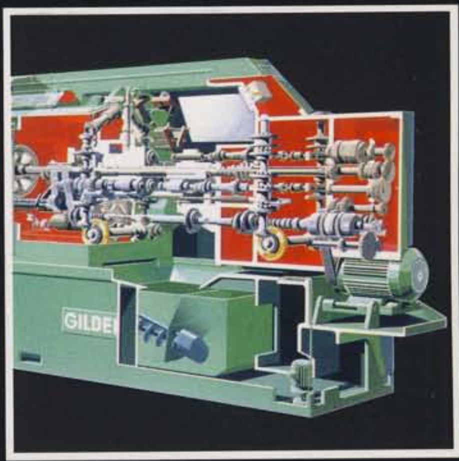
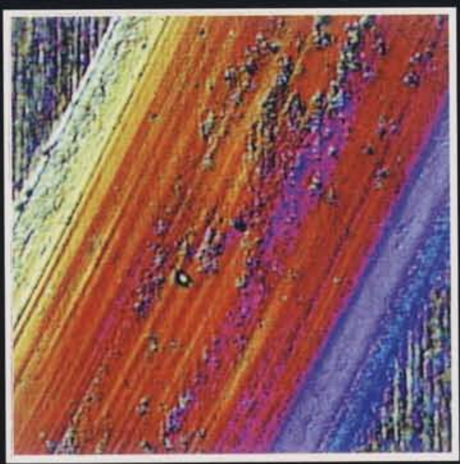
tribology in industry

YU ISSN 0354 - 8996
VOLUME 20
MARCH 1998

1





1979 - 1998
20 YEARS WITH YOU

YU ISSN 0354 - 8996

VOLUME 20
Nº 1
MARCH 1998.

tribology in industry

contents

B. IVKOVIĆ

Tribology in industry - 20 Years With You

In already distant 1978, The Council of Faculty of Mechanical Engineering in Kragujevac had brought a decision, at the proposal of the Scientific-Educational Board, on beginning with publication of a scientific journal entitled "TRIBOLOGY IN INDUSTRY".

The origins of the entitled "TRIBOLOGY IN INDUSTRY" journal lie in Publications of Laboratory for Metal machining and Tribology, that were published occasionally, as editions of Faculty of Mechanical Engineering, since 1974. During that period, from 1974. till 1978., 10 issues were published, in which the results were presented of the scientific-research work, realized through projects, mainly form the area of the tribology of metal cutting.

Members of the First Journal's Council were: S. Spasojević, from The Chamber of Commerce of Serbia; Mr. V. Kaličanin and Ž. Prokić - ZCZ; Prof. Dr Š. Šavar - Faculty of Machinery and Shipbuilding, Zagreb; Prof. Dr D. Zelenović - Faculty of Technical Sciences, Novi Sad; Prof. Dr Branko Ivković - Faculty of Mechanical Engineering, Kragujevac; M. Voljevica - Faculty of Mechanical Engineering, Mostar; Ž. Milutinović - The Chamber of Commerce of Kragujevac; and M. Lazić - Faculty of Mechanical Engineering, Kragujevac.

The Council was working, mainly with these members and small changes, until 1992., when ceased the need for its existence.

The First Editorial Board of the Journal consisted of: Prof. Dr B. Ivković - Faculty of Mechanical Engineering, Kragujevac - Editor in Chief; Prof. Dr R. Zgaga - Faculty of Machinery and Shipbuilding, Zagreb; prof. Dr S. Sekulić - - Faculty of Technical Sciences, Novi Sad; Prof. Dr M. Radovanović - Faculty of Mechanical Engineering, Belgrade; Mr. Z Palunčić - Faculty of Mechanical Engineering, Kragujevac - Secretary; F. Pavlović - Faculty of Mechanical Engineering, Mostar; R. Nikolić - FAM, Kruševac; and M. Simović, Editor.

Since 1986. till 1992. members of Editorial Board were also: Prof. Dr A. Rac, - Faculty of Mechanical Engineering, Belgrade; Prof. Dr J. Vitežanin - Faculty of Mechanical Engineering, Ljubljana; Prof. Dr M. Lazić - Faculty of Mechanical Engineering, Kragujevac.

Since 1992. until present time, the Journal is edited by an international Editorial Board whose members are famous scientists from several countries (Belarus, Poland, England, USA, Yugoslavia, Macedonia). The core of the Board consists of scientific workers from Faculties of Mechanical Engineering from Kragujevac and Belgrade, and Faculty of Technical Sciences from Novi Sad. With translation of texts for years are engaged Prof. Dr Ružica Nikolić (English) and Mr. A. Milenković (Russian).

The structure of the Journal did not vary significantly in past years. Constant sections, until today, were INTRODUCTION, RESEARCH, BOOKS AND JOURNALS, and SCIENTIFIC MEETINGS. Occasionally, there were sections like TRIBOLOGICAL DICTIONERY, FOR DIRECT PRACTICE, and NEWS, that existed in several issues, but except for the NEWS, they did not get the permanent character.

Abstracts of all the papers were published, until 1992., both in English and in Russian, on the last pages of Journal, in form of cards, as it is frequently done in scientific and expert journals. Since 1992., however, the structure of the Journal has changed somewhat. Abstracts of each paper are printed, in English and Russian, at the end of each paper, what seems to be more convenient for the readers, to have complete papers and abstracts at one place, and abstract in Serbian is printed at the beginning of each paper, below the title.

Besides publishing the Journal in Serbian, with abstracts of papers in English and Russian, since 1996. as separate issue is published the English version of the Journal, with separate ISSN number, entitled TRIBOLOGY IN INDUSTRY. In the first years of publishing the Journal had covered mostly the are of tribology of cutting, and tribometry, though there were also published articles from other areas of tribology. In last several years, however, in both issues (in Serbian and English) are present papers from almost all areas of tribology. In the Journal are present papers from Tribology of manufacturing processes (cutting and metal forming), Tribology of machine elements, Tribomaterials, Application of lubricants and lubrication systems, Diagnostics and maintenance of the tribosystems, Tribometry, and Terotechnology.

In past nineteen years, the largest number of papers were published by authors that were employed at Yugoslav Universities, scientific institutions and research departments in leading industrial systems. However, in last years, are present more and more papers of domestic authors that are working in industrial systems on jobs of products development, technology or maintenance of the production and other equipment.

The significant number of papers was published in the Journal by authors from Slovenia, Croatia and Bosnia, until 1991.

The Journal TRIBOLOGY IN INDUSTRY was all these years, and still is, the only Journal of scientific character, from the area of Tribology, on wider former Yugoslavian spaces, from Ljubljana to Skopje.

About one third of all papers was published by foreign authors. Among them there were papers written by authors from Russia, Belarus, England, United States, Poland, Greece, Bulgaria, Romania, Japan, Germany and Slovakia.

The users of the TRIBOLOGY IN INDUSTR Journal were, until 1991., all the libraries of all Universities, Faculties of Mechanical Engineering, and Scientific institutes in Republics of former Yugoslavia, as well as all the larger and medium size industrial systems of metal working industry on those spaces. The number of users had decreased since 1991., from known reasons, so today the Journal is sent to about 220 users in Yugoslavia and 60 in other countries.

Until 1991. the greater part of publishing costs was covered from the selling of the Journal, through subscription. Last several years, the Journal is being published mainly due to financial support of Ministry for Science and Technology of Republic of Serbia and Federal Ministry for development, science and environment, since due to existing state of the domestic industry, it was not possible to provide for enough financing from subscriptions.

In this year, in which the Journal TRIBOLOGY IN INDUSTRY comes twentieth time before domestic and foreign scientific and expert public, with both issues in Serbian and English, the special efforts will be done for Journal to enter all the environments where jobs are done, of both scientific and expert character, that are concerned with making the greater gross product through decreasing the production costs and increasing the work productivity.

The productivity level in our industrial systems and the low gross national product per capita, are consequences, to the great extent, of insufficiently organized constant fight for reducing the friction and wear, in numerous tribo-mechanical systems both in industry and transport. The effort is going to be done, through Journal TRIBOLOGY IN INDUSTRY, to point out to a large number of people to the fact, known in all the developed countries, that, by application of existing, and creation of the new tribological knowledge, the conditions are created for increasing significantly, both gross national product and productivity of exiting industrial and transportation systems, even without expensive investments and introducing the new technologies. Experience from the developed world point that by application of tribological knowledge and solutions, even 40 times larger profit can be realized with respect to investments. In some industrial systems energy consumption decrease, through application of tribological knowledge, was as much as 10 %. It is useful, on this occasion too, to remind ourselves that by application of tribological solutions, savings are also realized by lowering the maintenance costs, lowering the production costs, that are appearing due to breaks in production processes caused by wear of elements and production and other equipment, by lowering the investments into the new equipment (the working life is increased for the existing equipment), by lowering the consumption of lubricants and by lowering the labor costs.

In Jubilee year, an issue is going to be reserved for publishing the review papers from different areas of tribology, in order to provide for the readers the useful insight into the existing level of our knowledge, and to create conditions for forming the new research programs and new approaches to application of existing knowledge from the area of tribology in industrial and transportation systems.

UDK 621.9.025.7.003

RESEARCH

C. GHEORGHIES, O. GHEORGHIES

Prediction of Case-hardening Steel Behaviour in Rolling Tribosystem

In order to follow the tribological behaviour of case-hardening steel 12 MoMnCr12XS, the rolling pure friction test on a tribomodel have been used. From the distribution on the surface layer depth of the structural shanges, distinguished by X-ray diffraction method, the following conculusions can be drawn: the existence -in inner of the surface layer of the case-hardening steel- of the difference between mechanical and thermal effects which develop during pitting test; this fact is considered as a negative factor on the structural and dimensional stabilities; the existence on surface layer depth of a nonhomogeneity for inner second order tensions, this fact shows that it is possible that some microcracks appear in this area; the existence of a contact pressure limit which can be stressed the case-hardening steel.

***Keywords:** steel, tribomodelling, structure*

1. INTRODUCTION

The machine-building researchers' interest has recently been the question if certain expensive materials can be replaced by less costly ones. Thus, in the field of bearing manufacturing attempts are made to replace the steel RUL-1 (STAT 1456/1-80) by case hardening steel 21MoMnCr12XS (STAT 791-80).

The paper presents the results of experiments carried out to test case-hardening steel behavior for pure rolling friction and linear-contact.

2. PRELIMINARY CONSIDERATIONS

The pure rolling friction is a complex process of physical, chemical, mechanical and metallurgical nature. It leads to damage by pitting wear of the surface layer. The surface layer has a decisive role in tribological behavior of the steel during pitting tests. The surface layer begins from the physical separation limit of the two bodies that are in contact. It stretches into the inferior of each body to the depth where the disturbance of the crystalline lattice ceases [8, 9]. The thickness of the surface layer depends on the type and intensity of stress. It varies from several atomic layer thickness (in case of wear by chemical processes) until *500-1000* μm (in case of dry friction). The surface layer has a complex structure. One of the complete pattern for the surface layer has been given by L. I. Bershadskii [9]. In his conception, the surface layer is presented taking into account the interaction between the solid body and lubricant.

Constantin Gheorghies,
University "Dunarea de Jos" of Galati
Ovidiu Gheorghies,
University "Al. I. Cuza" of Iasi, Romania

In order to study the behavior of the surface layer in damage processes (friction and wear), the notions of tribosystem, tribomodel and triboelement have been used [3, 6, 8, 10]. The tribosystem is an ensemble formed of four elements: the base triboelement; mobile triboelement; intermediate material; working medium. The specific feature of a tribosystem is the presence of friction and its result: wear and fatigue. Data from literature [1, 3, 4] have allowed to male a classification of the tribosystems on the base of the triboelements relative motion. Thus, according to [2, 8] there are: sliding (friction and antifriction); sliding-rolling (antifriction); rolling with forced sliding (friction and antifriction); sliding-rolling (antifriction); rolling with forced sliding (friction and antifriction); abrasive and cavitation tribosystems.

The tribomodel is a tribosystem that is manufactured on based on the similarity theory and performs the same functions as real tribosystem.

The test of the materials on tribomodel presents some advantages [8, 10] versus the test "in situ" because it allows:

- the finding of the commanding parameters which lead to a minimizing or maximizing the damage processes of triboelements;
- the application of the multifactorial planning methods of experiments.

The tribomodelling methods [11] should keep in mind the following aspects; the characteristics of triboelements and tribocontacts; the establishing the testing con-

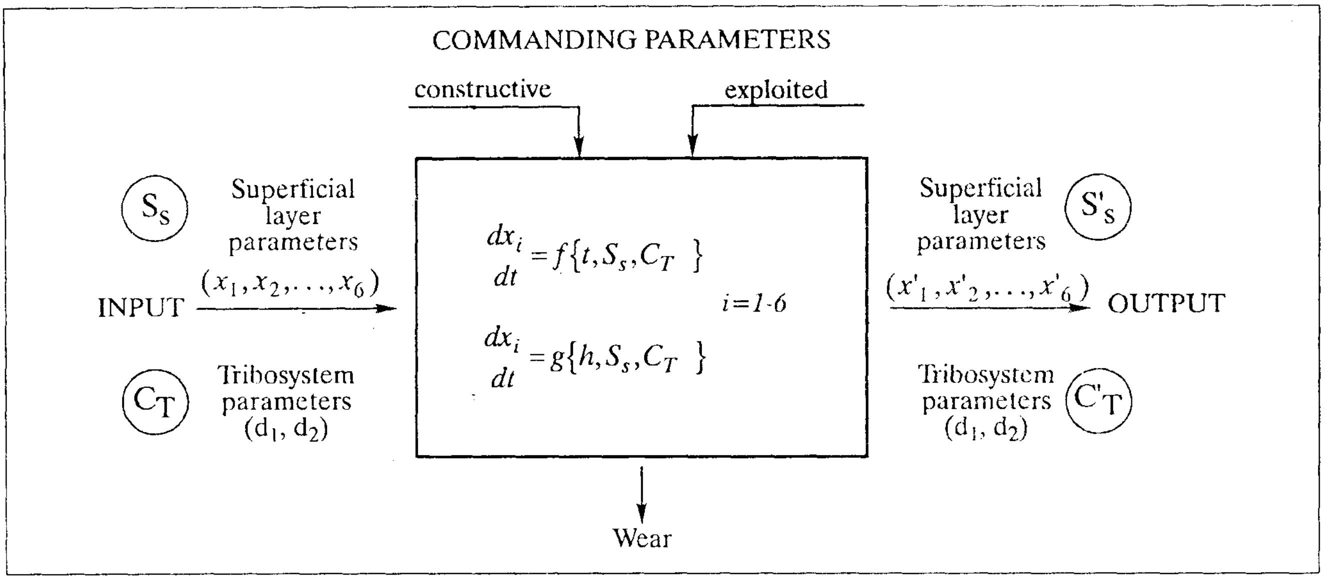


Fig. 1. Cybernetic model for tribosystem

ditions; the selection of the quantitative and qualitative parameters showing damage degree; the finding of the mathematical models in order to establish the dependence between the damage choice parameters and tribophysical ones.

3. CYBERNETIC MODELLING OF TRIBOSYSTEMS

In order to establish and to control the action of the main factors that determine the damage process by pitting, for the tribosystem, the concept of structural cybernetic model [10, 11] has been used. For the same purpose, Czichos [3] -in some works -has used the concept of the energetically cybernetic model. Using of the structural cybernetic model enabled to characterize the surface layer from the physical point of view and not energetic.

In frame of the structural cybernetic model, the tribosystem is presented as a black-box where are designed input parameters (S_s, C_t); commanding parameters (U); output parameters (S_s', C_t') and the parameters which assess the damage degree of the surface layer, as e. g. wear. This model, which allows to follow -in a systematic manner-the changes of the input parameters of the surface layer subjected to pitting process, is presented in figure 1.

The input-output parameters can be grouped as: geometrical (macro and microgeometry - x_1); mechanical (hardness - x_2, tension state x_3); physicometallurgical (chemical composition x_4, structure - x_5, purity - x_6) parameters. Ones from mentioned parameters, for e. g., hardness - x_2, tension state - x_3 and structure - x_5, can be changed in a convenient manner. In this way, the durability of the tribosystem can be controlled, within certain limits, at one's choice.

Parameters (C_t) of the tribosystem can be: level of noise, shape and dimension of contact area, d_1, clearance between triboelements, d_2.

Commanding parameters (U), called external factors, are the parameters which can modify ones from the parameters of the surface layer. These parameters can be grouped in: constructive (shape of triboelement-U_1, dimension of triboelement - U_2); working parameters (kinematics - U_3, energetics - U_4, working medium- U_5).

In the black-box, the input parameters X_i, $(i=1\text{-}6)$ are subjected to changes -in relation with time, t, or depth, h (as in this paper) under action of commanding parameters, U_j, $(j=1\text{-}5)$. The knowledge of function "f" or "g" allow to describe the evolution of X_i-parameters and, finally, the estimate both the history and prediction surface layer behavior in various stress conditions (e. g. pitting process).

