

tribologija u industriji

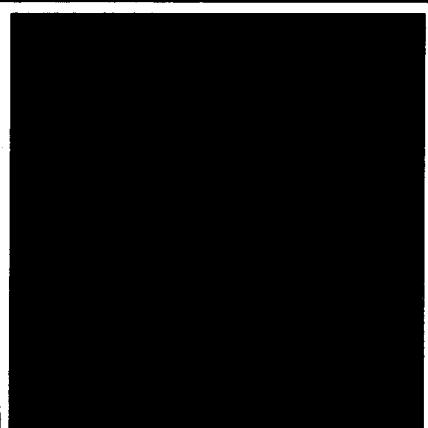
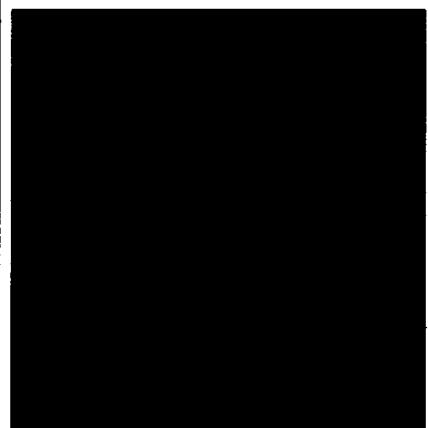
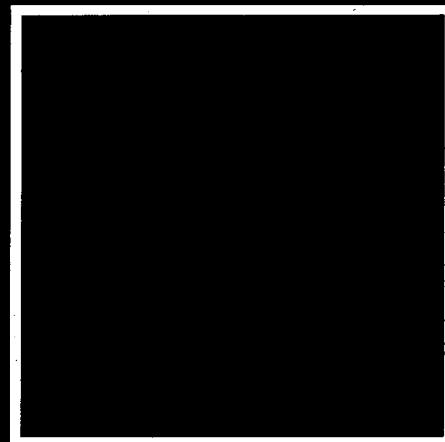
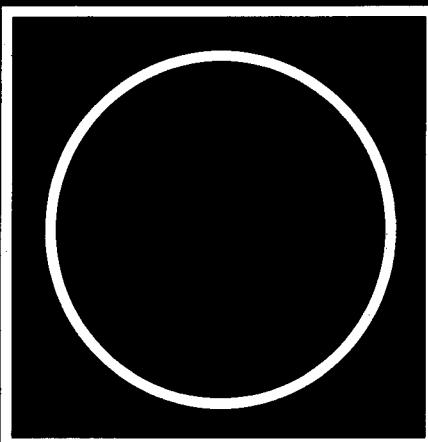
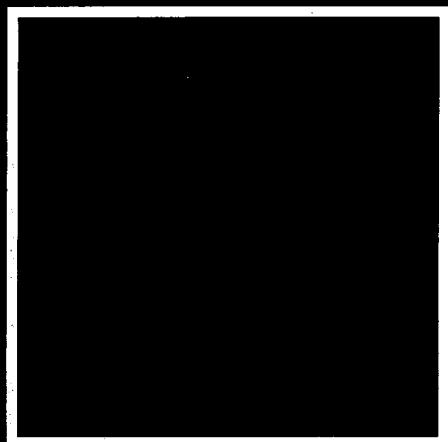
tribology in industry ◊ трибология в промышленности

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Nauka i tehnologija o prenosu i rasipanju masa i energije u mehaničkim sistemima



tribologija u industriji

tribology in industry ◇ трибология в промышленности

sadržaj ◇ contents ◇ содержание

UVODNIK INTRODUCTION ВВЕДЕНИЕ	YUTRIB'95 - Četvrta međunarodna konferencija o tribologiji ◇ The Fourth Yugoslav Conference on Tribology YUTRIB'95 ◇ Четвртая Югославская конференция по трибологии	67
ISTRAŽIVANJA RESEARCH ИССЛЕДОВАНИЯ	D. K. BOUZAKIS, N. M. VIDAKIS: An Evaluation Method of Thin PVD Films Adhesion, Using The Impact Test and a FEM Simulation of The Contact Response ◇ Метод прорачуна адхезије танких PVD филмова ударним тестирањем и МКЕ симулацијом одговора на контакт ◇ Расчёт адгезии тонких покрытий воспроизведением ответа на контакт методом конечных элементов	69
	ŽARKO SPASIĆ: Održavanje i tribološki opis tehničkih sistema u CIM ambijentu ◇ Maintenance and Tribological Description of Technical Systems in The CIM Environment ◇ Обслуживание и трибологическое описание технических систем в CIM среде	76
	M. BALACEANU, A. POPESCU, I. TUDOR: Erosion Resistance of TiN Hard Coatings Deposited by Ion Plating ◇ Отпорност на егоизу TiN чврстих prevlaka formiranih jonskim prevlačenjem ◇ Эрозионная устойчивость твёрдых TiN покрытий полученных ионным нанесением	83
	S. SEKULIĆ, S. BOGIĆEVIĆ: Metodologije za određivanje pouzdanosti reznog alata podržane računaram ◇ Methodology for Determination of The Cutting Tools Reliability Supported by The Computer ◇ Методики определения падёжности режущего инструмента поддерживаемые компьютером	86
NOVOSTI NEWS НОВОСТИ	92
KNJIGE I ČASOPISI BOOKS AND JOURNALS КНИГИ И ЖУРНАЛЫ	94
NAUČNI SKUPOVI SCIENTIFIC MEETINGS НАУЧНЫЕ СОБРАНИЯ	96

YUTRIB'95

Četvrta međunarodna konferencija o tribologiji

Četvrta jugoslovenska konferencija o tribologiji održana je u Herceg Novom u hotelu "Plaža" od 27 do 29. Septembra 1995 godine uz učešće brojnih naučnih radnika iz zemlje i inostranstva.

Konferencija je održana pod pokroviteljstvom

- ▶ Srpske akademije nauka i umetnosti,
- ▶ Saveznog ministarstva za razvoj, nauku i životnu sredinu,
- ▶ Ministarstva za nauku i tehnologiju R. Srbije,
- ▶ Ministarstva za prosvjetu i nauku R. Crne Gore i
- ▶ Univerziteta u Kragujevcu.

Sponzori konferencije bili su

- ▶ NIS - Rafinerija "Beograd", Beograd,
- ▶ NIS - Fabrika maziva "FAM", Kruševac,
- ▶ RaR, Batajnica - Beograd i
- ▶ Modriča-Lube.

Prišlikom otvaranja Konferencije predsednik Organizacionog odbora Prof. dr Aleksandar Rac istakao je da su prve tri konferencije održane u Kragujevcu na Mašinskom fakultetu 1989. godine (200 učesnika, 81 saopštenje), 1991. godine (102 učesnika, 70 saopštenja) i 1993. godine (72 učesnika, 55 saopštenja).

Na ovogodišnjoj konferenciji prijavljeno je 118 radova i to 35 iz inostranstva (Grčka, Bugarska, Rumunija, Belorusija, Rusija, Poljska) i 83 iz skoro svih domaćih univerziteta, naučnih instituta i većih industrijskih sistema. Na Konferenciji je učestvovalo 115 naučnih radnika od kojih je 18 bilo iz inostranstva.

Uvodna predavanja po pezivu bila su saopštена na plenarnoj sednici, a ostala naučna saopštenja održana su po sekcijama.

U sekciji A koja se odnosila na Fundamentalne aspekte trenja i habanja saopšteno je 12 radova. Na sekciji B koja se odnosila na Materijale i prevlake izloženo je 12 radova, a u sekciji C sopšteno je 26 radova iz oblasti Tribologije mašinskih elemenata. Nešto, manji broj radova (24) izložen je na sekciji D koja se odnosi na Tribologiju obradnih procesa. O dijagnostici i održavanju tribomehaničkih sistema govorilo se na sekciji E (prijavljeno 10 radova), a o Primeni maziva na sekciji F (prijavljeno 15 radova).

Poslednjeg dana konferencije prezentirani su rezultati istraživanja dobijeni realizacijom naučno-istraživačkih projekata finansiranih od Ministarstva za nauku i tehnologiju u proteklom petogodišnjem periodu i to:

- Razvoj programa za modifikovanje i regenerisanje kontaktnih slojeva tribomehaničkih sistema i informacionih sistema,
- Istraživanje na razvoju metoda za karakterizaciju novih i konstrukcijskih materijala,
- Razvoj tehnoloških osobina i karakterizacija novih legura na bazi aluminijuma i željeza.

Prezentacija rezultata rada ostvarenih na ovim projektima na ovoj konferenciji izvedena je po predlogu ministarstva za nauku i tehnologiju R. Srbije.

Mot konferencije bi je **ŠTEDNJA ENERGIJE I MATERIJALA SMANJENjem TRENJA I HABANJA**, jer kako pokazuju poslednja svetska iskustva, kroz primenu postojećih i razvoj novih triboloških znanja moguće je ostvariti velike uštede energije i materijala u proizvodnim i transportnim procesima. U uvodnoj reči Prof. dr Aleksandar Rac ukazao je, pored ostalog, na neophodnost razmene mišljenja, transfer znanja i iskustva između naučnih i stručnih radnika i to na samo na konferencijama koje se u ovoj oblasti sve češće organizuju i kod nas i u svetu, već i kroz neposredne kontakte u svakodnevnom radu.

Za vreme održavanja konferencije učesnicima je podeljen Zbornik sinopsisa prijavljenih i prihvaćenih ra-

dova štampanih uporedno na srpskom i engleskom jeziku. Prema upstu organizacionog odbora sinopsisi su pripremani na jednoj stranici formata A4 na srpskom jeziku i drugoj stranici na engleskom jeziku, tako da je imalo uvek dovoljno prostora za izlaganje sastina svakog rada. Štampanje zbornika sinopsisa pre konferencije na srpskom i engleskom jeziku omogućilo je praćenje konferencije na oba jezika bez učešća prevodioca. Ovakav način organizovanja konferencije ocenjen je kao optimalan.

Naučni odbor konferencije izvršiće u toku ove godine recenziju svih saopštenih radova i predložiti jedan ograničeni broj za štampu u časopisu **TRIBOLOGIA U INDUSTRIJI** koji ima međunarodni karakter. Manji broj radova biće predložen za štampu u časopisu **BALKAN TRI-**

BOLOGY koji izdaje Balkan Tribology Association sa sedištem u Sofiji, čiji je član i suosnivač Jugoslovensko društvo za tribologiju.

Na konferenciji je data informacija o dve značajne manifestacije na međunarodnom planu iz oblasti tribologije.

Prva informacija se odnosi na Drugu balkansku konferenciju o tribologiji koja se održava početkom juna 1996 godine u Solunu u organizaciji Balkanske tribološke asocijacije i na kojoj je već prijavljen znatan broj rada iz celog sveta od Japana i Amerike do skoro svih balkanskih zemalja. Druga informacija se odnosila na Svetski kongres o tribologiji koji se održava u Londonu 1997 godine i u čijoj organizaciji učestvuje i Jugoslovensko društvo za tribologiju.

Pozdravnu reč učesnicima konferencije uputili su:

Prof.dr Milun Babić, ministar u vladu R. Srbije,

Prof.dr Rajko Tomanović, pomoćnik direktora NIS-a u ime JUNG-a, Dejan Tomašević, predstavnik Jugoslovenskog društva za motore i vozila, Ljuba Pavlović, direktor hotela "Plaža" i

Prof. dr Branko Ivković, predsednik Jugoslovenskog društva za tribologiju.

Prema mišljenju većeg broja učesnika konferencije saopšteni radovi bili su na visokom naučnom nivou. Poseban utisak ostavili su radovi iz balkanskih zemalja, jer ukazuju na značajan razvoj tribologije kao nauke i tehnologije o procesima trenja i habanja i na ovim prostorima.

The Fourth Yugoslav Conference on Tribology YUTRIB'95

The Fourth Yugoslav Conference on Tribology was held on October 27 to 29 1995. in Herceg Novi, the town at the Adriatic coast. There were 115 participants, scientific workers from Yugoslavia, Russia, White Russia, Romania, Bulgaria, Greece and Poland. Out of 118 accepted abstracts 99 papers were presented, divided into six sessions.

The Conference program included several areas of tribology that are related to the fundamental aspects of friction and wear, tribology of machine elements, tribology of machining processes, materials and coatings, diagnostics and maintenance of the tribotechnical systems and application of lubricants.

Четвёртая Югославская конференция по трибологии

Четвёртая югославская конференция по трибологии состоялась с 27 по 29 октября в городе Херцег Нови, находящемся на азиатическом побережье. В работе Конференции приняли участие 115 научных работников из Югославии, России, Румынии, Белоруссии, Болгарии, Греции и Польши. Из ста восемнадцати представленных докладчиков девятнадцать выступили со своими докладами. Работа Конференции проводилась в шести рабочих группах.

На Конференции обсуждались вопросы, касающиеся разных областей трибологии: фундаментальные аспекты трения и изнашивания; трибология деталей машин; вопросы трибологических процессов обработки, материалов и покрытий; проблемы диагностики и обслуживания трибомеханических систем и использование различных смазок.

D. K. BOUZAKIS, N. M. VIDAKIS

An Evaluation Method of Thin PVD Films Adhesion, Using The Impact Test and A FEM Simulation of The Contact Response

ISTRAŽIVANJA

1. INTRODUCTION

Hard layers that are used to coat several machine elements and cutting tools are nowadays a usual and reliable alternative for the improvement efficiency and productivity in several applications. The main advantage of thin coatings is the excellent tribological and wear behaviour that they provide, which is a very significant parameter, especially for coated pieces, being usually exposed to heavy normal and tangential loads. Although a lot of conventional tests are used in order to characterize coatings regarding their adherent behaviour, none of them gives quantitative information about the coating behaviour under dynamic loading conditions. A new control technique has been proposed by Knotek et al. [1], the so called impact test. During this test a plane coating-substrate compound is exposed to a Hertzian contact pressure, by impacting its surface by means of a cemented carbide ball. The configuration of the test is illustrated in fig. 1 [1]. This coating impact test permits variable impact force and frequency as well as number of impacts. Similar, as these for fatigue life, diagrams can be obtained through the impact test. Thus, curves of contact load capacity versus number of impacts have been established for various combinations of coatings - substrates. Results of such tests are shown in fig. 2 [1].

Furthermore the failure mode that is observed can give qualitative information about the adhesion and the cohesion of the thin film.

To describe the stress field that is developed during such a test and to give critical values for various stress components that seem to contribute to the initiation and to the development of coating failure, FEM simulation of the impact test has been developed.

