University Review

2010
Vol. 4, No. 2

Progressive Technologies in a Special Technology

Alexander Dubček University of Trenčín

Izhevsk State Technical University

Alexander Dubček University of Trenčín
Izhevsk State Technical University

University Review

Alexander Dubček University of Trenčín

Izhevsk State Technical University

Publishing House:
Alexander Dubček University of Trenčín
Izhevsk State Technical University

University Review

(The international scientific journal founded by two universities from the Slovak Republic and Russian Federation)

This journal originated with kindly support of Ministry of Education of the Slovak Republic

Editorial Office

Študentská 1, 911 50 Trenčín, Tel.: +421 (0) 32 7 400 279, +421 (0) 32 7 400 277
dubovska@tnuni.sk, harakalova@tnuni.sk

Redaction

Harakaľová Ľubica, Ing., Alexander Dubček University of Trenčín

Publishing House

Alexander Dubček University of Trenčín, Študentská 2
911 50 Trenčín, Slovak Republic

Izhevsk State Technical University, Russian Federation

Graphic Design

Slezáková Zuzana, Mgr.

Technical Information

University Review Vol. 4, No. 2
Trenčín: Alexander Dubček University of Trenčín
2010, 50 p.
ISSN 1337-6047
EV 3723/09

CONTENTS

CONTRIBUTORS

Oto Barborák, Lenka Bartošová, Mária Ličková, Jozef Eliáš
Faculty of Special Technology, Alexander Dubček University of Trenčín, Slovakia
E-mail: bartosovalenka@centrum.sk, barborak@tnuni.sk, elias@tnuni.sk, lickova@tnuni.sk
Imrich Andrejčák
Faculty of Environmental and Manufacturing Technology, Technical University, Zvolen, Slovakia
E-mail: andrejcak@vsld.tuzvo.sk

Zuzana Jamrichová, Ján Tvarožek, Peter Lipták, Ivan Kopecký, Jozef Majerík,
Rozmarína Dubovská, Ivan Baška, Monika Pilková
Alexander Dubček University of Trenčín, Slovakia
E-mail: jamrichova@tnuni.sk, tvarozek@tnuni.sk
E-mail: liptak@tnuni.sk, kopecky@tnuni.sk
E-mail: dubovska@tnuni.sk, majerik@tnuni.sk, baska@tnuni.sk
E-mail: pilkova@tnuni.sk

Radek Plechač, František Manlig, František Koblasa
Department of Manufacturing Systems, Technical University of Liberec, Czech Republic
E-mail: radek.plechac@tul.cz, františek.manlig@tul.cz, frantisek.koblasa@tul.cz

Jiří Šafka, Petr Keller
Department of Manufacturing Systems, Technical University of Liberec, Czech Republic
E-mail: jiri.safka@tul.cz, petr.keller@tul.cz

Sergej Nikolajevic Pasynkov, Alexander Ivanovic Korshunov, Izhevsk State Technical University, Russian Federation
E-mail: pasynkov@istu.ru, korshunov@istu.ru
Ivo Hlavatý, VSB Technical University, Ostrava, Czech Republic
E-mail: ivo.hlavaty@vsb.cz

Reviewers

Bella Vladimír, prof., PhD., Ing.
Marek Jiří, prof., Dr., Ing.
Kuric Ivan, prof., Dr., Ing.
Vodička Jan, Ing.
Dubovská Rozmarína, Prof., Ing., DrSc.
Hrubý Vojtech, Prof., Ing., CSc.
Stodola Jiří, Prof., Ing., DrSc.
Barborák Oto, Assoc. prof., Ing., CSc.
Lipták Peter, Assoc. prof., Ing., CSc.
Híreš Ondrej, Assoc. prof., Ing., CSc.
Mäsiar Harold, Assoc. prof., Ing., CSc.
Lipták Peter, Ing.
Kopecký Ivan, Ing.

NON - METALLIC MATERIALS IN TEXTILE AND CLOTHING INDUSTRY

Oto Barborák, Lenka Bartošová, Imrich Andrejčák

Non – metallic materials, in particular composites and technical plastics have been used extensively to produce all types of manufacturing machines and devices. Such materials are used to manufacture functional components of machines or auxiliary equipment of various types. Their parameters, in particular technical ones, make them a good choice in replacing metallic materials. Non – metallic materials can be efficiently used to produce high speed components (for instance gears, toothed flat belts, etc.), power elements in the manufacturing process (plastic shuttles in weaving machines, needle carrier in needle looms, etc.), plastic hoses to distribute fluids (oils, water, steam supply, etc.). In addition, the surface treatment of components has been extensively used, such as for instance plastic coating. Thus, the components feature minimum noise, do not require intense lubrication, their production is cost efficient, etc. Non – metallic materials provide a wide range of properties, such as efficient working at higher temperatures, resistance against wear and stability in terms of dimension and shape. To identify the material composition and technical parameters is a very complicated task as manufacturers do not make these data public. Following experiments and analyses, it is estimated that it is dealt with technical plastics, such as various types of polyamides and teflons.

Textile and clothing industry make use of many machines and devices, and those made of non – metallic materials are used extensively. In particular, those technical plastics are commonly used whose technical parameters comprehensively replace the attributes of metallic materials. They are for instance the following (trademarks).

TECHNICAL PLASTICS SUITABLE TO PRODUCE THE COMPONENTS OF MACHINES AND DEVICES [8]

A. Special plastics

PVDF - polycrystalline fluoroplymer material that is distinguished by sound mechanical and electrical properties. Compared with other fluoro – based materials, PVDF has higher tensile strength, compression strength, higher resistance against wear and better stability of dimensions during the temperature changes.

PEEK – material offering very good mechanical strength, toughness, resilience against wear and UV radiation. PEEK makes it a good choice for applications with long - term static load at high temperatures and for sliding and friction surfaces with high demands for lifetime (for instance slide bearings in machines).

PI – polyimide is known for thermal stability, excellent mechanical properties maintained at the temperature up to 240°C (for short excursions as high as 450°C). PI makes it a good choice to produce slide bearings and elements working at high temperatures.

PAI – provides exceptional strength at high temperatures, outstanding impact toughness and rupture energy and excellent resistance against wear. PAI can be used continuously up to 250°C while maintaining the stability of dimensions and shape. When filled with graphite and teflon (PAI+Gr+PTFE), it is suitable for manufacturing slide bearings and abrasion resistant applications with a high load up to 250°C. It is the self – lubricating material.

PPS – polyphenylensulfide – is the plastic with high resistance against creep and wear, excellent stability of dimensions and outstanding chemical resistance. PPS is suitable to produce pulleys and sliding bearings with high loads.

B. Tefllons

PTFE – fluoropolymer plastic with a filling (+ 25% amorphous C) has increased hardness and sound resistance against creep and wear. Carbon enhances the thermal conductivity and lowers the thermal expansion of the material which makes it a good choice in constructing sliding bearings and slide ways.

PTFE + 60% bronze – when powder bronze is blended with PTFE, high thermal conductivity of the material is achieved and the compression strength is increased by approximately 60%. The plastic has good tribological properties and excellent resistance against wear. Outstanding properties make it a good choice for producing slide bearings and abrasion resistant elements.

C. Polyamides

Polyamide PA 6 – a polycrystalline thermoplastic comprising extruded polyamide 6 offers excellent strength, elasticity and resilience which make it a good choice to produce slide bearings and clutch segments.

Polyamide PA 4.6 – maintains high toughness, resistance against creep and abrasion which make it a good choice for producing gears, slide bearings and machine components working at higher temperatures (up to 155°C).

Polyamide PA 6.6 – when compared with PA6, PA 6.6 is distinguished by better mechanical qualities, lower factor of friction, higher hardness and abrasion resistance which make it a good choice to produce pulleys, slide bearings and slide elements.

II. SELECTED TECHNICAL PARAMETERS OF TECHNICAL PLASTICS

Technical parameters of the above mentioned technical plastics make them an excellent choice in constructions of the manufacturing equipment. These properties predetermine plastics to be applied in the future in the production of the functional and auxiliary components as their parameters outclass the metallic materials in many ways. The selected informative parameters of the technical plastics listed are provided in the table below (Tab. 1).

III. EXAMPLE APPLICATIONS OF TECHNICAL PLASTICS IN THE PROGRESSIVE TEXTILE AND CLOTHING DEVICES

Demanding requirements placed on materials used in industries necessitate to examine and develop new materials with outstanding properties.

The process of developing and applying new progressive materials ranks among the future trends of enhancing the quality of production. Further development of new construction materials is imperative since traditional ways of increasing the strength of metallic materials by

Tab. 1

Technical plastics	Measured mass $g.cm^{-3}$	Yield point $N.mm^{-2}$	Ductility %	Melting temperature °C
PVDF	1,79	50	up to 20	175
PEEK	1,31	110	20	340
PTFE	2,16	not applicable	300-400	not applicable
PA 6	1,14	80	up to 50	220
PA 6.6	1,14	90	up to 50	255
PTFE + 60% bronze	3,80	not applicable	100-160	not applicable

for instance added substances, heat treatment, forming are very limited and not always economically efficient. Therefore, technical plastics represent a new progressive trend in this field.

A. Surface treatment of the machine sewing needles [1]

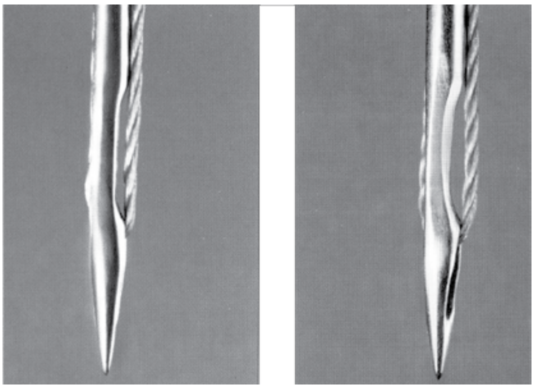
When moving a needle on the fabric, friction and heat develop causing damage to the surface layer of the needle. Consequently, the needle gets worn out, in particular its tip. When sewing, not only the fabric can be damaged but also the upper synthetic thread can be melted and the tiny melted parts can be separated and pasted to the needle surface. At high revolutions of the sewing machines, the conditions, quality of sewing and labor productivity deteriorate significantly. That is why the needle manufacturers pay high attention to the needle surface treatment to guarantee for instance the surface hardness. Selecting the correct surface treatment of a needle lowers the friction coefficient /factor/ between a needle, sewed and sewing material, thus reducing the generation of insufficient seams.

Teflon surface treatment of the sewing machine needle is one of the progressive technologies when teflon is applied to the chemically bound needle surface which is mainly used to sew synthetic materials. Before applying teflon (trademark for polytetrafluorethylene), the needles are phosphatized and the subsequently applied teflon coating serves as the protective layer of the needle to eliminate bounding of the melted parts of the thread. The teflon layer causes the heat to be removed from the needle in a slower manner than by applying other surface treatments. The surface treatment together with a new design of the sewing machine needles guarantee the reduction of friction during the interaction of the needle and sewed material as well as the better needle resistance to buckling. They are the GEBEDUR needles (Fig.1) – for instance SAN 5 needles.

By special reinforcement of the joint working elements, the SAN 5 needle has higher deflection resistance than a standard needle. As far as softness Čm 120 – 140 is concerned, the resistance of the SAN 5 needle against deflection is as much as 25 % higher than that of the standard needle (Fig.2).

B. Plastic gears and belts in the sewing machines [7]

Gears and toothed belts made of technical plastics (Fig.3) significantly decrease the noise of sewing machines. When compared to metallic materials, technical plastics are of lower mass which is an advantage for the sewing machine dynamics, which consequently brings about reduction of vibrations and shocks. This phenomenon has a significant impact on the enhanced quality of the final products.



a b

Fig. 1: The shape of the eye
a- standard, b- type SAN 5

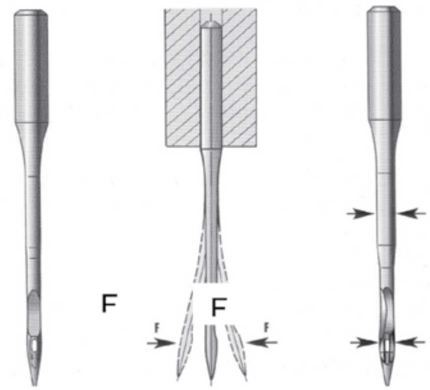
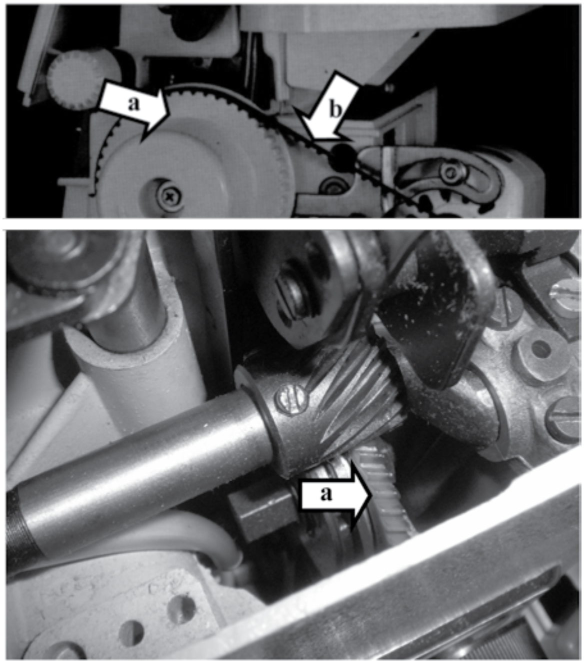


Fig. 2: Side stress and deflection of a needle
afftected by the force a- standard, b- type SAN 5



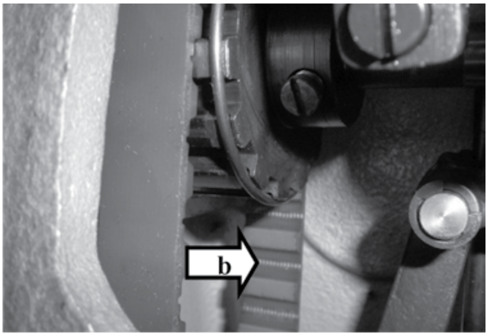


Fig. 3: Technical plastics used in a sewing machine
a- gear, b- toothed belt

C. Heddles suspended on the weaving machines [3]

Several producers of weaving machines have used advantageously innovated heddles made of plastics (Fig. 4). Plastic heddles may decrease the mass of a loom by up to 70%, and decrease the noise as well. In particular, they are recommended for weaving the special textile materials.

D. Plastic shuttles in looms [2]

In shuttle weaving machines, shuttles (Fig.5) acquire a substantially high velocity of „v“, supplied by the gear system. The energy supplied causes noise and shocks. In operation, the gear system components wear out and require to be set up frequently. Upon flying, the shuttle represents a free led item moving along the beam and the shuttle course. In order to decrease the noise, shuttles made of technical plastics have been used.

