which may cause damage of the die. It is known that, from the moment of contact of the impact-extruded part and the side surfaces of the die recess, the friction forces hinder filling of the part of the die recess A (Fig. 1), facilitating filling of the part of the die recess B. It is recommended for the design of closed tools that the compensator is placed at the point which will be the last filled by the impact-extruded part material. In that case, at the moment of approach of the impact-extruded part material to the compensator (K, Fig. 6), part of the die recess (B) will be already filled up, so that the impact-extruded part material will start to penetrate the small gap between die parts 3 and 4 and will form a rim on the frontal surface, which will grow as long as the compensator is being filled (due to the increase of pressure in the die recess). Prevention of formation of the frontal rim can be done in two ways: The first is to previously form the impact-extruded part in a special tool, wherein a

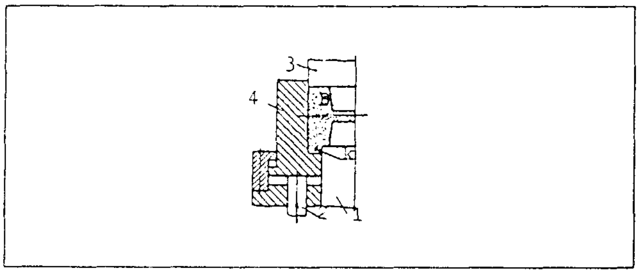

Fig. 6.

distribution of mass must be achieved which will provide for all parts of the recess to be filled at the same time during the forming in closed die. The second way is to provide for the same conditions of the impact-extruded part material leak both in the upper and in the lower part of the die recess, i.e. to provide the same direction of action of friction forces on the side surfaces of the die part 4. This, again, can be achieved in two ways: 1. forming is to be achieved with the backward movement of the die parts 1 and 2 and immobile die part 4; and 2. forming in the die with unfixed die part 4 (i.e. mobile in its axial direction). In the last case, the die part 4 moves under the effect of friction forces, preventing formation of the frontal rim and provides for an active effect of the friction forces (partial utilization of the active effect of the friction forces).

5. CONCLUSION

On the basis of the above presented, but also on the basis of other information from the literature, the following can be concluded:

i) Development of some new technological processes of metal forming by deformation can be based on research of deformation friction and on the grounds of these research works possible diagrams of this process can be elaborated, which will, beside other things, provide also for: higher quality of impact-extruded parts, higher utilization of impact-extruded part material, longer die life, higher production rate etc.

ii) Solution of the complex influence of the contact friction in the technological process of forming by deformation basically consists of a rational connection of the reduction of negative influence of the friction and in the transformation of, mainly, reactive effect of the friction forces into an active one. Although such solutions can be used only in specific stages of the process and only on some parts of the contact surfaces between the impact-extruded part and the die, excellent technical and economical effects can be achieved.

iii) Implementation of elaborated diagrams of technological processes of forming by deformation with the active effect of friction forces is possible only by use of specially designed tools and, most frequently, on multi-operation machines.

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UDK 621.9.625.7.003

RESEARCH

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The Effect Of Nitriding and Material Matching on The Reduction of Wear of Tribo Pair Tappet/Cam in A Diesel Engine

The paper gives a review of a selection of material, i.e. material matching, for tappet/cam pair in a diesel engine timing, since the wear resistance and endurance of the observed tribo pair depend on the proper matching of materials. The taken example, tappet/cam of a diesel engine, illustrates the importance of hardening procedure and material matching and describes some damages (failures) that might occur during engine operation. Tests have proved that chilled grey iron tappets offer the best exploitation (service) characteristics (the lowest wear and the highest scuffing resistance). For tests performed on a high-speed diesel engine the author used a combination of plasma nitrided tappets mated with camshaft whose cams have been chilled. This combination applied in an engine powering a vehicle has given a very good performance and proved to be reliable which is not the case when gas nitrided tappets are in question.

Keywords: *material matching, nitriding, wear, scuffing, valve tappet, camshaft.*

1. INTRODUCTION

Modern technical development imposes more stringent operating conditions on machines and engines. The intensification of operating processes in machines and engines is connected mainly with speed and load increase ant the reduction of mass (weight). When engines are in question the tendency moves towards continuous increase of specific power, meaning that levels of mechanical, thermal, aerodynamic and hydrodynamic stresses of mated components are considerably increased which again increases the probability of failure due to wear and fatigue. Tests [1] have shown that *80%* of all tribologic problems encountered in machine building industry is attributed to sliding and rolling elements, one fourth of which goes to wear. The wear can have much greater effect on material fatigue than stress concentration although nominal stresses are of relatively low level. The excessive wear of engine components disturbs normal engine running, increases fuel/oil consumption, increases vibrations, noise and exhaust gas emissions. So, for example, the excessive wear of cylinder/piston engine assembly increases air pollution by *25%* [2]. The most common types of wear "adhesive wear" and "contact fatigue" are respectively identified as scuffing and spalling in tappet/cam functioning [3, 4, 5].

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Adhesive wear occurs when metallic surfaces in relative motion are either in contact without lubrication or where boundary conditions are obtained. Under these conditions wear will occur by adhesion in the junctions and subsequent shearing of these welds, and also by "ploughing" due to the displacement of the surface of one part by the asperities of the wear. Scuffing is the surface damage due to welding and ploughing, frictional wear as the loss of metal resulting from these two factors, and seizure is the ultimate stoppage of motion when the friction force can no longer be overcome. Any treatment which may be effective in combating scuffing may therefore also combat wear and seizure.

There is still no unique approach to the adhesion mechanism process - scuffing. It is however, considered that, for the realization of a tighter bond, adhesion between atoms, on mating surfaces in a cold state, the absence of any type of film is essential [1]. Since there is always a film, either oil or oxides or other impurities, on metal surfaces it is necessary that stresses reach a certain value in order to destroy such film. For metal particles adhesion their mutual solubility in a solid solution of mated metals is of utmost importance. The better the solubility the greater the inclination to adhesion-scuffing. The scuffing usually occurs at such spots where contact stresses are excessive as is the case of tappet/ cam pair in an internal combustion engine. Therefore when selecting materials for cam and tappet a great attention must be paid to their possibility to match (mate) since the reliability and endurance of such tribo pair will depend on the right choice [6].

Contact fatigue is a fatigue-cracking phenomen associated with high Hertzian contact stresses at the mating surfaces, which leads to "spalling", pitting, flaking, or delamination of surfaces. Therefore pitting is the failure of a surface, manifested initially by the breaking-out of small roughly triangular portions of the material surface. This failure is primarily due to high stresses. Fatigue failure is initiated at a point below the surface where the highest combined stresses occur. After initiation a crack propagates to the surface, and it may be that the subsequent failure mechanism is that the crack than becomes filled with lubricant, which helps to lever out a triangular portion of material. Heavily loaded surfaces will continue to pit with increasing severity with time. Pitting is affected by the size of contact (shearing) stresses, properties and microstructure of mating surface contact faces, as well as by the type of lubricant.

Under high stress concentrated contact conditions typical of cam / tappet interfaces, the classically determined hydrodynamic lubricant film thickness becomes very small, approaching the typical surface roughness height.

This indicates that physical asperity contact occurs and the lubrication mechanism involves elastic deformation of both surfaces representing on elastohydrodynamic type of lubrication.

Spalling resistance is improved by 1) strengthening the material with heat or surface treatments, and 2) avoiding stress raisers in the material.

The resistance to wear is improved by lubrication-by reducing friction coefficient, by improving mated surfaces machining quality, and by strengthening material surfaces using heat treatment or chemical / thermal treatment or by applying some other layers on mated surfaces. By reducing friction in an engine we achieve not only the increase of components endurance, but also fuel economy. For example, friction reduction of *10%* results in *5%* better fuel economy in petrol engine and *7%* in diesel engine [2]. In the case of tribo pair tappet/cam the most frequently used methods to improve wear resistance are as follows: induction hardening, local electric arc remelting, case hardening and nitriding. It must be pointed out that, from the aspect of endurance, it is not irrelevant which method will be applied. Therefore, only the right selection of tappet/cam materials and their appropriate heat treatment or chemical/thermal treatment will provide a reliable long term running free from wear and scuffing. In that respect some tests on wear resistance of certain combination of mated materials used for tappet and cam as well as of types of nitrided layer on the tappet have been performed [7], in view of the fact that data available in literature appear to be rather scarce [8, 5]. Tappets, i.e. valve tappet plates were nitrided in ammonia and in gas mixture plasma (ion) while cams were chill hardened in the process of casting. It was found that nitrided zones (layers)obtained by ion nitriding showed higher wear resistance than those obtained by gas (conventional) nitriding in ammonia.

2. TEST CONDITIONS

To realize the effect of material matching on the tribo pair tappet/cam wear and scuffing, two groups of tests were performed: engine and rig tests. Rig tests were carried out on the tappet/cam pair so that both tappet and cam materials had been alternatively changed. The existing technologic equipment available in production enabled the author to perform wear resistance tests on special samples with nitrided layers obtained by various nitriding procedures. The testis were carried out on Amsler machine. The test samples were *30 mm* dia. discs, *10 mm* thick, made of Č.4732 steel, hardened and tempered prior to nitriding to reach hardness of $HB=270\text{-}300$. After hardening and final machining one group of samples was submitted to nitriding in ammonia by conventional procedure: *25h* at 510^0C, while the other group was submitted to plasma nitriding, with variable ratio of N_2 and H_2. Parameters used for ion nitriding were as follows: temperature: 500°C, time 12h, voltage *450-600W*, current density $30\ A/m^2$ and vacuum *200-400 P.* Prior to plasma nitriding samples had been cleaned from oxides and other impurities by spattering in hydrogen stream for one hour.

Due to scarcity of data on characteristics of mating various combinations of tappet/cam and owing to available technology facilities, in addition to testing wear and scuffing resistance of nitrided valve tappets used in a high speed diesel engine, the author also tested changes of dimensions and surface roughness. Therefore, before and after nitriding in gas and plasma, diameters and surface roughness were measured. Initially valve tappets were *41.8 mm* in dia., *4 to 5 mm* made of Č.4732 steel, hardened to $HB=270\text{-}300$.

Due to high Hertzian pressures the quality of cam and tappet surfaces finish is of great importance for their endurance. Some renown world engine manufacturers are of opinion that the reliable operation of this tribo pair depends more on the quality of machining than on the application of phosphate layer. Therefore they specify $R_a=0.10\ \mu m$ for the specific mating surfaces of tappet/cam.

Engine tests on the tribo pair tappet/cam were performed on a test bench and in service.