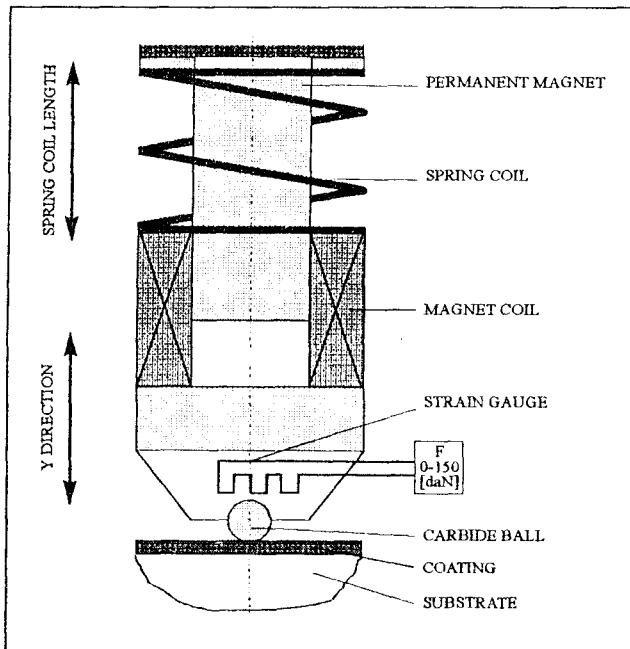


Fig. 1: Principle of the impact test
Princip udarnog testa
Прицип испытания на удар

Professor Dr.-Ing. habil. Bouzakis K.-D.,
Research Assistant Dipl.-Ing. N. M. Vidakis
Aristoteles University of Thessaloniki (AUT),
Dept. of Mechanical Engineering

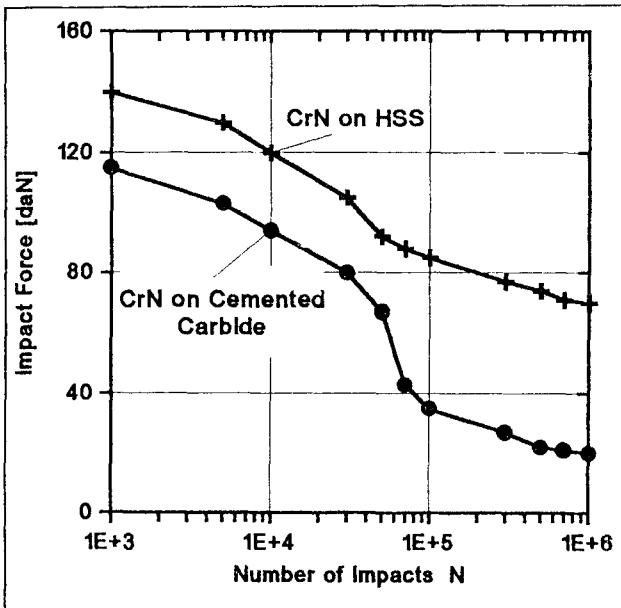


Fig. 2: Fatigue of CrN coated high-speed steel and cemented carbide.

Zamor kod CrN prevučenih brzoreznih čelika i tvrdih metala
Усталостът при покрития CrN на бысторежущих сплавах и твердых сплавах

The stress field occurring during the point contact between an elastic ball and an elastic homogeneous semi-infinite space was described analytically by Hertz [2]. The elastic problem of a ball indentation onto a coated surface has been widely examined using analytical [3,4,5] as well as numerical methods to describe the stress field [6,7,8,9]. The main observation regarding the stress field is that the coating does not affect significantly the overall stiffness of the coating substrate compound, even if it has considerably higher elasticity modulus in comparison to the substrate material. Thin coatings 1-8 [μm] ad like flexible films, following the deformation of the substrate without affecting it. However, coating parameters as its thickness and elasticity modulus, strongly aged the stress distribution within the coating and along the interface.

In order to accelerate the impact test, heavy loads 50-120 [daN] are applied onto the coated compounds. Considering the radius ($R_b=2.5$ [mm]) and the material properties ($E_b=65000$ [daN/mm^2], $v_b=0.2$) of the cemented carbide spherical indentor, such loads can lead to nominal Hertzian pressures from 600 to 1000 [daN/mm^2].

According to the Hertzian description of the stress field at the contact region, the maximum equivalent stress occurs beneath the center of the contact circle, within the substrate material and it has a value of $0.55 \cdot P_{max}$. Such nominal stress cause extended plasical deformation of the soft substrate. The problem of plasical deformation in Hertzian contact cases, has been examined analytically for the axisymmetric problem of the homogeneous isotropic elastic-plastic half space [10] and by means of FEM

calculations for the plane problem of a rigid cylinder indentation onto a coated plastic half space [11].

The plastic deformation of the substrate leads to an increased contact area between the indentor and the plane surface. The interdependency between the ratio of the real radius of the contact area a_o^* to the nominal Hertzian one $a_{o,hertz}$ and the normal maximum Hertzian pressure $P_{max,hertz}$ normalized to the shear yield stress K , has been described for the case of the plane strain configuration, for the application of cylinder on plane [12].

A corresponding curve for the axisymmetric configuration can be obtained by using an experimental procedure. Thus, with the successive application of gradually increasing contact loads, by forcing a cemented carbide ball against an elastic plastic substrate and measuring the formed imprint, modified values for the radius of the contact circle and the maximum surface pressure can be performed.

The modified maximum contact pressure is given by:

$$P_{max}^* = \frac{1.5 \cdot F_{max}}{\pi \cdot (a_o^*)^2} \quad (1)$$

Consequently the modified semi-elliptical pressure distribution is of the form:

$$P^* = P_{max}^* \cdot \sqrt{1 - \frac{x^2}{(a_o^*)^2}} \quad (2)$$

By means of the above mentioned equations, the loads of the FEM simulation described in the following sections, are defined.

2. IMPACT TEST ON COATED SPECIMENS

The tested specimens have been inspected by means of profilometer and of Scan Electron Microscope (SEM). Furthermore, in order to investigate the failure modes, micro spectrum analyses on the contact region have been carried out. Herewith, die geometrical and material features of crater can be obtained. The geometrical characteristics are the crater diameter; maximum depth and shape.

The material features indicate whether coatings have failed with adhesive or cohesive failure. In general, films with poor adhesion suffer from delamination at the interface (adhesive failure) or buckling of the film, whereas films having strong bonds to the substrate material from cracking and chipping (cohesive failure). Mixed failure modes have been observed as well. fig. 3 illustrates a SEM photograph of a crater of a steel substrate, coated with a TiAlCN film of 2.5 [μm] thickness.

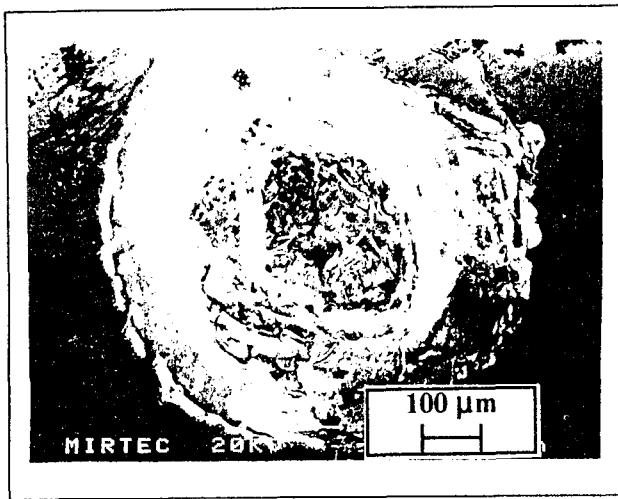


Fig. 3: SEM picture of impact tested TiAlCN coating on 100Cr6 substrate, $F_{max}=75$ [daN], $N=8 \times 10^5$ impacts.

SEM slika udarno testirane TiAlCN prevlake na 100Cr6 podlozi, $F_{max}=75$ [daN], $N=8 \times 10^5$ udara
СЕМ рисунок испытания на удары покрытия TiAlCN на основании 100Cr6, $F_{max} = 75$ [dN], $N = 8 \times 10^5$ удара

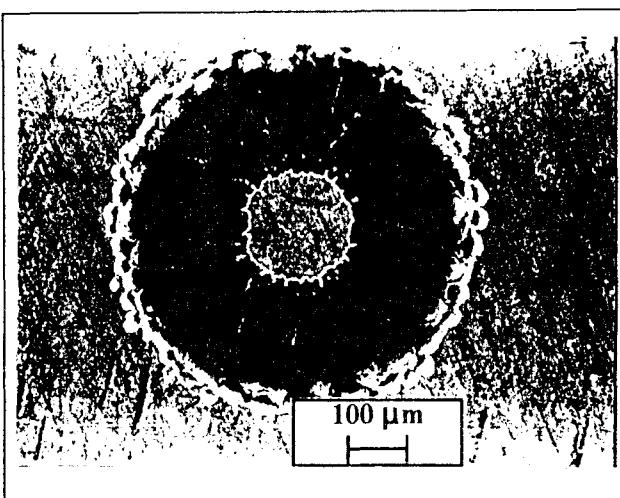


Fig. 5: SEM picture of impact tested MoN coating on 100Cr6 substrate, $F_{max}=50$ [daN], $N=4 \times 10^4$ impacts.

SEM slika udarno testirane MoN prevlake na 100Cr6 podlozi, $F_{max}=50$ [daN], $N=4 \times 10^4$ udara
СЕМ рисунок испытания на удар MoN покрытия на основании 100Cr6, $F_{max} = 5$ [dN], $N = 8 \times 10^4$ удара

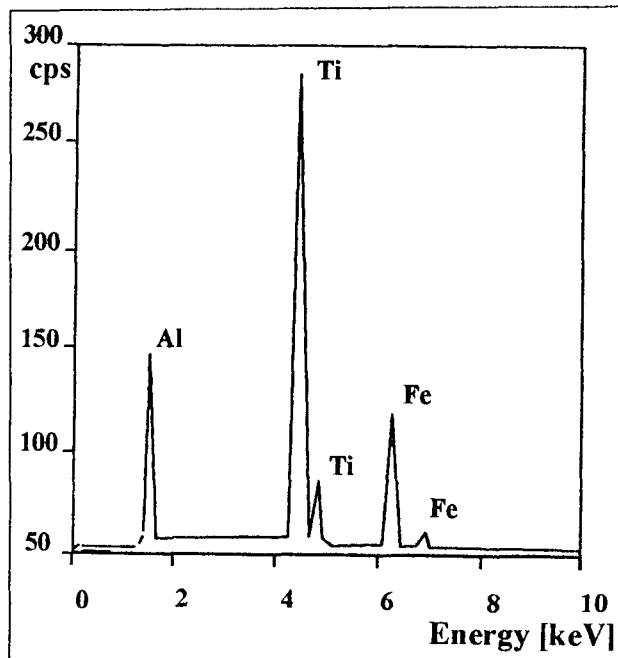


Fig. 4: Micro spectrum analysis of impact tested

TiAlCN coating within the contact region
Mikrospektralna analiza udarno testirane
TiAlCN prevlake u okviru kontaktne zone
Микроспектральный анализ испытания
на удар покрытия TiAlCN в зоне контакта

The failure mode is cohesive since the micro spectrum analysis within the contact region, illustrated in fig. 4., indicates that except of the substrate material (Fe) that has been exposed, coating remains (Ti, Al) still exist. The micro spectrum is almost similar, regarding its shape, for the whole area, that contact circle captures.

Fig. 5 illustrates a similar SEM photograph of a crater for a specimen consisting of 100Cr6 steel substrate coated by a 2 [μ m] thick MoN coating. The spectrum analyses indicate that the failure mode is adhesive. Fig. 6 gives the micro spectrum analysis in the center of the contact

circle and indicates that coating still exists there. Fig. 7 gives the micro spectrum in the area between the center and the vicinity of the contact circle, i. e. the darker area of the crater. This diagram shows clearly that MoN coating has been delaminated.

During the impact test, coatings fail generally in the vicinity of the contact circle. Moreover, in both cases coatings seem to suffer less in a region close to the center of the contact circle, even though these areas are the

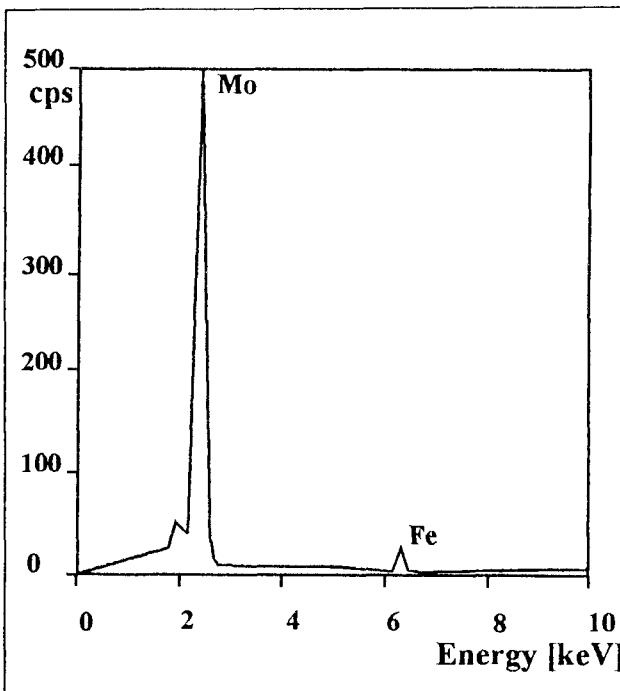


Fig. 6: Micro spectrum analysis of impact tested

MoN coating, within the crater central area.
Mikrospektralna analiza udarno testirane MoN
prevlake u centralnoj zoni kratera
Микроспектральный анализ испытания на
удар MoN покрытия в центральной зоне кратера

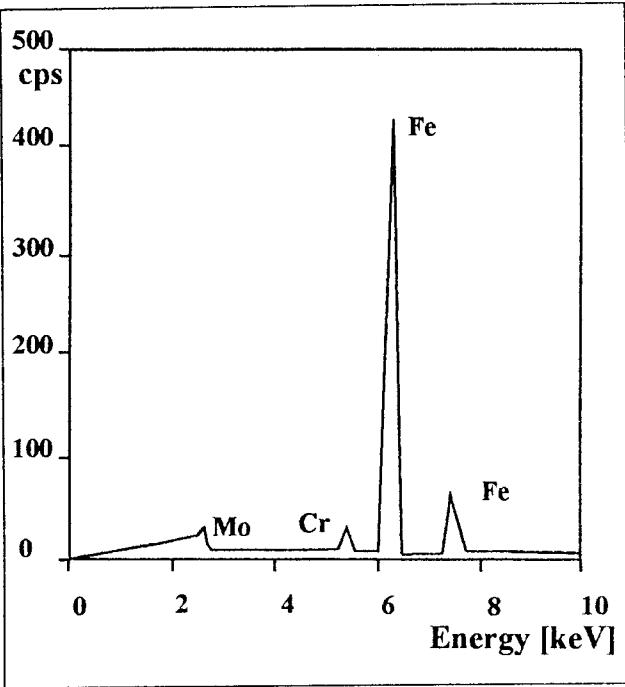


Fig. 7: Micro spectrum analysis of impact tested
MoN coating, adjacent to the central area
Mikrospektralna analiza udarno testirane MoN
prevlaka, u zoni bliskoj centralnoj
Микроспектральный анализ испытания на
удар MoN покрытия в подцентральной зоне

most pressed by contact surface loads. Thus, in the first case (TiAlCN on steel substrate), chipping is less extended near the center of the contact circle. This effect is more visible in the case of MoN film having poor adhesion. In this photo, the delamination of the film, exists from an area close to the vicinity of the contact region to an area about $(0.25-0.3) \cdot a_o^*$ away from the center of the contact circle.