Fig. 4: Innovated shapes of the plastic heddle eyes

E. The needle bearing part in needle looms [2]

Needle looms have been utilized widely in the textile industry. Needle looms feature versatility and fast operation. The bearing part and the needle movement are supported by a gear rack made of technical plastics offering sufficient toughness while decreasing the noise of both the needle and the loom (Fig. 6).

F. Slides in textile spinning machines [3]

In yarn production, the movement of a slide (Fig.7) on a ring is utilized to achieve the required sinuosity and the final delicacy of the yarn. When moving, the slides made of technical plastics acquire higher velocity mainly for the reduced friction between the slide and the ring.

SUMMARY

Today, technical plastics represent significant construction elements in producing functional components of any manufacturing machine. Technical parameters of technical plastics replace those of metallic materials and are applied not only in auxiliary and stationary components of the manufacturing equipment, but also in the functional components. By applying technical plastics, significant economic efficiency in the production of machines can be achieved. In addition, significant economic efficiency is achieved on the part of the machine users (higher manufacturing performances, lower operating costs, noise reduction, etc.). Technical plastics have been utilized globally by the manufacturers of the textile and clothing machines.

The paper was developed under the VEGA 1/0421/08 project.

Fig. 5: Shuttles of various size and various positionings of weft pirns

Fig. 6: Needle movement in looms

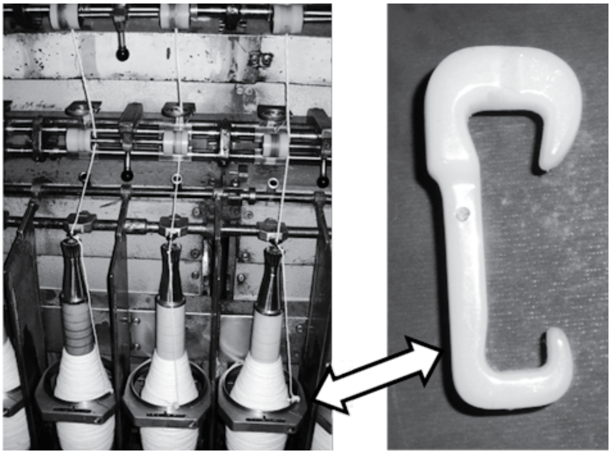


Fig. 7: Position of a slide in spinning machines

Literature

1. BARBORÁK O., BERAN J., BOŽKOVÁ O.: Strojová šijacia ihla. Trenčianska univerzita A. Dubčeka, Trenčín, 2005, (ISBN 80-8075-084-X, EAN 9788080750848
2. BARBORÁK O., CHRPOVÁ E.: Tkacie stroje v textilnej výrobe. Trenčianska univerzita A. Dubčeka, Trenčín, 2006 (ISBN 80-8075-103-X, EAN 9788080751036)
3. BARBORÁK O.: Stroje a zariadenia v textilnom priemysle. Trenčianska univerzita A. Dubčeka, Triptych, Trnava, 2010,(ISBN 978-808075-441-9, EAN 9788080754419)
4. MOHYLA, M. – MOHYLA, P. : Strojírenské materiály II. VŠB –technická univerzita Ostrava 2006. ISBN 80- 248 – 1019 - 0
5. PROKSA, M.; MURGAŠ, M.; KOTRAS, P.; KICKO, J.; HUDÁK, J.: Materiály a technológie – príručka. STU materiálovo-technologická fakulta, Bratislava 1996. ISBN 80-227-0628-0 (1.vydanie-1. dotlač)
6. PTÁČEK, L. a kolektív: Náuka o materiálu II. Akademické nakladatelství CERM, spol. s r. o. Brno 2002. ISBN 80-7204-248-3
7. Photographs by authors
8. Brochures and web sites of the technical plastic manufacturers

RADIAN FREQUENCE IMPACT OF ITS OWN LONGITUDINAL OSCILLATION OF VEHICLE TRAILOR COMBINATION ON POWER INTENSITY IN JOINT AND ON TRAILOR'S ACCELERATION

Zuzana Jamrichová, Ján Tvarožek

Abstract

Article deals with Radian Frequency Impact of its Own Longitudinal Oscillation of Vehicle trailer combination on Power Intensity and on Trailer´s Acceleration while starting. It shows relation between the spring´s biggest deformation in joint and radian frequency of its own longitudinal oscillation and some other performance. This relation is later used for determination of optimal spring firmness in joint. This method is being compared with spring firmness in joint.

Key words

radian frequency, acceleration, own longitudinal oscillation, spring firmness, spring preload, deformation, joint stressing

1ST TRAILER ACCELERATION WHILE VEHICLE TRAILER COMBINATION STARTING

The highest trailer acceleration while starting the vehicle trailer combination is given by following relation

$$a'_{max} = \frac{c}{m'} \bar{x}_{max} - g_{\varphi} \quad [m \cdot s^{-2}] \tag{1}$$

while:

c	spring firmness in joint $[N \cdot m^{-1}]$,
m'	trailer´s weight [kg],
$\bar{x}_{max}$	the biggest joint deformation, $\bar{x}$ vector expressing,
g	gravitational acceleration [9, 806 65 N],
φ	factor of roadway resistance, given by relation $\varphi = \sin \alpha + f \cos \alpha$ (2)
α	roadway slope angle [°],
f	factor of wheel road resistance.

It is valid to use the following formula: for the biggest strength in trailers joint with the towing car
$F'_{max} = c\,\overline{x}_{max}$ (3)

Both these values α'_{max}, F'_{max} are thus the biggest deformation function in joint $\overline{x}_{max}$. This biggest deformation is function of variables´ set

$$\overline{x}_{max} = f\,(c, m, m'\,\overline{C}, \zeta, \overline{x}_0) \quad (4)$$

while:

m	weight of towing car,
$\overline{C}$	increasing driving power speed in regard to weight unit of towing,
ζ	allowance in trailer´s joint with towing ca,
$\overline{x}_0$	spring preload in joint.

It is possible to simplify relation $\overline{x}_{max}$ on six variables by summarizing first three variables into radian frequency of its own longitudinal oscillation of vehicle combination

$$\omega_x = \sqrt{\frac{c}{v\,m}} \quad (5)$$

while:

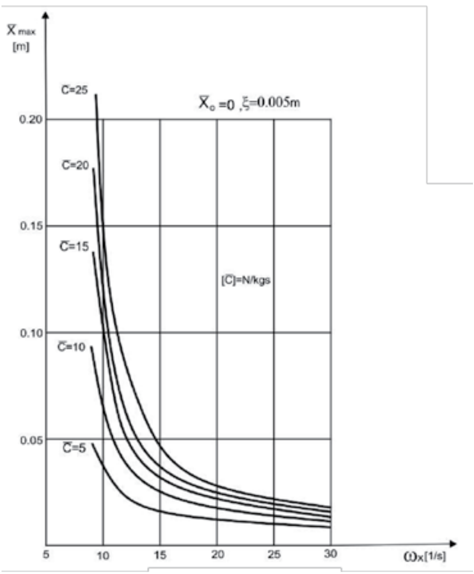
$v = \dfrac{m'}{m + m'}$ is proportionate trailer´s weight.

It turned out that this taken relation $\overline{x}_{max} = f\,(\omega_x, C, \overline{\zeta, x_0})$ (6)

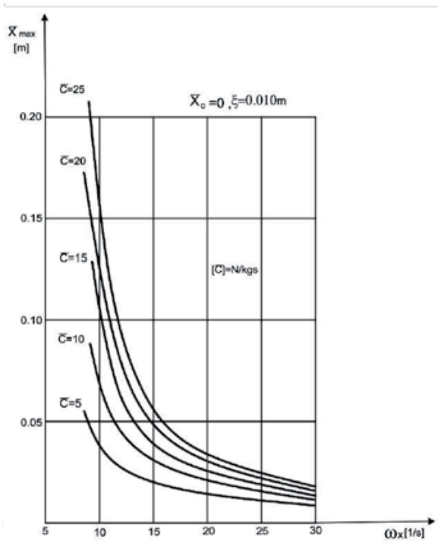
is possible to express by graph system

$$\overline{x}_{max} = f\,(\omega_x, \overline{C}) \quad (7)$$

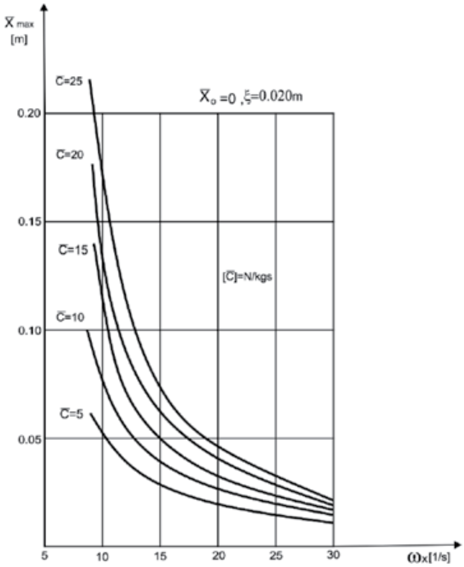
For various values $\overline{x}_0$ and ζ. Calculation results are represented through graphical relations in graphs 1-8.



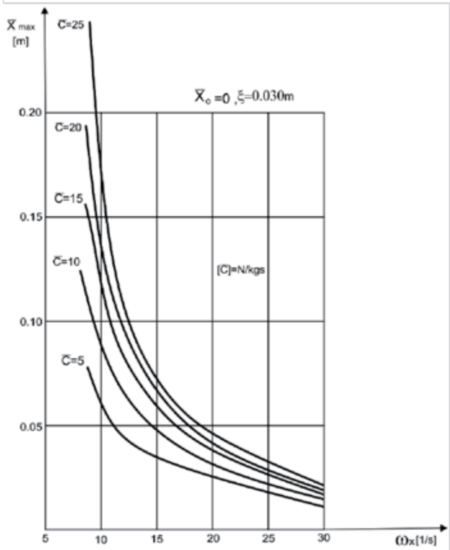
Graph 1: Relation $\overline{x}_{max} = f\,(\omega_x, \overline{C})$
for $\overline{x}_0 = 0$, $\zeta = 0{,}005$ m



Graph 2: Relation $\overline{x}_{max} = f\,(\omega_x, \overline{C})$
for $\overline{x}_0 = 0$, $\zeta = 0{,}010$ m



Graph 3: Relation $\overline{x}_{max} = f(\omega_x, \overline{C})$
for $\overline{x}_0 = 0$, $\zeta = 0{,}020$ m



Graph 4: Relation $\overline{x}_{max} = f(\omega_x, \overline{C})$
for $\overline{x}_0 = 0$, $\zeta = 0{,}030$ m

Comparison of corresponding graphs for various values $\overline{x}_0$ confirms previous conclusion [3] regarding little influence of preload $\overline{x}_0$ to biggest spring deformation size and biggest trailers acceleration. Other three values mainly, ω_x and $\overline{C}$ have rather big influence. Sensitivity of biggest deformation $\overline{x}_{max}$ into change ω_x is large mainly for little values of radian frequency ω_x.

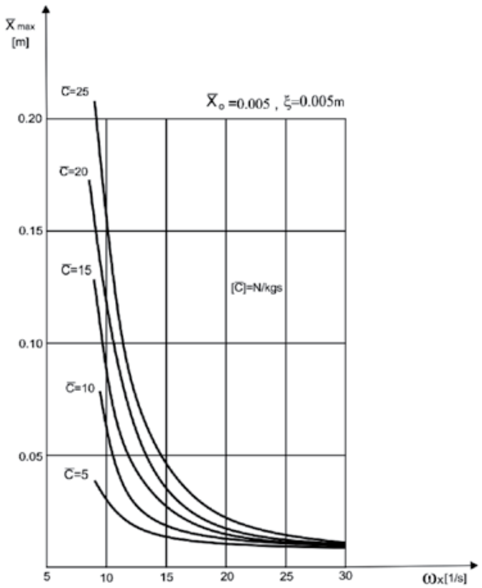
As it results from the relation (5), radian frequency ω_x is function of three values c, m,m', which is possible to express after application of proportionate trailer´s weight υ, by only two values c and vm. Thus it would be beneficial to investigate, how the biggest strength in joint is varying F'_{max} and biggest trailers acceleration a'_{max} if it varies ω_x following the change of one or the other of these values / following the change c or v m).

By graphs 5-8 and formula (3) following relation has been stated $F'_{max} = f(\omega_x,\zeta)$ while υm = 2 000 kg for $\overline{C} = 5N.kg^{-1}.s^{-1}$ (graph 9) and for $\overline{C} = 25N.kg^{-1}.s^{-1}$ (graph 10).

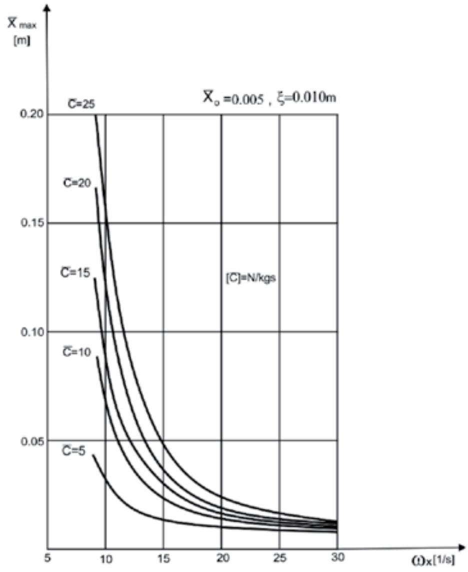
From graphs 9 and 10 it is obvious, that while υm = constant factor have curves $F''_{max} = f(\omega_x,\zeta)$ minimum, that with growing allowance ζ turns to lower values ω_x. Allowance influence ζ on power dimension F'_{max} is relatively big. Relation of the biggest acceleration of trailer $a'_{max} = f(\omega_x,\zeta)$ while vm = constant factor, has similar development as function $F'_{max} = f(\omega_x,\zeta)$, because following the formula (1) the biggest acceleration of trailer mainly depends on formula $\frac{c}{m'}\,\overline{x}_{max}$

which in accordance with relation (3) can be written as follow $\frac{F'\,max}{m'}$.

Accordingly this function has (while m' = constant factor) minimums under the same values ω_x as function $F'_{max} = f(\omega_x,\zeta)$. This implies, it is possible to find such radian frequency ω_x, under which F'_{max} and a'_{max} are minimal.