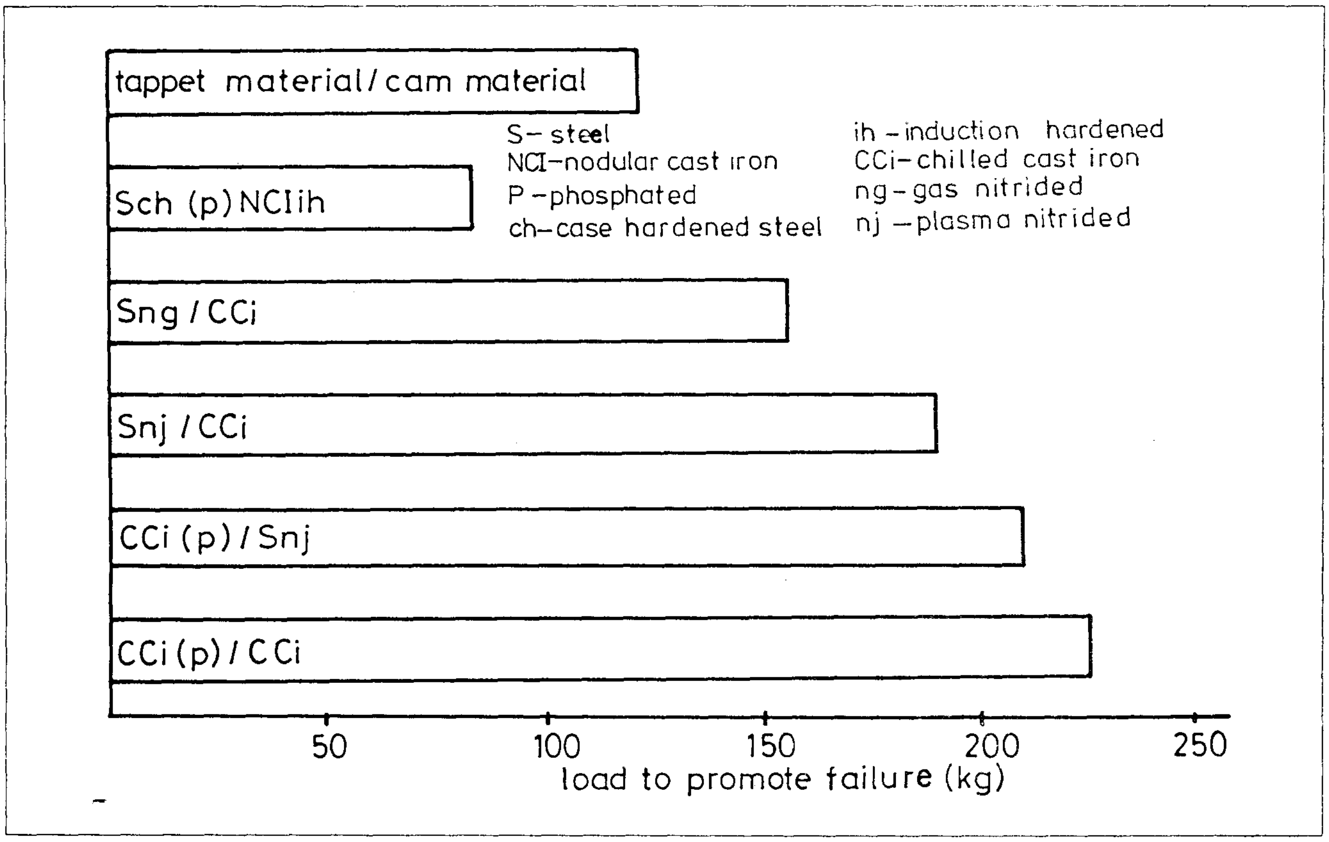

Fig. 1. Comparative durability of cam and tappet material combinations

3. TEST RESULTS

Fig.1 shows results obtained by testing wear and scuffing resistance of various combinations of mated materials.

It can be seen that chilled-phosphated grey iron tappets mated with chilled grey iron cams show the best exploitation characteristics, i.e. the lowest wear and the highest scuffing resistance under the excessive load. Hardness obtained by chilling was *540 to 570 HV*. In extremely heavy operating conditions the first damage (failure) that will occur on so mated surfaces is pitting. Somewhat poorer results are obtained with the combination chilled-phosphated grey iron tappet mated with ion nitrided cams (HV_1=*610-650*), of the camshaft being made of medium carbon steel. Possible failure in engine service is tappet pitting. Still poorer results are obtained with steel plasma nitrided tappets (HV_1=*660-710*) mated with chilled grey iron cams. Mating of steel gas nitrided tappets (HV_1=*680-730*) with chilled cams shows very poor scuffing resistance because hard nitrided layer tends to flake under excessive loads which ultimately leads to scuffing. The worst results are obtained with case hardened steel tappets (HV_1=*610-730*) mated with induction hardened nodular iron cams. Such mating leads to intensive cam wear and frequent scuffing at moderate loads. From the aspect of wear and technology production facilities a combination of plasma nitrided Č.4732 steel tappets mated with grey iron camshaft whose cams have been chilled, has been selected for a high-speed diesel engine. Engine tests have shown that the above mating gives good results since no wear of seizure has been experienced in exploitation (service). The same combination except for tappets that were gas nitrided did not give satisfactory results during engine tests. After *100h* of engine running the tappet compound layer (Fig.2) formed during gas nitriding started to flake.

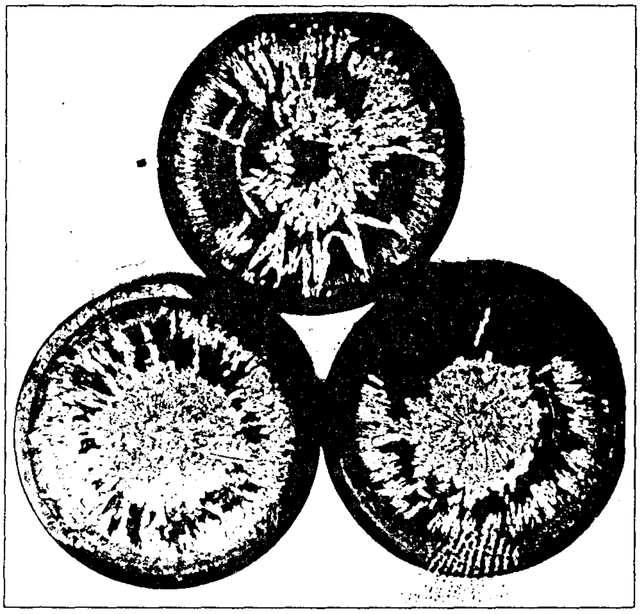

Fig. 2. Gas nitrided tappets upon removal from the engine that performed 100h running

This actually means that the nitrided layer, i.e. its compound layer formed during gas nitriding is susceptible to wear and cracking, then to flaking and eventually to scuffing when in addition to adhesive an abrasive wear is initiated. All the above is the consequence of high Hertzian pressures that occur in operation.

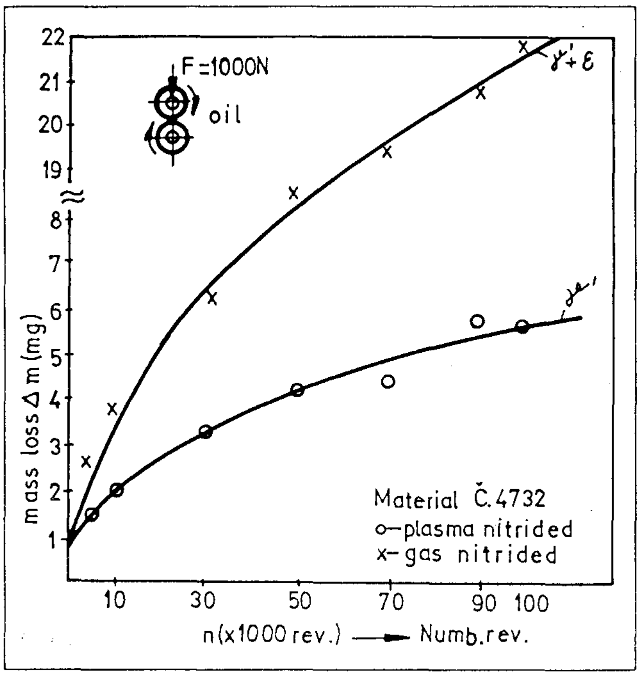

Fig. 3. Resistance to wear found with plazma nitrided (γ') and gas nitrided ($\gamma'+\varepsilon$) samples

Rig tests performed on ammonia and plasma nitrided samples show that plasma nitrided samples under conditions of γ'- phase formation have higher resistance to wear and scuffing than those nitrided in ammonia (fig.3).These differences are mainly due to the variety of nitrided layer properties. During plasma nitriding a monophase compound layer (fig.4). of γ' is formed. This layer has considerably lower friction coefficient than duplex compound layer ($\gamma'+\varepsilon$) which is formed during gas nitriding. The duplex compound layer is more brittle and porous in comparison with γ' compound layer.

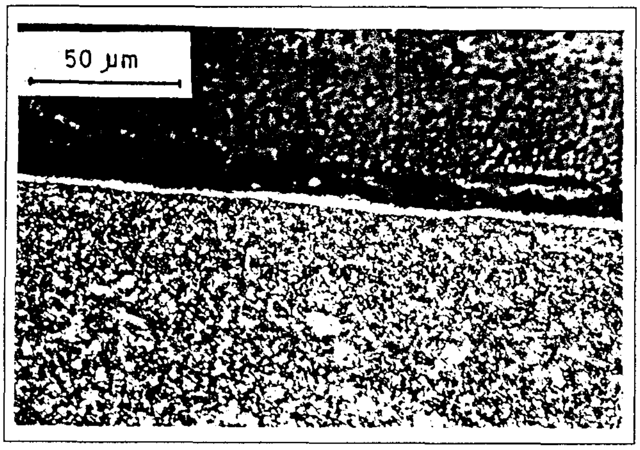

Fig. 4. Microstructure of valve tappet nitrided in plasma gas mixture (x400)

It can be seen, in Figs, 4 and 5, that duplex compound layer is approximately 6 μm thick while the monophase compound layer is about *2 μm* thick. The identification of compound layers has been made by *x-rays*. Thus although surface hardnesses obtained by ion and gas nitriding are approximately the same (*640-710 HV_{03}*), and nitrided layer thickness almost identical (*0.5 mm*) their exploitation properties-resistance to wear and scuffing - are different.

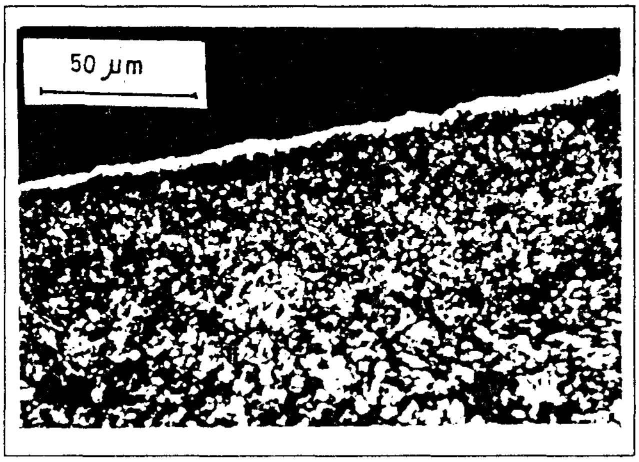

Fig. 5. Microstructure of valve tappet nitrided in ammonia gas (x400)

In addition to the mentioned basic differences in behavior to wear and scuffing of monophase and duplex compound layers obtained by gas and plasma nitriding, respectively, they variously affect dimensional changes and surface roughness. Dimensional changes with plasma nitriding seem to be *10 to 13%* lower than those occurring with ammonia nitriding, while surface roughness is lees changed with plasma than with ammonia nitriding. Generally speaking, the finer the machining the greater the roughness. For example if surface R_a prior to nitriding reads *0.1 μm*, after nitriding it will be *0.2 μm*. If, however, R_a before nitriding reads *0.6 μm* it appears to be approximately the same after nitriding, and if R_a before nitriding equals *1.2 μm* its value after nitriding goes down.

4. CONCLUSION

On the basis of obtained results one cane conclude as follows.

1. Material matching for tribo pair tappet/cam is of utmost importance from the aspect of wear and scuffing and consequently endurance.
2. Chilled-phosphated grey iron valve tappets mated with chilled cams show the best exploitation (service) characteristics. The worst characteristics are obtained by case hardened tappets mated with induction hardened steel cams.
3. Plasma nitrided valve tappets mated with chilled cams show higher resistance to wear and scuffing

than those nitrided in ammonia which experienced flaking of the compound layer during engine running.

4. In addition to higher resistance of plasma nitrided layers to wear and scuffing, in comparison with those nitrided in ammonia, the former cause 10 to 13% less tappet dimensional changes.
5. Compound layers obtained by plasma nitriding are of monophase (γ') nature and, are more ductile than duplex compound layers ($\gamma'+\varepsilon$) obtained by ammonia nitriding which appear to be more brittle and susceptible to flaking.