In the present paper, in order to interpret the observed fatigue failure behaviour, a FEM simulation is developed for the description of the developed stress field during the impact test.

3. FEM SIMULATION

The used model for the simulation of the impact test consists of 2500 isoparametric, rectangular, four noded elements, with two degrees of freedom per node and plane, axisymmetric and plastic capabilities. For the distinctive test stress situation the axisymmetric feature has been used. Taking advantage of the symmetry, only one half of the semi-infinite compound was modeled. A modified Hertzian distribution, as previously described, has been chosen for the loading stage of the impact test. The surface nodes that fulfill the equation:

$$\frac{x^2}{(a_o^*)^2} \leq 1 \quad (3)$$

are subjected to a surface vector of magnitude, described by the equation (2). The pressure profile consequently consists of 30 pressure vectors. In order to create a general simulating model, independent of the configuration and loading conditions of one single test, a parametric FEM approach has been conducted by using a parametric design language.

The coating material is assumed to be elastic without any load limit. Material properties for the coatings, necessary for the FEM analyses such as elasticity moduli and Poisson constants, have been obtained through the nano-hardness tests [13]. The substrate material possesses multilinear kinematic hardening properties according to the Besseling model, also called sublayer or overlay model [14]. The material response is represented by a set of von Mises yield criteria, each with an appropriate yield stress and weighting factor, which are derived from the uniaxial stress-strain curve. The uniaxial behaviour is described by a piece-wise linear stress-strain curve, starting at the origin, and continuing through five stress-strain points.

The axisymmetric model has been built in terms of multiples of a_o^* , in a way to represent conveniently the axisymmetric half space. The coating and the substrate are assumed to be perfectly bonded together, whereby no interfacial sliding is allowed. The solution is nonlinear due to the nonlinear substrate material properties and the choice of the large deformation effect on the overall stiffness matrix. Consequently the solution procedure of the FEM calculation is iterative and comprises two stages, i. e. the loading and the relaxation situation, respectively of the compound during the impact test.

The model has been tested for the homogeneous elastic case. The comparison between the Hertzian and the arithmetical solution proved the convenience of the developed model for the simulation of the impact test.

The material properties for the indenter and the compound coating-substrate are given in TABLE 1:

TABLE 1: Material properties used for the calculations

Component	Material	E [daN/mm ²]	v
indenter	Hard metal	65 000	0.23
coating 1	MoN	30 000	0.23
coating 2	TiAlCN	38 000	0.23
substrate	100Cr6	21 000	0.30

The yield stress of the specially heat treated 100Cr6 steel is 135 [daN/mm²].

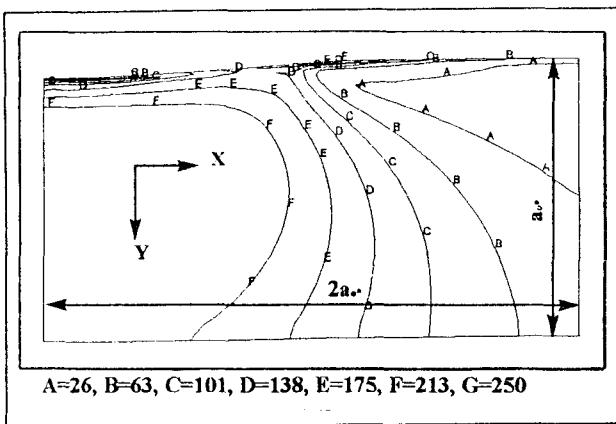


Fig. 8: Equivalent stress contours of the coating- substrate compound for the loading stage
Linije ekvivalentnog napona para prevlaka-podloga u fazi primene opterećenja
Линии эквивалентного напряжения пары покрытие-основание при приложении нагрузки

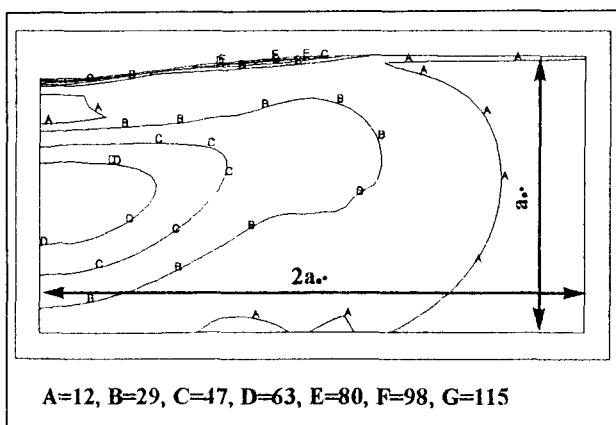


Fig. 9: Equivalent stress contours of the compound for the relaxation stage
Linije ekvivalentnog napona para u fazi bez opterećenja
Линии эквивалентного напряжения пары в ненагруженном состоянии

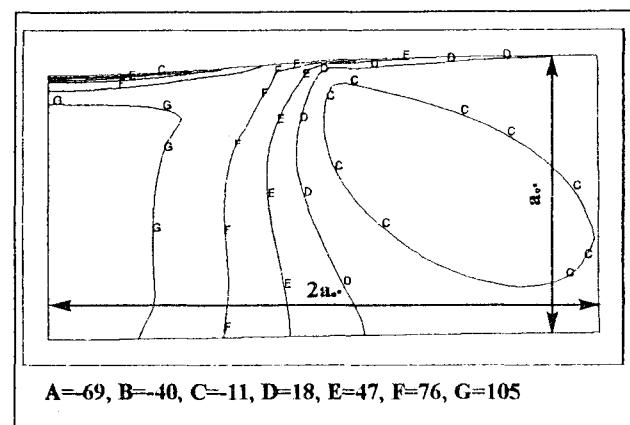
4. DISCUSSION OF RESULTS

The developed FEM model has been used for various cases, changing parameters, such as the thickness and the elasticity modulus of coating. The developed equivalent stress distribution during the loading stage for one case is illustrated in fig. 8. The same behaviour is illustrated in fig. 9 for the relaxation stage.

The model represents the case of 100Cr6 coated with TiAlCN of $2.5 \mu\text{m}$ thickness, for impact load 75 daN . The nominal Hertzian radius of the contact circle and the surface pressure in this case are $a_{o,hertz}=0.206 \text{ mm}$ and $P_{max,hertz}=516.3 \text{ daN/mm}^2$ respectively, whereas the corresponding modified values due to the plastic deformation are $a_o^*=0.262 \text{ mm}$ and $P_{max}^*=872 \text{ daN/mm}^2$ respectively. The influence of the plasticity on these values is evident. The decrease of the maximum surface pressure, due to the increase of the radius of the contact circle, is significant and, especially for such high contact loads.

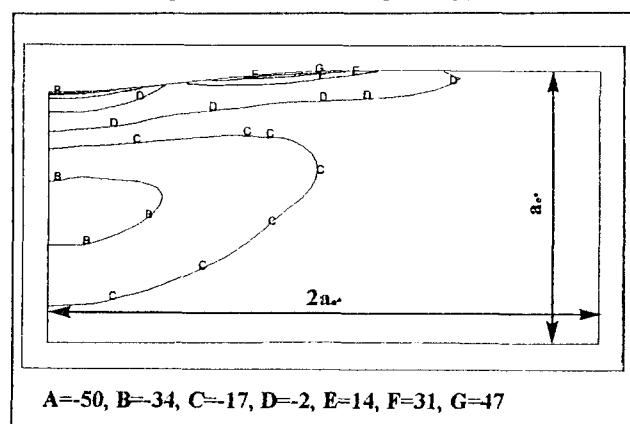
The stress contours indicate the volume under plastic deformation. This deformation is observed from the interface downwards to the substrate and the largest part is created during the first few impacts. During the relaxation stage at the end of the contact, while the indenter is moving upwards, remaining strain can be observed within the substrate. Since coating follows the substrate, the result is a "permanent" elastic deformation of the coating and a light elastic deformation of the substrate, due to the tendency of coating to return to the initial plane shape.

The same behaviour can be observed for the case of maximum orthogonal shear stress contours during the loading and relaxation stages. The corresponding distributions are illustrated in fig. 10 and fig. 11 respectively. The stress distribution gives critical values for the maximum stresses that seem to cause damage to the coating. These critical stresses have mean values different from zero.



A=-69, B=-40, C=-11, D=18, E=47, F=76, G=105

Fig. 10: T_{max} stress contours of the coating substrate compound, for the loading stage
Linije napona T_{max} spoja prevlaka-podloga u fazi primene opterećenja
Линии напряжения T_{max} соединения покрытие-основание при нагрузке



A=-50, B=-34, C=-17, D=-2, E=14, F=31, G=47

Fig. 11: T_{max} contours of the coating substrate compound, for the relaxation stage
Linije napona T_{max} spoja prevlaka-podloga u fazi bez opterećenja
Линии напряжения T_{max} соединения покрытие-основание без нагрузки

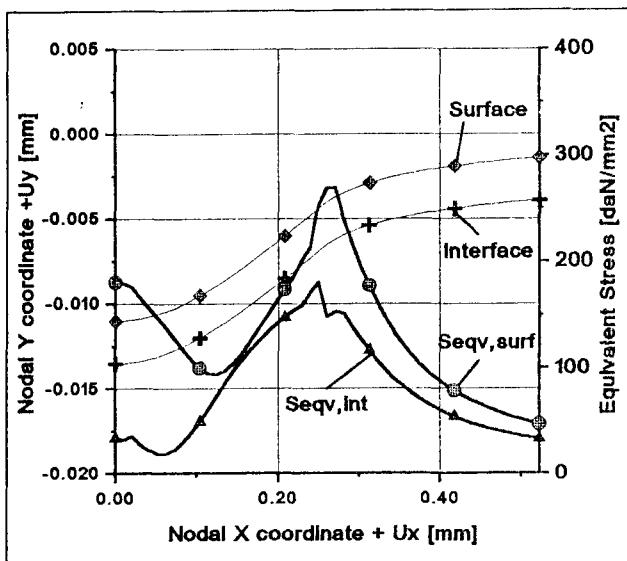


Fig. 12: Equivalent stress and deformation, along surface and interface, during the loading stage
 Ekvivalentni napon i deformacija, na površini i ispod nje, u fazi primene opterećenja
 Эквивалентное напряжение и деформации на поверхности и под ней при applicationе нагрузки

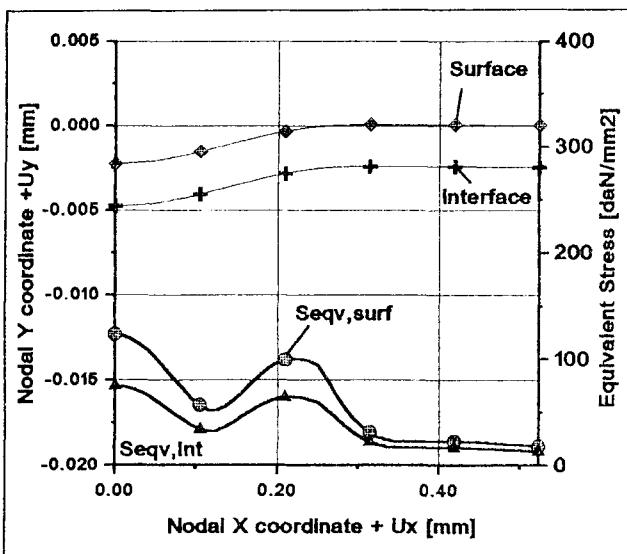


Fig. 13: Equivalent stress and deformation along surface and interface, during the relaxation stage
 Ekvivalentni napon i deformacija, na površini i ispod nje, u fazi bez opterećenja
 Эквивалентное напряжение и деформации на поверхности и под поверхностью слоя без действия нагрузки

The stress field can be described more representative, while moving along a certain direction, that may give information about potential failure modes. Fig. 12 illustrates the deformation of the coating in a form of the initial nodal x-coordinate plus the displacement of the node versus the same values for the y-coordinate.

This information is given for the surface as well as the interface. The horizontal axis represents a movement from the center of the contact circle equal to $2 \cdot a_0^*$ parallel to surface. The equivalent stress distribution along sur-

face and interface is also shown. The according results for the relaxation stage are presented in fig. 13.

The high values of the equivalent stresses that have been developed near the vicinity of the contact zone are caused by the high tensile stress that appears there. This is the mostly endangered position for the initiation of coating cracks, especially for very hard and brittle coatings, even if they have adequate adhesion to the substrate material. In general thin brittle films are very sensitive to tensile stresses, although they are capable enough to stand high compressive stresses.

The local maximum of the equivalent stress near the center of the contact region is due to the high compressive stresses that appear in this area. This behaviour of the developed equivalent stress distribution, along coating surface and interface, can be used to interpret the crack initiation circumferential to the contact circle. TiAlCN film seems to suffer from this kind of high tensile stresses. The calculated values indicate coating fatigue tensile strength and not static one, since the coating withstands these values for many impacts without breaking.