Graph 5: Relation $\overline{x}_{max} = f(\omega_x, \overline{C})$
for $\overline{x}_0$ = 0,005m ζ = 0,005 m



Graph 6: Relation $\overline{x}_{max} = f(\omega_x, \overline{C})$
for $\overline{x}_0$ = 0,005m ζ = 0,010 m

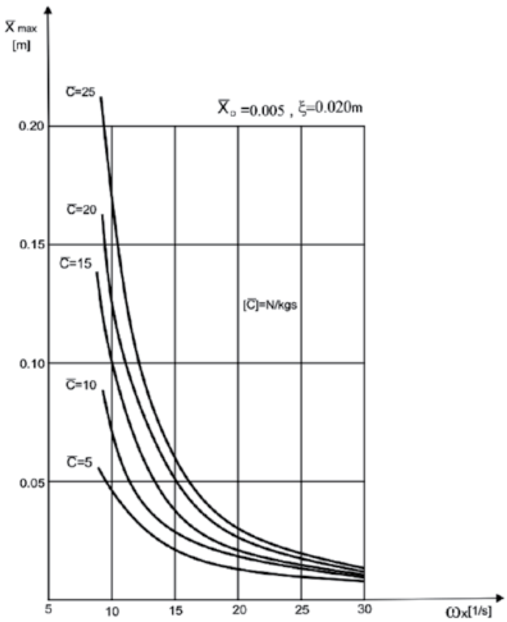
On the contrary if the radian frequency ω_x changes due to modification of term υm, while constant spring rate c = constant factor, have according relations (1) and (3) relations $F'_{max} = f(\omega_x,\zeta)$, $\frac{c}{m'}\overline{x}_{max} = f(\omega_x,\zeta)$, while c = constant factor, while their determination was
c = 800 000N/, $\overline{C}$ = 25 N . kg^{-1}. s^{-1}, m = 5 000 kg, $\overline{x}_0$ = 0,005 m.

With growing radian frequency ω_x while (c = constant factor) thus declines the biggest strength in joint F'_{max} and growths $\frac{c}{m'}\overline{x}_{max}$ term size and so does the biggest trailer ´s acceleration a'_{max}. It implies, i tis not favorable to have υ too small (e.i. big ω_x), either too big (e.i. small ω_x). Relative trailer´s weight used to mainly be between υ = 0,25 – 0,5, which in our case correspond with ω_x = 18 – 25,8 s^{-1}. This range υ really covers medium part of graphs, where there are not too big strengths in joint nor is big trailer´s acceleration.

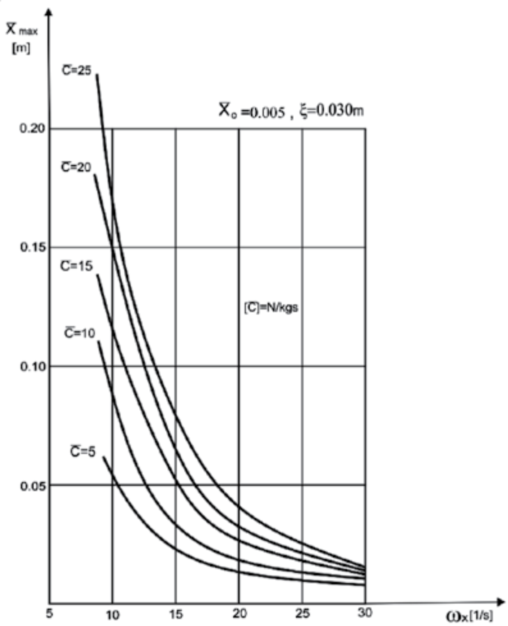
Hereinafter we demonstrate, what shape $F'_{max} = f(\omega_x)$, relation has while υm = constant factor, if we recalculate that for several various values υm.

Following values were selected υm = 1 000 kg, 2 000 kg and 3 000 kg while $\overline{C}$ = 25 N . kg^{-1}. s^{-1}, m = 5 000 kg and $\overline{x}_0$ = 0,005 m. There are curves on graph 11 F'_{max} that are specified for allowances in joint ζ = 0,01 m and on graph 12 for ζ = 0,02 m. From both expressed graphs it is visible that curves $F'_{max} = f(\omega_x)$ while υm = constant factor have (while certain value $\overline{C}$, x_0, aζ) irrespective to υm size minimum always by the same value ω_x. This value ω_x is thus optimal radian frequency ω_{xopt}, because it matches the least joint stress.

Thus it is possible to find optimal radian frequency ω_{xopt} for every towing automobile characterized by values $\overline{C}$, m, x_0 while selected allowance size ζ . We can see ω_{xopt} = 21,6 s^{-1} on graph 11 and ω_{xopt} = 18,25 s^{-1} on graph 12.



Graph 7: Relation $\overline{x}_{max} = f(\omega_x, \overline{C})$
for $\overline{x}_0$ = 0,005m ζ = 0,020 m



Graph 8: Relation $\overline{x}_{max} = f(\omega_x, \overline{C})$
for $\overline{x}_0$ = 0,005m ζ = 0,030 m

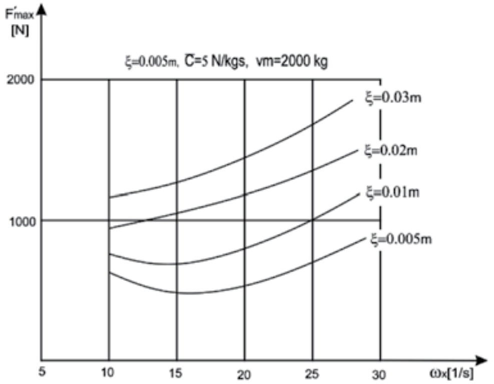
Optimal radian frequency importance consist in the fact, that It is possible to find optimal spring firmness in joint c_{opt} for certain trailer allocated to towing automobile thanks to ω_{xopt}. It results from finding that in graphs 9, 10, 11 and 12 ω_x changes following spring firmness in joint change c and also from relation (5) according to which it is possible to write

$$c_{opt} = \nu m \omega^2_{xopt} \tag{8}$$

However, trailer´s weight m’ is not the only value. In operation its size changes from m'_{min} (e.i. empty trailer´s weight) to m'_{max} (e.i. loaded trailer´s weight). Thereby υ and real radian frequency ω_x change and consequently other two values change: the biggest strength in joint and the biggest trailer´s acceleration.

If trailer´s acceleration does not matter, it is favorable to use for optimal firmness c_{opt} setting according the formula (8) and to take into an account the biggest trailer´s weight m'_{max}. Under smaller weights (in the mentioned range m'_{min} - m'_{max}) the power in joint will be always lower. In some cases and especially in case when there is some special sensitive equipment installed on trailer, trailer´s acceleration strength can be on the contrary critical. It is necessary to take into an account the smallest trailer´s weight while setting optimal firmness c_{opt} so that this acceleration would not reach too big values. There were used only two extreme cases. Having specific project it is necessary to come out from vehicle combination needs, trailer and equipment installed on it, and out of their analysis we can set up conditions for spring firmness in joint.

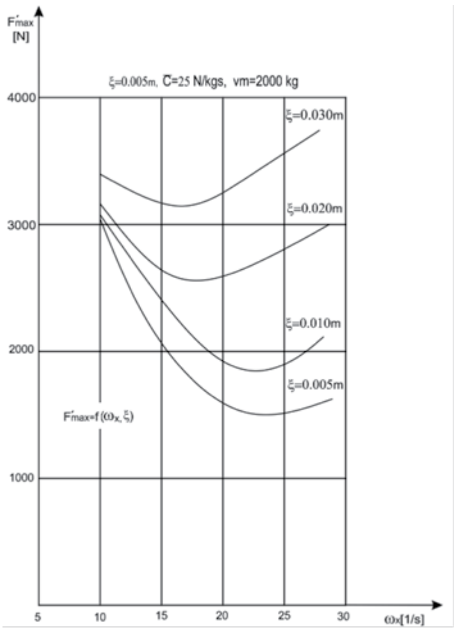
Having case of towing device project we would proceed by mentioned way. Still, in reality we use appropriate towing automobile that is already equipped with the lifting equipment / including spring mounting/ for projected trailer. In such case we have to check how differentiate real spring firmness in lifting equipment of towing device from calculated optimal firmness. If the required op-



Graph 9: Relation $F'_{max} = f(\omega_x,\zeta)$

$\overline{x}_0$ = 0,005m $\overline{C}$ = 5 $N.kg^{-1}.s^{-1}$

for vm = 2000 kg



Graph 10: Relation $F'_{max} = f(\omega_x,\zeta)$

$\overline{x}_0$ = 0,005m $\overline{C}$ = 25 $N.kg^{-1}.s^{-1}$

for vm = 2000 kg

timal firmness is lower than the real one, it is good to spring back the towing rod / e.i. to place spring between springle of towing rod and own towing rod/. The overall firmness of joint will decline by this serial by-spring sequencing.

If, on the contrary the spring firmness in the towing device is smaller as it is required , it is essential to replace this spring by the one that has bigger firmness or to add another spring to the original one in parallel. Possibilities of such adjustments should be kept in minds already while constructing lifting devices on towing automobiles. Necessity of realizing those adjustments together with the economical point of view should be always evaluated first.

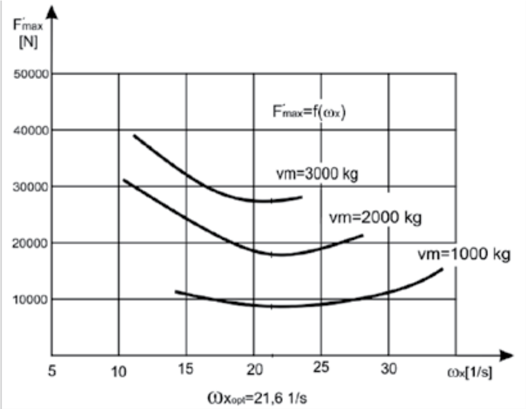
We should deal with such spring firmness in joint and its stating, however the joint stressing should as small as possible. This spring firmness depends on towing vehicle weight transformed into system of units SI as follow

$$c = 100\ m \pm 300\ 000, \qquad (9)$$

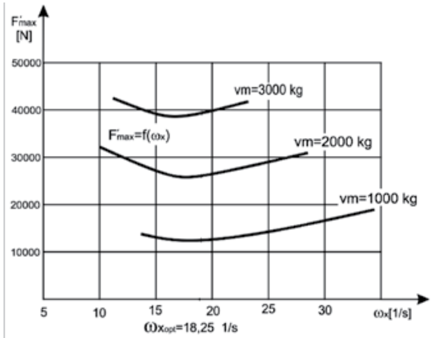
where weight m comes in kg and spring firmness c comes in N / m.

Formula (9) comes from analysis of the smallest joint loadings having three vehicle combinations. Their weight figures and towing vehicle type are presented in table numb.1. Resulting from the last column of this table all three examined vehicle combinations have almost the same nominal weight of trailer (υ ~ 0,4). Formula (9) does not take into an account size of υ. Lets compare then firmness stated according the formula (9) with the values calculated according the formula (8) by various nominal trailers´ weights.

For this comparison, we use cases reported on the graphs 11 a 12. Towing vehicle´s weight is = 5 000 kg and three various nominal trailers´ weights are υ = 0,2, υ = 0,4, υ = 0,6. It implies from formula (9), that the optimal spring firmness in joint is = 200 000 N/m having medium value



Graph 11: Relation $F'_{max} = f(\omega_x, vm)$ for ζ = 0,01 m



Graph 12: Relation $F'_{max} = f(\omega_x, vm)$ for ζ = 0,02 m

c = 500 000 N/m, no matter what the size υ and ζ are. If for stating optimal spring firmness we use the formula (8), it is necessary to take into an account optimal radian frequency of its own oscillations of vehicle combination, stated in graphs 11 and 12. Graph 11 shows that having ζ = 0,01m, ωxopt = 21,6 s^{-1} and picture 12 having ζ = 0,02 m is ω_{xopt} = 18,25 s^{-1}. Values of optimal spring firmness calculated from the formula (8) are reported in table 2 for both cases. These results are shown on graph 13 c = f (υ) together with firmness range marking, that was calculated out of formula (9). Picture shows that formula (9) does not cover all firmness values by its range calculated from graph (8) for changing value υ. Consequently it is necessary to mention that range of formula (9) is so large, it is possible to make easily serious mistake while its use.

$$(\upsilon \left[\frac{m'}{m + m'}\right])$$

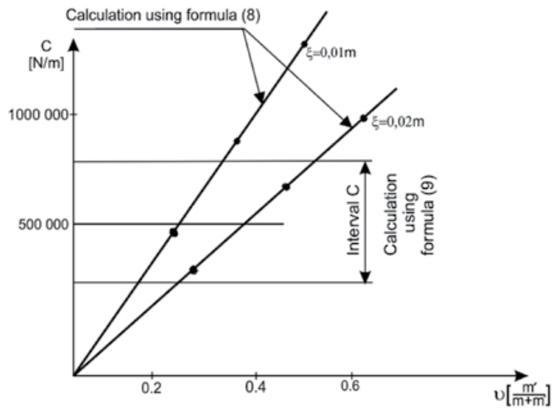
Besides these two formula (9) disadvantages in comparison with formula (8) it is necessary to report other two disadvantages. It is particularly the fact, that allowance influence ζ is partially taken into an account only by mentioned extensive range c. Fourth disadvantage is influence neglect of value $\bar{C}$. Method of optimal firmness stating that uses formula (8) takes into an account the influence of υ, ζ, $\bar{C}$, x_0 values.

Tab. 1: Loading of vehicle combinations´ joint and their impact on weight figures

Towing vehicle	m [kg]	m'[kg]	$Y \left[\frac{m'}{m + m'}\right]$
GAZ – 69	5 430	3 500	0,392
ZIL – 133	10 300	6 400	0,383
JAZ – 214	20 000	14 000	0,412

Tab. 2: Optimal Spring Firmness Values

$v \left[\frac{m'}{m + m'}\right]$	c [N / m]	
	ζ = 0,01 m	ζ = 0,01 m
0,2	466 000	333 000
0,4	932 000	666 000
0,6	1 398 000	999 000



Graph 13: Calculation Comparison of Optimal Spring Firmness following the graphs (8) and (9)

CONCLUSION

From introduced article we can thus draw following conclusions. Formulas (1) and (3) enable simple formulation of the biggest trailer´s acceleration a'_{max} and the biggest strength in the joint of vehicle combination F'_{max} mainly because there exist the biggest spring deformation in joint $\overline{x}_{max}$, which represents the function of several other values and that can be obtained from graphs on pict. 1 – 8. These formulas are then more simple than formula (9), where exists 8 values while expressing the biggest strength. There has been relation of the biggest joint deformation found $\overline{x}_{max}$, on the radian frequency of its own longitudinal oscillations ω_x. It is easily possible to find the value $\overline{x}_{max}$, through the graph system $\overline{x}_{max} = f(\omega_x)$. This value is essential for formula (1) and (3) and their calculations. Relatively small influence of spring prestress in joint on the size of the biggest deformation $\overline{x}_{max}$ [3], [4] has been confirmed. Solution results show applicabilty of relative trailer´s weight range $\upsilon = 0,25 – 0,5$. There have been shown various ways of optimal value stating ω_{xopt} (for minimal joint stressing) and by this through formula (8) the way of optimal spring firmness in joint c_{opt} has been shown as well. Essential is to recommend, to adjust firmness in joint while creating the vehicle combination (e.i. while selection of towing automobile for trailer). Firmness in joint should be adjusted so that it would be close to optimal value as much as possible. By comparison of various firmness in joint stated by formulas (8) and (9), there arisen advantages of stating firmness in joint mentioned in this article.