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Influence of "Bio-diesel" Fuel on Diesel Engine Parts and Motor Oil

This paper presents the results of effects of "Bio-Diesel" fuel on engine parts and engine oil over a long period of operation of a Diesel engine. The tests have been conducted under laboratory conditions on standard test benches and with standard attending equipment at the IMR. NIJ Institute. Two types of engines of the same class and similar performance, but with different fuel injection systems, had been selected for these tests: one with direct injection, and other with indirect injection. "Bio-Diesel" was used as fuel. This fuel is obtained by the reesterification of rape oil and it represents methyl ester of rape oil. SAE 15W40 lubrication oil of API CD/SF grade was used to lubricate these engines, and analyses were made at NIS - RN Belgrade on standard equipment and with the standard methodology applied. The purpose of these tests was to answer the question whether it is possible to operate Diesel engines with direct and indirect injection on "Bio-Diesel" fuel, to quantify the effects of such fuel on the engine functional characteristics, to determine the extent to which engines could be run on "Bio-Diesel" on a long-term basis, and to initiate the formation of a standard and methodology for testing the quality levels of this fuel.

Keywords: *Engine, "Bio-Diesel", testing.*

1. INTRODUCTION

At the beginning of 80ties, in world, and particularly in Europe, intensive research was initiated on possibilities of producing alternative types of fuel, which would adequately replace Diesel fuel, the production of which is based on limited natural resources. Of particular importance for exploitation are fuels obtained on the basis of plant cultures. For our country that was a special challenge when we found ourselves in situation in which oil derivatives were almost inaccessible to us. In this period, using our own technology, we managed to produce several types of fuel suitable for operating Diesel engines which were based on oils obtained from plants. The best results from the point of view of economic mass production physical/chemical characteristics were shown by the fuel produced by the reesterification of rape oil representing its methyl ester. Since this fuel differs from Diesel fuels, it was necessary to perform complex homologation tests on this fuel which we named as "Bio-Diesel". These tests were conducted with the aim to find weather it is possible to operate Diesel engines on "Bio-Diesel" fuel, to determine the effects of such fuel on engine functional characteristics, to determine engine durability or its working life, and thereby the effects of this fuel on engine parts wear and on engine lubrication oils of standard production. In this paper we have presented that part of those complex tests which we believe is the most interesting for presentation, and which relate to the tests on the effects of "Bio-Diesel" on engine parts wear and engine oil properties.

2. TEST METHOD

The tests have been conducted under laboratory conditions on standard test benches and attending equipment and in accordance with standards for testing Diesel fuels. Two types of engines of similar characteristics and application had been selected among the most widely spread types in our country. Their specifications are shown in Table 1.

Table 1. Diesel engines specifications

	Indirect Injection Engine	Direct Injection Engine
Number of cylinders	3	3
Cubic capacity	2500 cm^3	2500 cm^3
Compression ratio	17.4:1	16.5:1
Rated power	31 kW /2250 r.p.m	34.5 kW /2250 r.p.m
Maximum torque	149 Nm /1400 r.p.m.	162 Nm /1400 r.p.m
Minimum specific fuel consumption	255 g/kWh	237 g/kWh

"Bio-Diesel" was used as fuel in both engines, and comparison was made with the results obtained in operating

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engines on conventional fuel. Some of physical/chemical and heat characteristics of both "Bio-Diesel" and conventional fuels related to those on which the comparison was made are show in Table 2.

Table 2: Physical/chemical and heat characteristics of "Bio-Diesel" fuel and conventional Diesel fuel

Item N°	Fuel characteristics	Diesel Fuel	"Bio-Diesel" Fuel
1	Gravity at 15°C(g/ml)	0.839	0.888
2	Destillation: Start Point 5% 10% 30% 50% 70% 90% End Point	230 232 240 270 298 326 347 400/94	287 330 335 338 344 355 379 384/98
3	Viscosity (mm^2/s) at 20°C 40°C	6.37 4.30	8.14 5.00
4	Cloud Point (°C)	+7	-5
5	Filterability (°C)	+4	-7
6	Pour Point (°C)	+1	-11
7	Coke content (mass) 100% 10%	0.028 0.072	0.12 1.20
8	pH	0.100	0.384
9	Russian Method Cetane Index ASTM 976 IP	56.5 56.0 56.5	58.4 - 46.8
10	Flash Point (°C)	85	175
11	Sulphur Content (%)	0.2	-
12	Hd (MJ/kg) Marder's formula	42.6	36.1

SAE oil of 15W40 grade and API CD/SF class from the regular production had been selected as lubricant. Each of these two engines operated on "Bio-Diesel" *300 working hours* continuously in stages, and changes during one stage are shown in table 3.

Table 3: Changes in operating mode during one stage

Mode Item Number	Scale Load [kp in %]	Speed [r.p.m.]	Engine WorkingHours [min]
1	0	500 ±30	10
2	60	1300	20
3	0	500 ±30	10
4	50	2250	20
5	0	500 ±30	10
6	100	1300	20
7	0	500 ±30	10
8	100	2250	20
		TOTAL:	120

Samples of engine oil were taken for analysis every *50* engine working hours, with care taken that the total quantity of make up oil and consumption during operation do not exceed *1/3* of the volume of oil specified for each of the engines. Before the tests, both engines were factory overhauled, micro-measurements were taken and all vital parts were visually inspected. During the test runs, all functional characteristics were monitored, which means that included also: engine oil pressure, oil temperature, blow-by, and the volume (level) of oil in the engine sump (i.e. the consumption of oil).

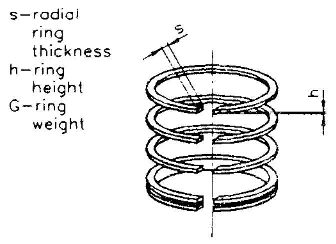
At the and of the tests, both engines were dismantled, visually inspected and micro-measurements were taken on all vital parts of both engines.

3. TEST RESULTS

Test results showed that in both engines power degradation occurred in an average amount of about *5%*, that torque was reduced also for about *5%*, that the volume of injected fuel (measured by weight method) was increased by about *5-8%* on an average, the specific consumption of fuel was increased by about *3-7%* on an average, and that the temperature and smoke of exhaust gases were reduced. All these results relate to the comparison of functional operating characteristics of both engines with "Bio-Diesel" fuel in relation to Diesel fuel. It should be pointed out that no degradation of functional characteristics was found when their values at the beginning of the tests were compared with those at the end (i.e. after *300 working hours*) with both engines, both when "Bio-Diesel" and Diesel fuels were used. In this paper we shall comment particularly the results and their analysis in that part of the homologation tests relating to the effects of "Bio-Diesel" on the engine working life and its effects on the lubrication fuel.

3.1 Review and analysis of micro-measurements and observations in visual inspection of both engines

By comparing the micro-measurements made on both engines, the following results are obtained: The micro-measurements on both engines have shown that wear on characteristic parts was within the limits specified for the observed period of operation. To confirm these results, the inspection of mean wear values on the piston assembly of both engines was selected, since the changes occurring due to wear are most distinct on this assembly and because it is simultaneously exposed to the effects of both fuel and oil to a large extent. Fig.1 shows the mean values of wear on piston rings, Fig.2 illustrates wear on pistons, and Fig.3 on cylinder liners, both for engine with direct injection and for that with indirect injection.



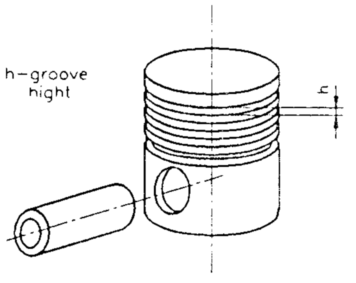
IDI

piston	1st RING			2nd RING			3rd RING			4th RING		
	Δs	Δh	ΔG	Δs	Δh	ΔG	Δs	Δh	ΔG	Δs	Δh	ΔG
1	13.2	6.6	12.3	7.0	2.2	4.0	7.0	4.6	2.6		0.6	1.9
2	11.8	3.8	5.7	5.6	1.6	2.6	5.6	4.0	2.2		3.0	1.9
3	15.0	4.0	6.0	8.0	2.5	2.8	7.2	1.0	1.8		1.6	1.3

DI

piston	1st RING			2nd RING			3rd RING			4th RING		
	Δs	Δh	ΔG	Δs	Δh	ΔG	Δs	Δh	ΔG	Δs	Δh	ΔG
1	17.0	10.2	9.4	6.8	3.6	4.8	6.2	3.4	3.3		0.4	4.3
2	17.6	8.8	12.6	3.2	1.6	4.9	5.6	2.6	3.3		3.2	4.0
3	18.2	12.0	10.6	3.8	2.6	3.2	5.4	2.2	2.9		0.8	3.7

Fig. 1 - Mean values of piston ring wear for direct injection engine and for indirect injection engine



IDI

piston	1st groove	2nd groove	3rd groove	4th groove
	Δh	Δh	Δh	Δh
1	0	2.5	0	0
2	5.0	0	0	0
3	0	0	2.5	2.5

DI

piston	1st groove	2nd groove	3rd groove	4th groove
	Δh	Δh	Δh	Δh
1	5.0	5.0	2.5	5.0
2	0	0	0	0
3	0	5.0	2.5	5.0

Fig. 2 - Mean values of piston wear for indirect injection engine and for direction engine

For other parts on which the micro-measurements were taken, such as piston pin, cylinder head gasket, valves, bearings, etc., no presentation is included due to space limitation, but with other parts also no wear beyond the specified limits for the observed period of engine operation was found.

3.2 Survey of tests on main physical/ chemical characteristics of engine oil samples taken during testing

Oil samples, as already mentioned before, after *50 hours* of operation for each engine separately were taken. On these samples the following characteristics were examined: viscosity at *40°C (mm^2/s)*, viscosity at *100°C (mm^2/s)*, flash point (°C), TBN (mgKOH/g), membrane filtration on *0.3μ* filter (g), metal content (Fe, Cu, Al) in %, water content in %, and fuel content in %. In addition to the curves showing changes in certain characteristics, the curves of the same characteristics in operation on Diesel fuel are given in all diagrams. Fig.4 shows the change in viscosity at 40°C for both engines, and its value does not exceed the limits set out for this grade and quality level of oil.

Fig. 5 shows the change in viscosity at 100°C, and this characteristics does not exceed the specified values.

The change in the TBN value was negligible over the entire test period and was considerably above the minimum limit allowable for both engines, and the course of its change is shown in Fig.6.

The content of solid matter in oil shows a constant increase of suspended solids, which means that the detergent and dispersing properties of oil were rated during the entire test. Somewhat higher values than those obtained in operation with Diesel fuel can be explained as due to inferior physical/chemical and heat properties of "Bio-Diesel" fuel reflecting on the quality of combustion, which is less favorable in comparison with the quality of Diesel fuel combustion. At the combustion of "Bio-Diesel" fuel, a higher volume of soot develops and suspends in oil, as can be seen on Fig. 7.

The content of metals in oil was monitored by the atomic absorption analysis. The content of Fe, Cu and Al was analyzed also. The content of iron (Fe) in oil samples from both engines shows an increase in the first *100* hours of operation, and then stagnates. Fig.8 shows the per cent increase, and the amount of that increase is not in such a percentage that would indicate a higher wear rate.