4. USED MATERIALS, PITTING TESTING MACHINE.

In order of follow the tribological behavior of case-hardening steel 12MoMnCr12XS, the rolling pure friction test on a tribomodel have been used. The tribomodel was mounted on an original four-ball machine. In figure 2 it is presented this tribomodel where: 1-testing roller; 2-pressing roller; 3-lever for transmission of pressing forces, F. The testing triboelement (testing roller) was manufactured of case-hardening steel. This roller had the dimensions: $\Phi_{outside} = 30\ mm$, $\Phi_{inside} = 20\ mm$; width, $l=12\ mm$. It was subjected to a thermal hardening treatment (heating in methane gas at $850\text{-}860\ ^oC$ and maintaining a period of two hours, being followed by a quenching in oil and annealing). The thickness of the hardened layer was of $0.6\text{-}0.8\ mm$ and the hardness of 62 ± 3 HRC. The pressure of contact, P, has been chosen

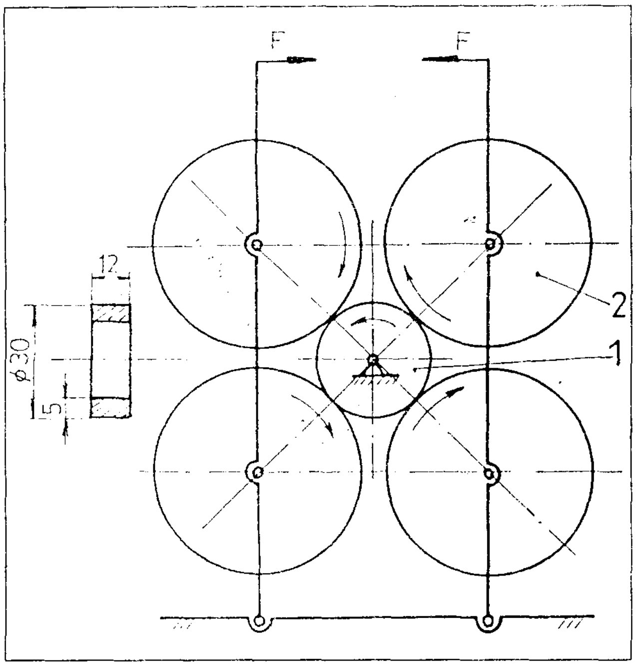


Fig. 2. Used tribomodel

in accordance with SKF standard and it had the value *1900 MPa, 3300 MPa, 4700 MPa*. During the pitting test of up to 10^6 cycles the linear-contact between triboelements were continuously lubricated with a special oil, ensuring a thermostatic control at 80 ± 1^oC.

5. EVALUATION OF THE STRUCTURAL CHANGES, EXPERIMENTAL RESULTS.

From all parameters of the surface layer, x_i, $i=1\text{-}6$, only tension state, x_3, and structure, x_5, have been studied. Thus, their distributions (as value) over the depth, h, of the surface layer after pitting test were investigated. In this aim, the tested rollers were electrochemically polished using a specially manufactured installation.

The chemical composition of the electrolyte was: H_3PO_4 - $750\ cm^3$; H_2SO_4-$180\ cm^3$; CrO_3-$100g$; H_2O-$280\ ml$. Density of electrical current of electrolytic cell was $i=0.7\ A/cm^2$. During polishing the sample (anode) by means of an engine was rotating with frequency of *6.25 Hz*. This motion assures a homogeneity of both concentration and temperature of electrolytic bath. Also, a cooling coil did not allow heating of the solution. By applying an electrolytic polishing technique, layers of $50\,\mu m$ thickness were successively removed from the tested triboelement.

After each polishing, the tested roller was mounted on a X-ray diffraction equipment, type DRON-3 ($XMoK\alpha$, $U=38kV$, $I=22\ mA$, $S_1=1\ mm$, $S_2=0.1\ mm$). From the x_3 and x_5 parameters, have been evaluated:

a) relative percentage of residual austenite, VR(%), using the relation: $\mathrm{VR}(\%) = [RA(\%)]_{h\neq0}\ [RA(\%)]_{h=0}$ is the percentage of residual austenite at sample surface, $[RA(\%)]_{h\neq0}$ is the same size inside of the surface layer at depth h;

b) the width B_{211} of (211) diffraction line corresponding to martensite phase from case-hardening steel (B_{211} is a size proportional to tetragonality degree, c/a, of martensite phase;

c) the width B_{220} of (220) diffraction line of ferrito-perlitic phase from steel (B_{220} is a size proportional to inner second order tension, σ_{II} from crystalline lattice);

d) the ratio (I_{min}/I_{max}) which is proportional to dislocation density, ρ, from crystalline lattice (I_{min} and I_{max}) are respectively minimum and maximum of (220) diffraction line.

In figure 3 it is presented the dependence of size $VR(\%)$ versus depth, h. From this results that:

a) in an initial stage of testing ($P=0\ MPa$), $VR(\%)$ decreases down to half its value from the surface to $500\,\mu m$ depth inside the surface layer;

b) at pressure $P=1900\ MPa$ and $3300\ MPa$, respectively, the developments along the depths have a quite similar appearance, while at $P=3300\ MPa$ is lower; this can be due to the resulting mechanical effects which develop and lead to a phase transformation of type $Fe\gamma \rightarrow Fe\alpha$

c) at pressure $P=4700\ MPa$, $VR(\%)$ varies in steps taking higher values that the initial ones; it is assumed that this is due to some local high temperatures which cause transformations of the type $Fe\alpha \rightarrow Fe\beta$. The appearance of thus high temperature has been mentioned by A. V. Orlov [12].

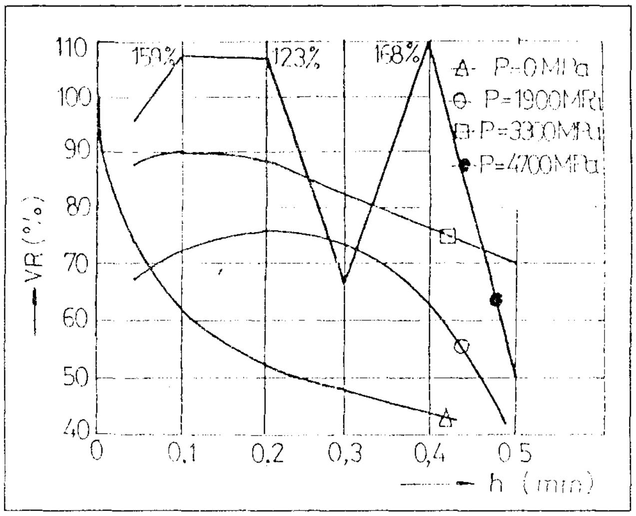


Fig 3. Dependence of VR(%) on h

In figure 4 it is presented the evolution along depth of the size B_{211}~c/a. Analyzing this figure results;

a) the magnitude of B_{211} is smaller for $P=1900\ MPa$ and $3300\ MPa$ comparative with the case when $P=4700\ MPa$; this fact can be explained by these mechanical effects which develop during pitting test and lead to disintegration of tetragonal martensite $Fe\alpha(TBC)$ in cubic martensite $Fe\alpha(BCC)$.

b) at pressure $P=4700\ MPa$, the size B_{211} varies in steps

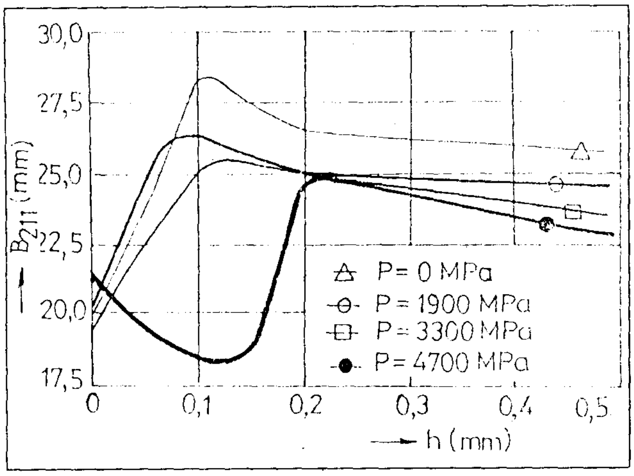


Fig. 4. Dependence of B_{211} on h

as relative residual austenite; this fact can explained by appearance of high temperatures inner surface layer which have various values at different depths; the correlation between the two sizes displays transformations of type $Fe\alpha(TBC) \rightarrow Fe\alpha(BCC)$ and $Fe\gamma \rightarrow Fe\alpha(BCC)$ or $Fe\alpha(TBC)$;

c) the size B_{211} strongly varies up to $200\,\mu m$ inside the surface layer and it follows a stabilization.

In figure 5 is displayed the dependence of size $B_{220} \sim \sigma_{II}(h)$. From presented data results: the inner second order tensions have a peak between $100\text{-}200\,\mu m$ depth, while the curves $B_{200} = B_{220}(h)$ are alternately placed for the three values of the pressure P. This can be accounted for by changes of the prevailing mechanical and thermal effects at various depths during pitting tests.

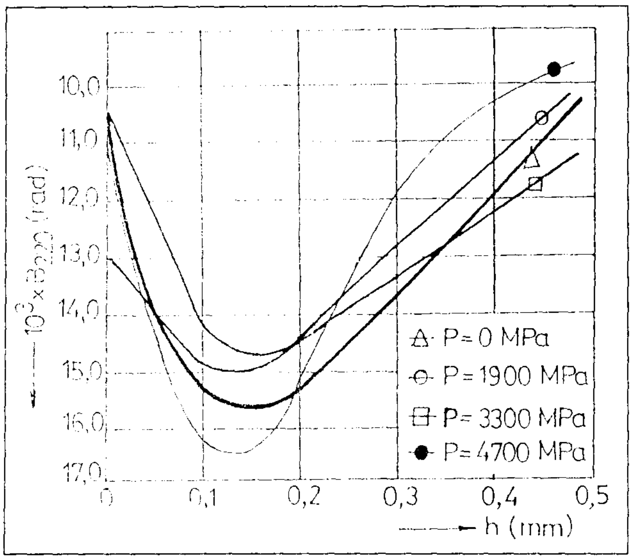


Fig. 5. Dependence of B_{220} on h

In figure 6 it is presented the evolution on surface layer depth of the size $(I_{min}/I_{max})_{220}$. The shapes of designed curves are similar for the three pressures. At $P=0\ MPa$ maximum of dislocations density is located at a depth of $300\,\mu m$ inside the surface layer. At pressure of $1900\ MPa$

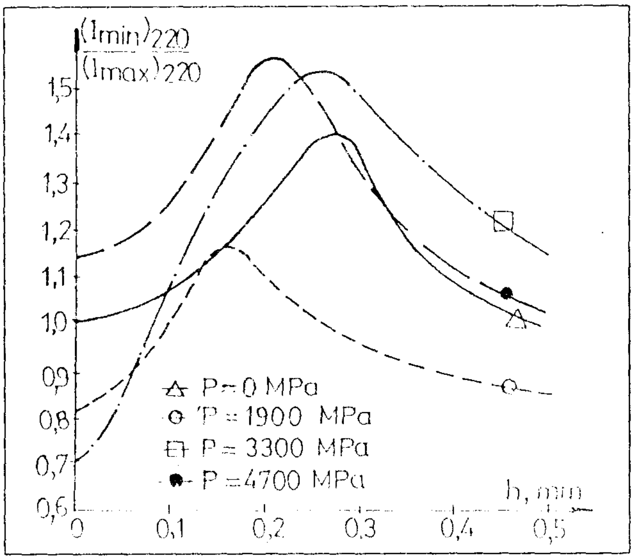


Fig. 6. Dependence of $(I_{min}/I_{max})_{220}$ on h

is found a decrease of the general dislocations density level. The maximum of this curve is situated near surface of the surface layer. For $P = 3300\ MPa$ and $P=4700\ MPa$ the maxima of curves remove inner of the surface layer, having the same values and are located in the same area approximately. This fact shows that the annealing thermal treatment is not enough or should be performed by an another diagram in order to reduce the level of the dislocations density.

6. CONCLUSIONS

- Using the concepts of the tribosystem, tribomodel, triboelement and surface layer it was possible to prepare a pitting testing program in order to establish the tribological behavior of case-hardening steel 21 MoMnCr12XS recommended for replacing the bearing-rolling steel RUL-1.
- From the distribution on the surface layer depth of the structural changes [$X3=X3(h)$ and $X5=X5(h)$] - distinguished by X-ray diffraction method-the following conclusions can be drawn:

a) the existence - in inner of the surface layer of the case-hardening steel - of the diference between mechanical and thermal effects which develop during pitting test; this fact is considered as a negative factor on the structural and dimensional stabilities

b) the existence on surface layer depth of a nonhomogeneity for inner second order tensions which, at depth of $100\text{-}200\,\mu m$, has a maximum value; this fact shows that it is possible that some microcracks appear in this area

c) the existence of a contact pressure limit which the case-hardening steel can be stressed; a higher pressure (over the mentioned limit) can lead to appearance of some phase transformations (e. g. $Fe\alpha \leftrightarrow Fe\gamma$) which are not recommended for case-hardening steel.

- The presented methodology and obtained data can be used in engineering design in order to replace some expensive materials with other cheaper but with similar performances.

7. REFERENCES

[1.] *Colins, I. A*, **Failure of Materials in Mechanical Design**, Ltd. John Wiley, New York, 1981

[2.] *Grudu, I., Palaghian, L., Gheorghies, C.*, **Structural Modifications in the Superficial Layer of Metallic Materials in Wear and Fatigue Processes**, Proceedings of International Tribology Conference, Nagoya 1990, Japan, vol. I, pp. 204-214

[3.] *Czichos, H.*, **Systemanalyse und Physik tribologische Vorgange**, Teill, Grundlagen, Schmirtechnik Tribologie, 22, 6, 1976

[4.] *Djanahmedov, A. H.* **Fiziko stohasticeskoe tribomodelirovanie**, Izd. Elm. Baku, 1988

[5.] *Ishlinskii, A. I., Kragelski, I. V. et. al.*, **Problemi iznashivanija tverdih tel i aspctimehaniki**, Trenie i iznos, 4, 1986

[6.] *Stefanescu, I., Gheorghies, C.*, **The influence of Thermomagnetic Treatment Applied to Rolling-Bearing Steel**, Acta Tribologica, 2, 2, 1994, pp. 137-146

[7.] *Babic, M., Jeremic, B., Milic, N.*, **Tribological Properties of Grain Surfaces**, Proceedings of BALKANTRIB'96, Thessaloniki, Greece pp. 151-158

[8.] *Gheorghies, C.*, **Structural Changes During Friction**, Wear and Fatigue Procceses (in romanian) Technical Publishing House, Bucharest, Romania, 1997

[9.] *Berdshadskii, I. I.*, **O vzaimosviazi strukturnih mehanizmov i dissipativnih potokov pri kineticekom trenii i iznose**, Trenie i Iznos, 2, 1989

[10.] *Duboka, C., Arsenic, Z., Milosavljevic, M.*, **Tribomutation in Tribo-mechanical Systems**, Proceedings of BALKANTRIB'96, Thessaloniki, Greece, pp. 710-710

[11.] *Grudu, I.*, **On the concept of tribosystem and tribomodeling criterion**, Proceedings of EURO-TRIB'85, Ecully, France, 3, 4, 2

[12.] *Orlov, V. A.*, **Ispitania konstructionih materialov na kontaktnuju ustalosti**, Izd. Mashinostroenie, Moskva, 1980

RESEARCH

UDK 621.919.2.001.42

D. AMARANDEI, M. COZMINCA, D. SEMENCIUC

Research and Method Concerning the Experimental Values of the Average Friction Coefficient on the Tool's Flank in Machining of Carbon Steels with Speeds up to 1000 m·min^{-1}

This paper refers to the friction phenomenon on the tool's flank in turning. A method used to determine the average coefficient of friction on the tool's flank is presented. This method is sustained by experimental research obtained in high speed turning of carbon steels (with speeds up to 1000 m·min^{-1})

1. THEORETICAL CONSIDERATIONS

Knowing the value, the distribution for the physical components (the friction force and the plastic deformation force) and the ratio between them is very important in theory as in practice because all these influence the wear's growth and its evolution speed. As the costs needed to restore the cutting properties of the tool and to replace it are going to increase the fabrication costs, it is very important to manage the friction and wear phenomenons in metal cutting.

A lot of scientific papers were published, regarding the external friction phenomenon, the friction coefficient and the factors of influence, but the results are sometime different and most commonly they have gotten different interpretations. An explanation for all these is the fact that all these aspects were treated using various simplifying hypotheses.