Literature

1. BALOG, J.: Diagnostikovanie a prognozovanie stavov pri údržbách strojov. SM3 – prípadová štúdia. SPU Nitra 2002.
2. FISHWICK, P.: Simulation Model Design and Execution, Prentice Hall 1995.
3. FURCH, J.: Možné přístupy pro stanovení optimálneho intervalu doby životnosti vozidla. In.:Zborník medzinárodní konference OPOTŘEBENÍ, SPOLEHLIVOST, DIAGNOSTIKA, Univerzita obrany Brno 2005.
4. CHOVANEC, A.: Simulation Modeling of Processes of Special Technology Depentability support. TnU AD, Trenčín 2006.

POSSIBILITIES OF USING CARBON MATERIALS AS CONSTRUCTION MATERIALS FOR SPECIAL TECHNOLOGIES IN OUT-OF-EUROPE CLIMATIC CONDITIONS

Peter Lipták, Ivan Kopecký

Abstract

Operation of devices and machinery under various climatic circumstances has an effect on determination of reliability operational parameters at projecting and construction of devices and machinery.

The work deals with determining of criteria of the special technique (selected electrical parts) operation under extreme conditions.

The end of the work summarizes experiences in servicing and repairs of the special technique (selected electrical parts) under climatic circumstances out of Europe.

Key words

serviceability of control and power supply mains of special equipment, special equipment, machines and devices, extreme climatic conditions, carbon materials

Control and power supply mains of special equipment and some electric devices of special equipment are engineered and designed for certain and defined climatic conditions. Carbon materials as construction materials play there an essential and non-neglect able role. The possibilities of their operation and application are stated in operation instructions as well as tactical-and-technical features in operation under certain, defined conditions. In practice there emerged a need to use and to operate special equipment also in extreme climatic conditions or in conditions which have not been specified up to now. (E.g. desert storms etc.). Control and power supply mains show as one of problem issues of special equipment, which may show different parameters in these conditions than stated by the manufacturer, but they may be still functional. These conditions can be simulated, mathematical model can be developed and evaluated and to recommend additional adjustments to the manufacturer and to the designer, so to use them in extreme climatic conditions, without breaching a continuity of its operation, or to define possible limits of parameter change. In the period of recent years the repairmen and operators face a challenge in practice of operation of control and power supply mains of special equipment, e.g. armament, machines and equipment (engineer equipment), namely to establish conditions in order to use some special equipment, e.g. electrical parts of equipment and devices even in critical situations, e.g. in emergency state and in disposing its consequences, as well as in meeting task abroad in extreme climatic and operational conditions. According to the fact, that special equipment already have been deployed and operated in such conditions, it is possible to generalize and to evaluate experience from its operation.

Results of evaluation and generalization and consequently results of simulated experimental tests, e.g. in simulation chambers can serve as a base for mathematical modeling and for an effective work of designers, manufacturers and users.

This task has been solved as a grant task of the Faculty of special technology of the Trencin University called by Alexander Dubcek in Trencin.

Description of unconventional operating climatic conditions for needs of a review of a quality and service reliability of control and power supply means of some special equipment from „MACHINES AND EQUIPMENT" class (engineer equipment) ".

As unconventional operating climatic conditions are considered all conditions, which deviate from values, being typical for Central European moderate climatic range. In literature [1] this environment is defined by an annex of values aligned in table 1.

An area, in which the selected machines and equipment were reviewed, is characterized as an environment with an increased corrosive aggressiveness, dusty environment with non-flammable dust, but deteriorating a nominal dielectric permittivity and an electric breakdown strength due to its conductivity, an environment with vibrations and environment with biological vermin.

Environment defined in such a way as a consequence of extreme climatic conditions, exercises an influence mainly on a corrosion resistance of materials. In addition, it has a non-neglect able influence also on parameters of electronic parts and parts responsive to electrostatic charge, to conductivity of the environment, forming a part of a special equipment, machines and devices. An impact of a quickly spreading corrosion on electric contacts, on connection and binding areas is to be taken into consideration, unless they are specially adapted for this environment. Non-conducting layers develop, resulting in sparkling and creation of electric arcs (transition actions). The same situation is at corrosion aggression on commutators, where a sparkling and abrasion of non-conducting layers and alluviation of worn particles into winding occur. Carbon materials, as construction component of these parts are not resistant against these impacts.

It is convenient to select during observation measurable or quantifiable values as variables dependent on climatic conditions for review of quality and service reliability of selected special equipment. As an example during effects by defined climatic conditions it is convenient to evaluate among depreciating processes an atmospheric corrosion of bearing parts of con-

Tab.1: Characteristics of a moderate climatic range

The lowest air temperature	-40°C
The highest air temperature	+40°C
The highest relative humidity	95%
The highest absolute humidity	60 g.m^{-3}
The highest intensity of solar radiation	1120 W.m^{-2}
The highest intensity of thermal radiation	600 W.m^{-2}
The highest air speed	20 m.s^{-1}

struction by measuring its range, depth of penetration, to evaluate a mass reduction of metal per surface unit etc. It is also needed to evaluate a time flow of corrosion action depending on a relative humidity and temperature, on a rate of air pollution. From a point of view of atmospheric ageing of organic materials, it is convenient to choose for evaluated data such parameters, which provably exercise an influence on a functionality and service ability of the equipment as a whole. For example, casings from organic materials on control voltmeters appeared as faulty in extreme climatic conditions due to atmospheric ageing of organic materials.

From a point of view of atmosphere pollution in reviewed ranges, it was needed to take atmosphere pollution into consideration to the extend of:

- Sulfur dioxide from 17 to 45 [$mg.m^{-2}.d^{-1}$]
- Chlorides from 0, 20 to 0, 30 [$mg.m^{-2}.d^{-1}$].

A starting point in reviewing an effect of humidity was the knowledge about the fact, that a humidifying of a surface in form of dew occurs in a contact of the colder surface with a humid air of higher or a same temperature at a relative humidity higher than 60-70 %, what is needed to take into consideration at relatively great changes of temperature by day and at night. Performing of measurements aiming to develop climatographs and to review the climatic areas is not a subject-matter of this article.

Possibilities to simulate extreme conditions

The influences having effect on parts during operation can be divided in mechanical and climatic. In selection of a sequence of particular tests the effects of particular environment must be taken into consideration, as well as their intensity, but also an affect on a particular product, equipment, and machine. It is necessary to get the maximum information on a status of a part before its destruction. It is convenient to simulate a sequence of influences of particular environments so as the environment will affect a part in a real usage.

Various types of simulation chambers are used in a simulation of effects of the environment on parts and equipment. Inside these chambers there is created an environment, imitating an environment, in which a use of products is supposed, e.g.:

- A test with a humid heat – a cyclic mode
- A test with a humid heat – non-cyclic mode
- A test with mildews
- A test of air tightness
- A test by a solar radiation
- A test by a atmospheric pressure
- A test by a variation in temperatures
- A test by a frost
- A test by a dry heat
- A test by a salt steam
- A test by a low pressure
- A test by a dust.

In case when equipment is deployed e.g. in terms of conditions with an increased concentration of exhaust emissions and in the coastal areas we would recommend the following tests:

- A corrosion test in a condensation chamber – aiming to verify a resistance of material and surface protections, in so far as it relates an effect of an increased humidity, possibly an increased concentration of SO_2 without effects of other factors,
- A corrosion test in a salt steam – aiming to verify a resistance of materials and surface protections in a coastal atmosphere with a decisive actor of a vapor of sea water,
- A test by a solar radiation – aiming to verify a resistance of a product against impact of luminous and thermal effects of a solar radiation,
- A test by a dust and sand – a simulation of desert conditions,
- A test by a dry and humid heat,
- A test with funguses – simulation of a biological attack of the material,
- A test by vibrations.

The above mentioned tests have proved their worth in a practice with regard to a subsequent operation of the equipment and material, e.g. in the areas of Northern and equatorial Africa, on the Cyprus Island, in Iraq and in Afghanistan.

Specification of the environs

The reviewed equipment was located in environment of the equatorial Africa and in area of Mediterranean Sea, on the Cyprus Island, in Iraq, in Afghanistan. The tests were performed on the equipment one month after a termination of a rain season.

In evaluating effects of the environment upon operating parameters namely effects of sulfur dioxide, hydrosulphide, chlorided ions, solid impurities and air humidity have been monitored. The areas of operation of special equipment were categorized based on scanned climatographs with reference to harmfulness of corrosion aggressiveness of the atmosphere as a parameter. It was interesting to monitor a change of electric parameters of control and power supply means of special equipment in consequence of e.g. a static charge during desert storms, conductivity of volcanic dust sediments etc.

Analysis of monitored achieved results of an operational reliability from a point of view of environment impact

The parts of machines and equipment were monitored with a specification for an electric generator and pressure equipment. About 100 equipments were monitored, which were operated in conditions of the environment – by a table 2. These equipments were manufactured in

Tab. 2: Overview of places of the operation with a description of conditions

Place of operation	Height above sea level [m]	Description of conditions
Eritrea Adi – Quala V - Africa	2300	Environs – agricultural farming soil
Eritrea Assab V - Africa	0	Distance from a shore about 2 km, environs a desert
Eritrea Barentu V - Africa	1700	Environs grazing land braky with hushes – many biological pests
Eritrea Gergera V - Africa	2100	Environs mountain terrain, grass and small hushes
Eritrea Schilalo V - Africa	1500	Environs grazing land braky with hushes
Cyprus Famagusta	0	Port town, equipment deployed about 5 km from a shore
Tripolis – Tagiura S - Africa	0	Port town, equipment deployed about 8 km from a shore
Benghazi S - Africa	0	Port town, equipment deployed about 8 km from a shore
Tobruk S - Africa	150	Semi-desert conditions with strong desert storms
Missourata S - Africa	50	Environs grazing land braky with hushes
Iraq- Ad Divaniyah	450	Semi-desert conditions with strong desert storms and sand containing as much as 4 % of salts
Afghanistan - Kandahar	1 000	Semi-desert conditions

Slovakia (Bratislava, Martin); in Czech Republic and in Ireland (a part of the equipment can be seen in table 3.).

Concerning the fact, that we monitored renovated objects, we selected criteria a flow of failures and renovations for a criterion of an operational reliability. Features of the renovated objects are represented by a H(t) value, a mean number of failures of a renovated object in t time t:

$$H(t) = \frac{1}{N}\sum_{i=1}^{N} n_i(t), \qquad (1)$$

where $n_i(t)$ is a number of failures of an i renovated object in t operation period,
N is a number of monitored objects.

From a statistics point of view it is suitable to use a feature of a parameter of flow of failures, which are expected in a short Δt time period. This feature is stated by the terms:

$$\hat{h}(t) = \frac{\Delta H(t)}{\Delta t} = \frac{\sum_{i=1}^{N}\left[n_i(t+\Delta t) - n_i(t)\right]}{N.\Delta t}, \qquad (2)$$

where Δ H(t) is an increase of a mean number of failures in a short Δt time interval, or a mean number of failures in a (t,t+Δt) time interval. In a computation it was possible regarding to a statistic assessment of a real number of failures in an 1 year operation period, to take into a consideration, that the failures of a renovated object is controlled by an exponential rule of a distribution with λ failure intensity. In a particular situation, table 3, the value of a mean number of failures of a renovated object in 1 year operation period (the tests were performed 1 month after termination of a rain season) a number from interval (0, 1 – 0, 4) in a so called settled condition of reliability (a status of a test run was performed before exporting abroad, in a condition of ageing we do not recommend to operate an equipment abroad).

Technical usage factor:

$$K_{tv} = T/\left(T + T_p + T_o\right), \qquad (3)$$

A readiness factor:

$$K_p = T/\left(T + T_o\right), \qquad (4)$$

Where

T is a mean period between failures of a renovated object,

T_p is a mean period of a downtime,

T_o is a mean period of repair.

Based on obtained experience and evaluated monitoring, measuring and statistic records it is needed to keep a well-established decreasing of a mean period between failures of a renovated object in extreme climatic conditions by 20% through an implementation of a regular cycle of equipment and material maintenance on the level of a medium service repair regardless a period of its operation in regular time periods and in periods defined after climatic turning points (e.g. rain season, sand storm, monsoon season etc.). In such a way it can be achieved, that an exponential increase of failure intensity is delayed and we stay in ergodicity regime on a device, machine and equipment.

It was proved as an important fact, that equipment, machines and devices are to be exported and operated in extreme climatic conditions only after a test run, or to create conditions that a test run is performed in stable and standardized climatic conditions. In necessary cases (after larger repairs directly in the field it is needed to simulate such conditions after having performed the repairs). After a computation of the period of equipment deployment after a repair, it is necessary to respect this fact. If neglected, the period from a beginning of an operation until the first failure after a repair will reduce.

Based on this experience it would be suitable in a future to adapt reliability features of exported machines, equipment and material or to establish them through a simulation method or modeling for extreme climatic conditions.

Carbon material in a sliding contact

The effect of unflavored climatic environs speeds up degradation effects of mechanisms of special equipment. A problem of an increased failure rate of annular conductors stood forth in assessing a failure rate of special equipment operated in unflavored climatic conditions, whose unreliable operation affected other mechanisms and in final implications also a general serviceability of special equipment.

A faster degradation of a sliding contact applies for both elements of a sliding contact on electric machines, i.e. for a brush and commutator or a brush and rings for alternating machines. Rate of wear of brushes must be respectable not only regarding a good commutation, but also regarding costs needed for maintenance of electric devices.

Knowledge of all effects, causing wear can result in effecting the process of wear, which necessarily reflects in an increased reliability of electric equipment.

Under a term of a service period we usually envisage either a decrease or a full decrement of utility of a given object. Service period of a brush resulted from a wear is defined only by a wear of its sliding surface, so only by a modification of its height, as well as by a wear of a brush as a whole. For next considerations it is very important to differentiate, that the service period of a brush is limited by:

- natural wear,
- an extraordinary, early wear.

A natural wear of brushes stands for a wear resulting a function of a brush as one of two elements of a sliding contact and also from a function of a brush as an element interceding a transfer of a current between a rotating commutator and a collecting equipment of an electric machine. The brush is worn in a natural way, as long as its height reduces to a minimal bearable limit during an adequate period.

If we had assessed a soundness of a selected quality of the brushes only by a rate of wear, we would have come to a standpoint, that the most suitable quality of brushes is the one, having the least wear. We also have to care for the brushes do not wear excessively a commutator and rings. It is to be noted, that a wear of brushes creates a carbon component of a patina, which very favorably affects a sliding contact brush-commutator of a ring.

A rate of wear of brushes can be expressed by absolute values:

- linear abrasion,
- volume abrasion,
- mass abrasion.