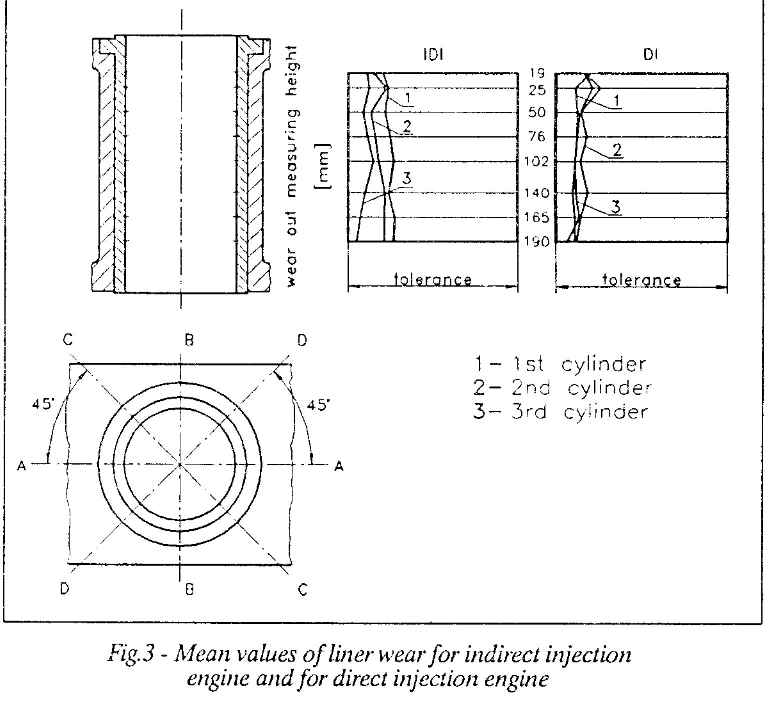


Fig.3 - Mean values of liner wear for indirect injection engine and for direct injection engine

The content of copper (Cu) in oil samples from both engines shows a gradual increase in the first *150* working

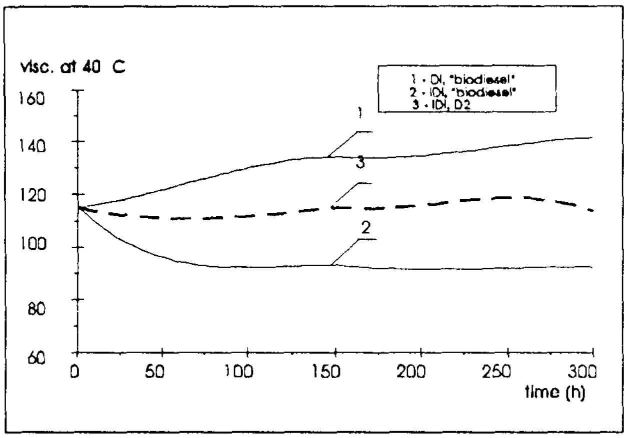


Fig. 4 - Change in viscosity at 40°C during 300 engine working hours

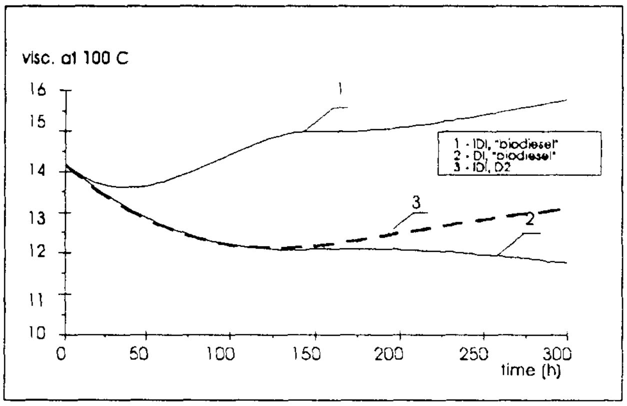


Fig. 5. Change in viscosity at 100°C during 300 engine working hours

hours, and then falls rapidly. The change in copper content in per cents is shown in Fig.9.

The content of aluminum (Al) in oil samples from both engines shows a rapid increase between *100* and *200* working hours, and then stagnates which can be seen from Fig.10.

From the presented diagrams it can be seen that none of the involved metals is more considerably present in oil samples and that their content does not indicate increased wear in any of the observed engines over 300 engine

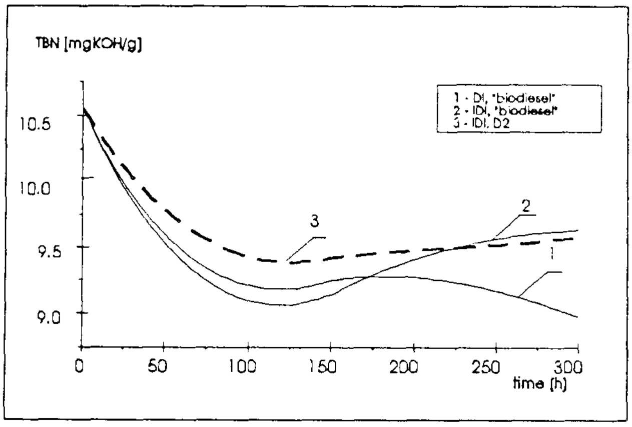


Fig. 6. Change in TBN during engine workung hours

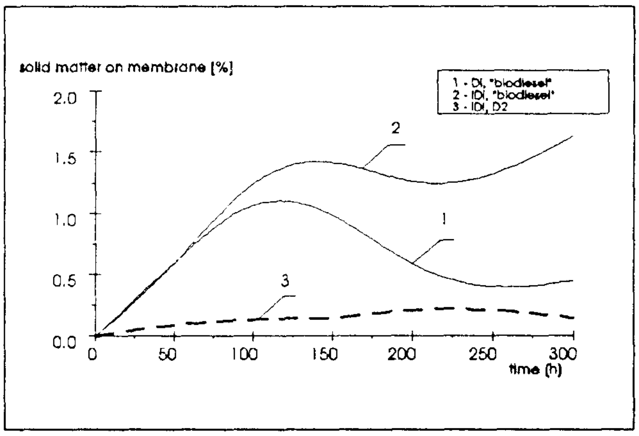


Fig. 7. Change in the solid matter content of oil during 300 engine working hours

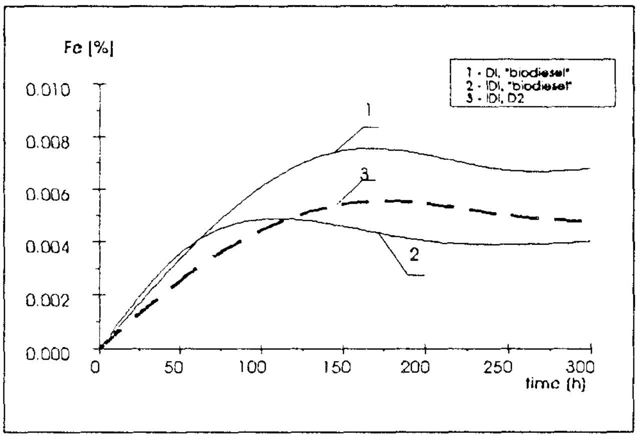


Fig. 8. Iron (Fe) content in oil samples from both engines

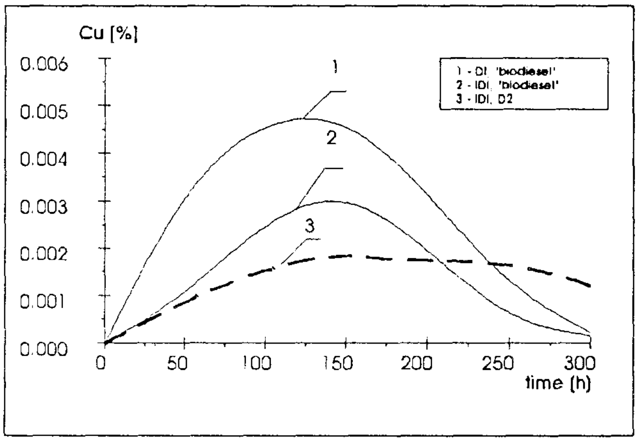


Fig. 9. Per cent content of copper (Cu) in oil samples from both engines

working hours. A water and fuel were not found in any of the samples. Engine parts did not have a uniformly distributed oil film, but spots with a thicker sticking layer of oil were found. Increased deposits of coke and soot were noted on engine parts, whereas paint and varnish deposits were reduced. Those phenomena are not characteristic when an engine runs on Diesel fuel, at least not after *300* working hours.

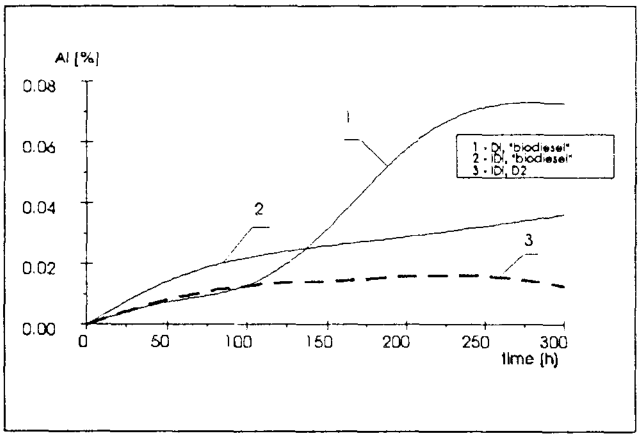


Fig. 10. Per cent content of aluminum (Al) in oil samples from both engines

4. CONCLUSION

During the test, both engines were run without breaks, and oil pressure, blow-by, oil temperature and consumption were within the specified limits. Micro-measurements taken on before and after operation showed that wear on parts of both engines was within the limits specified for the observed period of engine operation. SAE engine oil of 15/W40 grade and API/SF service met requirements for the observed period. Taking into account the phenomena noticed by visual inspection, it can be concluded that further investigation of the effects of "Bio-Diesel" fuel both on oil and engines parts is required, and that further work is necessary also to develop the methodology for testing lubrication oils used in engines running on "Bio-Diesel".

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RESEARCH

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Optimisation of The Tribology Characteristics of The Material for The Sealing Element on The Diesel Engine Water Pump

The tests of the reliability and service life of the diesel engine water pump show that the pump sealing presents the basic problem to which the special attention should be paid. The analysis of the sealing element mechanism underlines the need to improve its tribology characteristics. This can be done by changing the parameters of the material quality and its physical and chemical characteristics. The paper presents part of the laboratory testing of the water pump carried out in the IMR Institute. The optimisation of the tribology characteristics of the material for the sealing elements results in increased reliability and service life of the water pump thus influencing directly the improvement of the diesel engine quality.

Keywords: *sealing elements, reliability, service life, tribology characteristics.*

1. INTRODUCTION

There is no doubt that consideration of the usage quality and reliability of the diesel engine requests for consideration of a number of significant factors. In other words, in order to achieve the optimum level of the usage quality and reliability of the diesel engine it is necessary to accommodate the elements' quality and engine systems. In modern mechanical engineering, the mechanical elements, being the parts of the machines and mechanisms, determine, in a number of cases, on the value of technical parameters of the machines in which they are built in. Therefore it is of special importance to improve construction and production of the machine elements, develop highly productive and economic technological process, increase reliability and service life. In this context the accomplished tests on improving the reliability and service life as well as on general improvement of the usage value of the product produce the concrete solutions confirmed at the engine and vehicles market. Diesel engine tests that are permanently performed in the IMR Institute and which refer to the usage quality and reliability of the diesel engine, its elements and systems show where and when it is necessary to intervene in the sense of improving quality as well as the products' performances. Testing diesel engine water pump is only part of these activities. The paper presents one part of the tests on the water pump relevant to providing the sealing during diesel engine water pump exploitation. Simulation of the working conditions is performed on specially designed laboratory test stand. Water pump sealing is achieved by means of sliding link of the sealer and impeller. The analysis of the sealing mechanism stresses the need for accommodating the tribology characteristics of the contact elements, contained in the parameters of the material quality as well as in physical and chemical characteristics. The subject of the research were the sealers of the diesel engine water pump that differ in the sliding sealing ring and in other parameters such as sealer's dimensions, spring characteristics, etc.

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2. TESTING CONDITIONS AND METHODS

The test stand was developed for the purpose of testing the water pumps for several types of diesel engines. It enables the testing of the performances as well as long term testing of water pumps reliability and service life. The test stand contains the relief valves, rotational speed regulator, equipment for measuring the pressure, cumulative number of revolution, fluid temperature, etc.

After each installation a detailed analysis of the sealers was made; checking the geometric parameters, spring characteristics, etc. Fig. 2 presents the sealer while on Fig. 3 there is the water pump impeller. In order to get proper picture on specific parameters of the tribology sealing mechanism, before each removal of the water pump, the geometric characteristics of the impeler and sealing surface hardness are checked.