Some authors consider that between the tool and the chip, or between the piece and the chip, or between the tool and the piece, is a dry adhesive or abrasive friction, and some other authors solve the same problems for humide friction (considering the cutting fluid involved) or they consider that on the contact surface is a mixed friction, figure 1, [8, 19]. The bibliography relative to that subject shows that in order to determine the friction

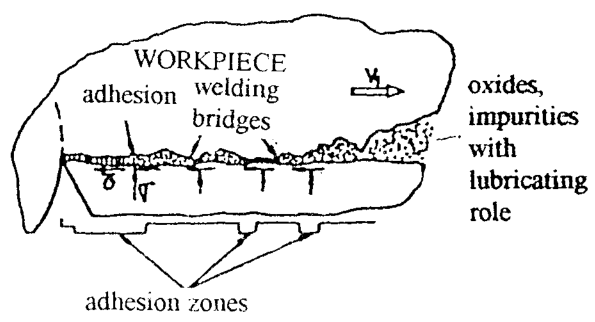


Fig. 1. The real contact surface in metal cutting using an edged tool

components and the friction coefficient both analytic and experimental methods are used.

The real extern friction forces in metal cutting depend on the real contact surfaces between the tool and the piece [4, 9]. For the tools with preset edge (figure 2), the friction surfaces for a section given by the plane made by the cutting speed, v, and the flowing speed of the chip, v_1, are given by the relations (1) and (2):

$$A_\gamma = l \cdot l_{c\gamma} \cdot \cos\eta \quad (1)$$

$$A_\alpha = l \cdot \frac{\Delta_\varepsilon}{\sin\alpha} \cdot \cos\eta \quad (2)$$

It is also shown that the friction force on that surface depends on the complex phenomena connected to friction and on the micro-topography of the surfaces in contact (figure 2). This force has three components: the tearing force for the adhesions and bridges (F_{ap}), the force needed for the elasto-plastic deformations (F_{dpl}) related to the chip flowing and the tearing force for the micro-roughness, relation (3) [17].

Reader Dr. Eng. Dumitru Amarandei,
"Stefan cel Mare" University of Suceava,
Professor Dr. Eng. Mircea cozminca,
"Gheorghe Asachi" University of Iasi,
Lecturer Eng. Dan Semenciuc,
"Stefan cel Mare" University of Suceava

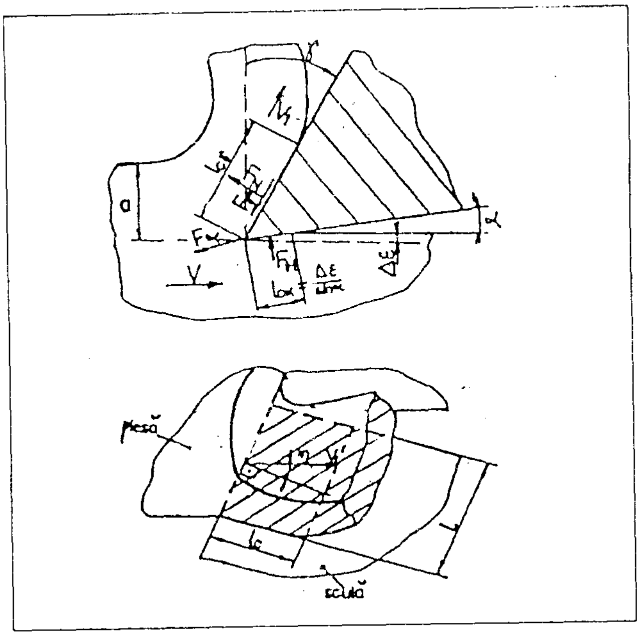


Fig. 2. The real area of contact

$$F, F' = F_{ap} + F_{dpl} + F_{fm} \tag{3}$$

The specialty literature [1...12] underlines that in order to determine in practice the friction force, the most used relations remain those based on Coulomb's dry friction laws (relations 4 and 5), or those written as functions of the force distribution on the contact surface (relations 6 and 7).

$$F = \mu_y \cdot \sigma_y \cdot f \cdot acdot\, C_{dl}^{n} \tag{4}$$

$$F' = \mu_a \cdot F'_N \tag{5}$$

$$F = \tau_{max} \cdot l \cdot l_{cy} \cdot \cos\eta \tag{6}$$

$$F' = \tau_a \cdot l \cdot \frac{\Delta\varepsilon}{\sin\alpha} \cdot \cos\eta \tag{7}$$

So, the calculation of the friction forces, using the relations mentioned above and based on the value of the friction coefficient, the plastic deformation force and the area of the contact surface, is difficult and imprecise, and that's why it is preferable to determine these forces by experiments. There are various constructions of devices used for experimental determinations of the forces and of the friction coefficient in cutting. The analysis of these devices showed that the dynamometric constructions used are very complicated, and sometimes they have not the reliability and the rigidity necessary for the researcher's scope. That's why they are used only for normal cutting speeds.

This paper presents a method for determining the force and the friction coefficient between the tool and the machined piece, and the experimental results obtained in semi-orthogonal turning, modeled as according to [5].

2. METHOD FOR DETERMINING THE FRICTION FORCE ON FLANK SURFACE

Determining the friction force on the flank surface in that case was made with an observation: the chip's forming disappears when the depth (a) of metal's layer in contact with the tool is equal to the elastic deformation (Δ_ε), ($a = \Delta_\varepsilon$) [3, 4]. In that moment, on the curves obtained by experiments (figure 3), for the components F_{ox}, F_{oy}, F_{oz} of the cutting force, a corresponding threshold appears.

It is obvious that when the feed is suddenly cut off, the force decreases until a certain value is reached and then the variation is along the arc *c-d* or a landing *g-h*. The length of the arc or landing depends on the paper's feed, but the moment of the appearance (points *d* and *g*) corresponds to feed's stop (figure 4).

Admitting that the cutting does not take place at a depth $a = \Delta_\varepsilon$, it results that the friction force on the contact surface with the machined piece can be considered as being the force corresponding to points *d* and *g* on the experimental curves. The corresponding value is the friction force on the flank surface, corresponding to the first rotation after the feed's stop. We can see that the arc (landing) appears to all curves, so it means that the friction force on the flank surface is consists of three components F_x, F_y, and F_z, and the resultant force can be obtained by relation (8).

$$F' = \sqrt{F_x' + F_y' + F_z'} \tag{8}$$

3. PHYSICAL-GEOMETRICAL MODEL FOR DETERMINING THE NORMAL FORCE (F'_N) TO THE FLANK SURFACE

The physical and mathematical model proposed for determining the normal force to the flank surface (F'_N) is described in [1,5], for high speed cutting. For a cutting tooth with a general shape edge, relative to the *MXYZ* system, figure 5, there were established (based on analytical and matrix geometry technics) the relations (9) between the components of the friction force (F), the plastic deformation force (F_N) on the rake surface, the components (F') and (F'_N) on the flank surface, the inertial component (F_i) and the experimentally measurable components F_{ox}, F_{oy}, F_{oz}.

$$\begin{bmatrix} -A_1 & B_1 & -C_1 & +N_1 \\ -A_2 & B_2 & -C_2 & +N_2 \\ -A_3 & B_3 & -C_3 & +N_3 \end{bmatrix} \cdot \begin{bmatrix} F \\ F_N \\ F' \\ F_N' \end{bmatrix} = \begin{bmatrix} +F_x \\ -F_y \\ +F_z \end{bmatrix} \tag{9}$$

This system (9) can be solved in two situations, in these cases:

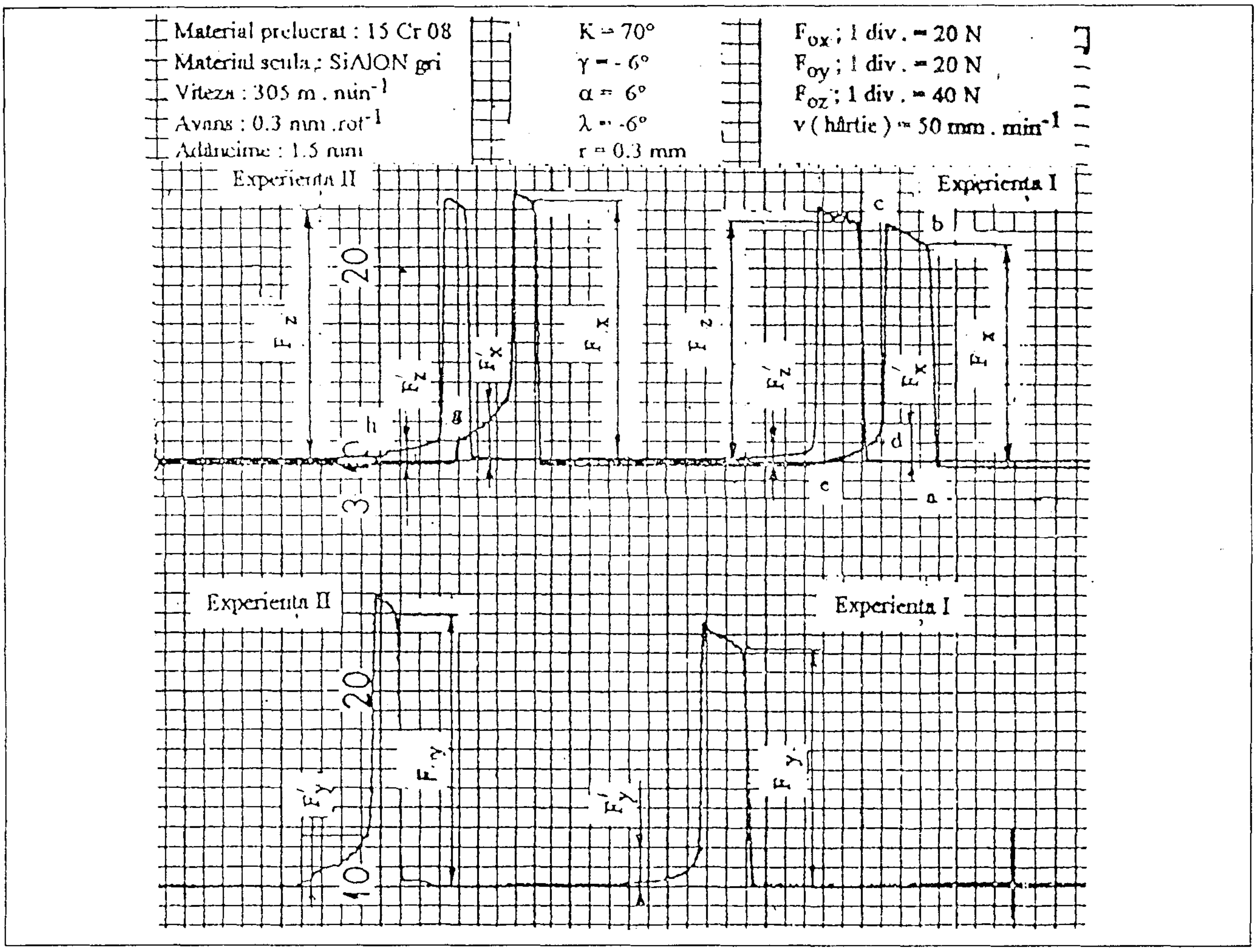


Fig. 3. Experimental curves obtained in static measurements in oblique turning of steels

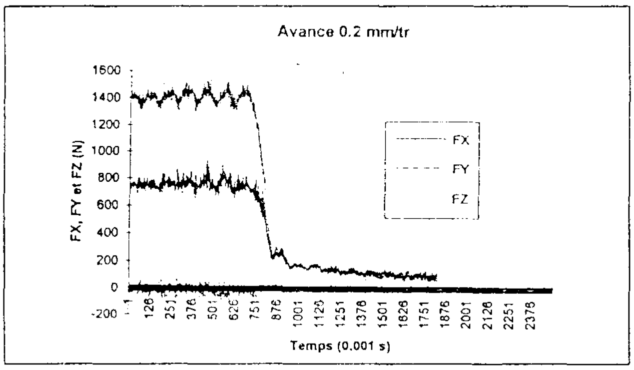


Fig 4. Experimental curves obtained in dynamic measurements in oblique turning of steels

1. - the friction coefficient on the flank surface is assumed as known, it is approximately constant, with values between 0.1...1.9 [13];
2. - the values of the component (F') on the flank surface are experimentally determined.

Knowing the coefficients A_i, B_i, C_i and N_i $(i=1, 2, 3)$, the friction force (F') on the flank surface or the friction coefficient μ', and the components F_{ox}, F_{oy}, F_{oz} experimentally obtained, after solving the system for one of two situations the components F, F_N, F' and F'_N and the ratio between them can be calculated.

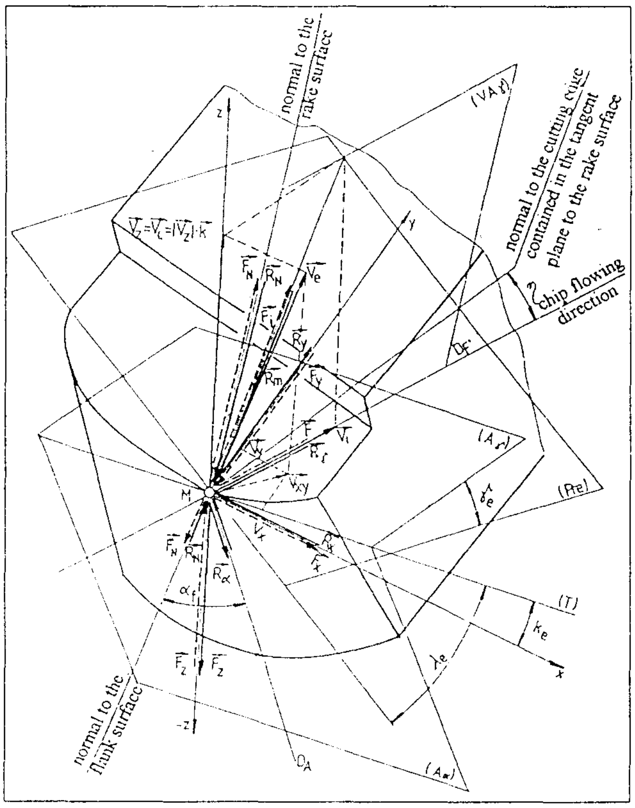


Fig 5. Physical-geometrical model for a cutting tool

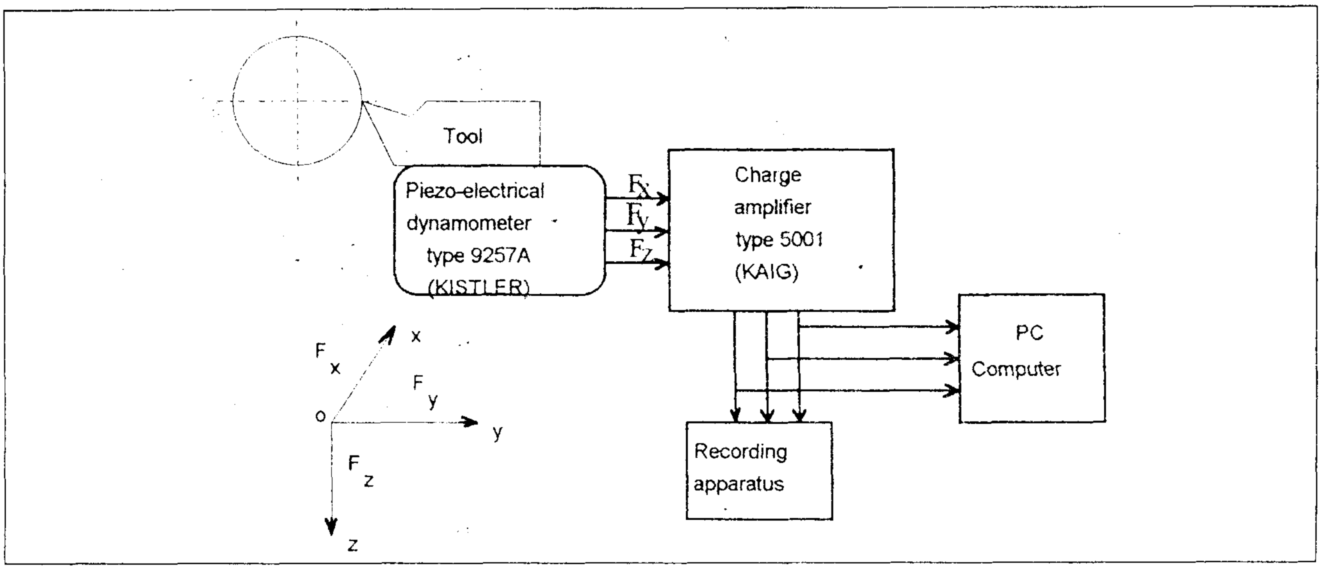


Fig. 6. Measurement, recording and statistical treatment of data chain

4. EXPERIMENTAL RESULTS.

4.1. Machining conditions

In order to determine the friction force and the friction coefficient on the flank surface, tests were carried out in cylindrical external oblique turning, using different cutting speeds [3, 4]. The experiments were made on a modified lathe, with a 16 KW engine and an electronic variator for the rotation. The workpiece had a disk shape, mounted between chuck and dead centre, made from OLC 45 steel. The tool used was a mineral-ceramic one (SiAlON CC 680 E), type SNUN, with the geometry $k=70, \gamma=6, \lambda=6, \alpha=6$. The measurement chain used was composed of a piezo-electrical dynamometer type 9527A (Kistler), a charge amplifier, a recording apparatus and the PC computer.