The wear of rings becomes evident basically as scabbing, creation of shadows and stains. Compared to a commutator the rings differ by a wear depending on a polarity of rings. The rings under cathode brushes wear many times more than under brushes of positive polarity. The metals always migrate to the cathode and the metal diminishes on the anode.

If metal-graphite brushes are used for machines with steel rings, then the above mentioned migration of metals results in coppering of rings under an anode brush. Copper from this brush mitigates to the cathode – ring. Because of this reason the metal-graphite brushes should not be used for steel rings.

Aiming to prevent an unequal wear of rings, it is suitable to change regularly a polarity of rings for synchronous machines and unidirectional electric devices with a sliding contact.

Creation of shadows and stains on the rings is another very significant effect. A patina (a commutator coating) on the rings is eroded by stains obviously limited in width and many times also in a length of brushes.

The reasons of creation of stains on the rings are various and often they can be explained in a simply way. Generally the stains on the rings can be formed:

- in an idle regime of the machine through effects of humidity and temperature through an electro-chemical way between a carbon and a metal,
- While in movement the stains come into being in bad mechanical conditions of a sliding contact, mainly in rings eccentricity, ring abrasiveness, in presence of greases, oil or impurity on a sliding surface, etc.,
- The latter mentioned kind of stains can come into existence also resulting effects of large currents in starting of the machine run.

If the stains are formed while a run of a machine, then a reason is hardly findable and usually it is necessary to look for suitable brushes, but also a suitable material of rings and to eliminate on the unfavorable operational conditions as well as a presence of impurities, oils, etc.

The features of a sliding contact between a carbon brush and a ring can be significantly influenced by a material used in a manufacturing of rings and a heat treatment of the rings.

The most frequently used material in a production of rings is alloys of copper. There is a large range of such alloys. Generally we can say that in any manner the contents of alloys should not exceed 5 %. Additionally these alloys should not contain even insignificant traces of aluminum. Presence of even marginal amount of aluminum results in an excessive wear of brushes as well as rings. Therefore it is logical that the most frequently used material is not brass but bronze.

Bronzes – tin ones, tin-zincous ones, or tin-phosphorous ones, are the most frequently used materials in production of rings. The most frequently used alloys:

Tin bronze – CuSn 5 –95 % Cu, 5 % Sn,

Cu Sn 1-99 % Cu, 1 % Sn,

tin – zincous bronze – 88 % Cu, 8 % Sn, 4 % Zn,

88 % Cu, 10 % Sn, 2 % Zn.

tin – phosphorous bronze – 89,5 % Cu, 10% Sn a 0,5 % P

The alloy structure is a decisive factor for features of a sliding contact. It depends if the rings are cast in sand-moulds, or centrifugal casts, centered, cut from a circle etc.

A fine structure of the rings is needed for a low wear of brushes as well as rings, and especially for their even wear. Refinement of a structure can be achieved through a fast cooling after casting, through a use of alloying elements etc.

The materials used for rings should have much higher rigidity that brushes.

Oxygenation of the material surface has an unfavorable effect on decrease of strain on a transition of sliding contact. It is very important to use an electrolytic copper in a production of bronze aiming to prevent an oxygenation of tin.

CONCLUSION

The grant mission was aimed at rising a problem of a possible operation of special equipment in various climatic conditions with regard on a keeping its functional capability. Regarding a large scale of a given problem the article deals with a possible access of experimental methods of selected parameters, e.g. an operational reliability. Next it would be apparently suitable to go on in an issue by a selection of additional criteria and parameters.

A versatile solution or a recommendation on how to provide a requested operational reliability regardless effects of an environment is not possible to be expected. The criteria for an assessment of a quality of reviewed machines and equipment embedded can be developed by an evaluation of experience gained on operated equipment, especially in extreme climatic conditions, by a modeling and simulation of possible effects of the environment with regard to a possible operation in such conditions. Experience with this activity proved a possibility of exportation and deployment of the machines and weapon equipment of the SR AF and of the SR crisis management in extreme climatic conditions, e.g. conditions out off Europe etc. With regard to a development in area of a command of combat activities, where a deployment of unified equipment in different climatic conditions is preferred, an importance of solving issues relating adaptation of the equipment to usage in different conditions is permanently increasing. This adaptation is to be taken into consideration not only in designing the equipment, but also in a logistic support of their activities and in offering technology drafts and a plan of their operation. Published lessons learned showed a possibility of an efficient approach e.g. a possibility of a prolonging of the service period of some technical equipment (pressure equipment, heavy-current equipment, and lifting equipment) in sustaining a needed operational reliability.

The published issue relates with a need to implement a unified system of quality assessment, codification and standardization in connection with integration in security structures. It will be necessary to pay attention to this area in the future also with reference to the unified assessment of an operational reliability of special equipment.

The report was developed within VEGA 1/0421/08 project.

Literature

1. LIPTÁK, P.: Vplyv korózia na vybrané vojenské technické zariadenia z pohľadu ich opráv. VA Liptovský Mikuláš, 1999.
2. KRUŽLIAK, J.: Prevádzková spoľahlivosť, diagnostika a údržba ženijných strojov. Vojenská akadémia, Liptovský Mikuláš, 2002.
3. BUKOVECZKÝ, J., BÍLÝ, M.: Životnosť a spoľahlivosť strojov. SVŠT Bratislava, 1986.
4. LIPTÁK, P., HLÁDEK, M.: Opravy ženijnej techniky. Vojenská akadémia Liptovský Mikuláš, 1999.
5. MIKURČÍK, J.: Kodifikačné minimum. In : BULL-1-3, Bulletin č.3 VSVaP Trenčín, 2003.
6. STN 010606 – 80 Spoľahlivosť v technike.

POSITIVE AND NEGATIVE THEORETICAL AND TECHNOLOGICAL ASPECTS OF DRY MACHINING OR WITH COOLANT APPLICATION

Jozef Majerík, Rozmarína Dubovská, Ivan Baška

Abstract

A coolant is a fluid which flows through a device to prevent its overheating, transferring the heat produced by the device to other devices that use or dissipate it. An ideal coolant has high thermal capacity, low viscosity, is low-cost, non-toxic, and chemically inert, neither causing nor promoting corrosion of the cooling system. Some applications also require the coolant to be an electrical insulator. While the term coolant is commonly used in automotive, residential and commercial temperature-control applications, in industrial processing, heat transfer fluid is one technical term more often used, in high temperature as well as low temperature manufacturing applications. Cutting fluid is a coolant that also serves as a lubricant for metal-shaping machine tools. There has never been a more critical time for work's production operations to drive costs down, achieve greater efficiencies whilst at the same time maintain manufacturing quality.It is estimated that on large scale production sites cooling lubricant can make up nearly 20% of the total manufacturing cost, the cost of purchasing, maintaining and disposing of cutting fluids is a significant factor when evaluating a machine's operating costs.

Key words

chip removal, coolant, machinability, PVD and CVD coatings, dry machining, cutting fluid, cutting conditions, cutting tool geometry, build up edge, P-M-K-N-S-H groups of ISO, production process costs

CONTRIBUTION OF COOLANT APPLICATION DURING MACHINING PROCESS

Its very important to ask a question „Where and when we need to apply coolant during machining process and when no?". Because various types of materials according to ISO standards needs different cutting conditions, cutting tools materials and last but not least dry or coolant machining process application. We can determined some cases when is possible to using cutting fluid nad when we cannot.

The propositions of cutting fluids in cutting production process application:

a. HRSA (Heat resistant super alloys) materials (S – group of ISO metallic workpiece material standard).
b. Drilling of the deep holes (in special technology maching process application). Very important is chip removal from the cutting area. Cutting tool (BTA, EJECTOR drilling head) have to internal input of cutting oil, and output is also very necessary.
c. In some cases also aluminium machining, because important is chip removal from cutting zone, when applying lower cutting speed. It exist a possibility to buld-up edge creation. Coolant can avoid of this negative effect.
d. Die&mould milling on vertical machining centers. Slot milling process. It needs to direct coolant or pressed air in front of milling cutter.
e. By the poor machinability materials (low alloyed steel, C<0,2%). Its necessary to increase cutting speed, or its not possible – speed limit of machine tool, then need more coolant directly into cutting area.
f. Stainless steel turning (M-group of ISO machined materials standard) needs cutting fluid. When machining stainless steels chip control and cooling are important to avoid plastic deformation. By using CoroTurn HP-cemented coated carbide insert, these problems can be overcome and cutting data can be raised.
g. Face rough milling of thin plates. Cutting fluid is a necessity. Its a risk of workpiece material overheating, then occurs problems with part geometry directed by technical documentation. Theraml deforamtion is also a big problem – cutting fluid requirement. When turning centers and its powered units usage during machining process, then coolant have to apply – not for machining process, but for machine tool components operating temperature.

The disadvantages of cutting fluid applications: (Dry machining)

a. Most of milling operations with changeable cutting carbide inserts, especially face milling and shoulder milling process. (almost 95% of milling process without coolant). Reason is interrupted process of material removal – milling. Temperature of porcess is almost 700 degrees, after coolant application starts to thermal shocks and consequently micro ruptures in cutting tool material when cutting. When stop coolant – tool life increases 4-times than normal.
b. Grey cast iron machining (only dry process). Combination of coolant and small chips called „slush“ – negative aspect of machining process, destroyes machine tool bearnings.

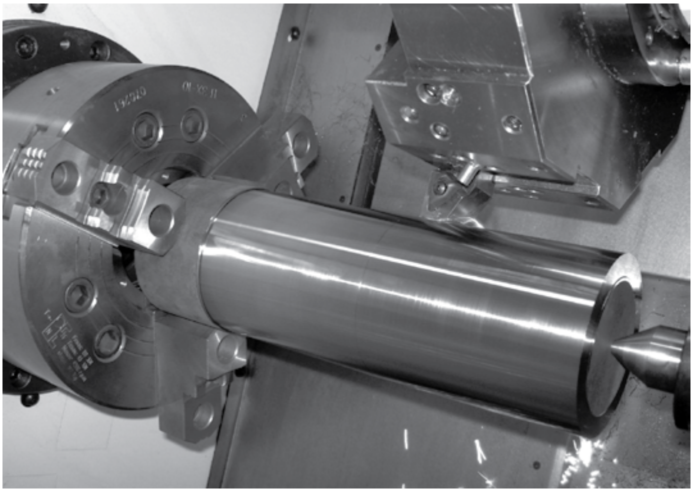


Fig.1: Hard turning example of 100Cr6 steel by COROMANT CC6050 mixed cutting ceramics cutting tool insert

c. Machining of hard materials (H – group of ISO mettalic workpiece material standard) over 55 Rockwell hardness. Machining with cutting ceramics and cubical boron nitride cutting tool inserts. Its originated high cutting forces during machining, chip removal is heat red-orange coloured. (See Fig.1). CC and CBN are bad heat wires. All generated heat comes into the chip – very high temperature.
d. During composite materials, graphite, wood and fiberglass machining.
e. Other cases: if workpiece format inestimables coolant application. (Assembly configuration).

POSITIVE AND NEGATIVE ASPECTS OF CUTTING FLUIDS IN MACHINING APPLICATON

Positive aspects of coolant machining:

a. Adequate and good coolant improves cutting tool life, especially in turning and drilling. But not at milling.
b. Emulsive cutting oil is very good preserving appliance and positive affects for all machine tool components and prevents against corrosion.
c. Lubricated CNC machine tool components and main parts have longer operating durability (working parts, working table, spindle, turret).

Negative aspects: hard machining, cast iron machining, HSC machining application.

COOLANT ELIMINATION FROM CUTTING PROCESS

Coolant elimination from cutting process brings decrease of overall manufacturing costs. Cutting fluid ater using is a dangerous refuse that would be discontinue to using and for what is necessary to paid (for its liquidation). There are several types of overall costs in order to apply coolant. There are water purchase, water modification, emulsive equipment purchase, periodical coolant maintenance, interfuse apparatus purchase (due to homogenity of coolant), daily coolant maintenance, coolant liquidation costs (ecology aspect), management costs (emission quotas, environment, how many tons of coolant is possible to liquidate annually?).

Coolant elimination is 17% decrease from overall costs to manufactured product.

PVD AND CVD COATINGS

The diffrerence between PVD (physical vapour deposition) and CVD (chemical vapour deposition) coatings is in its thickness. PVD coatings have sharper cutting edges and more stabile inserts than CVD. CVD coating appropriates high temperature and used for high cutting speed and bigger diameters. PVD is for lower cutting speed and smaller diameters.

PRACTICAL EXAMPLES OF APPLICATION

Steel turning (see Fig.2a) - The machinability of steel differs depending on alloying elements, heat treatments and manufacturing processes (forged, cast etc.) Steels can be categorized as unalloyed, low alloyed steel and high alloyed steel, all of which affect the machining recommendations for turning.

Heat resistant super alloys (HRSA) can be divided into three material groups; nickel-based, iron-based and cobalt-based alloys (see Fig.2b). The machinability of both HRSA and titanium is poor, especially in aged conditions, which impose particular demands on the cutting tools. In surface integrity is of upmost importance, but this limits cutting data.

Coolant should always be applied when turning HRSA or titanium alloys regardless of whether carbide or ceramic inserts are used. The coolant volume should be high and well directed. High pressure coolant (with coolant pressures up to 80 bars) is now common in modern machines and, together with the CoroTurn HP coolant supply technology (see page A 124), cutting speed can be increased by up to 20%, tool life by up to 50% and, last but not least, chip breaking can be considerably improved. Jet-break technology, using ultra high pressure coolant (with coolant pressures from 80 to 1000 bars) can be applied when using vertical turning lathes (VTL).

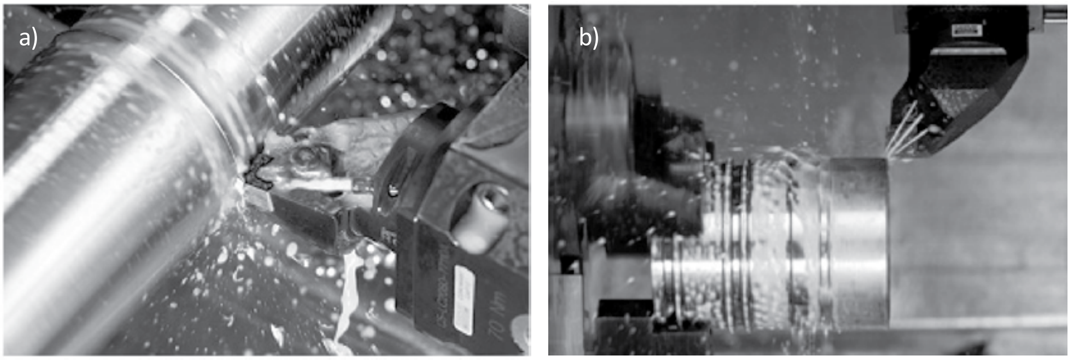


Fig. 2 a, b: a) Steel turning with coolant, b) HRSA turning (with internal cooant)

Turning steel with a hardness over 45 HRc (typically within the range of 55-68 HRc) is defined as hard part turning and is a cost efficient alternative to grinding. Hard part turning (Fig.3a,b,c) has been proven to reduce machining time and costs by 70% or more, and also offers improved flexibility, better lead times and higher quality. Hard part turning is a well accepted method, especially in the automotive industry. Typical components include: gear box housings, brake rotors, transmission gears, steering pinions, valve seats, engine blocks, pistons, cylinder liners and clutch housings. Hard Part Turning (HPT) without coolant is the ideal situation, and is entirely feasible. Both CBN and ceramic inserts tolerate high cutting temperatures, which eliminate the costs and difficulties associated with coolants. Some applications may require coolant, e.g. to control the thermal stability of the workpiece. In such cases, ensure a continuous flow of coolant throughout the entire turning operation.