Test methodology is adapted to the working conditions in the diesel engine service. The fluid is heated up to $T=80^oC$. The pump efforts are simulated by the relief valve. The pump rotation/min is derived from the engine service condition and it is $n=3800$ *o/min*. The pump working time on test stand is *50* hours. That is minimum time for which the wear of sealing surfaces is initiated. After that period the pumps were disassembled and geometric checking of the sealers and impeller was done.

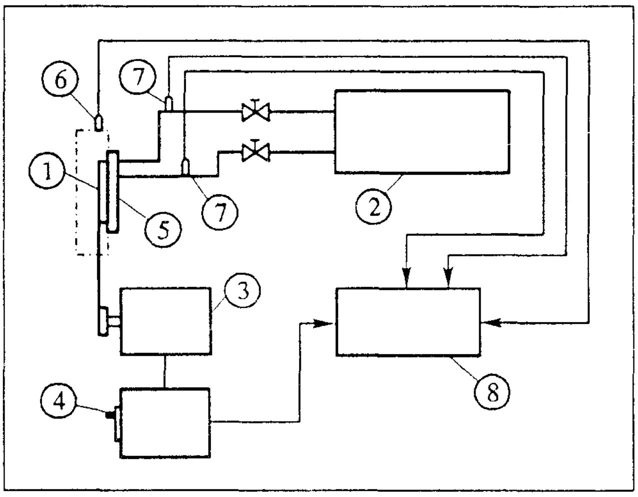

Fig. 1. Measuring and regulating installation 1-water pump, 2-water tank, 3-electric motor, 4-speed regulator, 5-adapter, 6-speed sensor, 7-preassure sensor, 8-data aquisition

3. TEST RESULTS

The paper presents part of the results obtained in the course of testing five water pump sealers. The Table 1 contains test results and the note therein defines the basic observations collected during visual check of the sealer and impeler. The medium wear is derived from the difference between the geometric values of the sealing ring before and after testing. Namely, before the sealer was installed in the water pump, it is necessary to measure the sealer ring thickness at four points at sealers

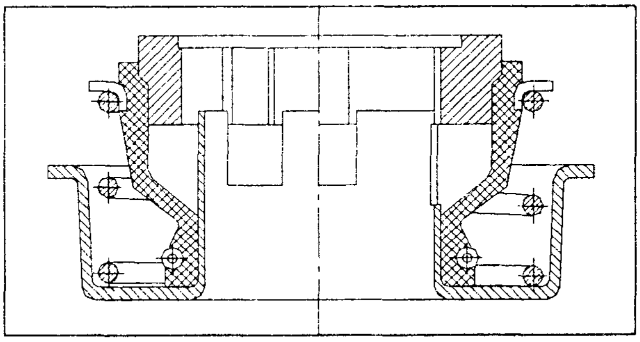

Fig.2. - Water pump gasket

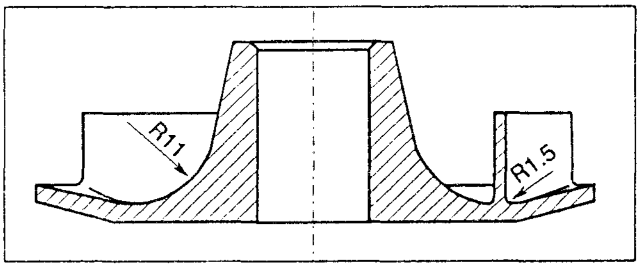

Fig.3. - Water pump implemer

circumference, shifted for 45°. After testing, the sealer is disassembled and measured again at the same points. The medium wear is calculated on the grounds of the wear of the specific points.

4. RESULTS ANALYSIS

The optimisation of the sealing tribology mechanism produces concrete results in improving quality of the products with high reliability and service life. The optimisation of the sealing tribology mechanism characteristics proved that by changes in material, i.e. its characteristics, it is possible to get extremely adapted tribology sealing mechanism with high reliability and life time. It

Table 1

Sample	Medium wear [mm]	Impeler hardness	REMARK
Sample 1	0.249	148	Spring force F=48,4 N Serious damage on impeler Visible at sealing ring
Sample 2	0.085	207	Spring force F=49,5 N Visible scratches on the impeler
Sample 3	0.04025	207	Spring force F=57,25 N Damages of the impeler and sealing ring of the sealer
Sample 4	0.008	450	Spring force F=49,5N Damages on the impeler and sealing ring of the sealer
Sample 5	0.0557	450	Spring force F=51,5 N No damage of the impeler and on the sealing ring of the sealer
Testing conditions; working time 50 h rotation speed 3800 o/min		pump effort about 1 barf low 60 - 70 l/min	

is necessary to stress that the authors of this paper were not in a position to participate directly in the decisions made by the producer of the sealers concerning the type of the material used and technology applied.

The shortcomings of the sealers observed during testing are in the sealing graphite element. Slight changes of its characteristics produce great changes in regard to wear during work, i.e. in providing necessary sealing of the water pump. Test results show in an obvious way that types of wear are quite diverse. On the other hand, increase of impeler hardness implied directly low wear value on the sealers. The test proved that the impelers with the great hardness of the contact sealing surface correspond, as to their tribology characteristics, to the sliding sealing ring of the sealer. This is confirmed by the low wear values of the sealing elements.

Optimisation of the sealing tribology mechanism produced the concrete results in improving the product usage quality with high reliability and life time. With this in mind it is also of great importance to know the reliability and life time of a diesel engine The test showed that based on the laboratory testing it is possible to predict water pump life time.

5. PREDICTING THE WATER PUMP LIFE TIME

Based on the previously conducted research work and derived parameters and using the hypothesis on linear wear accumulation, a criteria for estimating the sealer's life time was developed. The criteria is based on the results of testing the sealer, hypothesis on linear wear accumulation and parameters of the diesel engine working regime while exploited in tractor. On the grounds of results obtained during laboratory testing of the water pump with built in test sealers i.e. sealers' wear, working time (testing on the stand), number of water pump rotation during testing, the specific sealer's wear may be derived.

$$I_s = \frac{I}{T_I \cdot n \cdot 60}$$

where: I - total wear (mm)
n - rotation speed (o/min)
T - working time (h)

The above written formula enables the defining of the specific wear for each tested sample (Fig. 4).Using the specific wear parameter as well as the parameters of the engine service load, of the tractor in service, and the maximum allowed wear value of the sealing ring it is possible to estimate the sealer's life time. The maximum allowed wear of the sealer is adopted so that at maximum wear the spring force is $F_{min} = 40\,N$. Adopted maximum wear value is $I_s = 1.2\,mm$. The adopted parameters of the engine service load in the exploitation are:

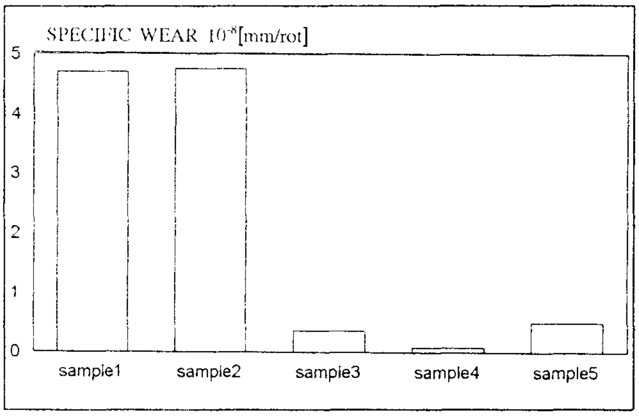

Fig.4.- Specific gasket wear

- engine speed $n_m = 1800\ o/min$
- belt drive ratio $i_p = 1.5$

The derived formula for estimation of life time is:

$$T_p = \frac{I_s \cdot n_m \cdot i_p \cdot 60}{I_u}$$

Based on this formula the predicted life time of the water pump for five samples is:

Sample 1	168.62 h	Sample 2	465.09 h
Sample 3	2247.05 h	Sample 4	17199.21 h
Sample 5	1620.39 h		

The above noted time life values of the sealer built in the water pump present at the same time the prediction of the diesel engine water pump life time. It must be mentioned that in the above formula we adopted the approximate 1 values for some influential factors (such as sliding speed, etc.) and these are not written in the formula.

6. CONCLUSION

The conducted research work enables the following conclusions: it is possible to test reliably the water pump under service load within this context the conducted research work is of great importance for estimating the quality of the test sealer and consequently for estimating the quality of the diesel engine water pump; the optimisation of the sealing tribology mechanism produced concrete results in improving the usage quality of the product with high reliability and life time; the developed criteria for estimating the sealer's life time enables the prediction of the sealer's life time as well as of the diesel engine water pump.

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RESEARCH

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The Calculation of The Heat Power Generation During The Formation of The End of Cylindrical Tube by Friction

The method of termofriction metal processing is a special way of metal processing by friction heat effect which is characterized by simplicity and very small energy consumption. This method for cylindrical tube ends formation is specially recommendable because the different forms of particular or total closed bottoms can be easily obtained. During the processing, beside an adequate way of heat generation by friction, the biggest problem is - determination of the heat power generation because many important process parameters depend on it. In this paper, first of all, the principle of forming the closed semispherical bottom on the cylindrical tube ends by friction by means of special tool - so called multicontact termofriction forming tool - is presented, and then the expression for the estimation of the generated heat power is derived. By analysis of the graphic presentation in the obtained equation, it can be concluded that both technological process parameters and constructive characteristics of the tool depend on the heat power generation.

Keywords: *friction, heat generation, formation, processing.*

1. INTRODUCTION

The method of termofriction processing metal (TFPM) understands the formation of in advance determined shape on the part of the work object (like the opening at the sample with full cross section, for example particular or total closed bottom of the tube ends, etc.) by adequate tool and exclusively by using the heat effect of friction [1, 2, 3]. This method, otherwise, is characterized by three effects which are very important in aspect of their application. First, the total absence of material overheat, since the process of the metal deformation occurs - because of the phenomenon of selfregulation of heat generation by friction - at elevated but constant temperature. Second, because of the presence of heat, the value of the needed force for material deformation considerably reduces, and third - the procedure of the processing is very simple. For this reason the TFPM method can be specially attractive during the shaping of the cylindrical tube ends, because, in this way, its openings can be narrowed or widened, and partly or totally closed bottoms can be obtained with different forms (semispherical, parabolical, etc.) as well. On the other hand, considering the geometrical form of the tubes, the application of TFPM to the formation of their ends can make difficulties in finding the adequate way of simultaneous heat generation by friction and formation, because in addition to this it is necessary to satisfy defined energetical, tribological and constructive conditions and requirements. On Mechanical Engineering Faculty in Niš, this problem was solved by special tool, so called multicontact termofriction forming tool (MCTFT). In this paper the calculation of the heat power generation by friction for the case of formation the closed semispherical bottom on the tube end by MCTFT is presented.

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2. FORMATION PRINCIPLE OF THE SEMISPHERICAL CLOSED BOTTOM BY MCTFT

The main parts of MCTFT are, so called, generative forming segments (GFS), one or several, whose construction makes simultaneous heat generation by friction and formation of warmed tube material possible. The GFS working surface has such form that a contact between GFS and external surface of the form, which is obtained from it, always happens along a line. Considering it by the tool aspect, i.e. from GFS aspect, this line defines, so called, generative forming edge (GFE) of the tool; it is the part of the GFS which directly makes the heat induction in the generative layer of tube material, and simultaneously shapes the heated material.