4.2. Experimental results and interpretation

The experimental values obtained for the friction force and friction coefficient on the flank surface as function of the cutting parameters allow to design the variation curves $\mu_\alpha=f(v)$, $\mu_\alpha=f(f)$ and $\mu_\alpha=f(a)$ in figures 7, 8, 9. Analysis of these values shows that force and the friction coefficient on the flank surface depend on the cutting parameters (v, f, a). For speeds up to *250 m/min*, the temperature rises to *400°C*, the mechanical characteristics of the work-material are less affected.

When the speed is greater than *200 m/min* the temperature rises, the material is much stronger plastified in the cutting zone, and its flowing resistance decreases. On the flank surface, where the material in contact with the tool is not so highly plastified, the friction is weak and so the friction force F (figure 7a), the normal force F_N (figure 8a) and the ratio between them (figure 9a) decrease for *47%*, *30%* and *24.7%*, respectively. For speeds greater than *750 m/min* the influence of the speed on the dete-

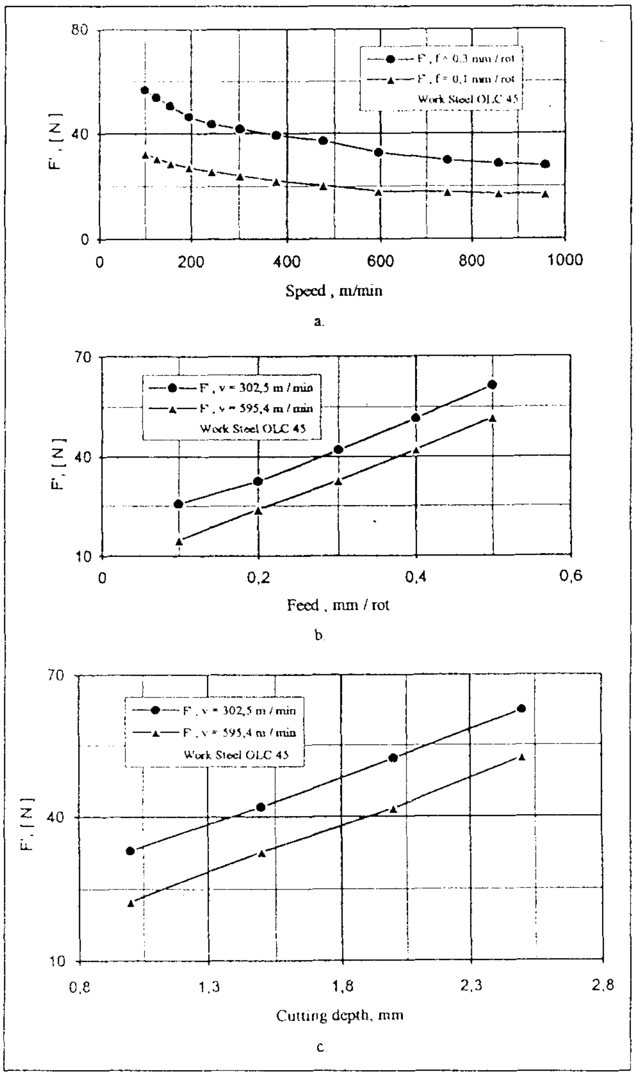


Fig. 7. Variation of the friction force on the flank surface as function of cutting parameters: a - speed; b - feed; c - depth of cutting

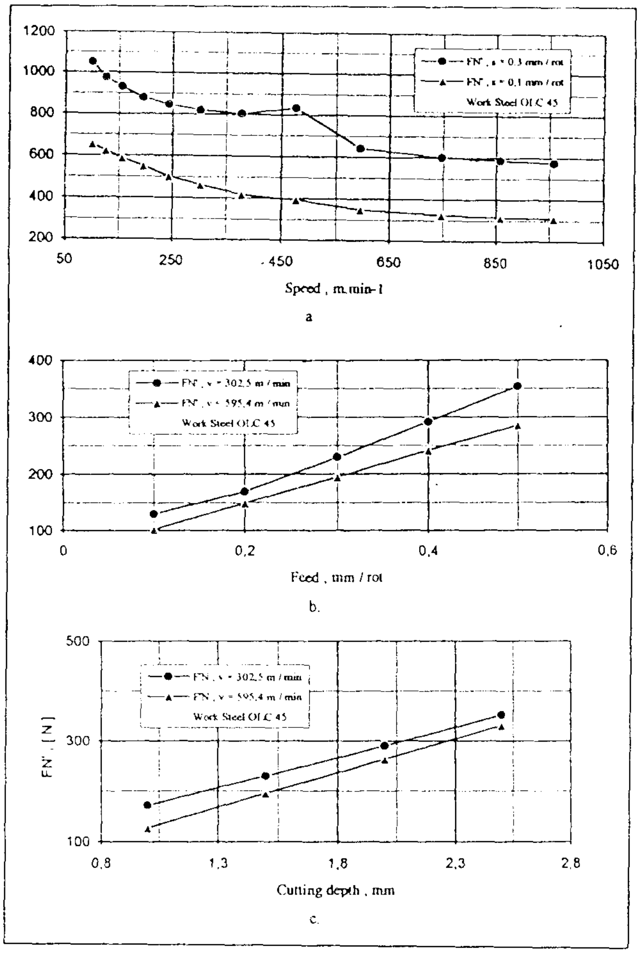


Fig. 8. Variation of the normal force to the flank surface as a function of cutting parameters: a - speed; b - feed; c - depth of cutting

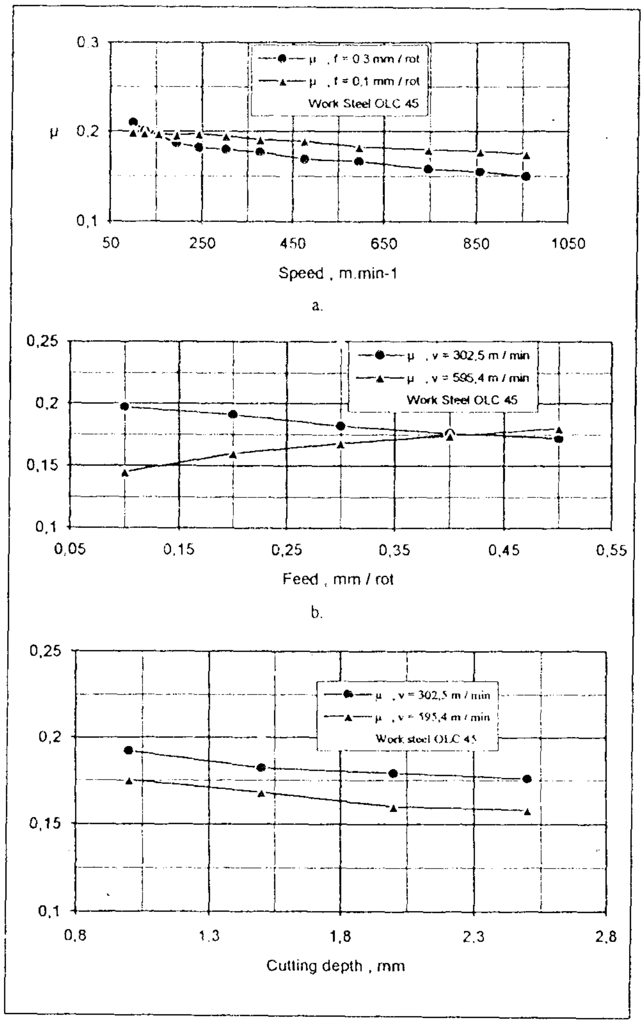


Fig. 9. Variation of the cutting speed and the friction coefficient as function of cutting parameters: a - speed; b - feed; c - depth of cutting

rioration of the physical components is much weaker. As a result, the friction force F increases for *33%*, while the normal force F_N is approximately constant and so their ratio is situated between *0.15...0.21.*

The feed's influence on the friction force F (figure 7b), the normal force F_N (figure 8b) and the ratio between them (figure 9b) is explained based on the fact that the tearing angle (φ) increases and the longitudinal coefficient of plastical compression (C_{dl}) decreases as the feed is higher. When the feed increases from *0.1* to *0.5* mm/rot, the friction force F and the normal one F_N increase from *25.7 N* to *62.1 N* and from *103.1 N* to *354.2 N*, respectively. The decreasing tendency of the friction coefficient as the feed increases can be explained because of the slower increase of the tangential friction stress on that surface, ascribing to the normal stress due to thermal effect.

The influence of the cutting depth on the friction force F (figure 7c), the normal force F_N (figure 8c) and the ratio between them (figure 9c) in oblique turning of OLC 45 steel, shows that the values of these components increase due to thermal stress, as a result of lower specific pressions on contact surface A.

5. CONCLUSION

The results obtained using the methodology proposed above are close enough to those obtained by other authors in their experiments [4]. The friction force and the friction coefficient on the flank surface of the tool depend on the cutting parameters, and their values decrease with an average of *25%* for *100-800 m/min* cutting speeds, as a result of a much more intense thermal effect, influencing the mechanical characteristics of the material.

NOTATIONS:

v	- cutting speed;
$f x a$	- ship's section;
μ_α	- friction coefficient on the flank surface;
μ_γ	- friction coefficient on the rake surface;
$\tau_\gamma, \sigma_\gamma$	- tangential, normal stress to the flank surface;
$\tau_\alpha, \sigma_\alpha$	- tangential, normal stress to the rake surface;
τ_{max}	- maximum tangential stress to rake surface;
(P_0)	- base plane;

(A_α)	- tangent plane to the flank surface, in M;
(A_γ)	- tangent plane to the rake surface, in M;
(P_{re})	- pressure plane (normal to the effect. speed)
vector $\vec{v}_c$	- the resultant speed, in M;
$\bar{T}$	- tool angles: cutting edge angle, rake angle, flank angle, cutting edge inclination angle;
$\kappa, \gamma, \alpha, \lambda$	- tool angles: cutting edge angle, rake angle, flank angle, cutting edge inclination angle;
$\kappa_e, \gamma_e, \alpha_e, \lambda_e$	- working angles: working cutting edge angle, working minor cutting edge inclination angle;
η	- angle between the chip's flowing direction and the vector N, measured in $(A\gamma)$ plane;
F_d	- cutting force;
F_x, F_y, F_z	- components of the cutting force along the axes of the Mxyz system;
F_N	- plastic deformation force;
F, F'	- friction force;
C_{dl}	- plastic deformation coefficient.

BIBLIOGRAPHY

[1.] *Amarandei, D.*, **Model privind structura fizica a fotelor de aschiere la prelucrarea cu viteza mare cu scula cu tais**, Analele Univ. 1-6, Suceava, 1993, pl.72-75.

[2.] *Amarandei, D., Cozminca, M., Mironeasa, C.*, **Relatie de calcul a coeficientului de frecare la aschiere**, Analele Universitatii, nr. I-6, Suceava, Sectiunea Mecanica, 1993, p.50-52.

[3.] *Amarandei, D.*, **Methodes experimentales appliquees a la modelisation de l' usinage par outil coupant dans le but de la determination des forces de deformation plastique et de frottement pendant la coupe a grande viesse**, Diplome d'Etudes Approf. de Mecaniquer, INSA Lyon, Franta, 1993.

[4.] *Amarandei, D.*, **Cecetari privind marimea fotelor de deformare plastica si de frecare la aschierea cu viteze mari a otelurilor carbon**, Teza de doctorat, Universitatea Tehnica "Gh. Asachi" Iasi, mai 1996.

[5.] *Amarandei, D.*, **Experimental method applied for modelling edge tool cutting with aim of evaluation the plastic deformation forces and friction forces at high speed machining**, 4-TH Yugoslav Conference of Tribology, 27-29 sept. 1995, Belgrad.

[6.] *Arndt, G.* **Ultra - High - Speed Machining: A Review and an Analysis of Cutting Forces**, Proc. Inst. Mech., Eng., 1973, vol. 187, 44/73, pag. 625-634.

[7.] *Arndt, G.*, **Ultra-High-Speed Machining**, Annals of the CIRP, vol. 21/1, 1972.

[8.] *Atanasiu, N.*, **Tribology in Forming Processes of the metallic materials**, Tribotehnica 87, The-5-th Conference on friction Lubrification and Wear, Bucureti, septembrie 1987, p.5-12.

[9.] *Belous, V.*, **Sinteza sculeor aschietoare**, Eitura Junimea, Iasi, 1980.

[10.] *Cozminca, M.*, **Bazele generarii suprafetelor pe masini unite**, Universitatea Tehnica "Gh: Asachi" Iasi, 1992, p.155-197.

[11.] *Desmond, F., M.*, **Principles and applications of Tribology**, Copyrrght, 1975, p.254-258.

[12.] *Elepin, A.P.* - **Scorostnoe rezanie i ego effectihnosti pri obrabotke vleakik materialov**, Sb. Nauki, TR /Gorki, Intlnj.vod Transp., 1988, 233, pag.55-62.

[13.] *Erdal, E., Elijah, K., Asibu, Jr.* - **Acoustic emission and Force sensor Fusion for monitoring the Cutting Proces**, Int. J. Mech. Vol. 31, No. 11/12, pag. 795-809, 1989.

[14.] *Ernst, H., Merchant, M.E.*, **Chip Formation Friction and High Quality Machining**, Surface Treatment of Metals, Preprints, 53, ASME, 1941.

[15.] *Ippolito, R., Tornincasa, S., Elepin, E.*, **Mecanica del taglio ad alta velocita**, Ustensil, 3/1985, p.45-51.

[16.] *Kravcenko, G.A.*, **O vleanii parametrov obrabotki na sili deisvuiosie na zadnei poverhnosti instrumenta**, Vestnik Masinostr., 6, 1989, p.41-43.

[17.] *Kronenberg, M.*, **Machining Science**, London, 1966

18.] *Merchant, M.*, **Mechanics of the Metal Cutting Process**, Journal of Applied Physics, vol. 16, no. 5, 1946, pag.267-575.

[19.] *Molinari, A., Dudzinski, D.* - **Stationary shear band in high-speed machining**, C.R. Acad. Sci., Paris, 315, Seria II, pag.399-405, 1992.

[20.] *Recht, R.F.*, **A Dymamic Analysis of High - Speed Machining**, Journal of Engineering for Industry, November, 1985, vol.107, pag.309-315.

[21.] *Zorev, N.N.*, **Despre interdependenta proceselor din zona formarii aschiei si din zona de contact a fetei de degajare a sulei**, Buletinul Construciei de Masini, nr. 12, 1963, p.198-207.

[22.] *Zorev, N.N., s.a.*, **Razvitie nauki o rezanii metallov**, Moskva, 1967.

UDK 621.9.01.003.1:621.892

RESEARCH

F. FLORIAN, D. I. ALEXANDRU

Synthetic Non-newtonian Fluids Based on Polymer Gels II. Rheology of Polymer Gels for Determine Their Flow in Pipe-line

The paper present the research developed for a more exact classification of the synthetic fluids based on a polymer gels into a non-Newtonian flow model, in the form: $\tau = \tau_0 + k \cdot S_n$ where τ is the shear stress, τ_0 the yield stress, S the shear rate, k and n materijal coefficients.

From the experimental results and adopted flow model were calculated the material coefficients values k and n, function of the yield stress and shear rate.

Keywords: *Synthetic fluid, Gel, Rheology, Non-Newtonian flow model.*

1. RHEOLOGY OF GELS

Rheological modeling of gels for pipelines technology is usually described by the Bingham plastic model (equation 1). But, they do not simulate fluid behavior, particularly in the low shear rate range (fig.1).