CONCLUSION

This article describes the question about dry or with coolant machining process application in production process. Its difficult to definite it, because, as paper deals, in some cases is neccessary to apply, and especially in hard and cast iron machining only without coolant.

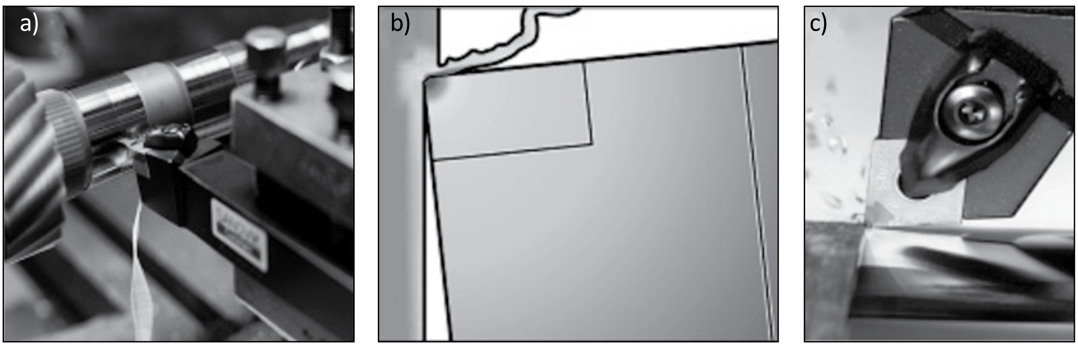


Fig.3: a) Hard turning of C120U steel (dry machining), b) schematic representation, c) dry hard turning

Literature

1. SANDVIK COROMANT: Technická příručka obrábění. AB Sandvik COROMANT, SE-811 81 Sandviken, Sveden, www.coromant.sandvik.com
2. SANDVIK COROMANT Příručka obrábění (Kniha pro praktiky). SCIENTIA s.r.o. Praha, Česká republika, 1997, ISBN 91-972299-4-6.
3. JAMBOR, J., MAJERÍK, J. Hard Die&Mould Milling Process with CAD/CAM system CATIA V5R18 support. In 20 th DAAAM Symposium 2009, Intelligent Manufacturing& Automation, Theory, Practice&Education. Austria Vienna (ACV), www.daaam.com, 25-28.11.2009.
4. MAJERÍK, J, BAJČÍK, Š. Tvrdé obrábanie nástrojmi z reznej keramiky a CBN (Hard Machining by Cutting Ceramics and CBN Cutting Tools), ITC 2009. VII. Mezinárodní nástrojářská konference : Sborník příspěvku. - Zlín: Tomas Bata University, 2009. - ISBN 978-80-7318-794-1. - 1 elektronický optický disk, [5 s].
5. MAJERÍK, J., ŠANDORA, J., DANIŠOVÁ, N. Použitie rezných nástrojov s PKD pri obrábaní (Machining application with polycrystalline diamond cutting tools) In 11. medzinárodná vedecká konferencia TECHNOLÓGIA 2009, 9.-10.9.2009, STU-SjF Bratislava, http:/technologia.sjf.stuba.sk
6. DANIŠOVÁ, N.,ZVOLENSKÝ, R.: Automated flexible manufacturing systems. In: KOD 2006: Zbornik radova / konf.(heslo) Simpozijum sa medunarodnim učešcem. 4. Konstruisanje, oblikovanje i dizajn. Palic, 30-31. maj 2006. - Novi Sad : Fakultet tehničkih nauka, 2006. - ISBN 86-85211-92-1. - S. 253-256

JOB SHOP SCHEDULING WITH AID OF COMPUTER SIMULATION

Radek Plechač, František Manlig, František Koblasa

Abstract

Computer simulation of discrete events as modern supportive tool finds its use mostly in the logistics and manufacturing design in the course of designing and reengineering of manufacturing and assembly processes. Its usage in the field of job shop scheduling and management is very sporadic. Article briefly familiarize with the possible use of this modern supportive method in the field, where it is possible to react fast and effectively on possible changes at the work shop (e.g. machine breakdown, workers illness, change of customer order etc.). This article also discuss possible usage of optimization methods as a tool to obtain most effective schedule regarding to the current state of workshop.

Key words

optimization, optimization methods, scheduling, simulation

Manufacturing companies are more and more focusing on customer demand, which is mostly reflected by implementation of the organizational actions based on Lean Manufacturing methods. Implementation of the lean structures is not enough. Important field is also production planning, because of the actual customer order and also the current work shop state has to be reflected in the manufacturing schedule. Great potential is hidden in the field of job shop scheduling. It is possible to precede quite a number of problems. No less important is also support of work shop planners, whose have to react quickly and effectively on the arisen problems in the workshop shop (e.g. machine breakdown, workers illness, change of customer order etc.).

Tendency of scheduling each task on actual available workplaces leads to more often usage of the so-called APS (Advanced Planning and Scheduling) systems and MES (Manufacturing Executive System).

Computer simulation in the combination with heuristic algorithms is proving itself as meaningful tool to support work on the lowest level of management. Its potential will be shown on example of stamping shop.

STAMPING SHOP EXPERIMETS

Model of Stamping shop was made in the simulation software Simcron MODELLER. It was made with respect to current manufacturing and organizational constraints. Model is reflecting e.g. variability of technological order, multi-machine operator handling, number of available setters and operators.

Heuristic methods together with priority rules where used during optimization. Maximal time of optimization was set to 15 minutes and maximal number of searched schedules was set to 10 000. Makespan, average lead time, average waiting time, sum of all order delays and machine utilization were used as objective functions. The results of each experiment were compared with the results of the non optimized model given by job order of production control IS system.

a. Order management given by priority rules

Any improvement was not reached during tests made by the base priority rules (e.g. sorting by customer deadline or process time) in comparison with non-optimized model. Contrariwise, some of them (e.g. sorting by smallest difference of customer deadline and job work remaining) showed worse results in all objective functions.

Tab.1: Result obtained by priority rule [1]

Optimized by priority rule \ Objective function	Makespan [d:hh:mm:ss]	ALT [d:hh:mm:ss]	AWT [d:hh:mm:ss]	SAD [d:hh:mm:ss]	MU [%]
Non optimized model	6:15:42:06	2:10:17:33	0:21:31:53	10:22:29:12	41,6
Customer dead line	6:15:42:06	2:10:17:33	0:21:31:53	10:22:29:12	41,6
Smallest difference between customer dead line and job work remaining	8:22:23:09	2:14:47:35	1:02:12:07	17:13:09:34	30,6

(ALT - Average Lead Time, AWT - Average Waiting Time, SAD - Sum of all delays, MU - Machine Utilization)

b. Usage of optimization algorithms

There were used five different optimization algorithms (Random Search, Greedy Search, Simulated annealing, Tabu Search, Genetic Algorithm). Each of these algorithms was compared with the non-optimized model thanks to the objective functions and the time of optimization.

Detailed experiments results are shown in [1]. The selection of most important results is in the tables 2, 3 and 4.

Table 2 shows comparison of optimization results given by different objective functions for five before mentioned algorithms.

Table n. 3 shows results comparison by different objective functions given by TB (Tabu Search). There are shown values of all algorithm parameters, when objective function minimum was obtained.

Tab. 2: Sample of results obtained by different algorithms (average value of objective function obtained by 5 runs) [1]

Objective function \ Optimization function	RS	GS	SA	TB	GA
Makespan [d:hh:mm:ss]	6:13:15:46	6:13:15:46	6:13:15:46	6:13:15:46	6:13:15:46
Average lead time [d:hh:mm:ss]	2:01:34:38	1:23:28:49	1:23:10:49	1:23:28:04	2:00:28:18
Average waiting time [d:hh:mm:ss]	0:13:07:27	0:11:04:21	0:10:50:22	0:11:05:19	0:12:13:23
Sum of all delays [d:hh:mm:ss]	10:20:30:20	8:22:10:58	8:19:11:31	8:22:09:46	9:15:20:17
Machine utilization [%]	42,4	42,5	42,4	42,5	42,4

(RS – Random search, GS – Greedy search, SA – Simulated Annealing, TB – Tabu Search, GA – Genetic algorithm)

Tab. 3: Results obtained by optimization algorithm TB (Tabu search) [1]

Optimized by objective function \ Objective function	Makespan [d:hh:mm:ss]	ALT [d:hh:mm:ss]	AWT [d:hh:mm:ss]	SAD [d:hh:mm:ss]	MU [%]
Non optimized model	6:15:42:06	2:10:17:33	0:21:31:53	10:22:29:12	41,6
Average lead time	6:13:15:46	2:12:22:55	0:23:27:02	10:09:46:11	42,3
Average waiting time	8:01:38:08	1:23:21:15	0:10:56:00	14:04:56:57	34,0
Sum of all delays	6:13:15:46	2:07:34:55	0:18:39:02	8:19:11:27	42,3

(ALT - Average Lead Time, AWT - Average Waiting Time, SAD - Sum of all delays, MU - Machine Utilization)

Tab. 4: Optimization results (Tabu search, objective function AWT) [1]

Optimization run n.:	Makespan [d:hh:mm:ss]	ALT [d:hh:mm:ss]	AWT [d:hh:mm:ss]	SAD [d:hh:mm:ss]	MU [%]
1.	8:01:38:08	1:23:21:15	0:10:56:00	14:04:56:57	34,0
2.	8:15:12:56	1:23:25:06	0:10:59:51	13:05:21:24	31,7
3.	7:23:38:08	1:23:28:48	0:11:03:33	12:17:18:18	34,4
4.	8:01:38:08	1:23:38:32	0:11:13:17	14:00:48:34	34,0
5.	8:13:12:56	1:23:42:05	0:11:16:50	13:08:34:19	32,0

(ALT - Average Lead Time, AWT - Average Waiting Time, SAD - Sum of all delays, MU - Machine Utilization)

PARTICULAR EXPERIMENTS CONCLUSIONS

- It is possible to get feasible manufacturing schedule with regard to recourse disponibility by computer simulation. Simulation is also able to reschedule fast in the case of temporary unpredictable manufacture constraints (e.g. machine breakdown, workers illness, change of customer order etc.).
- Optimization algorithms may not give an optimal solution of given problem, but they **can give us better solution** in comparison with non-optimized model or results given by priority rules.
- **It is possible to obtain relative improvement in very short time**, which is acceptable for field of operative planning and management of manufacture.
- The main problem in using optimization algorithms is to chose suitable optimization method and objective function (optimization by one objective function can negatively effect another see tab. n. 3).
- Optimization run which gives us minimal value of objective function may not be the best solution (see table n.4).
- Optimization algorithm can give more of “optimal solutions” with same objective function value but with different sequence of operations (see Figure 1).

CONCLUSION

Contribution of simulation and heuristic algorithms can not be neglected. Drafted problem and connected risks given by improper choice of optimization algorithm and objective function can be minimized by pilot project, which is suitable in term of anable the of testing different algorithm and settings. Results of this kind of project can be recommendation of the optimization algorithm and its setting – e.g. for given problem of model of stamping shop it showed, that usage of Tabu Search in the combination with the objective function of the sum of all delays is suitable.

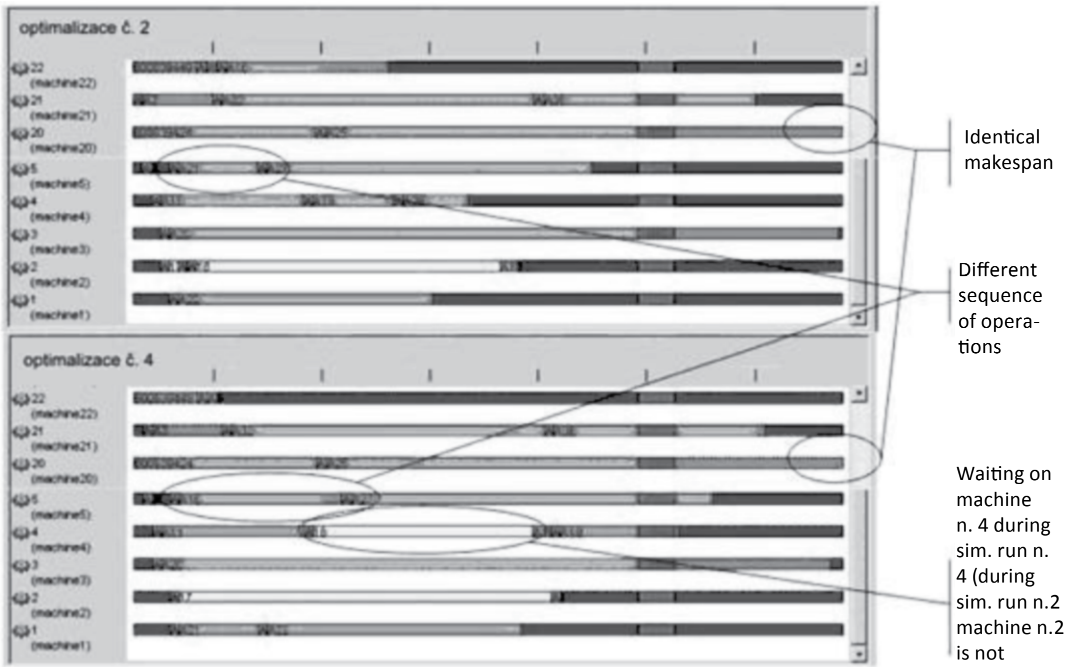


Fig. 1: Sample of the Gantt chart – optimization by objective function of makespan [1]

Literature

1. PLECHAČ, R.: Rozvrhování dílenských zakázek s podporou počítačové simulace. TU v Liberci, Katedra výrobních systémů, 2009, [Diplomová práce - vedoucí práce doc. Dr. Ing. František Manlig].
2. MANLIG, F.: Simulationgestützte Reihenfolgeplanung. Vědecká pojednání/Wissenschaft-liche Abhandlungen/Práce naukowe. Akademické koordinační středisko v Euroregionu Nisa. r. XIV, 2008 s. 196-201 ISSN 1801-1128
3. MANLIG, F. – VAVRUŠKA, J. – DUŠÁKOVÁ, A.: Podpora rozvrhování výroby pomocí počítačové simulace. Strojírenská technologie - zvláštní číslo, 2008, s. 157-160. ISSN 1211-4162

PRACTICAL EXPERIENCES WITH SANDVIK COROTURN HP TOOL

Jiří Šafka, Petr Keller

Abstract

Practical experiences with CorTurn HP tool in multifunction machining centre is the topic of this article. The advantages and disadvantages of this tool are presented. The practical tests of machining were done on Mazak Integrex 100-IV machine. At the end of the article the tool characteristics are summarized. This task is solved in the frame of research program of MSM 4674788501.