Figure 1 shows the formation procedure. Fixed (immobile) and unheated tube (1) is coaxial with MCTFT (2) which rotates around common axis and has translatory motion simultaneously in the direction of the same axis. At the moment when GFS (3) touches the external surface of the tube, because of the rotating motion of the

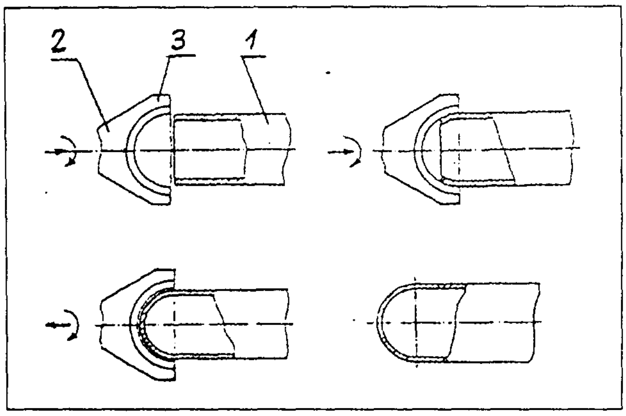

Figure 1. Scheme of formation of the semispherical bottom by MCTFT; 1 - the tube, 2 - MCTFT, 3 - GFS

tool, the friction moment appears, the heat is generated, and material of the tube heats up; simultaneously and because of the translatory motion of the tool, the heated material deforms and takes the shape which is determined in advance by the GFE form. After that, MCTFT, by return stroke, goes back on the starting position. The first contact GFS with tube is in points form which are placed in mutual section of the GFE with external edge of the tube opening; these points are so called starting generative points (SGP). Considering it from the tool aspect, the SGP points as well as the points placed on the GFE, during formation process, have a spiral motion around the common axis, but the step of the turn must be very small.

3. THE CALCULATION OF THE POWER GENERATION

By the analysis of the starting contact between the tool and the tube, figure 2., it can be concluded that between the opening of the GFS and external tube diameter there must be a radial clearance; the value of the clearance is $e=(D-D_S)/2$, where D - is a diameter of GFS opening (i.e., diameter of the tool opening) and D_S - is the external tube diameter. It is clear that the existence of the radial clearance cannot be avoided because if $e=0$, the tool and the tube will not make the friction grip. However, since the value of the radial clearance has influence on the geometrical precision of the forming shape its value must be at the minimum. It is obvious that these are two opposite conclusions so, it is necessary that $e \to 0$, but it must always be $e>0$.

Two other parameters are defined by radial clearance and these are: axial deviation (a) and angle of attack or the angle of friction grip of the tool (φ). The value of the axial deviation defines the dimension of the real deviation in regard to ideal form, until the angle (φ) on the GFE defines, the position of the attack points and the direction of the forces by which the tool at the starting point (later on PG points) loads the cylinder of the tube.

There is a relation between the radial clearance, the axial deviation and the angle of the friction grip of the tool

$$e = a \cdot tg(\frac{\varphi}{2})$$

and

$$sin\varphi = \sqrt{1-\left(\frac{D_s}{D}\right)^2} = \sqrt{1-\psi_2} \qquad (1)$$

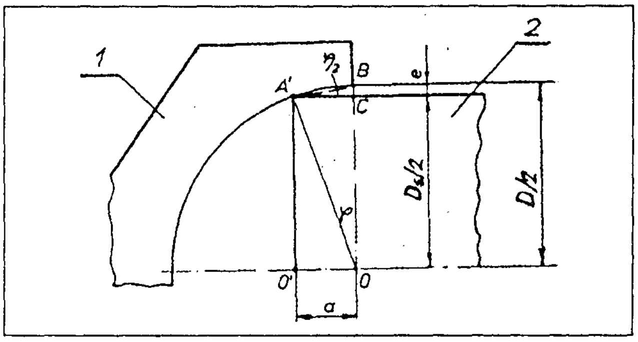

Figure 2. Starting contact of GFS (1) with tube (2)

Since the tool does both movements, the elements of the contact between GFS and the tube will be the points where the moment of rotation and axial force with tool to the tube are transmitted. At the beginning there are SGP, but because of simultaneous rotation and translation of GFS, the starting points contact becomes line contact and such contact remains to the end of the formation process. This means that each GFE, as the line of friction contact, represents a set of points by which the rotation moment and the axial force of the tool are transmitted to the tube.

In figure 3. is shown, in axonometry, the contact of a GFS with the tube during processing and a scheme of the load at an arbitrary point A being shaped. During the processing all the points of the GFE of the tool, as it was described, make spiral lines. At the same time the SGP points make spiral line on external surface of the tube and the rest of the points on external surface of the shaping semisphere.

The force F_N, by which GFS effects the tube in the given point A, figure 3a, has the direction of a normal N to the spiral line (LZ) which goes through this point; this is at the same time a normal on the lines of adequate parallel (LU) and meridian (LM), that goes through the same point. This conclusion is valid for any contact point. The direction of all forces which go through these points, cross at point O, in the center of GFS, as shown on fig. 4. From figure 4. follows that

$$F_N = \frac{F_A}{sin\theta} \qquad (2)$$

where: F_A-is an axial force of the tool and
θ- is an angle between the direction of the force F_N and the radius of the tool opening, i.e. radius of the GFS opening

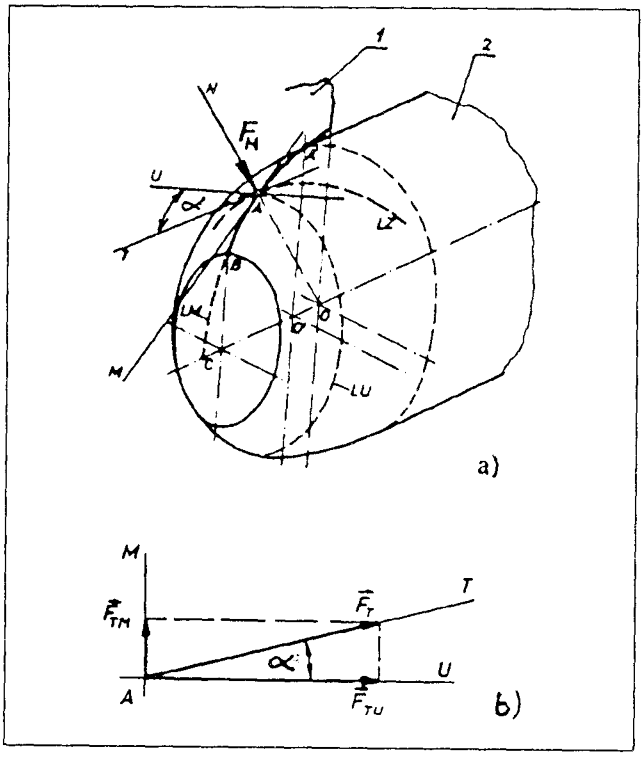

Figure 3. 1 - GFS; 2 - the tube; LZ - the spiral line; LU - the parallel line; LM - the meridian line; T - the tangent to the spiral line; U - the tangent to the parallel line; M - the tangent to the meridian line; N - the common normal

The total friction force F_T in point A has the direction of the tangent T on the spiral LZ; it lies in a plane which can be put through tangents on the parallel LU and meridian LM, as shown in figure 3b. This force can be separated on parallel F_{TU} and meridian F_{TM} components which work in a direction of adequate tangents, figure 3b, i.e.

$$F_{TU} = F_T \cdot \cos\alpha \quad \text{and} \quad F_{TM} = F_T \cdot \sin\alpha$$

However, since the slope angle of the spiral line is

$$tg\alpha = \frac{F_{TM}}{F_{TU}} << 1$$

then

$$F_{TU} >> F_{TM}$$

and it can be concluded that the total friction force equals to the parallel component only, i.e.

$$F_T \approx F_{TU}$$

and on the basis on the Amonton's low, it will be

$$F_T \approx f \cdot F_A$$

where f - is coefficient of friction.

Taking into consideration earlier approximations, to determine the heat power generation it is necessary, from kinetic aspect, to analyze the process which appears on the contact of GFS with the tube material. In that regard, observing the section on meridian of the forming shape

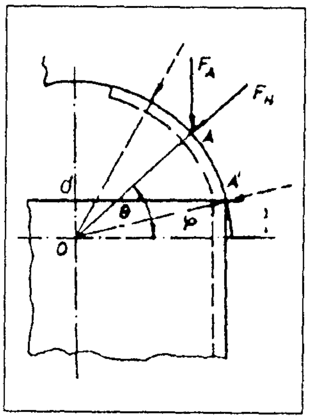

Figure 4.

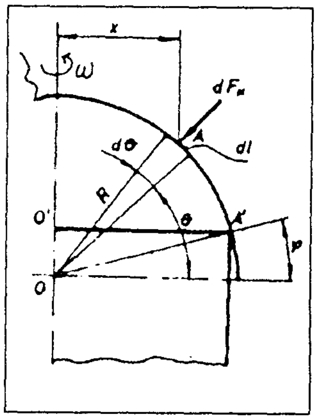

Figure 5.

(it is the line of the friction contact as well), figure 5., it can be concluded that, during the formation process the elementary length of this line dl, will be effected by the elementary friction force perpendicular to the figure plane, whose value is

$$dF_T = f \cdot dF_N = f \cdot p' \cdot dl = f \cdot p' \cdot R \cdot d\theta \qquad (4)$$

where: f- is a friction coefficient,
p'- is a pressure line, i.e. the load on unit length of the contact line,
R- is radius of the opening of the GFS.

The moment of this friction force for the rotation axis, will be

$$dM_T = x \cdot dF_T = R^2 \cdot f \cdot p' \cdot \cos\theta \cdot d\theta$$

and elementary power generation

$$dq = \omega \cdot dM_T = \omega \cdot R^2 \cdot f \cdot p' \cdot \cos\theta \cdot d\theta \qquad (5)$$

where: ω - is the angle speed of the GFS, i.e. angle speed of the MCTFT.

If it is considered that the force F_N, with which GFS of the tool loads the tube material, is uniformly distributed along the contact line, the unit pressure will be

$$p' = \frac{F_N}{R \cdot (\frac{\pi}{2} - \varphi)}$$

Considering the equation (2), the generation becomes:

$$p' = \frac{F_A}{R \cdot (\frac{\pi}{2} - \varphi) \cdot \sin\theta},$$

and the expression for elementary power generation becomes

$$dq = \omega \cdot R \cdot f \cdot \frac{F_A \cdot \cos\theta}{(\frac{\pi}{2} - \varphi) \cdot \sin\theta} \cdot d\theta \qquad (6)$$

By integration of expression (6) the power generation for one GFS of the tool is obtained in the form

$$q = \omega \cdot R \cdot f \cdot \frac{F_A}{(\frac{\pi}{2} - \varphi)} \cdot \left| ln\, sin\theta \right| \qquad (7)$$

If the tool has a total of k GFS, then its total power generation is

$$q_U = k \cdot q = \omega \cdot R \cdot f \cdot \frac{F_A}{(\frac{\pi}{2} - \varphi)} \cdot \left| ln\, sin\theta \right| \qquad (8)$$

where is $\varphi \leq \theta \leq \pi/2$.

Since ω, k and R are constants, under the condition that the friction coefficient and the axial force of the tool have constant values during the processing, the expression (8) can be presented in the form which is very appropriate for the graphic interpretation of power generation dependence on angle θ

$$q_U = q_U(\theta) = B \cdot \left| ln\, sin\theta \right| \qquad (9)$$

where constant B is

$$B = \frac{2 \cdot k \cdot \omega \cdot R \cdot f \cdot F_A}{\pi - 2 \cdot \varphi} \qquad (10)$$

Because of integration boundaries, i.e. $\varphi \leq \theta \leq \pi/2$, the total power generation can be presented approximately

$$q_U = B \cdot \left| ln\, sin\theta \right| \qquad (11)$$

and taking into consideration (1), it is also obtained

$$q_U = B \cdot \left| ln \sqrt{1 - \psi^2} \right| \qquad (12)$$

By analyzing the graphic illustration of the equation (9) which is shown in figure 6., it can be concluded that the biggest flux of heat is in vicinity of SGP. The first part of the curve corresponds to the position of the SGP, and because of its character - this is the place where GFS is, it isfrom the termical point of view, mostly loaded. It lies in interval $\varphi \leq \theta \leq \pi/4$, and this fact is important in constructing MCTFT and GFS as well.