Using the Bingham plastic model results in the pressure losess larger than observed in the field. The yield-power law model, developed by Herschel and Bulkley (equation 2), more accurately predicts gel rheology (fig.2).

$$\tau = \tau_0 + k_{pv} \cdot S \qquad (1)$$

$$\tau = \tau_0 + k \cdot S^n \qquad (2)$$

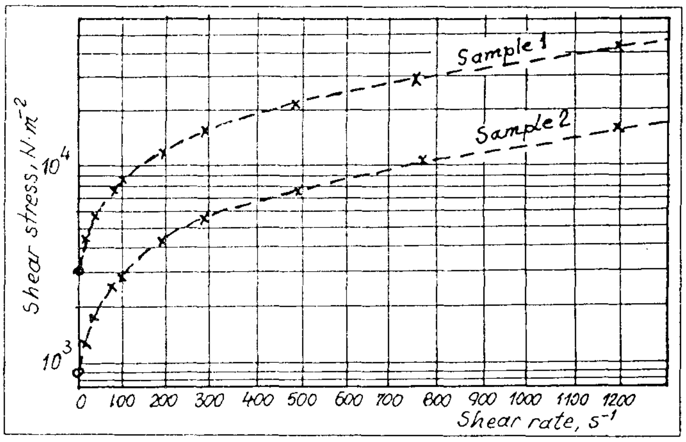


Fig. 2. Yield-power law modeling

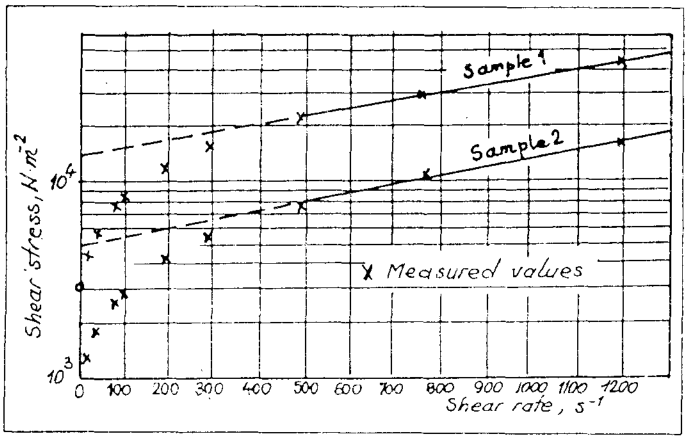


Fig. 1. Bingham plastic modeling (x - experimental values)

In these equations:

- τ = shear stress (the force per unit area required to move the fluid at a given shear rate);
- τ_0 = yield stress (the shear stress required to initiate flow or, the shear stress at zero shear rate);
- S = shear rate (fluid velocity divided by the radius of the pipe through which fluid is moving);
- k_{pv} = coefficient of plastic viscosity;
- k = consistency index;
- n = fluid flow index.

2. THEORETICAL ASPECTS

Based on the material constitutive relation, equation (2), and the following equality, for a viscometric movement (neglecting the mass forces):

$$2 \cdot \pi \cdot r \cdot L \cdot \tau = \pi \cdot r^2 \cdot \Delta p \qquad (3)$$

Florea Florian, Dragomirescu I. Alexandru
Icerp S.A., Ploiesti, Romania

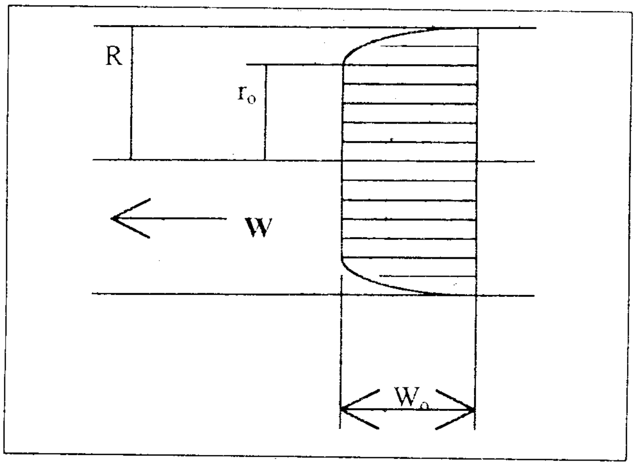


Fig 3. Gel flow in pipe velocity distribution

given the velocity distribution in the form:

$$dw = \left[\Delta p\cdot(2\cdot k\cdot L)^{-1}\right]^{\frac{1}{n}}\cdot(r - r_0)^{\frac{1}{n}}\, dr \qquad (4)$$

In relations (3) and (4): Δp is the pressure, L the length, r the radius and $r_o = 2\cdot L\cdot t_o\cdot(\Delta p)^{-1}$ is the radius of central zone which has a constant velocity, w_o (fig.3).

In (3) are presented the equations for shear rate and k parameter, in the following form:

$$S = (n+1)\cdot n^{-1}\cdot(R - r_o)^{-1}\cdot W_m\cdot A^{-1} \qquad (5)$$

$$k = \tau_w\cdot\left(1 - \frac{r_o}{R}\right)\cdot S^{-n} \qquad (6)$$

where $\tau_w = (\Delta p\cdot R)\cdot(2\cdot L)^{-1}$ is the wall shear stress, $W_m = Q\cdot(\pi\cdot R^2)^{-1}$ is the average velocity (Q=flow rate), $r_o = 2\cdot L\cdot\tau_o\cdot(\Delta p)^{-1}$ and:

$$A = 1\cdot 2n\cdot(3n+1)^{-1}\cdot\left(1 - \frac{r_o}{R}\right)^2 - 2n\cdot(2n+1)^{-1}\cdot r_o\cdot R^{-1}\cdot\left(1 - \frac{r_o}{R}\right) \qquad (7)$$

With relations (5), (6) and (7), k and n parameters can be determined. But, is necessary to have the values for R, r_o, τ_o, Δp, L, W_m and τ_w.

3. EXPERIMENTAL RESULTS

The capillary tube viscometer with a Poiseuille flow (ASTM D 1092) were used for measurements. For test, there were used two gels with characteristics presented (table 1) in the section I of this paper. The results of tests, at 300K, are shown in table 1.

The yield stress is calculated using the equation:

$$\tau_o = (\Delta p\cdot R)\cdot(2\cdot L)^{-1} \qquad (8)$$

The pressure (Δp) in the reservoir of the capillary tube viscometer was increased very slowly and the start-up

Table 1. Experimental values

Q, $m^3\cdot s^{-1}$ x10^{-8}	R, m x10^{-3}	L, m x10^{-3}	W_m, $m\cdot s^{-1}$	S, s^{-1}	Δp, MPa		τ_w, kPa		ro, $m\cdot 10^{-3}$	
					Sample no.		Sample no.		Sample no.	
					1	2	1	2	1	2
5	1.890	151.2	0.0044	9.4	6.84	2.00	4275	1250	1.326	1.361
	1.185	94.8	0.0113	38	9.10	2.90	5687	1812	0.625	0.588
	0.945	75.6	0.0178	75	12.00	4.00	7500	2500	0.378	0.340
	0.760	60.8	0.0275	145	16.00	5.60	10000	3500	0.228	0.195
	0.600	48.0	0.0442	292	24.00	8.65	15000	5406	0.120	0.0999
	0.515	41.2	0.0600	466	-	-	-	-	-	-
8	1.890	151.2	0.0071	15	7.30	2.25	4562	1406	1.243	1.209
	1.185	94.8	0.0181	61	11.20	3.55	7000	2219	0.508	0.480
	0.945	75.6	0.0285	120	15.00	5.00	9375	3125	0.302	0.272
	0.760	60.8	0.0441	232	21.00	7.35	13125	4594	0.174	0.149
	0.600	48.0	0.0707	472	33.00	12.00	20625	7500	0.0873	0.072
	0.515	41.2	0.0960	746	-	-	-	-	-	-
12.8	1.980	151.2	0.0114	24	8.00	2.55	5000	1594	1.134	1.067
	1.185	94.8	0.0290	98	13.60	4.50	8500	2812	0.418	0.379
	0.945	75.6	0.0456	192	18.60	6.50	11625	4062	0.244	0.209
	0.760	60.8	0.0705	371	28.00	10.10	17500	6312	0.130	0.108
	0.600	48.0	0.1130	755	47.00	16.90	29375	10562	0.0613	0.0511
	0.515	41.2	0.1540	1194	70.00	24.00	43750	15000	0.0353	0.0309

yield stress of a gel was determined when the gel began to flow.

The parameters k and n can be calculated using the relations (5), (6) and (7) and the experimental results presented in table 1, by the following method:

a) Shear rates, for various values of n (table 2) are calculated using relation (5) and (7) and the experimental results (table 1);

b) The shear rates thus determined are used, together with relation (6) and the results of table 1, to calculate the values of k factor and it's average site for various values of n (table 3);

Table 2

R, $m \cdot 10^{-3}$	r_o, $m \cdot 10^{-3}$	$1-r_o/R$	τ_w Nm^{-2}	n	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88
1.890	1.326	0.2984127	0.0044		21	20.9	20.8	20.7	20.6	20.5	20.35	20.2
1.890	1.243	0.3423281	0.0071		30.45	30.3	30.15	30.0	29.8	29.65	29.5	29.3
1.890	1.134	0.4	0.0114		43.4	43.2	43	42.75	42.5	42.25	42	41.75
1.185	0.625	0.4725738	0.0113		61.15	60.8	60.45	60.1	59.65	59.4	59.1	58.8
1.185	0.508	0.571308	0.0181		86	85.6	85.2	84.8	84.4	84	83.6	83.2
1.185	0.418	0.6472574	0.0290		127.75	127.2	126.65	126.1	125.5	125	124.4	123.9
0.945	0.378	0.6	0.0178		102.9	102.4	101.9	101.4	101	100.55	100.1	99.6
0.945	0.302	0.6804233	0.0285		153	152.4	151.75	151.1	150.4	149.75	149.1	148.5
0.945	0.244	0.741799	0.0456		233.75	232.8	231.8	230.9	229.9	229	228	227
0.760	0.228	0.7	0.0275		180.75	180	180.75	180	177.7	177	176.2	175.5
0.760	0.174	0.7710526	0.0441		275.6	274.5	273.4	272.22	271.1	270	269	268
0.760	0.130	0.8289474	0.0705		425.3	423.7	422	420.4	418.7	417.1	415.6	414.1
0.600	0.120	0.8	0.0442		343.5	342.2	340.8	339.5	338.1	336.8	335.5	334.2
0.600	0.0873	0.8545	0.0707		532.7	530.7	528.7	526.7	524.7	522.7	520.8	518.9
0.600	0.0613	0.8978333	0.1130		833	830	827	824	820.8	817.9	815	812.1
0.515	0.0353	0.9314563	0.1540		1302.2	1297.6	1293	1288.4	1283.6	1279.2	1274.8	1270.4

Table 3

R, $m \cdot 10^{-3}$	r_o, $m \cdot 10^{-3}$	$1-r_o/R$	τ_w Nm^{-2}	n	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88
1.890	1.326	0.2984127	4275		108.332	105.495	102.745	100.08	97.693	95.182	92946	90.582
1.890	1.243	0.3423281	4.562		98.150	95.239	92.425	89.705	87.199	84.779	82.318	79.938
1.890	1.134	0.4	5000		94.333	91.187	88.156	85.318	82.585	79.869	77.251	74.728
1.185	0.625	0.4725738	5687		96.022	92.587	89.288	86.119	83.133	80.207	77.281	74.525
1.185	0.508	0.571308	7000		108.399	104.073	99.932	95.966	92.167	88.530	85.000	81.621
1.185	0.418	0.6472574	8500		108.229	103.470	98.931	94.601	90.500	86.527	82.736	79.148
0.945	0.378	0.6	7500		105.476	101.104	96.923	92.927	89.031	85.379	81.815	78.442
0.945	0.302	0.6804233	9375	k	108.430	103.443	98.722	94.225	89.943	85.864	81.954	78.230
0.945	0.244	0.741799	11625		103.990	98.799	93.893	89.207	84.795	80.594	76.579	72.785
0.760	0.228	0.7	10000		103.960	99.032	94.368	89.892	85.677	81.648	77.797	74.136
0.760	0.174	0.7710526	13125		106.796	101.293	96.082	91.161	86.501	82.075	77.857	73.863
0.760	0.130	0.8289474	17500		107.726	101.713	96.063	90.717	85.693	80.939	76.439	72.196
0.600	0.120	0.8	15000		105.945	100.247	94.887	89.800	85.014	80.471	76.178	72.101
0.600	0.0873	0.8545	20625		109.057	102.738	96.792	91.199	85.937	80.986	76.314	71.905
0.600	0.0613	0.8978333	29375		113.619	106.544	99.918	93.712	87.898	82.461	77.343	72.548
0.515	0.0353	0.9314563	43750		122.651	114.121	106.540	99.471	92.879	86.731	80.974	75.605
					106.295	101.318	96.604	92.131	87.915	83.890	80.049	76.397

Table 4.

τ_w Nm^{-2}	$\tau_o + k \cdot S^{0.81}$	Error %	Error %	$\tau_o + k \cdot S^{0.82}$	Error %	$\tau_o + k \cdot S^{0.83}$	Error %	$\tau_o + k \cdot S^{0.84}$	Error %	$\tau_o + k \cdot S^{0.85}$	Error %	$\tau_o + k \cdot S^{0.86}$	Error %	$\tau_o + k \cdot S^{0.87}$	Error %	$\tau_o + k \cdot S^{0.88}$
4275	4251.7	0.54	4225.2	1.16	4199.5	1.77	4174.4	2.35	4148	2.97	4124.4	3.52	4098.7	4.12	4075.9	4.66
4562	4691.3	2.83	4661.4	2.18	4632.3	1.54	4603.9	0.92	4574.5	0.27	4545.3	0.36	4518.6	0.95	4492.5	1.52
5000	5253.6	5.07	5222.2	4.44	5191.7	3.83	5159.7	3.19	5129.1	2.58	5100.7	2.01	5072.4	1.45	5038.2	076
5687	5975	5.06	5940.9	4.46	5907.7	3.88	5875.1	3.31	5842.1	2.73	5810.9	2.18	5783.8	1.70	5755	1.20
7000	6921.5	1.12	6893.3	1.52	6866	1.91	6839.3	2.29	6814.6	2.65	6789.6	3.00	6766.2	3.34	6739.2	3.72
8500	8403.4	1.14	8387.2	1.32	8372.3	1.50	8358	1.67	8344.5	1.83	8334	1.95	8323	2.08	8308.6	2.25
7500	7534.9	0.46	7509.5	0.13	7485.2	0.20	7461.5	0.51	7443.6	0.75	7421.5	1.05	7402.8	1.29	7380.7	1.59
9375	9253.3	1.30	9247.9	1.35	9242.1	1.42	9237.2	1.47	9235.1	1.49	9232.3	1.52	9230.7	1.54	9225.8	1.59
11625	11814	1.63	11843	1.88	11872	2.13	11906	2.42	11940	2.71	11976	3.02	12014	3.35	12044	3.61
10000	10157	1.57	10162	1.62	10166	1.66	10174	1.74	10183	1.83	10192	1.92	10203	2.03	10212	2.12
13125	13072	0.40	13122	0.02	13175	0.38	13228	0.78	13185	1.22	13344	1.67	13405	2.13	13467	2.61
17500	17314	1.06	17450	0.28	17588	0.50	17733	1.33	17883	2.18	18035	3.06	18192	3.95	18351	4.86
15000	15040	0.27	15128	0.85	15217	1.45	15311	2.07	15409	2.73	15510	3.40	15610	4.07	15712	4.75
20625	20178	2.17	20380	1.18	20590	0.17	20804	0.87	21030	1.96	21256	3.06	21487	4.18	21722	5.32
29375	27674	5.79	28080	4.41	28499	2.98	28929	1.52	29379	0.01	29831	1.55	30297	3.14	30767	4.74
43750	38433	12.15	39179	10.44	39951	8.68	40744	6.87	41573	4.97	42416	3.05	43286	1.06	44166	0.95
Error average		2.660		2.327		2.125		2.082		2.055		2.270		2.524		2.890

c) The average percentage error related to τ_w values determined experimentally, is calculated with relation (2) using the average value of k (table 4).

For the sample no 1 should be selected those values of the parameters, k and n, for which the lowest error have been obtained. Thus, based of data presented in table 4, it results that the constitutive relation which expresses in the best way the behaviour of this gel, is:

$$\tau = \tau_{01} + 97\,915 \cdot S^{0.85} \tag{9}$$

In the same way are obtained the constitutive relation for the sample no 2:

$$\tau = \tau_{02} + 23\,352 \cdot S^{0.9} \tag{10}$$

The experimental values of yield stress for the gels are

$$\tau_{01} = 3\,000 \ Nm^{-2}$$
$$\tau_{02} = 900 \ Nm^{-2}$$

REFERENCES

[1.] *Scott, P.R.,Zijlstra, Kor N.*, **FLAGS Gas-line Sediment Removed Using Gel-plug Technology**, Oil and Gas Journal, Oct. 26., 1981, p.97-109.

[2.] *Hemphill, T., Campos, W.,Pilehvari, A*, **Yieldpower Law Model More Accurately Predicts Mud Rheology**, Oil and Gas Journal, Aug. 23., 1993, p.45-50.

[3.] *Florea, F., Antonescu, N.N.*, **Greases Material Functions Determination**, Ostfidern 1996, 2169-2176,10th International Colloquium, Technische Akademie Esslingen, 9-11.01.1996, Ostfildern.

UDK 621.9.025.7.42.003

RESEARCH

V. F. BEZAIZICHNY, V. V. NEPOMILUEV

Calculation of The Cutting Conditions Taking into Account The Criteria of The Cost and Productivity

It is known that the cost and productivity of mechanical machining greatly depend on the cutting conditions. Cutting conditions in it's turn are determined by the degree of the cutting tool wearability during the machining process. Therefore to calculate the optimum machining conditions taking into account the criteria of technological cost or productivity, it is necessary to know the dependence of the intensity of the cutting tool wear on the cutting conditions.