Fig. 14 illustrates the distribution of the maximum shear stress along the interface. The stress components of the stress tensor that compose T_{\max} , are σ_x and σ_y and is calculated by means of the following equation:

$$T_{\max} = 0.5 \cdot (\sigma_x - \sigma_y) \quad (4)$$

The distribution of the shear stress component at the interface indicates that shearing is low nearby the center of the contact circle and has a zero value in a distance about $0.25 \cdot a_0^*$ away from the center. Then T_{\max} starts

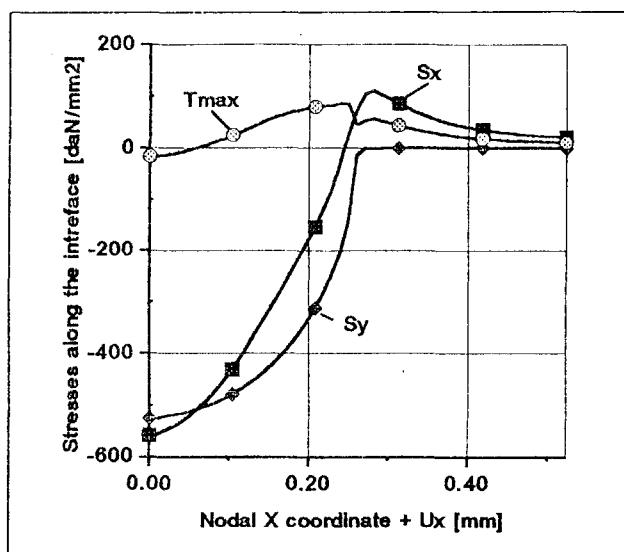


Fig. 14: Maximum shear stress along interface, during the loading stage
 Maksimalni napon smicanja ispod površine, u fazi primene opterećenja
 Максимальное напряжение сдвига при сдвиге под нагрузкой

increasing up to the vicinity of the contact circle where the absolute maximum appears.

This stress component is a potential failure factor that often causes adhesive fracture of the coding by destroying bonds between coating and substrate developed during the sputtering procedure. The alternate shearing during loading and relaxation stages may cause surface damage of the surface even if it is uncoated [15,16].

This behaviour of the T_{max} seems to affect MoN coating that has poor adhesion to the substrate material. Thus, this alternating shear stress destroys the links of MoN film with the substrate material within the area $0.25 \cdot a_o^* \cdot a_o^*$. When coating fails due to fatigue at the vicinity of the contact circle, owing to the high alternating tensile stresses developed there, the delamination is unavoidable. The above described failure procedure is visible in the SEM picture presented in fig. 5.

Failure modes like chipping (cohesive failure) or complete delamination (adhesive failure) of the coating may be combined with a fatigue spall formation of the substrate.

5. CONCLUSIONS

In the present paper, an experimental - analytical method that allows reliable indication of the adhesive and cohesive features of any kind of coating substrate system has been presented. The main conclusions that can be drawn using this method are:

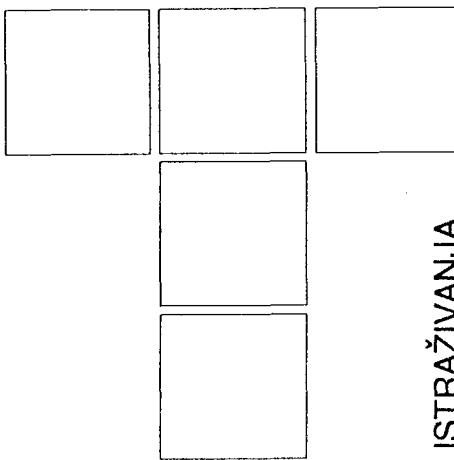
- The representation of the impact test results in a form presented of fatigue diagrams is not convenient. That yields from the fact that fatigue life diagrams ($S-N$ or $F_{max}-N$), are used for alternating stress situation that has a zero mean value. As it has been shown during the discussion of results, due to the plastical deformation of the substrate, critical stress have a non zero mean value. An adequate diagram for the representation of the critical stresses, would be a Smith diagram.
- The critical stress components that seem to affect the fatigue behaviour of thin films are high tensile stress on the circumference of the contact circle and shear stresses developed at the interface in between $0.25 \cdot a_o^*$ and a_o^* . This effect, has been explained by comparing the shape and the features of each crater with the developed stress distribution.

Critical values determined by the introduced calculation procedure can be considered as fatigue life limits of coated surfaces subjected to dynamic stresses.

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ŽARKO SPASIĆ



Održavanje i tribološki opis tehničkih sistema u CIM ambijentu*

1. UVOD

Kompjuterski integrirani tehnološki CIM-sistemi (CIM - Computer Integrated Manufacturing) integrišu sve kompjuterizovane aktivnosti jednog preduzeća. Aktivnosti funkcija održavanja i dijagnostike razvijaju se u okviru odgovarajućeg CIM-podsistema koji sadrži 10 modula. U projektovanju informacionih CIM-podsistema usvojena je arhitektura sistema otvorenih za povezivanje.

Serijs standarda ISO 9000 postavlja zahteve da se projektovani i realizovani CIM podsistemi i moduli permanentno inoviraju i modifikuju. Ciklus kvaliteta obuhvata sve aktivnosti integralnog upravljanja kvalitetom proizvoda i usluga (TQM - Total Quality Management). Zbog toga se u ovom radu posmatra CIM/TQM preduzeće u kome se problem metrologije znatno proširuje integracijom menadžmenta i kvaliteta na svim nivoima poslovanja.

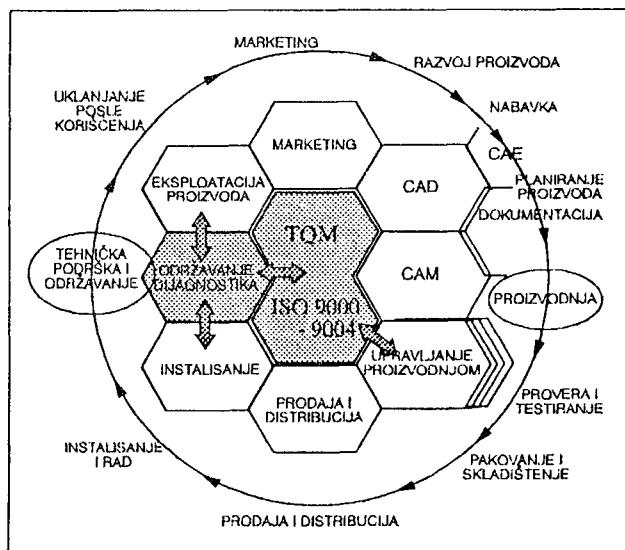
U radu se polazi od modela CIM/TQM sistema, prikazujući moduli CIM-podsistema za održavanje i dijagnostiku i daju primeri iz industrije.

2. ODRŽAVANJE I CIKLUS KVALITETA

Aktivnosti ciklusa kvaliteta u ukupnom poslovanju CIM/TQM preduzeća definisane su redosledno i kvalitativno standardom ISO 9004. Te aktivnosti utiču na kvalitet proizvoda i usluga, a na slici 1 prikazane su segmentima kruga/ciklusa. To su Marketing i istraživanje tržišta, Razvoj proizvoda, Nabavka, Proces planiranja, Proizvodnja, Provera i testiranje, Prodaja i distribucija, Instaliranje i rad, Tehnička podrška i održavanje i Uklanjanje nakon korišćenja.

Žarko Spasić
Mašinski fakultet Univerziteta u Beogradu

Informaciona integracija CIM/TQM preduzeća podrazumeva komponovanje CIM-podsistema i CIM-modula integrisanim bazom/podataka znanja kao jedinstvenim informacionim resursom. CIM-podsistemi su prikazani prema segmentima ciklusa kvaliteta, a jezgro posmatranog modela predstavljaju TQM-aktivnosti [1]. Još u fazi projektovanja projektant/konstruktor proizvoda uzima u obzir pogodnost proizvoda za održavanje. CIM-podsistemi i moduli upravljanja proizvodnjom u bliskoj su vezi sa aktivnostima organizacionih jedinica održavanja. Na osnovu tehničke dokumentacije vrši se instalisanje i počinje eksploatacija proizvoda u realnim uslovima. Podistem održavanja instalisane opreme zahteva odgovarajuću bazu podataka, a inteligentne komponente i bazu znanja.



Slika 1. Održavanje i ciklus kvaliteta (ISO 9000)
Maintenance and quality cycle (ISO 9000)
Обслуживание и цикл качества (ISO 9000)

3. INFORMACIONI CIM/TQM PODSISTEM

CIM/TQM podsistem za održavanje sa dijagnostikom realizovan je za potrebe nekoliko industrija [2] polazeći od referentnog CIM-modela Mašinskog fakulteta Univerziteta u Beogradu kao i referentnog CIM OSA modela.

Razmatrani informacioni CIM/TQM podsistem izведен je na modularnom principu projektovanja sistema otvorenih za povezivanje tako da su zadovoljene hijerarhijske relacije CIM-sistema sa CIM-podsistemima, modulima i segmentima.

CIM-sistem integriše sve CIM-podsisteme predužeća koji su integrirani i postavljeni na bazi jednog od referentnih modela. CIM-podsistem je integralni deo CIM-sistema a projektuje se na osnovu raspoloživih CIM-komponenti, uspostavljenog CIM-koncepta i informacionog sprezanja sa ostalim CIM-podsistemima. Moduli su niza hijerarhijska jedinica projektovanog CIM-podsistema. Predstavljaju kompjuterizovane celine sa definisanim ulazima (baza podataka, baza znanja, dokumentacija, parametri obrade podataka, zahtevi za transferima informacija, ugrađeni aplikacioni sistemi) i izlazima (modifikovana baza podataka, dopunjena baza znanja, dokumentacija, izlazni izveštaji, zahtevi i potvrde transfera informacija). Moduli se realizuju u više segmenata koji predstavljaju neku logičku celinu.

Projektovani CIM-podsistem sastoji se od konvencionalnih i inteligentnih CIM-komponenti. Osnova za projektovanje konvencionalnih komponenti je raspoloživi sistem relacione baze podataka. Osnova za projektovanje inteligentnih komponenti je software-alat za projektovanje ekspert sistema sa odgovarajućom bazom znanja.

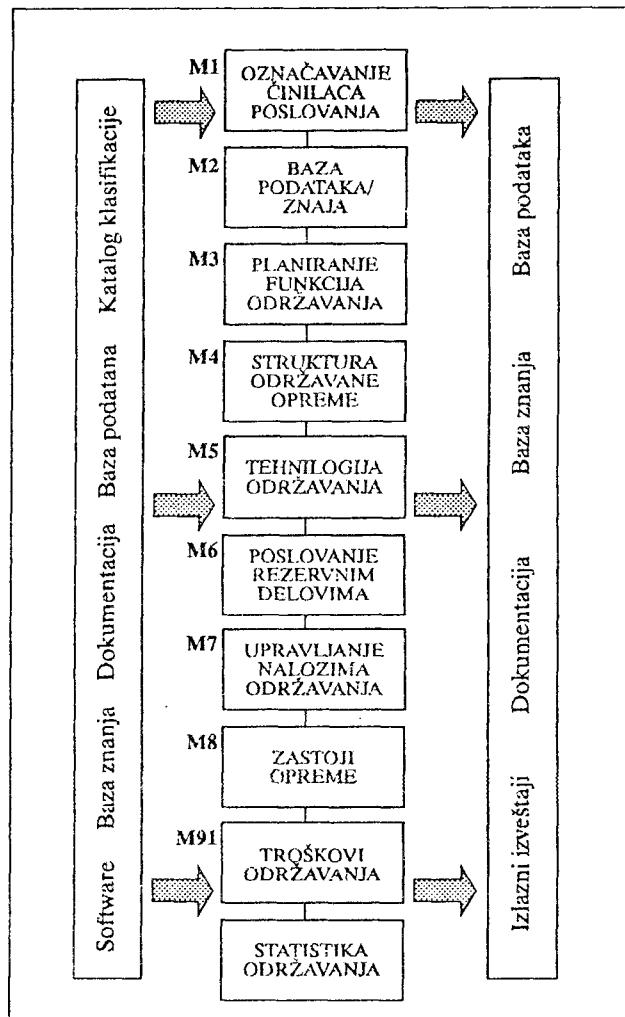
Na slici 2 prikazana je struktura CIM-podsistema sa logičkim redosledom uvođenja modula i potrebnim ulazima/izlazima. Moduli nose nazive: Označavanje činilaca poslovanja za održavanje i dijagnostiku; Baza podataka za održavanje i dijagnostiku; Planiranje funkcija i resursa za održavanje; Struktura održavane opreme; Tehnologija održavanja; Poslovanje rezervnim delovima; Upravljanje nalozima za održavanje; Zastoji opreme; Troškovi održavanja i Statistika održavanja i dijagnostike. U daljem tekstu sažeto se navode osnovne karakteristike svakog od ovih modula.

Modulom Označavanje činilaca poslovanja za održavanje i dijagnostiku obezbeđuje se jedinstveno označavanje svih činilaca poslovanja sa kojima posluju organizacione jedinice održavanja. Modulom Baza podataka za održavanje i dijagnostiku unose se podaci koji se u kasnijoj fazi integriraju sa znanjem definišući time informacioni resurs.

Planovi se prikazuju u vidu tabela koje se formiraju software-alatom za obradu tabela (LOTUS 1-2-3, Excel, Plan-Perfect i slično) što omogućuje tabelarno prikazi-

vanje podataka i razne vrste izračunavanja podataka po horizontali i vertikali. Takođe su mogući različiti prikazi grafičkih izlaza (stubičasti dijagrami, histogrami, kružni histogrami i grafikoni trendova). Planovi se definišu modulom Planiranje funkcija i resursa za održavanje koji je primenjenim software-alatima kompatibilan sa prethodnim modulom kojim se formira baza podataka.