Key words

CNC machining, high pressure, turning

Machining centres are widely used in production praxis. Due to this fact it is possible to work complex workpieces on the one clamping. The machining centres are equipped by different accessories and settings e.g. definition of a tool turning (tool spindle orientation), different possibilities of an angle tool positioning, high power cooling. The last mentioned accessory, high power cooling, is suitable for high production and high accuracy machining. High power cooling systems acquire using of adequate tools. One of such tool is CoroTurn HP (High Pressure) of Sandvik Company.

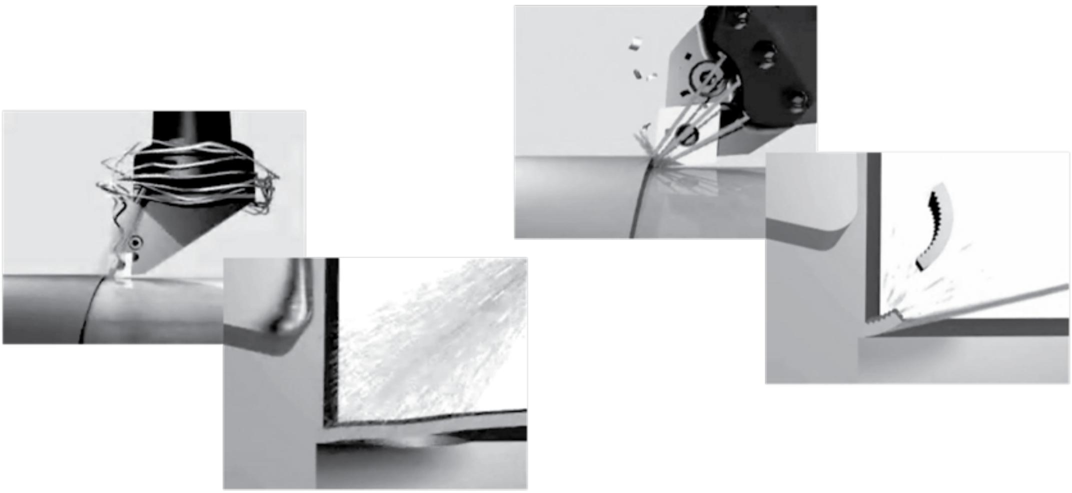
SPECIFICATIONS OF COROTURN HP TOOL

The CoroTurn HP tool (Fig. 1) has very massive construction. The clip part is made with Coromat Capto clamping system. It is a modular system that enables a repeatable accuracy and a rigid connection of a tool and a spindle. Coromat Capto is suitable for turning, milling, drilling tools that utilize cooling through a tool.

The main advantages of CoroTurn HP are a cooling fluid distribution system as well as a clamping system. The internal tool cooling is modified to help to a splinter production and its quick wash away from tooled material.

a) b) c)

Fig. 1: a – CoroTurn HP tools [4], b, c – cooling of CoroTurn HP tool demonstration [4]



a) b)

Fig. 2: a – standard tools with the internal cooling [4], b – CoroTurn HP tool with the internal cooling [4]

The tool is equipped with three special jet pipes (1 mm diameter) see in Fig. 3. All jet pipes are focused precisely onto the cutting tip onto the position, where the first contact between tool and a workpiece is. By a standard cooling is a splinter is only washed away. There is no active help by a splinter formation. The conduction of heating from a cutting tip and worked material is not sufficient as well. For the comparison of both cooling systems see Figure 2.

The overheating of a cutting tip is unwelcome event during machining. It can be the reason of its abnormal attrition or destruction. The attrition of a tool tip is markedly lower when high pressure cooling is used.

The high pressure cooling fluid has three effects:

1. Ensuring of a local cooling in a contact area of a cutting tip and worked material.
2. High speed wash away of splinters from cutting tips.
3. Assistance in splinter breaking into smaller parts and their wash away from a place of a cut.

Other important benefit of the use of this tool is a possibility to get the same quality of worked surface as by standard machining when the cutting speed is higher. It is possible due to the high pressure cooling (see Figure 4). The higher production and the financial costs saving are evident contributions. If the speed is the same as by standard machining, the quality of surface is higher.

PRACTICAL TESTS

Practical tests were done on the multiprofession machining centre Mazak Integrex 100-IV. It is situated at Department of Manufacturing Systems. The machine is equipped by lower pressure cooling than is recommended by the producer. The actual cooling pressure on the machine is 5 bars. The recommended pressure is 70 up to 140 bars. The tests were done on material 16 420. All cutting conditions are summarized in Table 1. As the cutting tip the tip CNMG 12 04 08 – PM of Sandvik Company was used. The resulting surface is displayed in Figure 5. The major test was divided into two parts. In the first part the standard cooling and in the second the cooling through the tool was used.

The cutting conditions mentioned above are the same as for the standard cooling as the cooling through the tool. The better splinter comparison was then possible. The result of such cutting conditions is visible in Fig. 5. The picture was taken during roughing operation. The splinters are shown on the left side of the picture for the standard cooling and on the right side for the cooling through the tool.

SUMMARY

The main benefit of the high pressure cooling is in a splinter production. The splinter is markedly shorter and it is better washed away from worked material. The intensive cooling cools the cutting tip just as the splinter. There is no over-

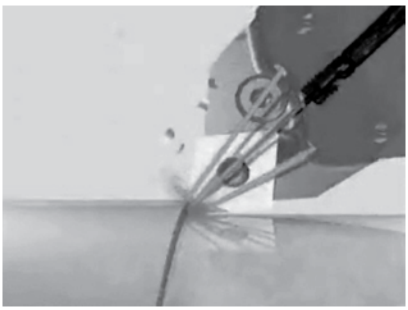


Fig. 3: sectional view of CoroTurn HP tool [4]

Fig. 4: axial turning (top – standard cooling, bottom – high pressure cooling and use of CoroTurn HP tool) [4]

Tab. 1: Cutting conditions for roughing and finishing

Axial turning of the material 16 420 Operation: roughing	CoroTurn HP tool
v_c [m/min]	375
a_p [mm]	1
f_n [mn/ot]	0.4

Axial turning of the material 16 420 Operation: roughing	CoroTurn HP tool
v_c [m/min]	400
a_p [mm]	0.3
f_n [mn/ot]	0.1

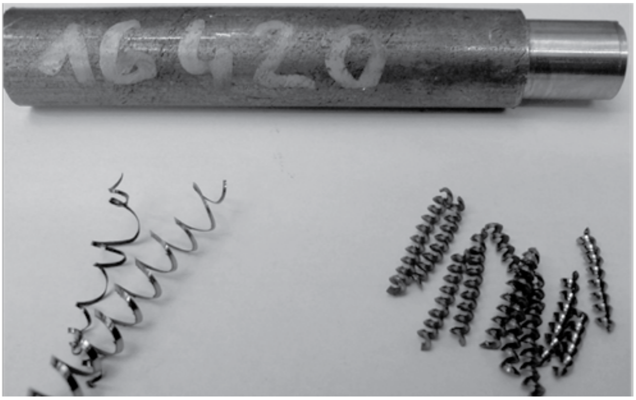


Fig. 5: tested sample and final splinters
Left side – using of the standard rinsing cooling,
Right side – using of the high pressure cooling through the tool

heating of the cutting tip and not so high attrition of it. During finishing operations the high pressure is suitable for quick wash away of the splinter. The possible scratching of worked surface is than minimized.

CONCLUSION

Although the used cooling pressure was not in the range that is recommended by tool producer, the results were very interesting. The result of the test is that the quality of worked surface is better than worked surface when the standard tool and cooling is used. If the surface quality is sufficient the increasing of cutting conditions and then production is possible. The surface quality will be comparable with the surface which is worked by a standard tool and cooling. This information is very useful for technology engineer. The machining time can be saved and already mentioned production can be increased. The other important benefit of the tool using is the very breakable splinter production. The splinter does not coil around a worked material or a tool. The next processing and manipulations with splinters is better. Because the tool is designed for machines with the high pressure cooling, it is necessary to take into account lower efficacy of cooling fluid and tools on machines with the standard rinsing cooling.

Literature

1. KELLER, P.: Představení obráběcího centra Mazak Integrex 100-IV. In: XVI. mezinárodní vědecké sympozium TU Liberec - TU Dresden 2007. Liberec 5. 9. 2007. ISBN 978-80-7372-247-0, CD příspěvků - ISBN 978-80-7372-248-7
2. ŠAFKA J.; KELLER, P.: Výroba tvarově složitých dílů na centru Mazak Integrex 100-IV. In: Setkání ústavů a kateder výrobních strojů a robotizace. Sborník příspěvků mezinárodní konference, Západočeská univerzita v Plzni. Plzeň 10.-11. 9. 2007. ISBN 978-80-7043-598-4
3. ŠAFKA J.; KELLER, P.: Problems with 5 Axes Cutting on Mazak Integrex 100 Machine.Strojírenská technologie, 2008, zvláštní číslo, s. 106-109. ISSN 1211-4162
4. Internetové stránky firmy Sandvik. [online]. [cit. 20. února 2009]. Dostupné na http://www.coromant.sandvik.com/cz
5. Internetové stránky firmy Misan (dodavatel obráběcích strojů Mazak). [online]. [cit. 20. února 2009]. Dostupné na http://www.misan.cz
6. ŠAFKA J.; KELLER, P.: Comparison of Multi-Profession Tools in Modern Machining Center.ACC, 2008, zvláštní číslo, s. 168-173. ISSN 1801-1128, ISBN 978-80-7372-379-8

NON-METAL MATERIALS IN SLIDING BEARINGS

Monika Pilková, Ivan Kopecký

Abstract

The smooth operation of sliding bearings working under various operation conditions depends on the choice of appropriate materials of the bearing pair: a bearing – a shaft. Since bearings and shafts are relatively expensive components, in the designing phase the material is chosen so that the cheaper part of bearing pair has to be worn out. Nowadays, plastic materials have been used extensively for their technological and economic advantages including minimum manufacturing costs.

Key words

sliding bearing, operation condition, plastics, composites

Metallic materials used to be almost irreplaceable in designing sliding bearings. Recently, non-metallic materials, such as plastics and composites, have been extensively employed in designing sliding pairs.

The performance of sliding bearings in single areas of sliding friction is affected not only by their material, but also by the friction factor value, wear measure, and other operational parameters, in particular the type of lubricant used, sliding speed value, load mode and value of the sliding pair, etc.

In addition to their lower weight and reduced manufacturing costs, sliding bearings made of plastics feature technological improvements as well. When compared to metallic materials, sliding ways of supports (lathes, horizontal boring machines, CNC machine tools) manufactured of composites are attributed advantages as follows:

- higher precision of ways,
- ability to absorb shocks and vibrations,
- greater load - carrying capacity,
- reduced friction factor – carbon fibre reinforced material acquires higher mechanical strength,
- less wear,
- higher chemical resistance,
- constant dimensions
- high strength and toughness per unit mass that can be adjusted to direction and type of stress,
- possibility to restore worn functional components,
- capability of performing emergency operation without lubricating (self-lubricating capability) [2].

These properties make plastic materials and composites be used for producing sliding bearings of the manufacturing machines.

SLIDING BEARING SURFACE INTERACTION

In mutual relative movement of two surfaces, the forces initiating movement must exert some work. It follows that surfaces touching each other are losing energy. Thus, scientific research in the domain of friction requires a systematic approach encompassing research of energetic dynamic effects and statuses on the physical conditions.

If two surfaces are pressed against each other, they adhere to each other on a particular spot of the touching area. Between the two surfaces, there is adhesiveness which is a form of mutual interaction initiating friction. Forces on the surface interface or adhesive forces depend on the distance of the surface areas being pressed against each other as well as physical properties of surfaces.

Surfaces with no adhesion and no expected adhesion being rubbed while moving, the surface interface is only manifested by material

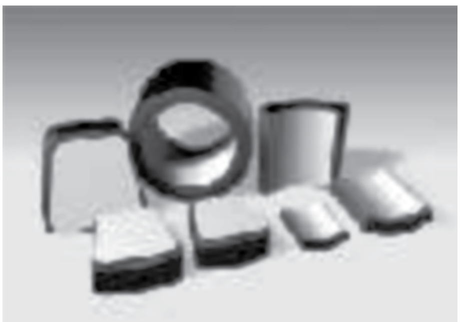


Fig. 1: Flexible metal - polymeric bearing with PTE (surface-teflon PTFE, interlayer–elastic copper fibres, bottom layer – steel)

Fig. 2: Steel sleeve with PTE surface

deformation and simultaneous relocation with relative motion. Thus, two types of interaction are being considered, such as relocation of material initiated by the roughness peak interface as shown in Fig. 2.1 or by macroshift initiated by moving a hard ball over a soft flat surface as shown in Fig. 2. 2.

SLIDING BEARINGS - COMMON FAILURES

Continuous tracking of failures of sliding bearings and their cause analysis serve as an important knowledge base and invaluable background data for developing new designs, for manufacturing and practical employment of these important machine components.

The overall state of damage or wear of the bearing sliding areas usually results from portions of abrasive, adhesive, erosive, cavitational and/or fatigue wear processes. Specific relevance of any of the portions mentioned gets changed with continuous wear, adjusting slide areas and with degradation of material and lubrication properties. It is important to analyze failure severity in terms of dependability and life of bearings. Sliding bearing failures can be caused by:

- conceptual errors,
- errors in manufacturing,
- operational errors,
- assembly errors.

Each group of errors can be divided into several subgroups with partial failure causes. Causes of partial failures frequently occur in combinations and their severity and consequences can vary significantly.

Material degradation causes conceptual errors that are often hidden. If actual conditions for bearings to operate properly do not match with required conditions, failures can occur. Causes of failure can include improper method of calculation, unsuitable geometrical shape of sliding areas (L/d proportion, bearing will, shape and area of the lubricating grooves), improper bearing material, incorrect lubricant, insufficient toughness of bearing pairs, incorrect position of A bush fitting, etc. It is necessary to assure that the bearing pair does not get distorted during assembly and operation since the process of deformation changes macrogeometry of functional areas.