Application of the method of the similarity theory allowed to get rather accurate and universal dependency of the cutting tool wear on the parameters of the cutting process, physics-mechanical and heat-physical properties of the treated and tool materials. The received dependency is used to determine optimum in the cost and productivity cutting conditions.

Keyword: *cutting, tool, wear, cost, productivity*

Research of different processes is connected with getting adequate mathematical relations. Such relations allow to manage the process and calculate it's results. However, the obtained relations should be accurate enough and have a wide sphere of application. It is known that the technological cost of the carrying out the operation depending on the cutting conditions, can be determined by the following formula [1]:

$$C_{TEHN} = C_M \cdot t_M + C_M \cdot t_{CM} \cdot \frac{t_M}{T_{MP}} + Z_I \cdot \frac{t_M}{T_{MP}} \quad (1)$$

where C_M is the full cost of one minute machine and worker operation without the time spent for the cutting tool; t_M is the machine working time; t_{CM} is the time for the tool change; T_{MP} is the period of the dimensional tool life; Z_I - expenditures caused by the cutting tool maintenance during the period of its life between resharpenings.

The technological productivity of the operation can be determined by the following:

$$Q_{TEHN} = \frac{60}{t_M + t_{CM} \cdot \frac{t_M}{T_{MP}}} \quad (2)$$

Machine time can be determined by the formula $t_M = \frac{\pi \cdot d \cdot l}{S \cdot V}$, where d and l are the diameter and the length of the treated surface in the direction of the feed; S is the feed; V is the cutting speed.

The period od the dimensional stability of the tool $T_{MP} = \frac{\Delta_{IZN}}{V \cdot h_{OL}}$ where Δ_{IZN} is the acceptable value of the radial wear of the cutting tool, h_{ol} is the dimensionless intensity of the radial wear.

There is a sufficient number of dependences to calculate the wear intensity of the cutting tool, however all of them have some disadvantages: either they have low accuracy (theoretical), or they have very limited sphere of application (empirical).

Cutting tool wear is an integrated process caused by the complex and intereffecting phenomena in the spots of tool contact with the chip and treated blank in the conditions of high temperatures and pressures. As a result of the wear there are changes in technological machining conditions, state of the surface layer and in the dimensions of the treated blank.

After theoretical analysis of the cutting process, and taking into account the main reasons of the tool wear by the method similarity theory, the following criteria dependence was obtained:

$$h_{OL} = c_I \cdot \left(\frac{\sigma_{BP}}{\sigma_I}\right)^{X_I} \cdot (BV)^{Y_I} \cdot (\mathrm{E})^{Z_I} \quad (3)$$

where c_I, X_I, Y_I, Z_I are the factors experimentally determined; σ_{BP} and σ_I are ultimate strengths of the machined and tool materials respectively, at the cutting tem-

Viatcheslave Feoktistovitch Bezaizichny,
Valery Vasilievitch Nepomiluev

perature; B, V, E are the criteria of similarity of the cutting process determined by the formulas [2]:

$$B = \frac{V \cdot a_1}{a}; \quad V = \frac{c \cdot B^X \cdot D^Z}{G^Y \cdot (1 - \sin\gamma)^{0.73}}; \quad E = \frac{\rho_1}{a_1}$$

ρ_1 - is the radius of the rounding of the cutting edge of the tool; a is the temperature conductivity coefficient of the machined material; $D = \frac{a_1}{b_1}$, $G = \frac{\lambda_p}{\lambda} \cdot \beta \cdot \varepsilon$ are the criteria of similarity of the cutting process; a_1 and b_1 are the thickness and width of the shear; γ, β and ε are the angle of cutting edge, the angle of taper and the vertex angle respectively; λ_p and λ are the heat condition efficiencies of the treated and tool materials respectively; c, x, y, z are the values depended on the properties of the machined and tool materials.

The criterion $\frac{\sigma_{VR}}{\sigma_I}$ takes into account the influence of the abrasive and adhesive phenomena on the process of the cutting tool wear. The B, V and E criteria show the influence of the diffusive and oxidizing ones.

Durable experiments were made and experimental data of other authors given in the papers [3, 4, 5, 6, 7, 8] were used to determine the values of the coefficients c_1, x_1, y_1, z_1 in the obtained criterion equation (3).

The values of the coefficients c, x, y, z obtained after the mathematical processing of the experimental results are given in table 1.

$k=1$ for monocarbide tungsten-cobalt hard alloys; $k=1.8$ for bicarbide titanium-tungsten-cobalt alloys; $k=1.5$ for high-speed steel; l is the ratio of heat conduction efficiencies of the tool and machined materials.

The value of x_1 for the first four groups of the machined materials is equal zero. This confirms the well-known fact that abrasive and adhesive kinds of the tool wear in cutting of these materials are not typical.

T - Student's criterion and F - the Fisher's criterion testings showed that all coefficients are meaningful and the obtained mathematical model is adequate for the tested dependence.

Representing the obtained dependence into formula (1) after some transformations we have the following:

$$C_{TEHN} = C_M \cdot \frac{\pi \cdot d \cdot l}{S \cdot V} + \frac{\pi \cdot d \cdot l}{S \cdot \Delta_{IZN}} \cdot C_1 \cdot \left(\frac{\sigma_{VR}}{\sigma_i}\right)^{x_1} \cdot \left[\frac{C \cdot \left(\frac{a_1}{a_a}\right)^{1+x} \cdot D^Z}{G^Y \cdot (1-\sin\gamma)^{0.73}}\right]^{Y_1} \cdot E^{Z_1} \cdot V^{(1+x)\cdot Y_1} \cdot (C_M + Z_1) \tag{4}$$

Cutting speed V_{minC} which corresponds to the minimum technological cost can be determined if we take the speed derivative, which was determined in the equation (4) and compare it to zero.

After some transformations we obtain the formula (5).

Maximum value of the technological productivity according to formula (2) will be in the case of

$$t_M + t_{CM} \cdot \frac{t_M}{T_{MP}} \rightarrow min \tag{6}$$

This condition will be right in the case if the cutting speed derivative, determined from the expression (6), is equal zero. After substitution of the values which expression (6) has and after differentiation we get the formula (7):

After transformation of the obtained expression (7) we get the formula for getting the cutting speed which cor-

$$V_{minC} = \left\{\frac{C_M \cdot \Delta_{IZM}}{C_1 \cdot \left(\frac{\sigma_{VR}}{\sigma_I}\right)^{X_1} \cdot \left[\frac{C \cdot \left(\frac{a_1}{a_a}\right)^{1+x} \cdot D^Z}{G^Y \cdot (1-\sin\gamma)^{0.73}}\right]^{Y_1} \cdot E^{Z_1} \cdot (C_M \cdot t_{CM} + Z_1) \cdot (1+x) \cdot y_1}\right\}^{\frac{1}{(1+x)\cdot y_1+1}} \tag{5}$$

Table 1. Values of the coefficients in formula (3)

Groups of the materials	c	x	y	z
Aluminium alloys	$1.79 \cdot 10^{-3}$	0	$3.14 \cdot \sqrt{k \cdot l}$	2.03
Copper alloys	$1.34 \cdot 10^{-3}$	0	$3.80 \cdot \sqrt{k \cdot l}$	2.63
Magnesium alloys	0.26	0	$2.71 \cdot \sqrt{k \cdot l}$	2.26
Carbon and alloy steels	$6.68 \cdot 10^{-8}$	0	$2.70 \cdot \sqrt{k \cdot l}$	3.79
Stainless and highheat resistant steels	$1.38 \cdot 10^{-8}$	1.88	$1.10 \cdot \sqrt{k \cdot l}$	1.66
Titanium alloys	$2.79 \cdot 10^{-11}$	3.49	$3.14 \cdot \sqrt{k \cdot l}$	6.31
Nickel alloys	$2.05 \cdot 10^{-7}$	2.30	$0.92 \cdot \sqrt{k \cdot l}$	1.70

$$\frac{\pi \cdot d \cdot l}{S} \cdot \left\{ -\frac{1}{V^2} + \frac{(1+x) \cdot y_1 \cdot c_1}{\Delta_{IZN}} \cdot t_{CM} \cdot \left(\frac{\sigma_{VR}}{\sigma_I} \right)^{X_1} \cdot \left[\frac{C \cdot \left(\frac{a_1}{a_a} \right)^{1+x} \cdot D^Z}{G^Y \cdot (1-\sin\gamma)^{0.73}} \right]^{Y_1} \cdot E^{Z_1} \cdot V^{(1+x) y_1 - 1} \right\} = 0 \quad (7)$$

$$V_{maxQ} = \left\{ \frac{\Delta_{IZN}}{(1+x) \cdot y_1 \cdot C_1 \cdot t_{CM} \cdot \left(\frac{\sigma_{VR}}{\sigma_I} \right)^{X_1} \cdot \left[\frac{C \cdot \left(\frac{a_1}{a_a} \right)^{1+x} \cdot D^Z}{G^Y \cdot (1-\sin\gamma)^{0.73}} \right]^{Y_1} \cdot E^{Z_1}} \right\}^{\frac{1}{(1+x) \cdot y_1 + 1}} \quad (8)$$

responds to the maximum treatment productivity (formula 8).

So, we can draw the following conclusion: the use of method of similarity theory allowed to get the universal dependence of the cutting tool wear intensity on the parameters of the cutting process and the physical-mechanical and heat-physical properties of the machined and tool materials.

The obtained dependence can be used to determine optimum of cost and treatment productivity cutting conditions; it can also be used to calculate machining error caused by the cutting tool wear; to choose the tool material grade for pure and semipure turning and to control the cutting process including adaptive one.

LITERATURE

[1.] *Molchanov G.I.* **Increasing of treatment efficiency on the lathe with program control.** - Soscow: Machinebuilding, 1979.-240 p.

[2.] **Optimization of technological conditions of the mechanical working of the aircraft engine parts** */V.F. Beziazichny, T.D. Kozhina, A.V. Konstantinov, V.V. Nepomiluev, A.N. Semyonov, T.V. Sharova, Y.P. Chisyakov.* - Moscow: MAI, 1993. - 184 p.

[3.] *Loladze T.N.* **Strength and wear resistance of the cutting tool.** - Moscow: Machinebuilding, 1982.-320 p.

[4.] *Makarov A.D.* **Wear and strength of the cutting tools.** - Moscow: Machinebuilding, 1966. - 263 p.

[5.] *Makarov A.D.* **Optimization of cutting process.** - Moscow: Machinebuilding, 1976. -278 p.

[6.] *Bobov V.F.* **Fundamentals of metal cutting theory.** - Moscow: Machinebuilding, 1975. - 344 p.

[7.] **Directory of the technologist machine-builder.** In two v. V. 2 / editors *A.G. Kosilova and R.K. Mescheriakov.* - Moscow: Machinebuilding, 1986, -496 p.

[8.] *Poduraev V.N.* **Cutting of the hard treated materials.** - Moscow: Machinebuilding, 1974. -590 p

RESEARCH

UDK 621.179.6.891.22

T. F. KALMYKOVA, T. M. MOISEEVA, O.V. KHOLODILOV

On Statistical Description of Solids Friction

A method is proposed of estimating the parameters of a special class correlation function. It is based on measurements of statistic of the studied phenomenon or FSFC. The only condition of applying the statistics is the requirement that the product of frequency range of the recorded radiation by time of recording is vastly larger than unity. A combined analysis of acoustic data and those of FSFC (roughness, size distribution of wear debris, etc.) have shown that the statistics are responsive to practically all phenomena accompanying friction and wear. The dependencies obtained of the statistics variation with external factors have enabled new criteria to estimate durability of friction joints to be formulated.

Keywords: *friction, wear, surface roughness, wear debris, acoustic irradiation*

1. INTRODUCTION

A number of tribological problems whose solutions are important for understanding solids friction require investigation of both statistical properties accompanying friction and wear (acoustic irradiation, heat generation, etc.), and study of fixed states of a friction contact (FSFC) involving surface roughness, wear debris and so on. It turns so, that separate parameters of these phenomena (intensity of acoustic irradiation, contact temperature) and FSFC realization (rough surface profile, wear debris size) are insufficient for unambiguous identification of a tribosystem state.

2. PROBLEM FORMULATION

Friction to proceed from the fact that the majority of the phenomena and FSFC can be presented as realization of a random field *(x, y)*, so a number of the tribological characteristics would depend on its correlation function behavior about zero. In this connection the problem of estimation and simulation of the function seems quite actual. A method has been proposed earlier to estimate correlation function parameters of a certain class random fields. The method is based on the use of functionals (statistics) belonging to the studied phenomena or FSFC [1, 2]:

$$a = \frac{2}{(\Lambda \cdot T)^2 \cdot ln(\frac{\Lambda}{\lambda_0})} \cdot \sum\sum_{k,l=0}^{(\Lambda T)-1} ln \left| \xi(x_{k+1}, y_{l+1}) - \xi(x_k, y_l) \right|$$

$$b = \frac{\Lambda^{a-2}}{16 \cdot T^2 \cdot \varphi(a)} \cdot \sum\sum_{k,l=0}^{(\Lambda T)-1} \left[\xi(x_{k+1}, y_{l+1}) - \xi(x_k, y_l) \right]^2$$

where: $\varphi(a) = \iint_{-1}^{\Lambda} sin^2 \frac{t}{2} \cdot sin \frac{p}{2} \cdot \frac{dt \cdot dp}{\left[(t^2 + p^2)^{2+\alpha} \right]^{0.5}}$ - is the tabulated function; Λ - transmission band; λ_i - frequency range of the recorded field; t - time of recording; T - sampling length. The only condition for their application is $\Lambda t > 1$.

Objects of the present investigation are the following: 1 - to substantiate invariance of proposed functionals for any nature random fields; 2 - to prove their stability for stationary fields and substantial sensitivity to variations in stability.

These problems can be traced on the example of the studied in friction contact acoustic fields and in case with mechanically induced random states of the friction contact (asperities of contact surfaces, structure of actual contact spots, fields of wear debris distribution).

Let us dwell on acoustic frictional phenomena and show the probability of the suggested functionals use to estimate the mechanism of frictional contact wearing by characteristic parameter *r(a, b)* in the space of statistics *(a, b)*.

T. F. Kalmykova, T. M. Moiseeva, O. V. Kholodilov
Metal-Polymer Research Institute named after V.A. Belyi of Belarussian Academy of Sciences,
Gomel, Republic of Belarus

3. OBJECTIVES AND METHODS

Friction investigations used the shaft-on-partial insert geometry (shaft - steel 45, insert - organic fiber reinforced thermoplastic). The composite choice was conditioned by diversity of acoustic irradiation sources and probability of direct effect on some of them, for e.g., by varying phase interaction in the polymer-fiber system or alternating the polymer matrix deformation properties. The regime (loads, sliding velocity, etc) were selected so as to realize different wear mechanisms.

The acoustic signal receiver was fixed on the insert and continuous recording of acoustic irradiation (AI) was performed followed by statistic processing. Simultaneously with acoustic information tribological parameters of the system were registered including friction coefficient, wear rate and temperature. Morphological analysis of wear debris was carried out using REM-PC complex.

4. RESULTS AND DISCUSSION

Experimental investigations have shown that during run-in the intensity of acoustic irradiation, its amplitude distribution and statistics a, b and r(a, b) are comparatively sensitive indicators of wearing. In particular, owing to plastic displacement and microcutting the actual contact spots of interacting surfaces show the rise of both the acoustic field intensity and its characteristic parameter. Further combined stabilization of the friction surface geometrical parameters and physico-mechanical properties results in stability of the studied functionals radiation intensity. So, the suggested functionals are indicators of friction induced variations of acoustic field. Note that characteristic parameter *r(a, b)* is a comparatively sensitive probe for such variations.

It has been established that increase in the polymer composite relative rigidity (*Ef/Em*, where *Ef, Em* - modules of fiber and matrix elasticity, correspondingly) leads to growth of characteristic parameter *r(a, b)*. For example, polyarylate-based composites filled by polyamide fiber with *Ef = 18.5 GPa* and *Ef = 135 GPa* display the growth of characteristic parameter *r(a, b)* by about *27%*. This can be attributed to high plasticity of the composite due to which a great number of acoustic radiation sources activate in the friction contact leading to change in emission intensity.

Interesting results were obtained when comparing statistic parameters of acoustic irradiation amplitude distribution and those of debris distribution by size [3]. Both distributions are of unimodular character with a prominent asymmetry.

It has been found out that the concerned distributions statistic parameters (asymmetry and excess) do not coincide and behave inadequately with changing friction conditions (for e.g., due to changed contact rigidity). Characteristic parameter of acoustic field *r(a, b)* correlates more closely with the character of damage in the friction contact. Particularly, when different wear mechanisms are realized in the contact, characteristic parameter *r(a, b)* preserves its stability (fig.1).