From the tube material aspect, the high initial heat flux, considering the character of the contact during the starting period of the processing, can cause abrupt heating and melting ofthe tube material. This fact can have negative consequences on the formation proces (like wearing and adhesion of material) what must be adequately eliminated (for example by reduction of axial forces of the tool, or by using any lubricant). In addition to that, since the generative flux abruptly decreases in the part where $\theta > \pi/4$, it can be expected that the tube material in the region $\pi/4 \leq \theta \leq \pi/2$ will not be heated enough by friction generated heat. From this aspect, considering the

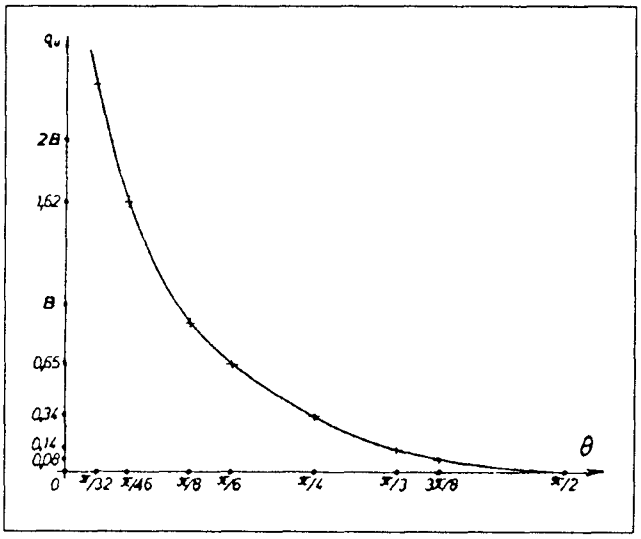

Figure 6.

length of the arc which remains to the end of the processing, there is a possibility that this region will not be totally closed. That is, in other words, the attention must be payed to the constructive characteristics of the GFS and to its working surface, because only in this way this problem can be solved.

4. CONCLUSION

Generally it can be concluded that, in formation process of the closed bottom on the cylindrical tube end by friction, it is best to determine the power generation mathematically for two reasons:

- first, some technological parameters depend on processing as the step of the tool, axial speed of the tool, etc.;
- second, the constructive parameters of the tool, like the working surface form of the GFS and GFE, etc. depend on the power generation.

These conclusions are confirmed at Mechanical Engineering Faculty in Niš during the formation of semispherical closed bottom on the ends of the aluminum alloy tubes.

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RESEARCH

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Design Specifics of Injection Molded Thermoplastic Slide Bearing Bushes

Taking into account tribological process in slide bearing, this paper highlights advantages and disadvantages of thermoplastics as a material for slide bearing bushes. Injection molding enables rapid and economical manufacturing of large series of elements which require no subsequent operations such as: grinding, painting, coating, etc. This procedure is realized by means of injection tool whose proper operation depends on implementation of technological requirements.

Insufficient knowledge on thermoplastics and in designing slide bearing bushes could lead to undesirable results such as: more complicated and thus more expensive tool manufacturing, increase of waist, presence of residual strains, lose of shape during cooling process, unstable working clearance, tec. The aim of this paper is to highlight realization of most favorable solutions in bush design, what enables desired life time under expected working conditions.

***Keywords:** Slide bearing bush, Thermoplastics, Injection molding, Favorable design, Injection tool*

1. INTRODUCTION

Since the basictial purpose of slide bearings (i.e. to enable movement of "free" element inside stationary one) can not be performed without friction, designer's task is to reduce it to a minimum. That can be done after detailed analysis of influential factors which generate tribological process in contact area between pivot and bearing bush. Influential factors are numerous and their general classification could be done as shown in the fig. 1.

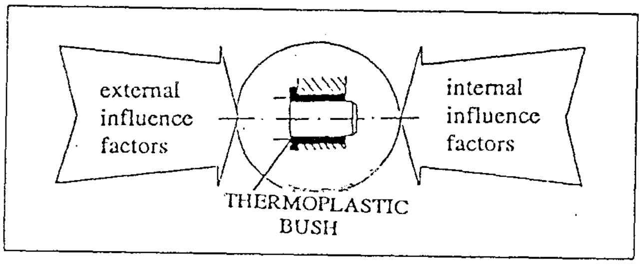

Figure 1. Influence factors and tribological processes in thermoplastic bearing

One significant internal factor is related to applied material. Thermoplastics are materials whose use increases constantly.

2. THERMOPLASTICS

Thermoplastics are non-metal, polymer materials (fig. 2). Thermoplastic masses are materials that as a basic component contain polymer compound. Their composition is complex since besides basic polymer they comprises various ingredients, such as: fillers, stabilizers, hardening agents, etc. (figure 3).

Therefore, there is great variety of types and permanent appearance of new or well known types with improved properties. Specifications for every single type are given by producer in a form of tables and diagrams. Recently, it is possible that most favorable material to be produced upon specified load and working conditions [7]. Quality and quantity of filler added to polymer depend on property or group of properties which should be emphasized.

Comparative diagram in figure 4 shows PTFE with no fillers and the same material with filler which increase pressure resistance, especially at higher temperatures. It is obvious that almost three times deformation decrease has been achieved.

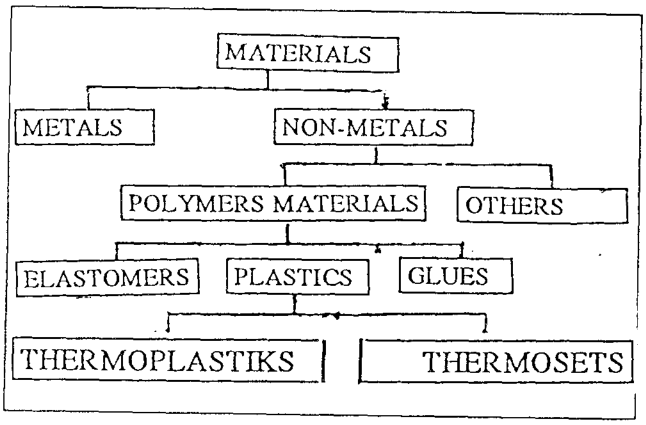

Figure 2. Material classification

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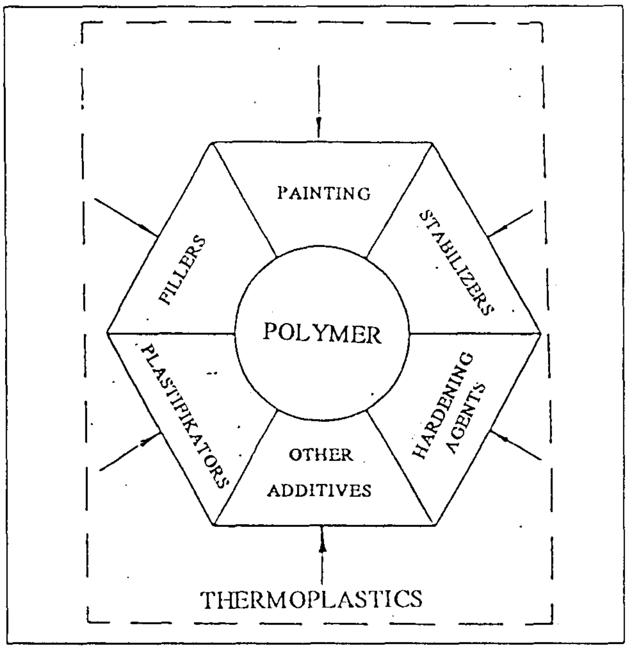

Figure 3. Thermoplastics contents

Specifications on thermoplastics obtained from technical literature and handbooks often do not guarantee the most favorable choice of material, due to difficulties in following rapid development in that field. More reliable data could be found in data banks of particular material producer. However, those specifications are obtained under standard laboratory conditions and are related to probes of prescribed dimensions, but not to a particular part made of it. Those values could be used for direct comparison between diferent thermoplastics only if the tests have been done using the same method under equal conditions. The most reliable data on thermoplastics behavior in working conditions are obtainable by analyzing successful applications or by adapting of those to a desired structure. Since properties of thermoplastics depend on numerous factors, it is obvious that all of them can not be taken into consideration for estimated working conditions.

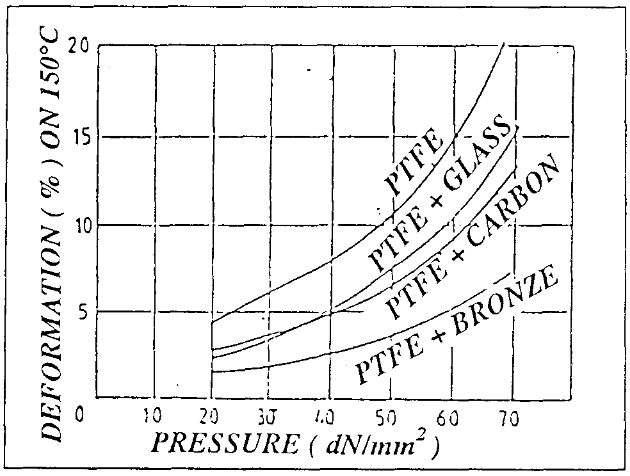

Figure 4. Strengthen PTFE for increased pressure resistance

Slide bearing manufacturing is significant applicaton field for thermoplastics which successfully substitute metals. Sensitivity to wear of thermoplastic bearing bushes is expressed by wear coefficient *K*, which values were found experimentally, and their specific values for particular materials are stated in the table (4).

If the values of allowed wear, pressure and velocity are all known, slide bearing lifetime (t) could be calculated upon formula:

$$t = \frac{1}{3600} \cdot \frac{h}{kpv} \tag{1}$$

Thermoplastics exposed to high temperature turn in viscose liquids without chemical changes, and than (under pressure) intricate shapes could be formed. Cooling intialize hardening process. Theoretically, this procedure could be repeated endlessly. Compared with other materials, that is obvious advantage, since poor quality parts could be used as a raw material, thus minimizing waste.

Nowadays, there are more than twenty basic processing methods, as well as their numerous modifications. The most widley used method to treat thermoplastics is injection molding.

3. INJECTION MOLDING

Injection molding is in use since 1930 as a modified procedure of well known method implemented on metals. Several modifications of injection molding itself are in use, but general concept is always the same. General idea is to transform raw thermoplastic into viscose, dense liquid which is able to penetrate (under pressure) cavities in injection tool. After a while, tool is being opened, and during hardening process material gains form of the tool. Such parts do not require further machining or painting, since the paint could be easily added to material at the beginning of the process. The whole method is suitable for automation in manufacturing and enables large series.

For that purpose, injection tools are needed, and expenses related to them are significant. Accordingly, injection molding is economical procedure just for larger series. Regardless of proper choice made while selecting materials for the specific part, insufficient knowledge on specifics of technology procedure, or neglecting it's significance, could lead to expensive manufacturing. Characteristics of such manufacturing are shown in figure 5.

Those undesirable effects could be avoided if designer in the final phase of creation adapt calculated values to specific production requirements and typical tool functions for particular thermoplastic.

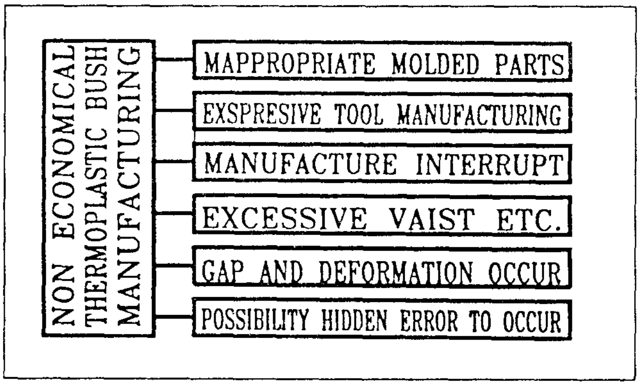

Figure 5. Non-economical manufacturing in thermoplastic bearing bushes

Precisely defined wall thickness, properly chosen roundings as well as anticipated humidity and temperature influence are some of conditions for favorable design of thermoplastic bearing bush, desired lifetime, and an economical manufacturing process [1].