Modulom Struktura održavane opreme definiše se delimična struktura opreme ili uređaja za održavanje. Delimična struktura obuhvata samo one sklopove, podsklopove i delove koji podležu nekoj od intervencija održavanja (pregled, kontrola, dijagnostika, ispitivanje, zamena, podmazivanje, remont i dr.). Struktura opreme definiše količinski i hijerarhijski odnos navedenih komponenti. Na slici 3 dat je primer delimične strukture mašina M-1 i M-2 koje imaju neke iste ugrađene delove (na primer, ležajevi). Koristeći navedene delimične strukture dobijeni su izveštaji o sastavnicama (struktorna, modularna i količinska) kao i o pregledima ugradnje (takođe struktturni, modularni i količinski). Strukturne sastavnice i pregledi ugradnje odnose se na celu definisanu strukturu. Modularne sastavnice i pregledi



Slika 2. Moduli CIM/TQM podsistema
Modules of the CIM/TQM subsystem
Модуль CIM/TQM подсистемы

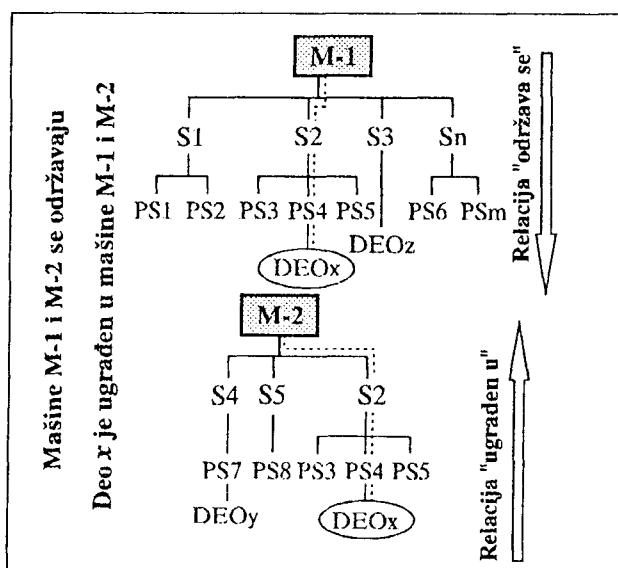
ugradnje odnose se na jedan definisani nivo ugradnje. Izveštaji o količinskim odnosima komponenti daju korisne informacije za planove nabavki i ukupno poslovanje organizacionih jedinica održavanja.

Modulom Tehnologija održavanja definisani su svi postupci intervencija održavanja na principima koncepta grupne tehnologije. Za definisanu klasifikacionu grupu određen je redosled intervencija, izvršioci, frekvencija intervencija kao i prepostavljeni vreme intervencije. Time je omogućeno da se izvrši sortiranje intervencija po izvršiocima i frekvencijama intervencija kako bi se pripremila potrebna dokumentacija. Ekspert sistem se koristi za ekspertize u ispitivanju i dijagnostici na osnovu integrisane baze podataka/znanja.

Modulom Poslovanje rezervnim delovima omogućen je uvid u trenutno stanje rezervnih delova po magacinima. Za određeni deo, izveštaj se daje na ekranu terminala dok se za ceo magacin štampa zbirni izveštaj. Zahtevi za nabavku standardnih ili izradu nestandardnih rezervnih delova dobijaju se na osnovu parametara za upravljanje zalihama rezervnih delova. Modul takođe signalizira prekомерне kao i dugo neupotrebljavane rezervne delove uz sračunavanje vrednosti ovih zaliha.

Modul Upravljanje nalozima održavanja predviđen je za definisanje potrebnih intervencija, njihovo izvođenje i kompjuterizovano praćenje kako bi se ubrzao protok naloga kroz pogone. Dokumenti Pregled stanja i Nalozi za rad prilagođeni su kompjuterizaciji aktivnosti kao i logičkoj vezi entiteta i relacija u bazi podataka (slika 4). U kasnijoj fazi, a na osnovu definisane baze znanja predviđena je ugradnja inteligentnih komponenti čime bi se tok dokumentacije automatizovao.

Modulom Zastoji opreme predviđeno je praćenje zastoja opreme po pojedinim mašinama kao i organizacionim



Slika 3. Sastavnica mašina za održavanje
List of the machine maintenance
Свјез обслуживаоцих машин

jedinicama u kojima su instalisane odgovarajuće grupe mašina. Zastoji se sprežu sa uzrocima što zahteva ažurno vođenje baze podataka sa formiranjem svih potrebnih entiteta i relacija.

Troškovi održavanja dobijaju se pretraživanjem podataka i izveštavanjem u okviru posebnog modula. Troškovi se definišu prema poslovanju organizacionih jedinica a treba da obuhvate ugrađeni ili potrošeni materijal i izvršeni rad. Troškovi se vezuju za mašinu, grupu mašina ili organizacionu jedinicu. Njihovo uspešno praćenje takođe zahteva ažurno vođenje baze podataka.

Statistika održavanja kao poseban modul projektovanog CIM-podsistema zahteva primenu odgovarajućeg software-alata (npr. SQC, STATGRAPHICS i dr.). Ovi paketi omogućavaju sva statistička izračunavanja, primenu velikog broja parametarskih i neparametarskih statističkih testova, kao i ostale analize neophodne u kontroli kvaliteta.

4. PRIMERI IZ INDUSTRije

U postavljenom konceptu CIM/TQM preduzeća potrebno je realizovati CIM-podsistem ODRŽAVANJE I DIJAGNOSTIKA prema zahtevima JUS ISO 9000 standarda. Na slici 4 prikazani su formati dokumenata za prikupljanje i ulaz podataka. Dokumentom Pregled stanja (UP12) upisuju se rezultati provera na objektima održavanja. Radni nalog (UP13) je dokument za sve intervencije održavanja (kvar, planske popravke, rekonstrukcije). Ulaz podataka o mestima podmazivanja objekata održavanja kao i izveštaj o podmazivanju prikazani su dokumentima UP24 i UP25.

Na slici 5 prikazan je izlazni izveštaj Karta podmazivanja. Za određenu mašinu se daju mesta podmazivanja, odgovarajuće mazivo/ulje i vremenske frekvencije kontrola (zamena filtra, kontrola kvaliteta ulja, kontrola nivoa ulja) kao i vrste intervencija podmazivanja (zamena, dopuna, podmazivanje).

Slika 6 prikazuje izlazni izveštaj Evidencija podmazivanja. Za izabranu mašinu i za svako njen mesto podmazivanja daje se ident broj maziva/ulja sa datumom podmazivanja, vrstom intervencije i količinom maziva/ulja. Na kraju izveštaja se daje zbir količina po vrstama maziva/ulja koje se upoređuju sa planiranim količinama.

Dokumentacija za prikupljanje podataka prilagođena je poslovanju kako bi se direktno koristila pre nego što se ažurira integralni informacioni resurs CIM/TQM preduzeća.

5. TRIBOLOŠKI OPIS PROIZVODA STEP STANDARDIMA I EXPRESS JEZIKOM

Informacioni opis proizvoda za ceo njegov životni ciklus definiše se STEP standardima (ISO 10303) (STEP -

Slika 4. Primeri dokumentacije CIM-podsystems "Održavanje i dijagnostika"
Examples of documentation of the CIM subsystem "Maintenance and diagnostics"
Примеры документации CIM-подсистемы "Обслуживание и диагностика"

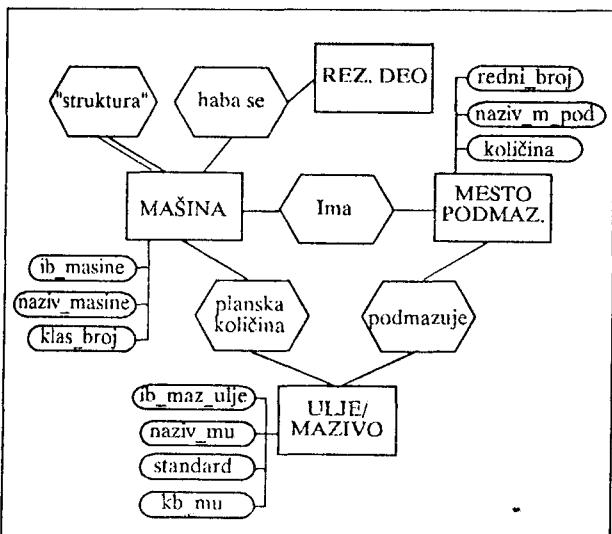
CIM/TQM preduzeće	TOPIS 6.0/rb	Datum:
ODRŽAVANJE	CPII: Održavanje i dijagnostika	10/06/95
	Copyright MCMXCV, MF-Bgd/SV	
KARTA PODMAZIVANJA		
Ib. mašine:	12103009	Naziv: STRUG PIREX-32
RB	Br	TK TK TK TZ TD TP
MP	Mesto podmazivanja	NP PU Vrsta maziva
====	n. k.	f. mu mu mu
01 REZERVOAR VRETENIŠTA CC	1 HD-50	IN 2M 1M 1M IN IN
02 REZ. MENJAČKE KUTIJE CC	1 HD-50	IN 2M 1M 1M IN IN

Slika 5. Format izveštaja "Karta podmazivanja"
Form of the report "Lubrication card"
Бедомосћи "картица смазывания"

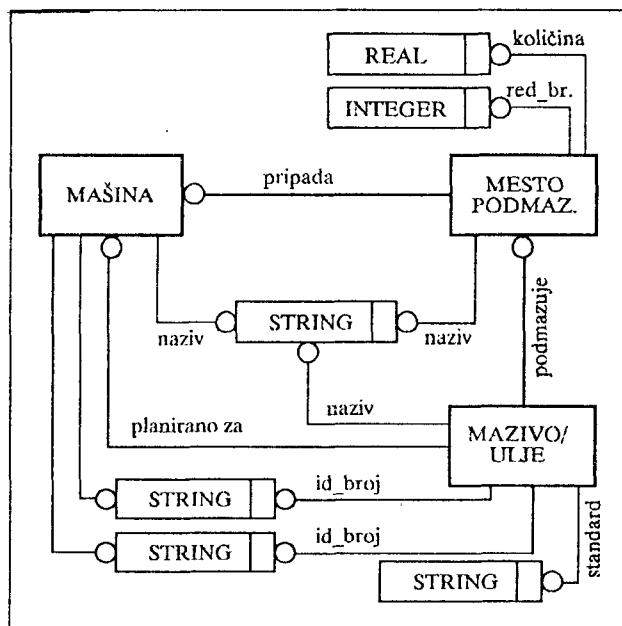
CIM/TQM preduzeće	TOPIS 6.0/rb	Datum:			
ODRŽAVANJE	CPII: Održavanje i dijagnostika	14/06/95			
	Copyright MCMXCV, MF-Bgd/SV				
EVIDENCIJA PODMAZIVANJA					
Id.broj	RB	Id.br.	Datum	Vr	
mašine	MP	mažine	maziva podmaz.	in Kol.	JM
=====	=====	=====	=====	=====	=====
12103009	01 REZERVOAR VRETENIŠTA	900090	15/11/94	Z 2.250 1	
			30/11/94	D 0.350 1	
			15/12/94	P 1.500 1	
				4.100 1	
02 REZ. MENJAČKE KUTIJE					
03 REZ. REV. KLIŽAČA					

Slika 6. Format izveštaja "Evidencija podmazivanja"
Form of the report "Lubrication evidence"
Форма ведомости "Учёт смазывания"

Standard for Exchange of Product Data Model) ili instrukcijama usvojenog jezika EXPRESS. Prikazani tribološki opis mašine koja se u CIM ambijentu održava obuhvata sva potrebna podmazivanja i zamenu delova usled habanja na osnovu preporučenog perioda eksploracije u uslovima preventivnog održavanja. Sličnim opisima za druge aktivnosti životnog ciklusa proizvoda de-



Slika 7. Baza podataka za tribološki opis proizvoda
Data base for the tribological description of the product
База данных для т.рибологического описания производств



Slika 8. Express predstavljanje baze podataka
Express representation of the data base
Скоростное представление базы данных

finišu se međuprostori (interface) za CIM/TQM integraciju. "Neutralnim" opisom proizvoda u odnosu na kompjutersku opremu raznih proizvođača omogućena je razmena podataka unutar CIM/TQM preduzeća kao i u njegovom poslovnom okruženju.

Slika 7 prikazuje rezultat informacionog modeliranja za tribološki opis dela (objekta održavanja). Baza podata-

SCHEMA base:
 ENTITY masina;
 ib_masine: STRING;
 naziv_masine: STRING;
 klas_broj: STRING;
 UNIQUE
 un1 = ib_masine;
 END_ENTITY;
 ENTITY mesto_podmazivanja;
 pripada: masina;
 redni_broj: INTEGER;
 naziv_m_pod: STRING;
 kolicina: REAL;
 END_ENTITY;
 ENTITY mazivo_ulje;
 planirano_za: masina;
 podmazuje: mesto_podmazivanja;
 ib_maz_ulje: STRING;
 UNIQUE
 un3: ib_maz_ulje;
 naziv_mu: STRING;
 standard: STRING;
 kb_mu: STRING;
 END_ENTITY;
 ENTITY date;
 day: INTEGER;
 month: INTEGER;
 year: INTEGER;
 WHERE
 days_ok: {1 <= day <= 31};
 months_ok: {1 <= month <= 12};
 END_ENTITY;
 END_SCHEMA: -- base schema

Slika 9. Shema posmatranog primera
Sheme of the considered example

ka sadrži tri glavna entiteta i pet relacija. Za entitete su navedeni osnovni atributi koji će se posmatrati na primeru opisa koji sledi. Prema definiciji pojma tribologije posmatraju se problemi podmazivanja i habanja delova.

Slika 8 daje prikaz prethodne baze podataka prema pravilima EXPRESS-G konvencija sa svim definisanim entitetima kao i tipovima atributa.

Kompletan opis prema jeziku EXPRESS sastoji se od jednog ili više delova koje nazivamo shemama. Za posmatrani primer navedena shema ima format prikazan na slici 9.

6. ZAKLJUČAK

- ▶ Kompjuterizacija aktivnosti održavanja i dijagnostike tehničkih sistema podrazumeva informacionu integraciju preduzeća u CIM ambijentu.
- ▶ CIM-sistem preduzeća sastoji se od integrisanih CIM-podsistema i CIM-modulima koji sadrže konvencionalne i inteligentne CIM-komponente.
- ▶ Postavljeni zahtevi standarda ISO 9000 podrazumevaju modifikaciju CIM-koncepta, informacione infrastrukture i baze podataka kroz usvojeni model CIM/TQM preduzeća.
- ▶ Definisanje tribološkog opisa proizvoda principima STEP standarda i konvencijama EXPRESS jezika do-

prinos je standardizaciji CIM međuprostora. Time je moguća razmena podataka o proizvodima kroz standardizovani model podataka kao osnove za informacionu integraciju.

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* Istraživanja se odnose na strateški projekt "CIM-modeli za upravljanje poslovno proizvodnim sistemima i njihov transfer ka drugim granama industrije" u čijem finansiranju učestvuje Ministarstvo za nauku i tehnologiju Srbije.

Maintenance and Tribological Description of Technical Systems in The CIM Environment

Maintenance and diagnostics of the tribotechnical systems is one of the activities of the quality cycle defined by the ISO 9004 standards. The mentioned series of standards imposes requirements that in the CIM/TQM company all the activities of the quality cycle must integrate informationally. This means that one of the CIM subsystems must be related to activities of maintenance and diagnostics of the manufacturing equipment and it must exchange information with other CIM subsystems.