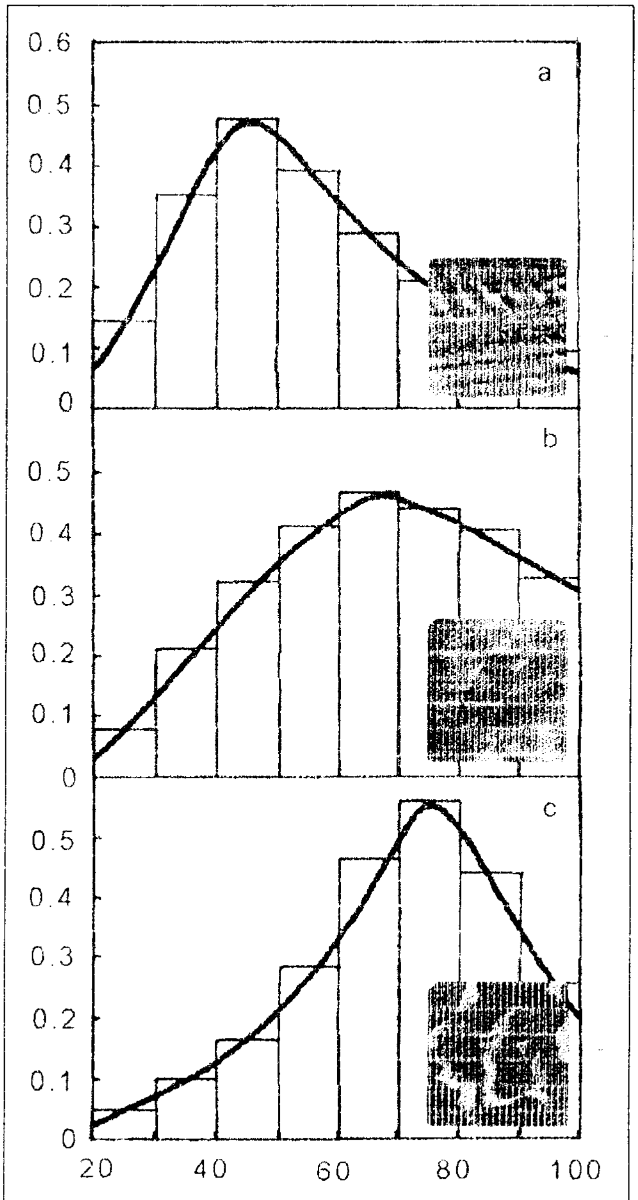


Figure 1. View of a polymer friction surface and wear debris distribution by size: a - abrasive wear, |r(a, b)| =6.2 rel. un.; b - fatigue, 4.8; c - at seizure, 9.8; thermoplast-steel 45 friction pair

The suggested statistics and deduced characteristic parameter $|r(a, b)|$ are sufficiently sensitive indicators of frictional interaction and correlate with changes in friction conditions. As for example, the relative value of characteristic parameter grows with velocity increase and simultaneously responds to contact rigidity changes (fig.2).

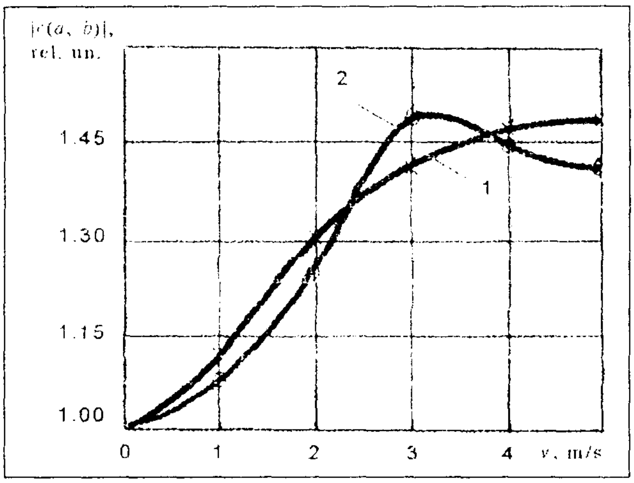


Figure 2. Relative variation of characteristic parameter r(a, b) versus sliding velocity:
1 - polycarbonate + fiber;
2 - polycarbonate + modified fiber

With increasing sliding velocity the amplitude distribution expands into the region of large amplitudes. The studied statistics vary too. The presence of coarse wear particles (formed at high velocities) points to the fact that plastic deformation processes localize in wide areas and fracture onsets in the near-surface layer with further microcrack penetration onto the friction surface and large fragments spalling. This rises activity of emission sources conditioned by the growth of microcracks in the polymer contact layer and total increase of the acoustic flow activity.

Further increase of velocity leads to rising surface temperature. The phenomenon of frictional heating of engaged material surfaces reduces both acoustic signal intensity and the studied statistics. The actual contact area of friction surfaces expands, which causes increased adhesive interaction leading to sticking. Sticking is accompanied by abrupt augment of acoustic signal and its statistics. It is evident that heating would evoke abrupt increase in the molecular constituent of the friction coefficient and result, in a number of cases, in seizure accompanied by spalling of large lumps from the friction surface. At seizure characteristic parameter *r(a, b)* shows jerky character.

5. CONCLUSION

The combined analysis of acoustic and fixed state data of the friction contact (debris distribution by size) has shown sensitivity of statistics to practically all phenomena occurring at friction and wear. The obtained dependences of these statistics on external factors made it possible to formulate new criteria for determining friction joint durability.

REFERENCES

[1.] *Kalmykova T.F. and Kholodilov O.V.*, **On Statistical Description of Rough Surfaces**, The Joint Soviet-American Conf. "New Materials and Technologies in Tribology", Abstracts, Minsk (1992), 201-202.

[2.] *Moiseeva T.M., Ostrovsky E.I., Kalmykova T.F. and Kholodilov O.V.*, **On statistical Description of Rough Surfaces**, J. of Friction and Wear, 14 (1993), 140-142.

[3.] *Moiseeva T.M., Kalmykova T.F. and Kholodilov O.V.*, **Multidimensional Statistical Analysis of the Problems of Tribosystem State Identification**, Proc. Int. Conf. "Computer Methods and Inverse Problems in Nondestructive Testing and Diagnostics", CM NDT-95, Minsk, Belarus (1995), 215-221.

UDK 621.836.004.6

RESEARCH

M. OGNJANOVIĆ, P. OBRADOVIĆ

Modelling of High-pressure Dynamic Sealing Joints

Modelling is a process by which one can extract from a real-world construction the elements important for the functioning, then to analyse their interaction or correlation, and finally to predict or to simulate how the real system would behave. For the design process, when the system is not yet fully defined, this method is the basic procedure. In this paper the modelling is applied on dynamic sealing joints design. Process is decomposed in the three operations which are: the selection of type of sealing, the selection of design parameters, and modelling of the shape of seal parts. The theory of fuzzy reasoning is used for the selection of sealing method and the optimisation method for selection of the seal parameters. The main limitations in optimisation process are tribologic characteristics; the objective function is service life of the sealing element. For the modelling of shape, the parametric method - which is very efficient in the design process - is proposed.

Key words: *Sealing, fuzzy reasoning, modelling, decision making.*

1. INTRODUCTION

The transformation of fluid energy into mechanical work and vice versa takes place in the closed space of the housing of system. The transfer of energy is a well known process and is based on the interaction between the flow of fluid and the movable parts of machine such as turbine blades and pistons. The loads - forces and moments - are transferred by elements such as shafts and axles inside the housing. The connections between movable and non-movable parts and housing must be well sealed. The seals have to be reliable within the given range of parameters such as pressure, temperature, density and chemical aggressiveness and other effects of operating conditions. Sealing joints are potentially critical places and the reliability of the whole system depends on their reliability. As every solution has certain shortcomings, the investigations in this field are based on the indentification of characteristics of existing seals, their improvement and developements of advanced sealing products. There is a high number of seal designs which ranges of application partially overlaped.

A tendency to develop new designs, as well as to improve the old ones, is present.

Modelling is an approach to the design process which permits a detailed analysis of requirements and limitations on the model, leading to the optimal solution for given operating conditions or, alternativelly, to the new constructions and ideas. This paper introduces a new conception of modelling for identification of acceptable solutions, selection of the sealing method and suggestion of new proposals for the designs of seals.

Prof. dr Milosav Ognjanović,
Prof. dr Pauna Obradović
Faculty of Mechanical Engineering, Belgrade

2. CHARACTERISTICS AND TYPES OF DYNAMIC SEALING JOINTS

If machine parts move relatively to each other, there are two basic methods of sealing: contact and non-contact types. The first group of sealing joints make contact on either radial (i.e., cylindrical) or axial (flat) surfaces. Compression seals, hydraulic seals and non-deformable seals are examples of radial seal joints. Axial sealing elements make contact through sealing rings which can slide along the axis, having adequate shapes and supports. Non-contact sealing joints (the second large group) may have clearance gaps, labyrinths or membranes. The first two methods actually reduce flow by increasing hydraulic resistance between moving surfaces, rather than stopping flow altogether.

The most important seal types are shown in Fig. 1. Some are suitable for sealing of rotating shafts and axles, others for axially moving ones, still others for either type, or for parts which both rotate and move axially. The decision which type should be selected depends on circumstances like relative speed, friction losses, accuracy and roughness of surfaces in contact. Furthermore, the properties of fluid such as density, temperature, operating pressure, chemical aggressiveness and abrasivity must also be considered. The selection of an adequate seal therefore is a complex problem which could be decomposed in the following activities shown in Fig. 2. The first

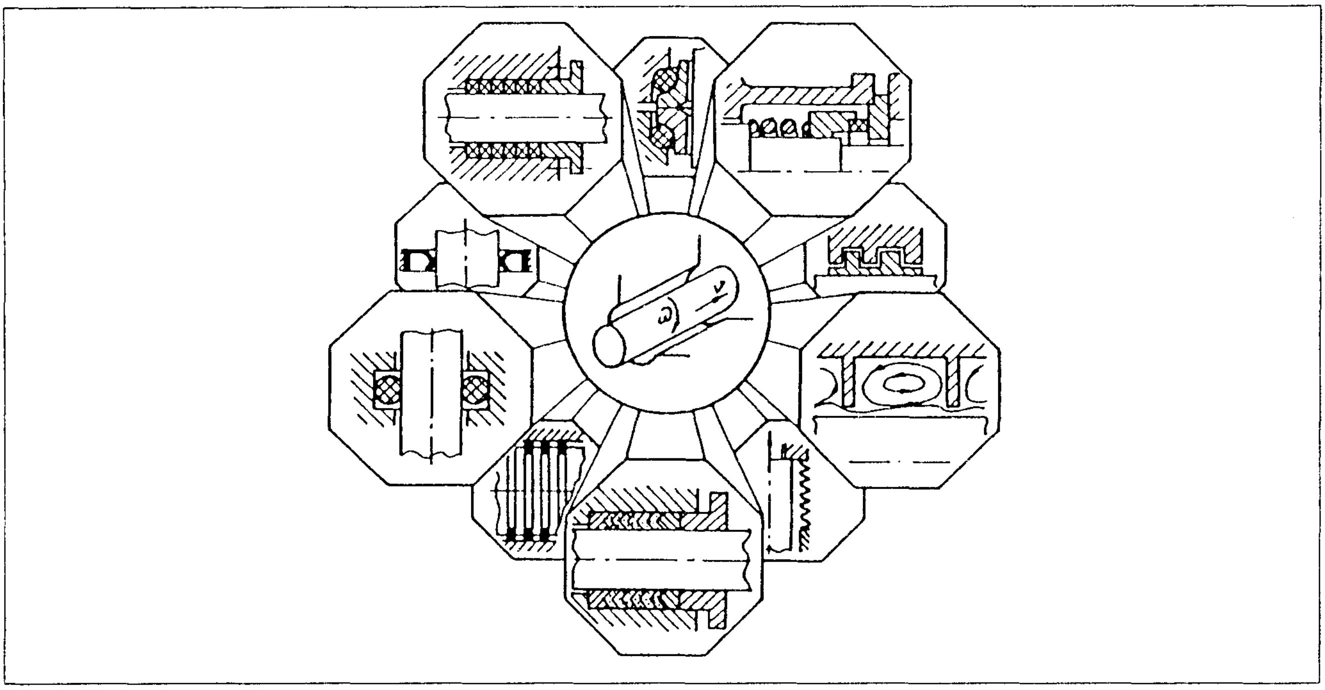


Fig. 1. The basic groups of sealing joints of mobile surfaces

step is the selection of type of seals. The complete method is given in section 3. The parameters such as dimensions, material, resistance, heat etc., are computed next, for the selected type of seal.

This activity is based on the use of a catalogue of standard parts, experimental results and analysis. If dimensions, or resistance, heating, or wear are unacceptable, the type of sealing connection should be changed. The structure of construction elements, 3-D models of sealing parts and their relationship are designed in the third phase. At this level some changes of selected parameters are still possible - even of the type of sealing as shown schematically in Fig. 2.

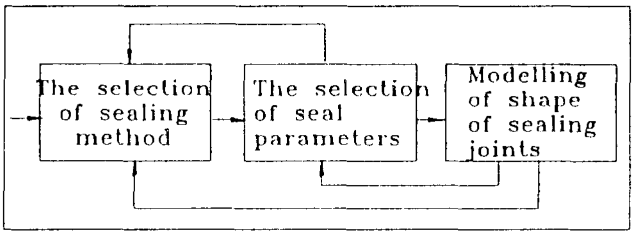


Fig. 2 The basic activities of selection and modelling of sealing joints

3. THE SELECTION OF TYPE OF DYNAMIC SEALING JOINTS

The decision which type should be selected depends on fluid properties such as density, temperature, operating pressure, chemical aggressiveness as well as operating conditions like relative speed, friction losses, accuracy and roughness of surfaces in contact. All these parameters could be quantified by measurements but the areas of application for individual types are not clearly delineated; some types overlap in certain ranges of use. This fact clearly shows the uncertainties in selection process due to poorly defined limits of application. The theory of fuzzy reasoning can be used for solving problems of this kind. This theory accepts poorly defined relationships between elements and it approaches the process of human reasoning. For any given case usually several seal types could be used, but none is obligatory.

By the fuzzy reasoning theory an element A is the member of the set X if the value of membership function $\mu_A(x)=1$, and is not the member of the set if $\mu_A(x)=0$. The limits of any set are not fixed; common regions may exist. The range of membership function is from *0 to 1*.

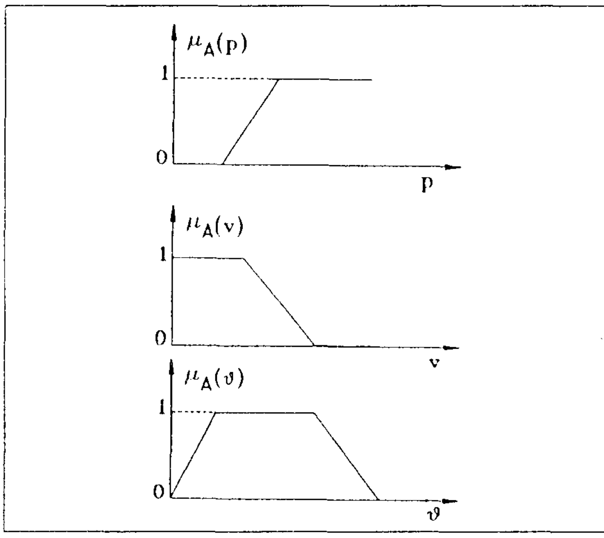


Fig. 3 The examples of membership function in the fuzzy set for compression seals

If the value of function $\mu_A(x)$ is close to 1, this would mean that its membership is "better". In the range between 0 to 1 the membership function is linear. For any type of sealing it is possible to form a set of n membership functions for n - operating conditions. Three functions for compression seals are shown in Fig.3. The number n for each one could be different.

The mean value of membership function is

$$\mu_A = \frac{\sum_{i=1}^{n} \mu_A(x_i)}{n}$$

All membership functions are not of the same importance for the decision making. To quantify their importance the weighting coefficients k_i are introduced. Their value could be $k_i < 1$ or $k_i > 1$. The mean value of membership function will be determined by the equation:

$$\mu_A = \frac{\sum_{i=1}^{n} k_i \cdot \mu_A(x_i)}{\sum_{i=1}^{n} k_i}$$

The first step is to develop a procedure for calculating the mean value of membership function $\mu_A, \mu_B, \mu_C, \dots$, for each type of sealing joint shown in Fig. 1 (types A, B, C,..).The sealing element with a greater value of membership function will be more acceptable. The solutions where even one fuzzy function is equal to zero are not acceptable.