3.1 Defining wall thickness

Wall thickness of thermoplastic bearing bushes can be defined using empirical equation:

$$S = 0.4 + \sqrt{0.1d}\ [mm] \qquad (1)$$

where d *(mm)* stands for pivot diameter.

When acquiring eventual values, one should respect technological experience which states that thickness should be between *1* and *6 mm* [1]. At larger pivot diameters, it is not advisable for wall thickness to be more than 6 mm due to possible deformations of bush, as shown in figure 7. In such cases, several layers of diminished thickness are recommended (figure 11). Thickness should not be under 1 mm, because thin bushes manufacturing require higher injection pressures, longer injection cycles and are jeopardized of improper filling of tool cavities. Whenever possible, bush should be of uniform thickness.

However, due to fixation in housing, structure requirements, and temperature compensation, bushes of unequal wall thickness are being made. In such cases, position of inlet channel is very important because it enables

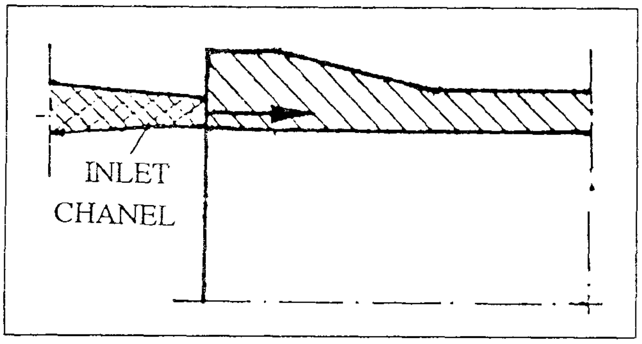

Figure 6. Properly positioned inlet channel considering wall thickness

proper filling of thinner walls throughout the thicker ones, as shown in the figure 6. Besides difficulties in filling the tool, and occurrence of residual stresses, inappropriate wall thickness could lead to deformations during cooling process. Some typical examples of such deformations are shown in figure 7.

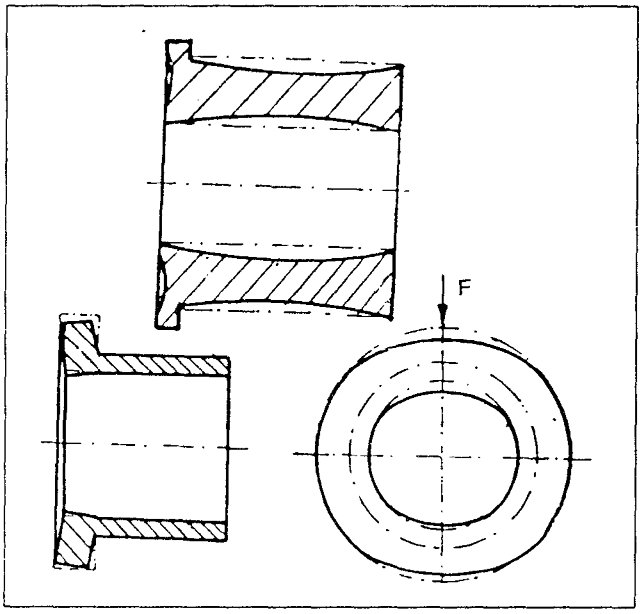

Figure 7. Deformations due to wrong wall thickness

While defining wall thickness, one should be aware of possibility to improve carrying capacity by using better thermoplastic or by adding ribs to the structure rather than by thicker walls. Numerous factors affect wall thickness, and most important ones are given in figure 8.

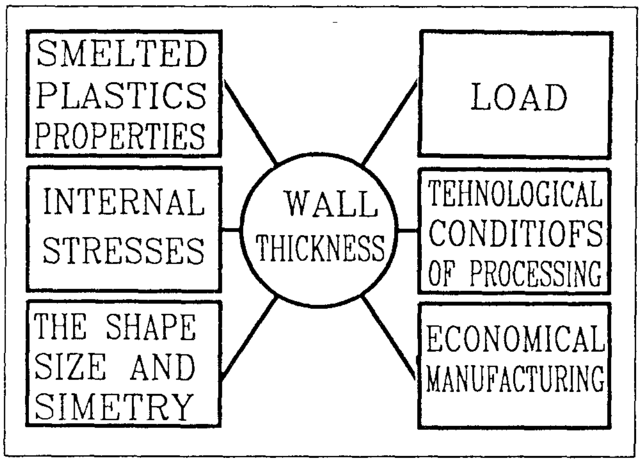

Figure 8. The most important factors for defining wall thickness

3.2 Radii and roundings

Size of roundings directly influence quality of molded parts and proper injection tool operation. Too small radii could lead to bad filling cavities in tool, and to occurrence of residual stresses which later cause cracks. Too large radii lead to deformations under cooling.

An example of undesirable solution, which prevents even cooling and causes residual stresses and deformations, is in figure 9-a.

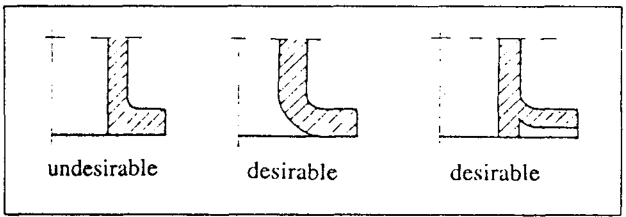

Figure 9. Comparative examples of proper dimensioning

Example shown in the figure 9-b is proper one because even cooling is provided, and suitable radii enable good tool filing.

Example 9-c is also acceptable one. Thinner wall thickness provides even cooling, and carrying capacity is increased by ribs positioned perpendicularly to bush axes. Ribs are also used for compensation of temperature and humidity influences. To enable proper tool filling and easy removing of objects from the tool, in such cases rounding-outs in the bottom and on the top of the rib are needed.

Some experience based recommendations on those roundings are given in figure 10.

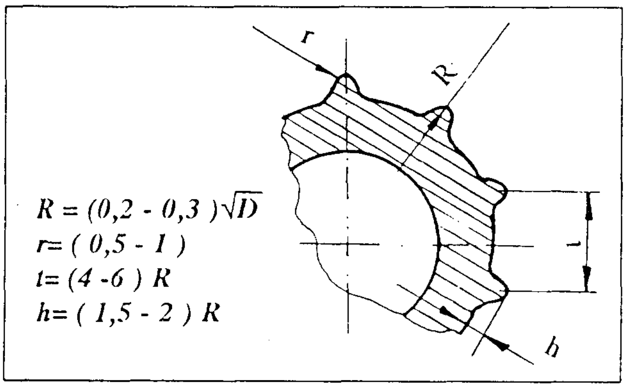

Figure 10. Recommended rounding dimensions

3.3 Working clearance compensation

Tribological processes in contact area between pivot and bearing bush generate heat expressed by temperature increase ΔT, which could be determined by empirical formula:

$$\Delta T = \frac{(pv)_{doz}}{4.18887\cdot\frac{\pi}{4}\cdot\left(2\cdot\frac{\lambda}{S}+\frac{\lambda_S}{48\cdot l}\right)}\ [^{\circ}C] \qquad (3)$$

Sum of environmental temperature To and that temperature increase must be less than allowed working temperature of bearing bush [4].

Important property of plastics is significantly less heat conducting coefficient λ value, compared to metals. As a consequence, cooling in contact area is less efficient, and temperature increase for plastic bearing bushes is larger than for metal ones under the same tribological conditions.

Thermoplastics have higher value of termal expansion coefficient α than metals. As a consequence, during tribomechanical system run, bearing bush spreads toward shaft axis, since expansion toward outer diameter is limited by significantly slower expansion of metal housing. It means that working clearance decreases, and that is the fact which should be taken into consideration [11].

Humidity in contact area of such tribomechanical system could lead to increased bearing bush,s volume. That also decreases working clearance and thus increases wear.

To compensate difference in termal expansion coefficient between metal housing and bearing bush, as well as volume change due to humidity, properly defined ribs should be added on outer diameter of bearing bush.

Well known working clearance calculation methods [5], [3] and recommendations approved in practice [11], as well as computer aided calculation on thermoplastic bearing bushes, all enable fast and precise estimation of bearing bushes volume change in expected working conditions. Favorable solution which would successfully compenssate such changes could be achieved through those estimations. Regardless of numerous known and practically approved designs [11], there is no general solution on thermoplastic bushes. It is advisable, therefore, to take into account as much experience based recommendations as possible. This approach guarantees achievement of adequate configuration which would be suitable for manufacturing, assembly, use and maintenance.

For large diameters and small rotation velocities, bearing bushes made of segments are suitable. Gap between segments enable unlimited expansion of bush under operation. One such solution implemented in dishwasher with good operational results, is shown in the figure 11. Both assembly channels and channels on the segment for controlled working clearance change could be noticed in the same figure. This solution enables segment fixation

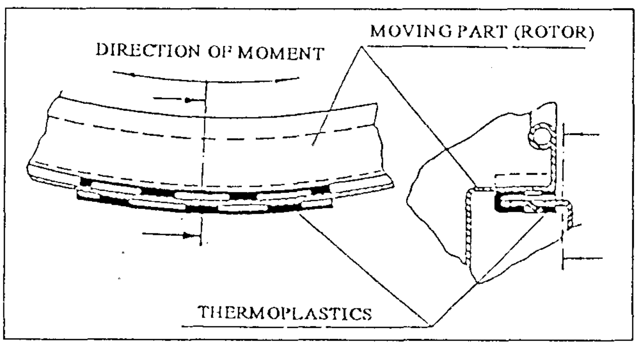

Figure 11. Segment of thermoplastic bearing bush for dishwasher

without additional assembly parts, a significant property for serial production aspect.

Solutions as shown in the figure 12, where the bush and the housing are both made in the same tool for reduced manufacturing and assembly time, are very frequent in serial production of domestic appliances. Longitudinal ribs compensate for poorer mechanical properties, compared to metal parts.

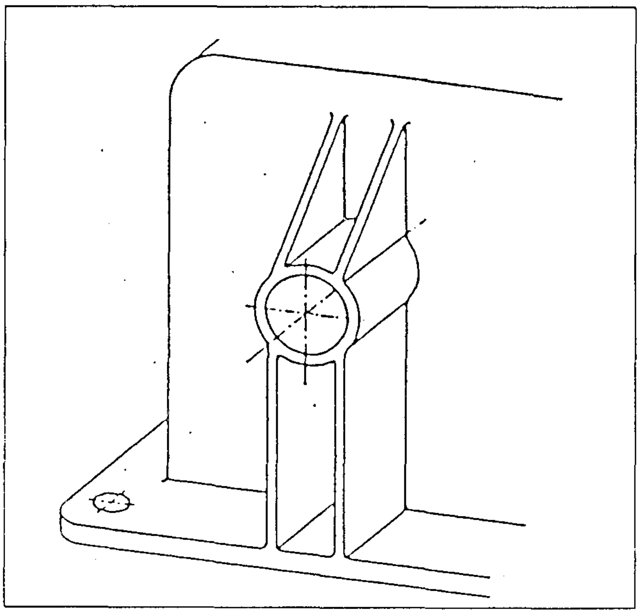

Figure 12. Vertical ribs to strengthen one - piece housing and bush

4. CONCLUSION

Choice of the most appropriate row thermoplastic, and precise calculations on bearing bush should be followed by considerations related to injection molding technology specifics and design solutions. Dimension correction in final design phase enables favorable design solution. This procedure enables economical manufacturing and proper tool operation. Bearing bushes designed in this manner should be reliable, of appropriate life time and easy reparable.

In the years to come, increased use of thermoplastics should be expected in slide bearing bushes manufacturing, as well as in production of tribomechanical systems in general.

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