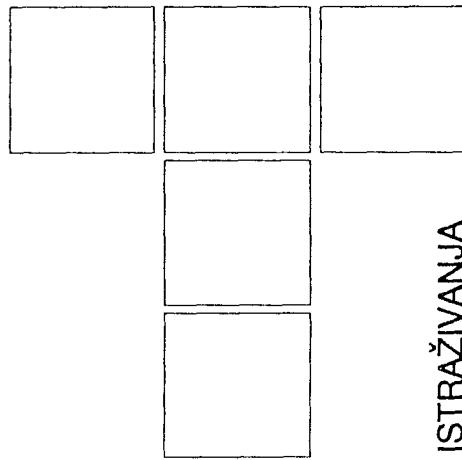
In this paper we start from the definition of the adopted model of the CIM/TQM company. The subsystems structure assumes realization of several modules for which the needed inputs and outputs are defined. The data base contains the large number of entities and relations of the relational model of the data base. As an example of the realized subsystem presented is the documentation for data acquisition, as well as the example of the tribological description of the machine by the EXPRESS language by which the activities of the parts life cycle are described by the STEP standards (Standard for the Exchange of Product Data Model).

Key words: CIM, maintenance, integration.

Обслуживание и трибологическое описание технических систем в CIM среде

Обслуживание и диагностика триботехнических систем является одной из деятельности цикла качества, определенного стандартами ISO 9004. Приведенная серия стандартов требует информационного единения всех мероприятий по качеству на предприятии CIM/TQM. Это значит, что одна из подсистем относится к мероприятиям обслуживания и диагностики производственного оборудования и что обменивается информацией с другими подсистемами CIM.

Авторы работы исходя из определения принятой модели CIM/TQM предприятия. Структура подсистемы подразумевает реализацию больших модулей для которых определяются нужные входы и выходы. В базе данных содержится большое число элементов и направлений её направляющей модели. В качестве примера реализованной подсистемы, показана документация сбора данных, вместе с информационным трибологическим описанием синтаксисом языка EXPRESS используемом при описании срока службы частей STEP стандартами.



M. BALACEANU, A. POPESCU, I. TUDOR

Erosion Resistance of TiN Hard Coatings Deposited by Ion Plating

ISTRAŽIVANJA

1. INTRODUCTION

The TiN coatings obtained by ion plating ensure the protection of the surfaces against some forms of erosion wear.

The erosion wear is specific to the valves with ball of the bore-hole pumps which assure the oil extraction.

The oil which enters the pump contains an appreciable quantity of sand, field water and natural gas. The flow velocity of this mixture through the interspace created between the ball and the seat achieves considerable values. The raising height of the ball from the seat depends mainly on the moving speed of the piston and on the apparent viscosity of the fluid. The presence of the gas in the fluid makes unstable the position of the ball.

The accidental change of the ball raising height makes the flow velocity vary within very large ranges from 0 to over 10 ms^{-1} . The field water contains a great quantity of resolved salts and have a prominent corrosive action. The corrosion products are cracky and little adhesive.

The sand in movement, having a hardness of $1400\text{-}1500\text{ HV}$, rapidly removes the corrosion products and digs the unprotected material. The, direct effect is the one of

local change of the ball and seat shape. The change of the geometric form leads to the accentuation of the troublesome character of the flow and to the intensification of the erosion process.

The delay of the degradation of the surface can be obtained by making the ball and the seat in stainless materials, of a great hardness. It is to be accepted the idea of delay, because the taking off from the material is due both to microcutting and to the microfatigue.

The intensity of erosion by microcutting is maximum at an impact angle of the abrasive grain ranging from 18 to 35° and the intensity of the erosion due to microfatigue is maximum at an impact angle of 90° [1].

Because of the construction of the valve, such critical angles cannot be avoided. To increase the period of functioning, the erosion due to microcutting must be decreased. This supposes that the eroded surfaces should have a greater hardness than that of the sand and a high resistance to corrosion.

The obtaining of a hardness surface more than $1500\text{ HV}_{0.1}$ can be achieved by TiN ion plating. The TiN layers has also anticorrosive qualities. Its hardness over $1700\text{ HV}_{0.1}$ makes the erosion processes develop only in conditions of microfatigue. The erosion velocity due to microfatigue of some anticorrosive surfaces is much less than the one due to microcutting.

Balaceanu M., Institute for Physics and Technology of Radiation Devices, Bucharest-Magurele, ROMANIA
 Popescu A., Tudor I. Petroleum-Gas University of Ploiești, Ploiești, ROMANIA

2. EXPERIMENTAL DETAILS

The TiN ion plating was achieved in an installation with glow discharge electron gun of an original conception [2]. The experimental research was achieved in two stages. The first stage - the one in laboratory - enabled us to settle the influence of the parameters of the ion plating process on the hardness and erosion wear of the thin films.

The erosion attempts were made on a laboratory rotating installation. On the vertical axis of the installation is placed a rotator like support on which three tablets are mounted equispaced and having TiN covered surface oriented under a certain impact angle of the abrasive grains.

The whole assembly is passed in a tight vat in which is the fluid that contains abrasive particles. The working medium was made up of raw oil having 25% field water and 3% sand from the well with the maximum grain structure of $90 \mu\text{m}$.

In the second stage we pursued both the determination of some characteristics of TiN coatings on the valves and the conduct in operation, in the conditions of the well of the plated valves.

3. RESULTS AND DISCUSSION

3.1 TiN plated samples

Working at a constant power of the electron gun of 12.6 kW, which determines an evaporation rate of the titanium approximately constant (0.40 g min^{-1}), the samples were plated at substrate bias voltages ranging from 1 to 5 kV and N_2 flow rates from 33 to $65 \text{ cm}^3 \text{ min}^{-1}$. The N_2 flow rate and the voltage applied on the substrate influence very much the value of the TiN coating microhardness.

For a N_2 flow rate of $50 \text{ cm}^3 \text{ min}^{-1}$, the optimum microhardness can be obtained at bias voltages of 3.5 kV (Fig. 1).

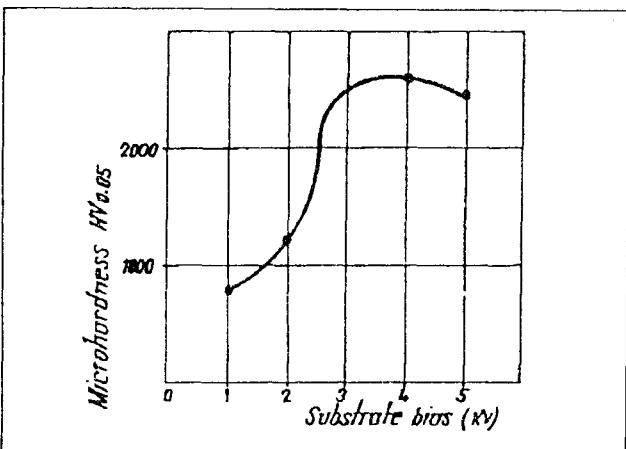


Fig. 1 Microhardness of TiN coating as a function of substrate bias (N_2 flow rate = $50 \text{ cm}^3 \text{ min}^{-1}$)
Mikrotvrdoca TiN prevlake kao funkcija prednapona podloge
(brzina kretanja $\text{N}_2 = 50 \text{ cm}^3 \text{ min}^{-1}$)
Микротврдосъсть ТиН покрития в функции
преднайряжения основания (скорости
движения $\text{N}_2 = 50 \text{ cm}^3 \text{ min}^{-1}$)

The dependence of the microhardness on the substrate bias may be explained by the fact that once with the increase of the bias voltage it is to be noted an increase of the current density and of the substrate temperature, that determines - as it is known [3] - the improvement of some characteristics of the coating (compactness, dimensions and orientation of the grains).

As regards the influence of the N_2 flow rate, it is to be noted the existence of an optimum field of values of this parameter which determines the getting of films with microhardness over $2000 \text{ HV}_{0.05}$ (Fig. 2)

The attempts of erosion took place at an abrasive grain velocity of 7.85 m s^{-1} and an impact angle of 75° . The wear was established by a gravimetric way. The variation of the

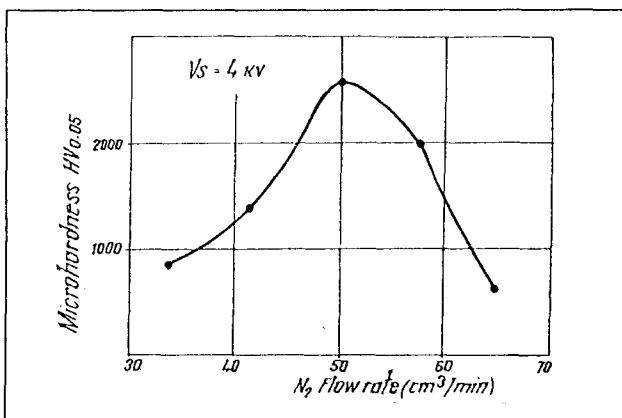


Fig. 2 Microhardness of TiN coating as a function
of N_2 flow rate (V_s - substrate bias)
Mikrotvrdoca TiN prevlake kao funkcija brzine
kretanja N_2 (V_s -prednapon podloge)
Микротврдосъсть ТиН покрития как функция
скорости движения (преднайряжение основания)

wear depending on the coating microhardness is presented in Fig. 3. It is to be noted a decreasing erosion wear with the increasing microhardness value.

The erosive wear is much less for the TiN covered surfaces than for the uncovered ones (Fig. 4)

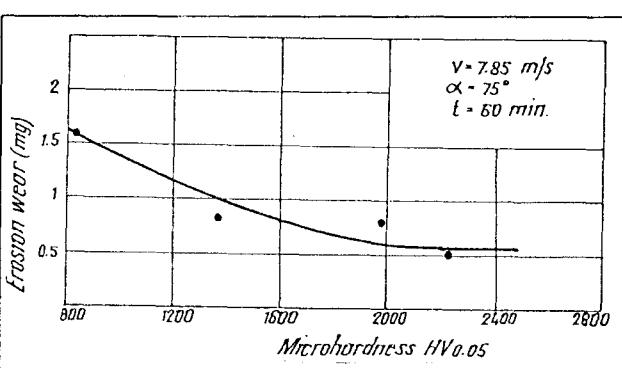


Fig. 3 Erosion wear as a function of TiN coating microhardness
(v - abrasive grain velocity, α - impact angle, t - wear time)
Erozijono habanje kao funkcija mikrotvrdocene TiN prevlake
(v -brzina abrazivnih zrna, α -udarni ugao, t -vreme habanja)
Эрозионное изнашивание как функция
микротврдосъсть ТиН покрития (в-скорость
абразивного зерна, а-угол удара, т-время износа)

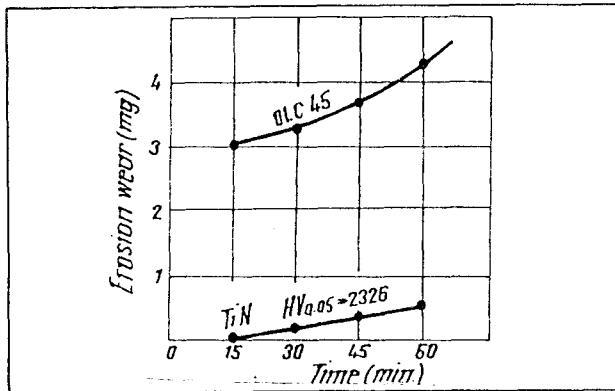


Fig. 4 Erosion wear as a function of wear time
Eroziono habanje kao funkcija vremena habanja
Эрозионное изнашивание как функция времени изнашивания

3.2 TiN plated parts

The obtained coatings had microhardness values ranging from 1600 to 1900 HV_{0.05}

The coating thickness was measured by microscope, on a normal cross-section on the layer and substrate.

The values were about 9 µm on the seat and 5 µm on the balls respectively.

Functional tests

In the conditions of the well, the wear of the valve seat begins with the removal of material from the region immediately placed under the conicity on which the ball is placed (Fig. 5).

The place in which a "pocket" is formed because of the erosion will depend on the local characteristics of the material (structure, hardness, quality of surface)

The wear continuously advances along the conicity until a canal that makes the valve out of work is formed.

The functional tests made in the wells on a set of 10 valves showed an increase in the lifetime of the TiN plated

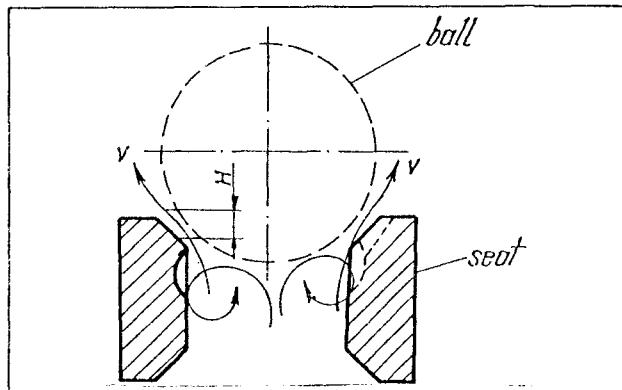


Fig. 5 The flow of the fluid through the valve with ball
(v - flow velocity, H - raising height of the ball)
Tok fluida kroz ventil sa kuglicom (v-brzina toka,
H-rastuća amplituda kuglice)
Поток жидкости через клапан с шариком (v-скорость
потока, H-возрастающая амплитуда шарика)

valves compared with the uncovered ones of approximately 3 times (from 50-60 days to 130-170 days)

4. CONCLUSIONS

The research showed that by using an ion plating installation with glow discharge electron gun, TiN coatings of a high quality can be obtained, which assure an important increase of the lifetime of the plated valves with ball

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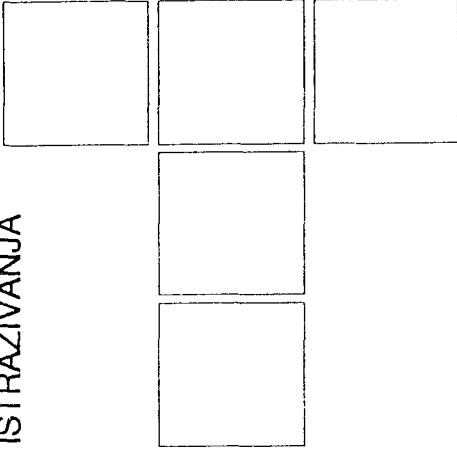
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Otpornost na eroziju TiN čvrstih prevlaka formiranih jonskim pre-vlačenjem

TiN tvrdi filmovi dobijeni su pri instalaciji za jonsko prevlačenje pomoću elektronskog pištolja sa svetlucavim pražnjenjem. Ovaj rad je namenjen prezentaciji uticaja nekih parametara jonskog prevlačenja (?-prednapon podlage, ?-brzina kretanja N2), na otpornost na eroziju kod TiN filmova. Kao primenu TiN filmova izabrali smo onu u naftnoj industriji, uglavnom kod ležišta i kuglica ventila crnih pumpi.