4. THE COMPUTATIONAL PROCEDURE OF SEALING JOINT

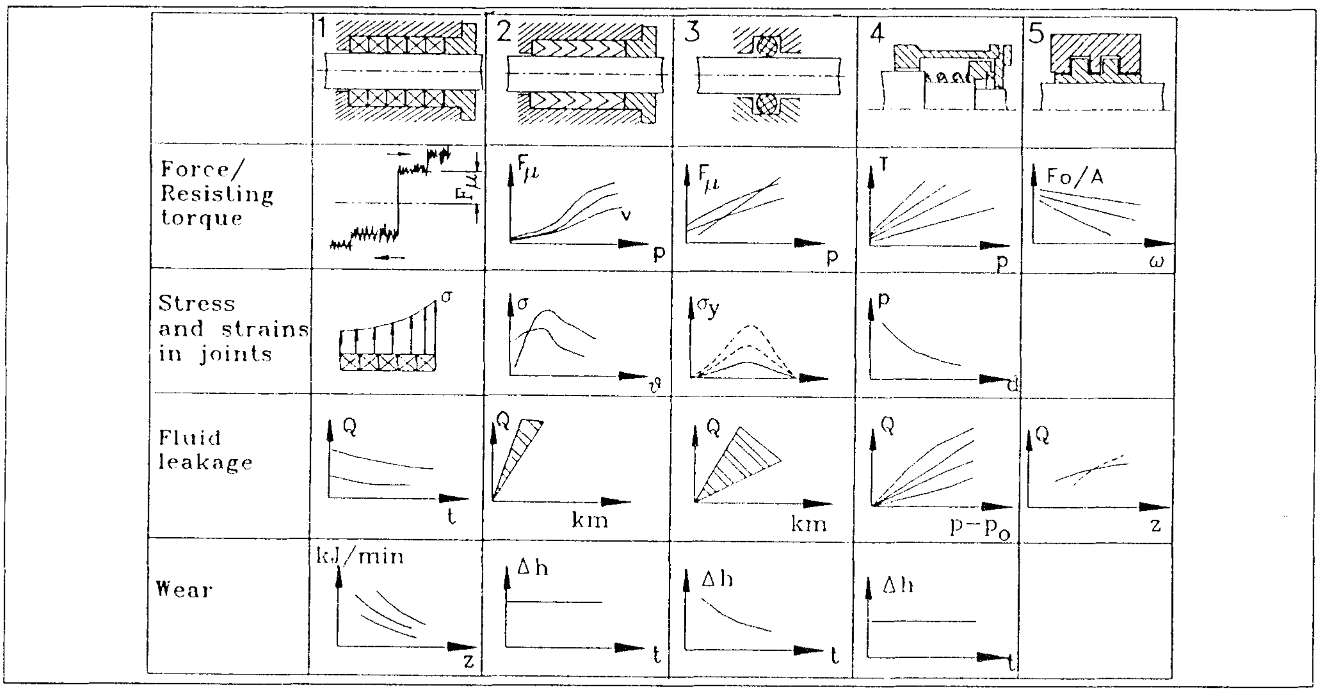
The computation is a procedure to establish the correlation between dimensions, material, operating parameters and operating conditions. After selection of the type of seal, using the method described in the section 3, the computation of sealing joints follows in such a way that dimensions, materials, friction losses, wear, leakage of the fluid and heating are kept within the acceptable values. The chosen characteristics of these parameters are given in Table 1.

The relationships are obtained mainly from the results of experimental investigations but some could be calculated. For example, the axial resistance in compression seals (1) - Table 1, could be either measured or calculated if dimensions, pressure, material and roughness of surfacess are known. The stress in sealing parts, fluid leakage, and wear are in mutual correlation. In the case of spindle packing, (2) and sealing rings (3), the relations are based on other theories because the tribologic processes are different. Axial sealing joints (4) are suitable for high slip velocities and have lower contact pressure and resistance. Non-contact sealing joints (5) have the best caracteristics for these conditions. The sealing principle there is quite different. It is based on the increased hydraulic resistance of fluid flow through the clearance gaps in the connection.

The selected tribologic variables in Table 1 show that sealing connections belong to the tribologic systems.

The tribologic variables such as forces in the contacts, stress, resistances, wear, heating etc. depend on the de-

Table 1. Sealing elements with basic tribologic caracteristics



sign parameters. They represent the boundary conditions which are basis for the computation of dimensions. As here are several conditions and the design parameters should satisfy all limitations in an optimal way. The optimisation model is developed for that purpose and its basic scheme is shown in Fig. 4. Design parametrs of sealing connections such as diameters, thickness, lengths and material characteristics are marked as $x_1, x_2, x_3, \dots x_n$ and they represent the vector of independent variables $X(x_1, x_2, x_3, \dots x_n)$. Limitations such as resistance forces, stress, fluid leakage, wear, etc. depend on these parameters $x_1, x_2, x_3, \dots x_n$ and on operating conditions (pressure, temperature, velocity, etc.). These limitations are marked as $g_i(x_1, x_2, x_3, \dots x_n)$ and they define the optimisation range $D(x_1, x_2, x_3, \dots x_n)$ from which the optimal set of parameters is selected. The objective function $f(x_1, x_2, x_3, \dots x_n)$ should be the maximum service life for that seal. The result of this optimisation process is the vector of optimal variables $X(x_1, x_2, x_3, \dots x_n)$ which belongs to the optimisation range $D(x_1, x_2, x_3, \dots x_n)$ and which satisfies the objective function f.

5. MODEL OF THE DESIGN PROCESS OF SEALING CONNECTIONS

The modelling makes possible highlight those characteristics of objects which are important for the entire analysis, to make certain transformations and simulations and to draw out the conclusions. Models are extensively used in the design process and they represent the language of designers. In Fig. 2 the basic operations in the developing process of sealing elements are shown and in Fig. 5 the complete model with all its modules and knowledge database is given. The design process is performed through analysis and synthesis.

Analysis is the process which provides data and knowledge necessary for the further development of the design process. The knowledge database represents the organised set of data, calculation and analytical procedures. The operations and activities that permit the transformation of data and knowledge into the basic design information make the information module. In the synthesis the digested information is used for building the model of product. This process takes from the database individual general design elements of sealing connections. The module for the selection of a seal, shown in Fig. 3, is used within the general information module and synthesis procedure. It features as a separate entity and the following calculations are performed according to the algorithms which are classified in the knowledge database.

General scheme of the optimisation model for sealing elements is shown in Fig. 4. The design elements are those parts of sealing elements which are used in different arrangements. They might be developed as parametric models, so by change of parameters the elements could be adapted for the different uses and conditions. The design elements could be also constructed in a mo-

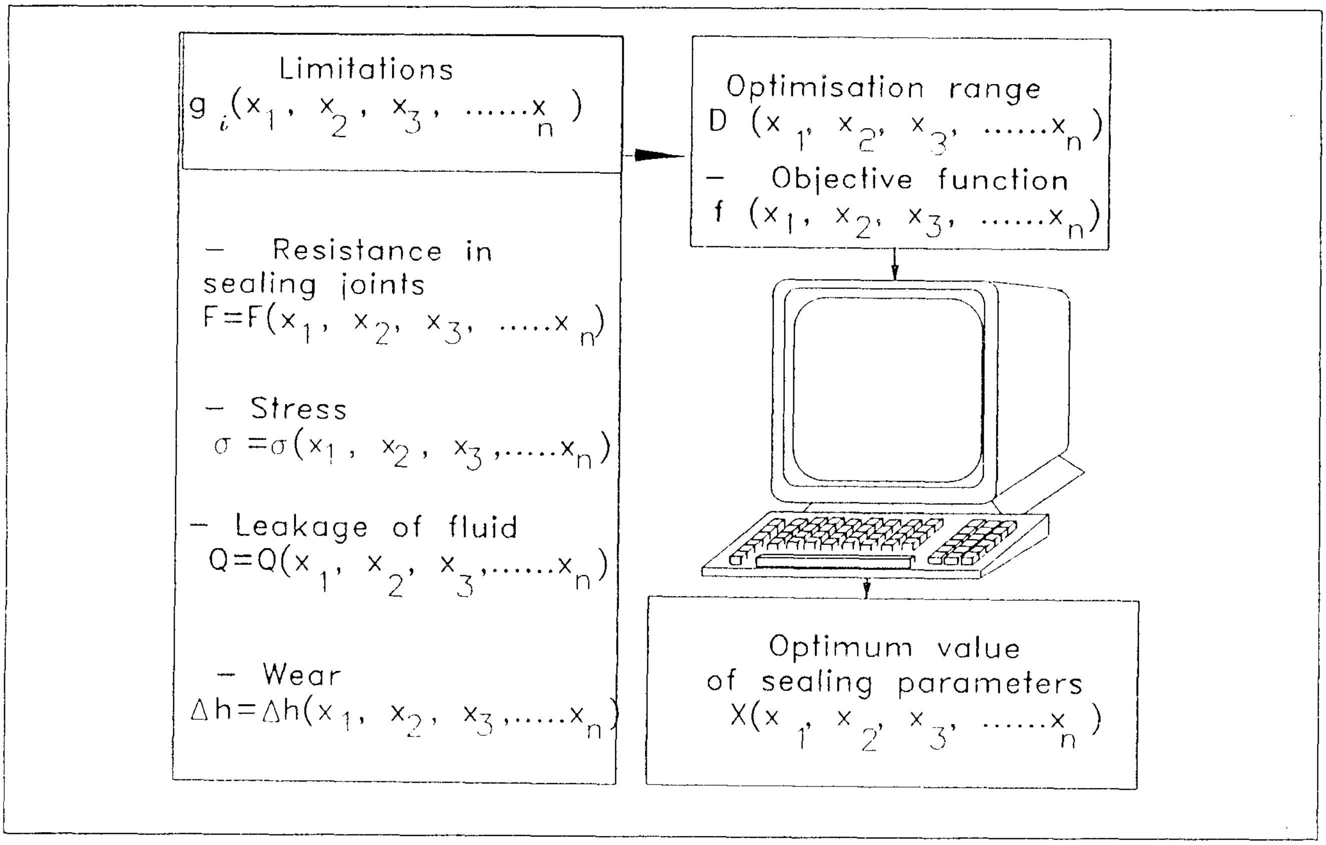


Fig. 4. The optimisation scheme of design parameters of sealing joints

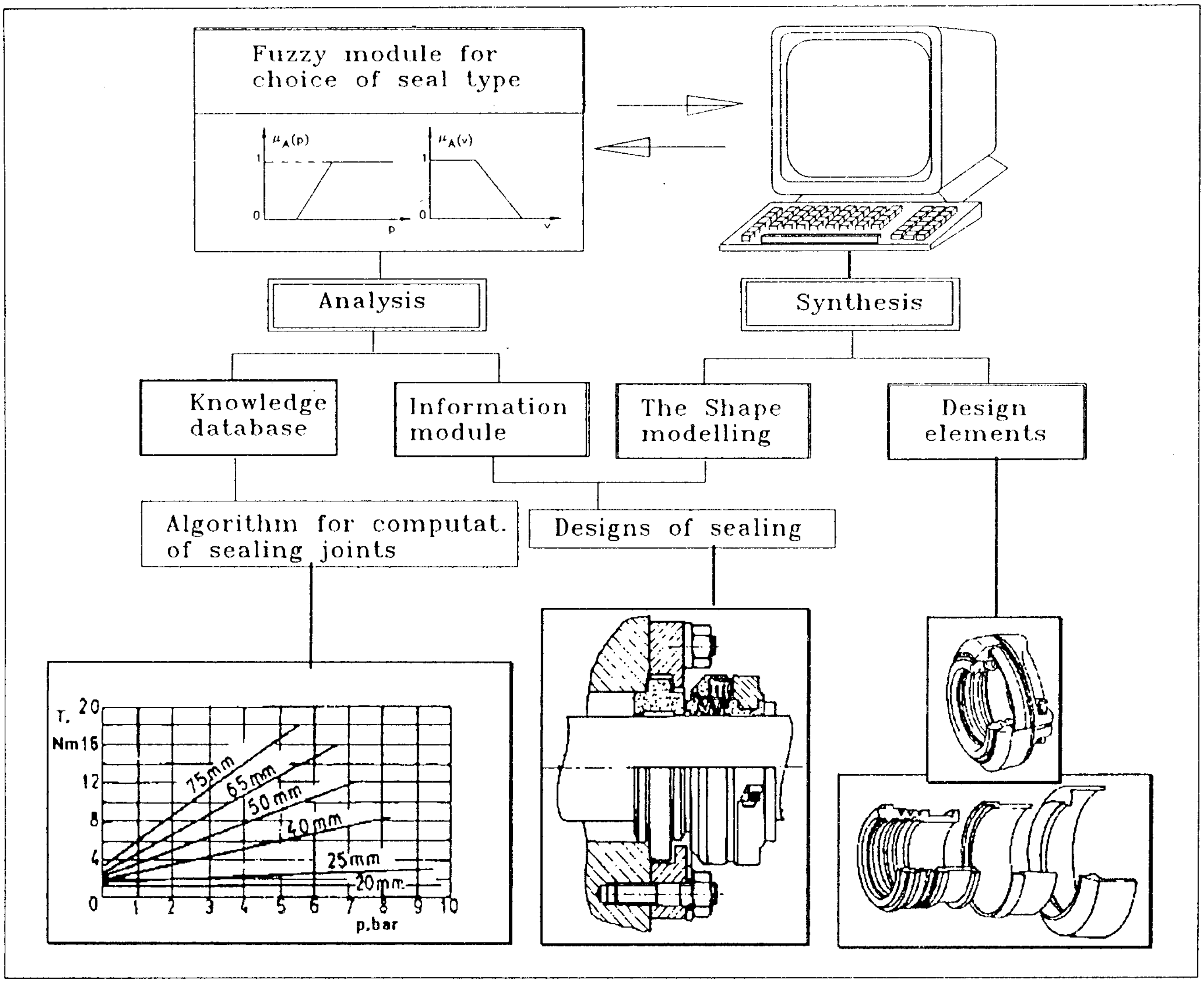


Fig. 5 The Design process of dynamic sealing joints

dular fashion, which might be included in larger constructions.

6. CONCLUSION

This examination of problems in the development of design of seals for given operating conditions finally leads to the following conclusions:

The sealing joints are tribologic systems with interacting surfaces in relative motion. Design parameters are obtained as the result of optimal adjustment of their tribologic parameters. The application of mathematical modelling permits the simulation of operating conditions and the balance of the parameters could be achieved.

The design process of sealing joints consists of three activities: the selection of sealing method, the computation of design parameters and finally the modelling of sealing parts shape.

The fuzzy reasoning method is proposed for the selection of sealing joints type. This theory makes possible the decision making in the condition of uncertainties. The design parameters, for the chosen sealing type, result from the optimisation model based on the tribologic parameters of the system.

Modelling of shape of sealing parts and the whole entity is based on the results of previous two activities. This is a part of the design process whose steps are presented here in some detail.

REFERENCES

[1.] *Ognjanović M.*, **Strengt and sealing of housings under pressure**, - Faculty of Mechanical Engeneering, Belgrade 1997. (in Serbian)

[2.] *Stanger N., Hass W., Mюler H. K.*, (1994) **Abdichten auf kleinem Bauraum**, - Spinger - Verlag, Konstruktion 46, 2 - 8.

[3.] *Glienicke J., Launert A., Schlums H.*, (1994) **Gasgeschmierte Axialgleitringdichtungen für hohe pv-Werte**,-Springer-Verlag, Konstruktion 46, 17-23.

[4.] *Müller H. K., Flajejew S. W.* (1991) **Gasgeschmierte Gleitringdichtung als Lagerabdichtung für Flugtriebwerke**, - Springer-Verla, konstruktion 43, 31-35.

[5.] *Childs D. W., Nolan A.S., Kilgore J. J.*, (1990) **Test Results for Turbulent Annular Seals, Using Smooth Rotors and Helically Grooved Stators**, - ASME Journal of Tribology, Vol. 112, 254-258.

[6.] *Hawkins L., Childs D.W., Hale KI.*, (1989) **Experimental Results for Labyrinth Gas Seals With Honeycomb Stators: Comparisons to Smooth - Stator Seals and Theoretical Predictions**, - ASME Journal of Technology, Vol. 111, 161-167.

[7.] *Haas W., Müller H.K.*, (1987) **Beruhrungsfreie Wellendichtungen fur flussigkeitsbespritzte - Dichtstellen**, - Konstruktion, 39, No 3, 107-113.

[8.] *Young L.A., Lebeck A.O.*, (1982) **Experimental evaluation of a mixed friction hydrostatic mechanical face seal model considering radial taper, thermal taper and wear**, - ASME - Transactions, Journal of Lubrication Techniq., 104, No 4, 439-448.

[9.] *Suganami T., Masuda T., Oishi N., Shimazu T.*, (1982) **A study on thermal behavior of large sealring**, - ASME - Trans. Journal of Lubrication Technology, 104, No 4, 449-453.

[10.] *Estion I.*, (1982) **Dynamic analysis of noncontacting face seals**, - ASME - Transactions, Journal of Lubrication Technologies, 104, No 4, 460-468.