Эрозионная устойчивость твёрдых TiN покрытий полученных ионным нанесением

Твёрдые TiN покрытия получены электронным ионным нанесением. В настоящей работе рассмотривается влияние некоторых параметров ионного нанесения на микротвёрдость и эрозионную устойчивость TiN покрытий. В качестве примера использования TiN покрытий было исследовано их применение в нефтяной промышленности, исследовались покрытия наносимые на опоры и шарики подшипников клапанов всасывающих насосов.



S. SEKULIĆ, S. BOGIČEVIĆ

Metodologije za određivanje pouzdanosti reznog alata podržane računarom

1. UVOD

Prikupljanje podataka o otkazima reznog alata je odgovoran i dugotrajan posao. Međutim, obrada podataka je takođe zatmetna i ako se izvodi u ručnom postupku zahteva, takođe, značajno poznavanje statistike kao i obimnu obradu podataka. Da bi se olakšao rad obradivaču, u radu se iznose tri metodološka pristupa. Prva dva odnose se na nedovoljno reprezentativne uzorke $N \leq 50$. Prvi za uzorke $5 \leq N \leq 10$ i drugi za $11 \leq N \leq 50$. Oba pristupa se baziraju na medijalnom rangu pri određivanju funkcije raspodele. U prvom medijalni rangovi se određuju za sve otkaze u uzorku, dok se u drugom oni grupišu u intervale pri čemu se broj intervala kreće u granicama $5 \leq z \leq 8$. Treći metodološki pristup odnosi se na reprezentativne uzorke $N > 50$ i $N > > 50$, pri čemu se otkazi takođe grupišu u intervale. Za sve metodološke pristupe pored određivanja funkcije raspodele otkaza daju se i granice intervala poverenja, na osnovu d_α testa, čije vrednosti zavise od veličine uzorka za usvojenu veličinu rizika α . Pored toga određuje se srednje vreme bezotkaznog rada.

2. PROCEDURE ODREĐIVANJA POUZDANOSTI REZNOG ALATA

2.1 Nedovoljno reprezentativni uzorci

2.1.1 Nedovoljno reprezentativni uzorci $5 < N < 10$

Za sve otkaze uzorka određuju se medijalni rangovi po obrascu:

$$MR = \frac{J - 0.3}{N + 0.4} \quad (1)$$

gde je j - redni broj otkaza uređenih u nizu u rastućem poretku.

Zatim se metodom najmanjih kvadrata određuju konstante u Weibull - ovoj raspodeli koja se primenjuje pri analizama pouzdanosti alata.

$$F(t) = 1 - \exp \left[- \left(\frac{t}{\eta} \right)^\beta \right] \quad (2)$$

$$R(t) = 1 - F(t) = \exp \left[- \left(\frac{t}{\eta} \right)^\beta \right] \quad (3)$$

$$f(t) = \frac{dR(t)}{dt} = \frac{\beta}{\eta} \cdot \left(\frac{t}{\eta} \right)^{\beta-1} \cdot \exp \left[- \left(\frac{t}{\eta} \right)^\beta \right] \quad (4)$$

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{\beta}{\eta} \cdot \left(\frac{t}{\eta} \right)^{\beta-1} \quad (5)$$

Dr Sava Sekulić, dipl. ing. red. prof.
Sava Bogicević, dipl. ing. asistent
Institut za industrijske sisteme, Fakultet tehničkih nauka,
Univerzitet u Novom Sadu

Za određivanje veličina intervala poverenja funkcija raspodele otkaza primjenjen je da test (Kolmogorov - Smirnov) gde je $d_\alpha = f(N, \alpha)$, pri čemu se varira veličina rizika ($\alpha = 0.01, 0.05, 0.10, 0.15, 0.20$). Gornja zavisnost izražena je u analitičkom obliku:

$$d_\alpha = C_\alpha \cdot N^n \quad (6)$$

gde C_α i N zavise od α .

Srednje vreme bezotkaznog rada je određeno na osnovu funkcije raspodele (2).

U intervalu (t_{min}, t_{max}) je

$$F(t_{sr}) = \frac{1}{t_{max} - t_{min}} \cdot \int_{t_{min}}^{t_{max}} F(t) dt \quad (7)$$

Vrednost određenog integrala

$$I = \int_{t_{min}}^{t_{max}} [1 - \exp \left[-\left(\frac{t}{\eta} \right)^\beta \right]] dt \quad (8)$$

predstavlja površinu omeđenu krivom $F(t)$ u intervalu (t_{max}, t_{min}) .

Veličina površine određena je primenom Simpsonovog pravila.

$$F(t_{sr}) = \int_{t_{min}}^{t_{max}} F(t) dt \approx \frac{h}{3} \cdot \left[F(t_{min}) + F(t_{max}) + 4 \cdot \sum_{i=0}^{k_2-1} F(t_{2i+1}) + 2 \cdot \sum_{i=1}^{k_2-1} F(t_{2i}) \right] \quad (8')$$

gde je: k - broj intervala ($k=100$);
 $h = (t_{max} - t_{min})/k$

$F(t_{sr})$ predstavlja visinu pravougaonika iste površine i osnove $t_{max} - t_{min}$ (sl. 1.).

Kada je poznato $F(T_{sr})$ iz funkcije raspodele (2) sledi da je:

$$T_{sr} = \eta \cdot \left\{ -\ln \left[1 - F(T_{sr}) \right] \right\}^{\frac{1}{\beta}} \quad (9)$$

2.1.2 Nedovoljno reprezentativni uzorci $11 \leq N \leq 50$

Ova metodološka varijanta nastala je iz prethodne, izložene u 2.1.1. Za nju se svi otkazi grupišu u jednake vremenske intervale Δt , a za svaki od intervala t_i određuje se srednje vreme otkaza kao zbir svih otkaza u posmatranom intervalu podeljen sa brojem otkaza u njemu. Nakon toga se određuju medijski rangovi za svaki od intervala, tako da se procedura sprovodi kao da je u pitanju uzorak od z otkaza, koja je data u 2.1.1. Broj intervala se kreće $5 \leq z \leq 8$. Za nereprezentativne uzorke $N \leq 50$ neke od sekvenci na ekranu redosledno do izlaza date su na zbirnoj slici 2.

2.1.3 Reprezentativni uzorci $N > 50$ i $N > > 50$

Pri obradi podataka za reprezentativne uzorke polazi se od diskretnih definicija pouzdanosti.

Ako se posmatra ukupno N alata i ako je nakon isteka vremena t , $N(t)$ broj ispravnih alata, a $n(t)$ broj alata u otkazu, onda se pouzdanost može izraziti

$$R(t) = \frac{N(t)}{N} = \frac{N - n(t)}{N} \quad (10)$$

Funkcija raspodele otkaza (verovatnoća pojave otkaza) je komplement pouzdanosti

$$F(t) = 1 - R(t) = 1 - \frac{N(t)}{N} = \frac{n(t)}{N} \quad (11)$$

Frekvenca otkaza definiše se kao

$$f(t) = \frac{\Delta n}{N} \quad (12)$$

gde je Δn broj alata u otkazu u intervalu vremena Δt .

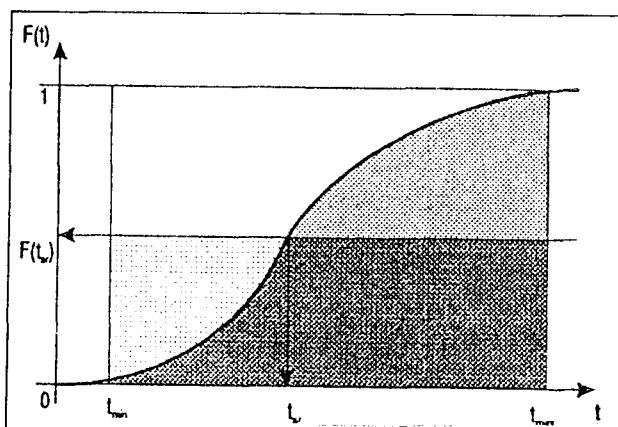
Intenzitet otkaza

$$\lambda(t) = \frac{\Delta n}{N}(t) = \frac{f(t)}{R(t)} \quad (13)$$

Pored gore navedene četiri karakteristike srednje vreme bezotkaznog rada iznosi

$$T_{sr} = \frac{i}{N} \cdot \sum_{i=1}^N \Delta t \cdot t_{im} = \\ = \frac{i}{N} \cdot \sum_{i=1}^N [n(t_i) - n(t_{i-1})] \cdot t_{im} = \sum_{i=1}^N f(t_i) \cdot t_{im} \quad (14)$$

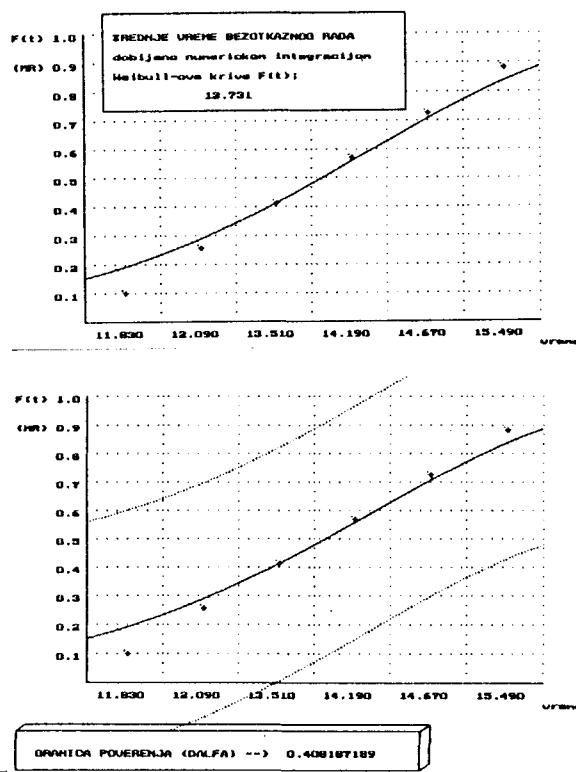
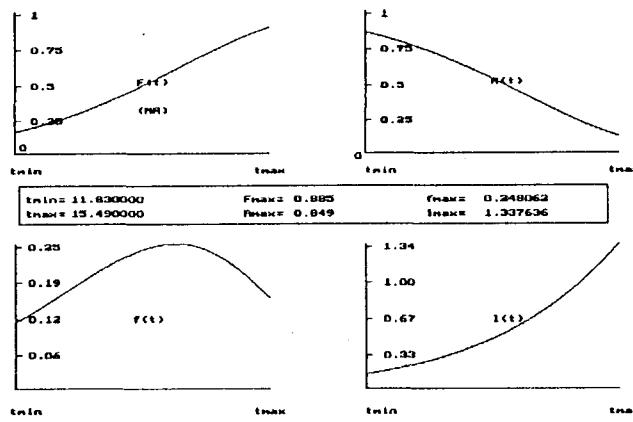
gde je t_{i-1} vreme na početku a t_i na kraju i-tog intervala odnosno tim vreme u sredini i-tog intervala. Gornji obrasci pogodni su za određivanje empirijskih karakteristika, a izvedeni su iz osnovnih definicija teorije pouzda-



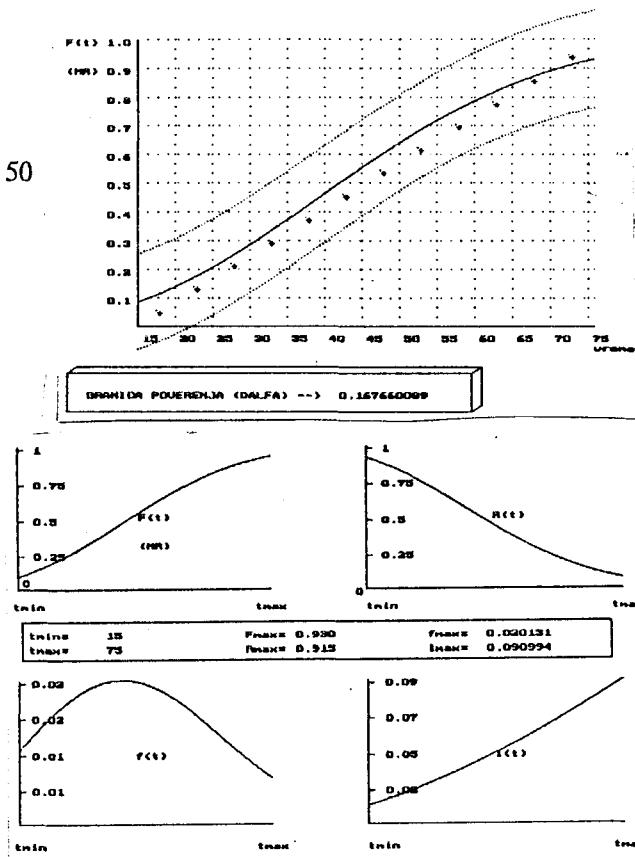
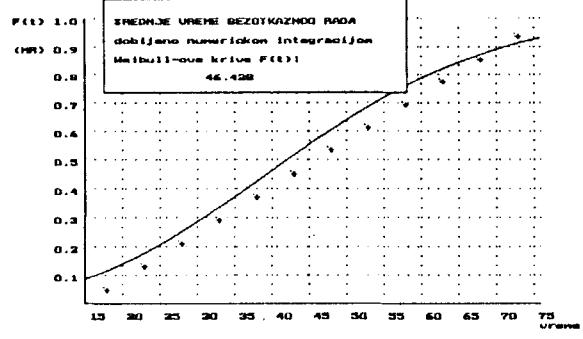
Sl. 1. Grafička interpretacija određivanja T_{sr}
 Graphical interpretation of determination of T_{sr}
 Графическое изображение определения T_{sr}

alat 1	11.83000
alat 2	12.09000
alat 3	13.51000
alat 4	14.19000
alat 5	14.67000
alat 6	15.49000

a) $5 \leq N \leq 10$



plat 1	23.30000	plat 20	39.75000	plat 39	43.00000
plat 2	22.60000	plat 21	31.00000	plat 40	34.00000
plat 3	63.50000	plat 22	64.00000		
plat 4	31.80000	plat 23	21.30000		
plat 5	31.30000	plat 24	24.50000		
plat 6	29.60000	plat 25	32.00000		
plat 7	39.75000	plat 26	40.30000		
plat 8	31.70000	plat 27	54.30000		
plat 9	71.00000	plat 28	56.00000		
plat 10	31.00000	plat 29	37.00000		
plat 11	23.30000	plat 30	30.00000		
plat 12	48.00000	plat 31	29.20000		
plat 13	46.00000	plat 32	39.75000		
plat 14	32.00000	plat 33	39.60000		
plat 15	54.80000	plat 34	54.00000		
plat 16	39.00000	plat 35	54.00000		
plat 17	24.20000	plat 36	21.20000		
plat 18	38.00000	plat 37	19.00000		
plat 19	36.00000	plat 38	29.00000		



Sl.2. Neki ekranски излази за $N \leq 50$
Some screen outputs for $N \leq 50$.
Некоторые выходы на экране для $N \leq 50$

nosti i na osnovu njih mogu se nacrtati histogrami promene kao i izračunati T_{sr} .

Za nesimetričan raspored frekvence koji se najčešće javlja kod tehničkih sistema najviše je u primeni Weibull-ova raspodela (2). Iz izraza (2) sledi

$$[(1-F(t))] = \exp \left[\left(\frac{t}{\eta} \right)^{\beta} \right] \quad (15)$$

pa se nakon dvostrukog logaritmovanja dobija

$$\ln \left\{ \ln \left[\frac{1}{1-F(t)} \right] \right\} = \beta \cdot \ln t - \beta \cdot \ln \eta \quad (16)$$

označimo li sa

$$y = \ln \left\{ \ln \left[\frac{1}{1-F(t)} \right] \right\} \quad (17)$$

izraz dobija oblik

$$y = \beta \cdot x - \beta \cdot \ln \eta \quad (18)$$

koji predstavlja pravu liniju sa uglom nagiba β i odsečkom $b = \beta \ln \eta$. Prema tome određivanje parametara Weibull-ove raspodele može se svesti na određivanje ugla nagiba prave i odsečka u Weibull-ovom listu verovatnoće. Polazeći od jednačine (16) koja predstavlja pravu oblike

$$y = a x + b \quad (19)$$

i primenjujući za nju metodu najmanjih kvadrata, tj da je zbir kvadrata pojedinih grešaka minimalan, dolazi se do sistema linearnih jednačina

$$\begin{aligned} \sum (x_i \cdot y_i) - a \cdot \sum (x_i)^2 - b \cdot \sum x_i &= 0 \\ \sum y_i - a \cdot \sum x_i - b \cdot N &= 0 \end{aligned} \quad (20)$$

odnosno

$$\begin{aligned} A_1 \cdot a + B_1 \cdot b &= C_1 \\ A_2 \cdot a + B_2 \cdot b &= C_2 \end{aligned} \quad (20')$$

gde su

$$\begin{aligned} A_1 &= \sum (x_i)^2; \quad A_2 = \sum x_i = B_1; \quad B_2 = N; \\ C_1 &= \sum (x_i \cdot y_i); \quad C_2 = \sum y_i \end{aligned}$$

Gornji sistem ima rešenja

$$a = \frac{D_a}{D} = \begin{vmatrix} C_1 & B_1 \\ C_2 & B_2 \\ \hline A_1 & B_1 \\ A_2 & B_2 \end{vmatrix} \quad (21)$$

$$b = \frac{D_b}{D} = \begin{vmatrix} A_1 & C_1 \\ A_2 & C_2 \\ \hline A_1 & B_1 \\ A_2 & B_2 \end{vmatrix} \quad (22)$$

Zamenom se dobijaju konstante a i b pa je

$$\beta = a; \quad \eta = \exp \left(\frac{b}{\beta} \right)$$

Na osnovu gore izloženog parametri raspodele funkcije otkaza određuju se grafoanalitičkim postupkom. U tom cilju prikupljene podatke o otkazima alata ($N > 50$), treba svrstati u jednake intervale Δt , koje obuhvataju dijapazon otkaza Δt , tako da je

$$\frac{\Delta t}{\delta t} = k = \text{const.}; \quad 8 \leq k \leq 12$$

Kada je poznata funkcija verovatnoće lako se mogu odrediti teorijske vrednosti pouzdanosti

$$R(t) = 1 - F(t) \quad (23)$$

teorijska frekvenca

$$f(t) = \frac{\Delta n(t)}{N} = \frac{N(F(t)_i - F(t)_{i-1})}{N} = F(t)_i - F(t)_{i-1} \quad (24)$$

i intenzitet otkaza:

$$\lambda(t) = \frac{f(y)}{R(t)} \quad (25)$$

Provera hipoteze provodi se kao u prethodnim slučajevima preko d_α testa (Kolmogorov - Smirnov).

Srednje vreme bezotkaznog rada određuje se prema obrascu (14)

Za reprezentativne uzorke $N > 50$ neki od karakterističnih izlaza dati su na Sl. 3 (a i b).

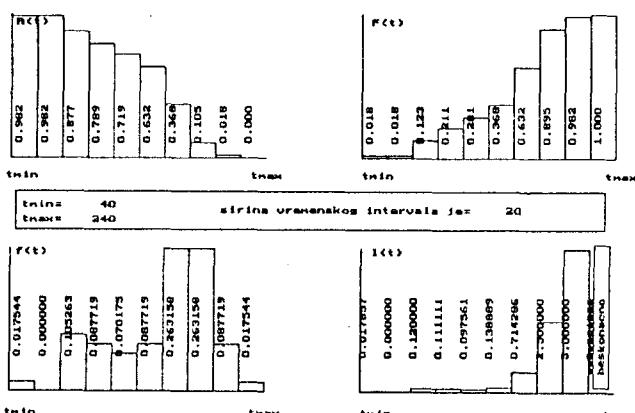
slat 1		slat 20		slat 39	
slat 2		slat 21		slat 40	
slat 3		slat 22		slat 41	
slat 4		slat 23		slat 42	
slat 5		slat 24		slat 43	
slat 6		slat 25		slat 44	
slat 7		slat 26		slat 45	
slat 8		slat 27		slat 46	
slat 9		slat 28		slat 47	
slat 10		slat 29		slat 48	
slat 11		slat 30		slat 49	
slat 12		slat 31		slat 50	
slat 13		slat 32		slat 51	
slat 14		slat 33		slat 52	
slat 15		slat 34		slat 53	
slat 16		slat 35		slat 54	
slat 17		slat 36		slat 55	
slat 18		slat 37		slat 56	
slat 19		slat 38		slat 57	

Sl.3a Neki od ekranskih izlaza za $N > 50$
Some of the screen outputs for $N > 50$.
Некоторые выходы на экране для $N > 50$

	$t(t-1)$	$t(t)$	$t(\text{ini})$	$n(t)$	$n(t-1)$
1	40	60	50.000	1	1
2	60	80	70.000	0	1
3	80	100	90.000	6	7
4	100	120	110.000	5	12
5	120	140	130.000	4	16
6	140	160	150.000	3	21
7	160	180	170.000	15	36
8	180	200	190.000	15	31
9	200	220	210.000	5	56
10	220	240	230.000	1	37

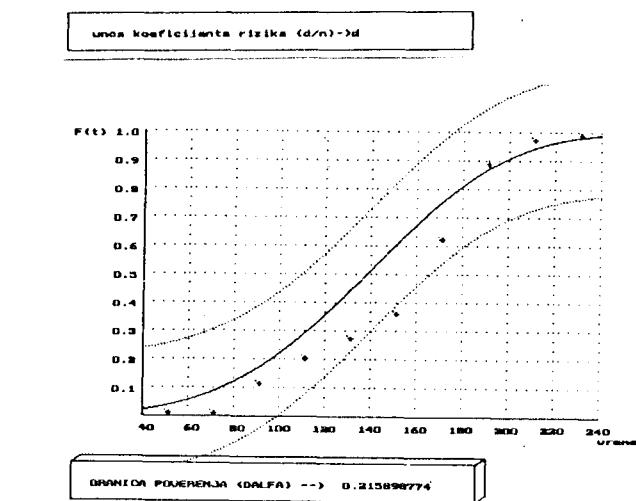
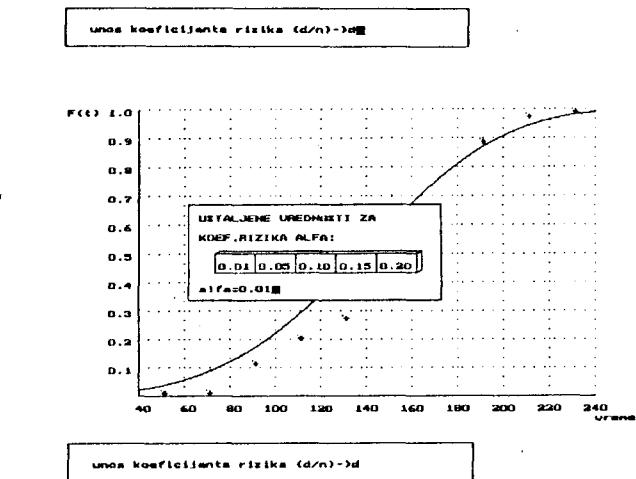
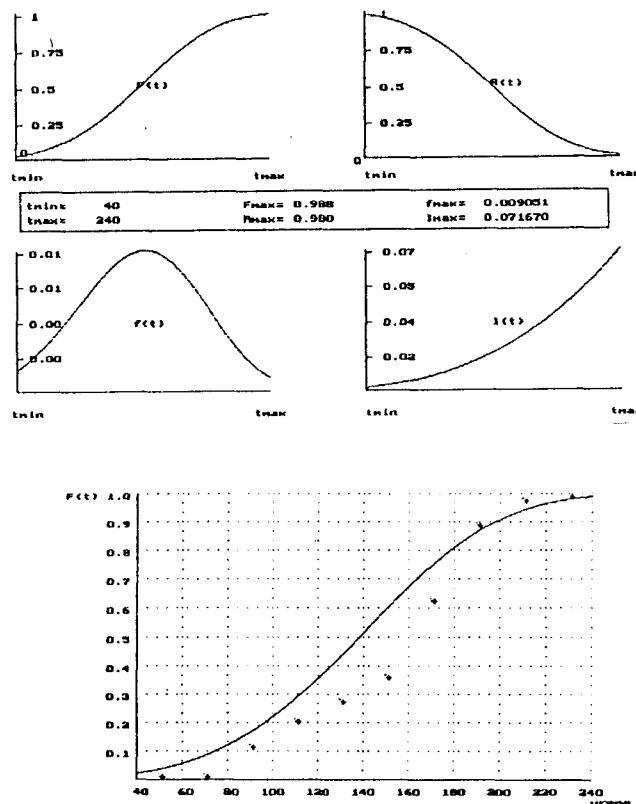
F(t)	R(t)	r(t)	I(t)	n(t)/n(t-1)
0.017544	0.982456	0.017544	0.017547	50.000000
0.017544	0.982456	0.000000	0.000000	0.000000
0.1228807	0.877193	0.105263	0.120000	940.000000
0.210536	0.789474	0.087719	0.111111	350.000000
0.280702	0.719298	0.070175	0.097561	320.000000
0.368421	0.631579	0.067719	0.138889	750.000000
0.631579	0.368421	0.263158	0.714286	2550.000000
0.894737	0.103263	0.263158	2.500000	2850.000000
0.982456	0.017544	0.067719	5.000000	1050.000000
1.000000	0.000000	0.017544	beskonečno	230.000000

SUMA = 9090.000
SREDNJE VРЕME U RADU = 159.474



x1=n(t-1)	x2=n(t)/(1-F(t))	x3=n(t)	x4=n(t-1)
Na osnovu metode najmanjih kvadrata, dobija se:			
beta --> 3.876		-13.781940	
alpha --> 163.398		-17.139341	
Po uslovima koji ne mogu da budu zadovoljiti jednačinu, raspodjeli se:		-9.145153	
$F(t)=1-\exp(-(t/\alpha)^{\beta})$		-6.779397	
$R(t)=1-F(t)=\exp(-(t/\alpha)^{\beta})$		-5.404141	
$r(t)=dR(t)/dt=\alpha\beta(\alpha t)^{\beta-1}\exp(-(\alpha t)^{\beta})$		-3.095999	
$I(t)=r(t)/R(t)=\alpha t/\exp((\alpha t)^{\beta})$		-0.007561	
SLEDI GRAFIČKI PRIKAZ		4.257902	
0.000000	0.000000	7.469907	
0.000000	0.000000	0.000000	0.000000

SUMA=A2+B1 SUMA=C2 SUMA=A1 SUMA=C1
42.968900 -11.229005 206.999042 -46.425644



Sl.3b Neki od ekranских излаза за $N>50$
Some of the screen outputs for $N>50$.
Некоторые выходы на экран для $N>50$

3. ZAKLJUČCI

Na osnovu napred izloženog mogu se doneti sledeći zaključci:

- da su sa predložene tri metodologije obuhvaćene sve veličine uzoraka,
- obrada podataka je vrlo pouzdana, precizna, laka i brza,
- predložene metodologije mogu se koristiti ne samo za određivanje pouzdanosti alata, već i bilo kojeg tehničkog sistema.

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Methodology For Determination of The Cutting Tools Reliability Supported by The Computer

In the paper are presented three methodological approaches to determination of the cutting tools reliability as a function of the sample size. The first two are related to the statistically insufficiently representative samples, while the third one is related to representative and very large samples. Besides determination of the basic reliability indicators (distribution function, reliability, frequency, intensity and medium time of flawless operation), methodology also contains testing of the distribution functions. Based on the developed program supports realized in the computer language "Turbo Pascal 6.0" the processing realized simply, where, besides the analytical and numerical outputs are also obtained the graphical representations (histograms and curves) of the cutting tools reliability indicators.

Key words: cutting tool, reliability, sample, medium time of flawless operation.

Методики определения надёжности режущего инструмента поддерживаемые компьютером

В работе изложены три подхода определению надёжности режущего инструмента в зависимости от величины образца. Первых два относятся к образцам статистически недостаточно обоснованным, та́кда как третий подход касается статистически достаточно представленных образцов и крупных образцов. Наряду с определением основных показателей надёжности (функция распределения, надёжность, частотность, интенсивность и средний срок безотказной работы) методика охватывает и исследование функции распределения. На основании разработанной программной поддержки, реализованной на Языке Турбо Паскаль 6.0, обработка проводится очень просто, при чём наряду с аналитическими и числовыми выходами получаются и графические изображения (хисиограммы и кривые) показателей надёжности режущего инструмента.