IMPACT OF TEMPERATURE ON MATERIAL DEGRADATION OF THE SLIDING BEARINGS

Temperature ranks among one of the most important factors effecting a wide array of tribologic properties of friction materials in sliding bearings. In many cases, elevated temperature occurs due to specific environmental conditions. Temperature ranges in which it is still possible to assure operation in the domain of liquid and combined friction for the bearing materials and lubrications used are of 100 to 200 °C.

From the perspective of sliding bearing positioning, high operational temperatures can be considered temperatures ranging from 200 to 750°C. In order to position shafts at such operational temperatures, it is possible to employ sliding bearings working under dry or boundary friction [3].

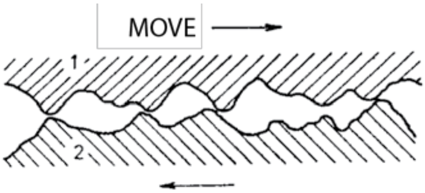


Fig. 3: Roughness peak interface that may not initiate relative motion without deforming roughness peaks

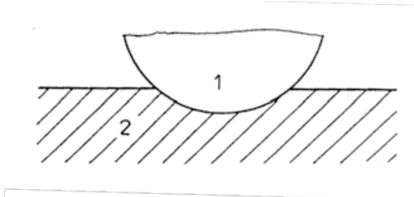


Fig. 4: Macroshift of hard half-round 1 on the surface of softer body 2, making body No 2 relocate during the relative sliding motion

At high temperatures, sliding bearing operation can cause several problems:

- high temperature is a cause of accelerated degradation of lubrication which in turn makes the applied lubrication lose its lubricating properties and the wear process in general very fast;
- high temperatures simplify and enable diffusion and create alloys on the contact surfaces of two metals – such as on the bearing journal and bearing;
- in some cases, chemical reaction products can increase the value of wear;
- hard oxides of certain metals have the function of abrasive particles, thus changing the essence of the wearing process itself;
- at high temperatures, there are changes in dimensions of the sliding pair components and in mechanical properties of material surface layers of the rubbing pair. Elasticity and strength modulus values are changing. Losing dimensional accuracy makes the operational tolerance change.

Dependable operation requires to eliminate as much as possible the negative effects of elevated temperatures on the sliding pair. At high temperatures, it is not possible to use common bearing materials, but rather a combination of materials having higher thermal resistance with special composite blends (Fig. 5).

Fig. 5: Heat – resistant sliding bearing [8] (base – soft steel, interlayer – sintered porous bronze casting, sliding surface – composite blend PEEK and PTFE)

To solve the problem, it is also possible to use design materials containing suitable lubricants (so called self – lubricating materials) in their structure or to combine using bearing materials of higher thermal resistance with selecting a suitable solid lubricant and suspension.

Manufacturers of sliding bearings offer following materials to be used at high temperatures:

- ceramic bearing materials;
- sliding materials made of metallic powder;
- carbon containing materials.

Ceramic Bearing Materials

To be used at high temperatures, those ceramic materials are suitable whose structure makes possible solid lubricants to be used. They are e. g. ceramic materials containing silicon carbide - SiC. Such materials feature high thermal resistance, very low temperature expansion factor, resistance to wear, very high hardness, high corrosion resistance, strong thermal conductivity, excellent sliding properties and high resistance to thermal shocks.

Disadvantages of ceramic materials include their brittleness and costs. SiC material has no self – lubricating properties, therefore greasing of the sliding pair with a solid lubricant, such as graphite shall be performed during operation.

Sliding Materials Made Of Metallic Powders

Sliding materials made of metallic powders are used to manufacture self-lubricating porous bearings through powder metallurgy. When machining ferrous or bronze powder through the procedures of pressing, sintering, calibrating and oil saturation, products with the required properties and shape accuracy are produced. Sintering temperature for ferrous powders is approximately of 1100 °C and for bronze powders of approximately 800 °C. As far as temperatures are concerned, the suitable temperature range is from -10 °C to +80 °C for porous bearings to be used under normal operation. It is not the metal sintered to decide whether suitable for using at the temperature in question, but the type and properties of oil or other suitable lubricant used to impregnate bearings.

Several companies engaged in producing sliding materials offer self-lubricating construction materials comprising equally distributed solid lubricant (graphite, MoS_2 or WS_2) in the metallic matrix (bronze, iron or nickel). Disadvantage of these products is, however, their high costs [5].

Carbon Materials

Materials containing carbon are advantageously used for sliding bearings in special operational conditions. They are suitable for sliding bearings working without lubricating in the mode of dry friction at low temperatures (up to - 200 °C) or at very high temperatures of approximately 450 °C and under special conditions in shielding gas of up to 2000 °C. Temperatures at which materials are used depend on the environment (oxidizing, reducing) as well as on the impregnation agent used.

Plastic And Composite Materials

In industry, following three composite types have been used extensively nowadays:

- microcomposite materials - the longest transverse dimensions of reinforce range from 10^0 to 10^2 mm, when compared to metals and their alloys they have lower density, thus more appropriate proportion of tensile strength and elasticity modulus to density, microcomposite materials have high specific strength (σ_{pt} / ρ) and high specific modulus (E/ ρ),
- macrocomposites – containing a reinforce of transverse dimension of 10^0 to 10^2 mm, they are mainly used in civil engineering (reinforced concrete, polymer concrete, etc.), macrocomposites can be also be clad metals, multilayer materials and constructions,
- nanocomposites – materials with polymer matrix – dimension of particle reinforce is given in nm. [3]

Regarding sliding bearings to be used at higher operational temperatures, the lowest temperature ranging to 350 °C, it is advantageous to use sliding bearings made of plastic and composite materials (table 1).

The critical properties of composites suitable for sliding bearings to be used in manufacturing machines are as follows:

- low friction coefficient and resistance to wear,
- shock resistance,
- notably high elasticity (in particular PA and POM materials),
- ability to reduce specific pressure with own elasticity,
- self-lubrication,
- high operational temperatures: 250 up to 310°C ,
- excellent resistance to chemical agents and corrosion,
- very strong creep resistance, even at elevated temperatures,
- resistance to strong radiation,
- minimum noisiness,
- very good dimensional stability and excellent resistance to wear in a wide range of operational conditions,
- minimum maintenance requirements,
- good properties related to electrical insulation and good dielectric properties.

CONCLUSION

Most composites were designed for particular uses, and that is why the range of their properties is so wide and distinctive. Concerning their properties, it is possible to take note of a wide range of operational temperatures, distinctively different mechanical properties or strong resistance to chemical agents. Nonetheless, composites are attributed a common feature which is the low factor of friction even under various lubricating conditions.

Fig. 6: Material Thordon GM2401- composite (unique abrasive resistance, employed under abrasive water conditions as a bearing in pumps up to P_n = 1,4 MPa)

Tab. 1: Basic information to calculate thermoplastic sleeve of a radial sliding bearing [6]

Basic parameters of the sliding bearing sleeve		Basic parameters of a shaft		General parameters	
Parameter	Basic unit	Parameter	Basic unit	Parameter	Basic unit
Bearing – inside diameter	d_1 [mm]	Type of lubricant	-	Environmental temperature	T [^{0}C]
Bearing – outside diameter	d_2 [mm]	Direction of machining in relation to sliding direction	-	Static load	F_r [N]
Bearing width	b [mm]	Roughness	R_z [µm]	Static load time	t_r [hour]
Bearing material	-			Operational load	F_b [N]
				Number of revolutions	n [1.min^{-1}]
				Movement direction	-
				Type of load	-
				Type of load	ED [%]
				Required life	L [hour]
				Allowed wear	V [%]

Literature

1. BARBORÁK, O.: Základy stavby výrobnej techniky. TnU AD, TRENČÍN 2007. ISBN 970-80-8075-194-4
2. EHRENSTEIN, G. W.: Polymerní kompozitní materiály. Nakladatelství Scientia, PRAHA 2009. ISBN 978-80-86960-29-6
3. PTÁČEK, L. a kolektív: Náuka o materiálu II. Akademické nakladatelství Cerm, spol. s r. o. BRNO 2002. ISBN 80-7204-248-3
4. BARYSZ, I.; ČILLÍK, L.; ŽIAČIK, A.; PFLIEGEL, M.: Klzné uloženie - konštrukčné a teoretické riešenia. Vysoká škola dopravy a spojov v Žiline, ŽILINA 1995. ISBN 80-7100-282-8 (1.vydanie)
5. PROKSA, M.; MURGAŠ, M.; KOTRAS, P.; KICKO, J.; HUDÁK, J.: Materiály a technológie – príručka. STU materiálovo-technologická fakulta, BRATISLAVA 1996. ISBN 80-227-0628-0 (1.vydanie-1.dotlač)
6. www.imp.cz , 31. 3. 2010
7. www.ronn.sk/produkty/ronn-kompozity/, 12.01.2010
8. www.wolkoplast.cz/cs/, 31.3.2010

CHARACTERISTIC OF COATING WC + 12% CO

Mária Ličková, Jozef Eliáš

Abstract

The article deals with research of coating AMDRY 927 (WC + 12% Co) structure with AMDRY 956 (NiAl) layer after spraying.

Key words

coating, plasma spraying, base material, thermal processing, plasma heating, diffraction analysis, phase analysis

A high refractoriness or hot strenght, an increased hardness, corrosion resistance, resistance to abrasive or erosive wear or resistance to avoid other strains are common requirements in the present processing. It is necessary to apply advanced materials in order to meet the mentioned needs. Application of an appropriate base material (substrate) and a surface layer with special properties seem to be one of the possibilities when dealing with the problem [1, 2].

Various technologies of spraying protective coatings have been developed. The technology of thermal plasma arc spraying is one of the advanced technologies. It can be called plasma spraying of metallic and ceramic powder materials. Protective coatings are formed on the surfaces of machine parts and details when the thermal spraying method is employed. With regard to a high temperature of the plasma arc the method is suitable for high fusible materials spraying including oxides, carbides, nitrides, borides, cermets and others. Lightly fusible metals and some plastics can be sprayed in this way [1, 2, 3].

The functional coatings with improved quality as compared to the original parts from the compact materials can be applied by plasma spraying of various powder materials [1].

The technology of plasma spraying offers wide possibilities of applications in practice in electrotechnical, automotive, aircraft, textile and chemical industries.

Tab. 1: Chemist of Ni-based superalloy LVN 10

C [%]	Ti [%]	Ta s Nb [%]	Mo [%]	Co [%]	Cr [%]	Al [%]	Fe [%]	Ni [%]
0,03/0,07	4 /1	1,5/2,5	3,8/5,2	1	11/13	5,5/6,5	0,5	rest

EXPERIMENTAL METHOD

Plasma coatings were sprayed on the cylindrical sample surfaces made of Ni - based superalloy (LVN 10 - table 1) using the SNECMA plasma spraying equipment by the company PLASMA-TECHNIC AG. The torch distance from a base sample was 120 mm, current from 400 to 600 A, voltage from 52 to 68 V and used argon and hydrogen plasma gasses.

Coating of powder AMDRY 927 (WC + 12% Co) with interlayer of powder AMDRY 956 (NiAl) was sprayed on the base material (substrate-alloy LVN 10). The grain size of used powders ranges from 30 µm to 50 µm.

The common metallographic methods were employed during investigation of a coating after spraying and heat influence as follows: NEOPHOT 32 optical microscope for material expertises, Hanemann microhardness tester for microhardness test (HV 20) according to STN ISO 4516 standard and diffraction analysis using DRON 3M X-ray equipment for phase analysis.

WC + 12% Co coatings with interlayer in condition after spraying

The powder AMDRY 927 (WC + 12% Co) was used for spraying as a base material. Cobalt content (12 %) with occurrence of less impurities quantity (0.1% Ni and 0.3% Mo) was verified by the chemical analysis of the powder. The powder grain size varied from 40 µm to 50 µm with typical lumpy shaped grains shown in Fig. 1.

By the phase analysis the following contents of phases were verified: WC, Co as well as less quantity of W_2C, WO_3. The interlayer, given in Fig. 2, is formed by AMDRY 956 NiAl powder with the grain size about 50 µm. A good powder feeding to a spraying nozzle was provided due to a globular shape of particles. The coatings comprised of two layers after spraying. The former included AMDRY 956 (NiAl) powder with a coating thickness 80 µm and the latter metallic-ceramic coating included AMDRY 927 powder (WC + 12% Co) with a coating thickness 200 µm.

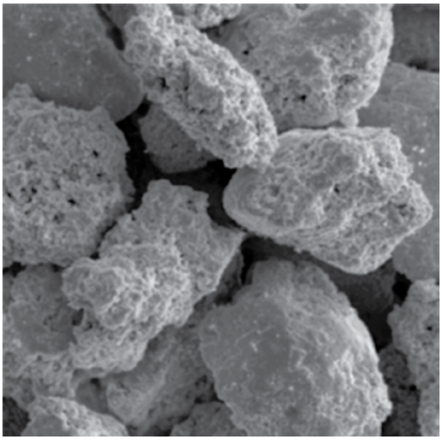


Fig. 1: Morphology
of AMDRY 927 powder (WC + 12% Co)

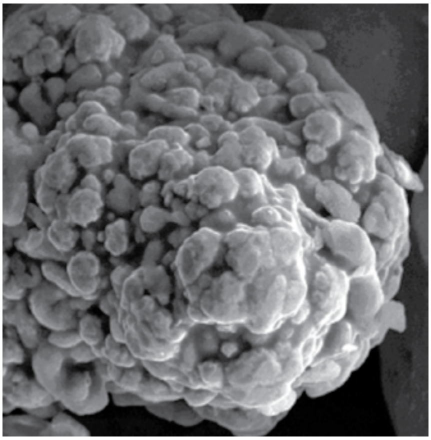


Fig. 2: Morphology
of AMDRY 956 powder (NiAl)

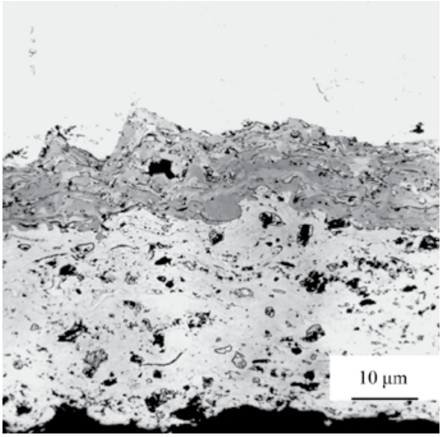


Fig. 3: Plasma coating AMDRY 927 (WC + 12% Co) with interlayer AMDRY 956 (NiAl) after spraying

Microstructure of a coating with a sharp and compact interface comprising the both layers is shown in the Fig. 3. It is evident that particles of both layers are deformed as given by the structure. Metallic-ceramic layer consisting AMDRY 927 powder (WC + 12% Co) is very dense and almost without pores indication. Negligible quantity of the pores in layer could result from flowing of hard WC particles in mechanical grinding or polishing. In the layer were measured the microhardness values HV 20 = 2 271 and HV 20 = 1 301 in some other areas.

Using X-ray diffraction analysis occurrence of the phases WC, Co, W_2C, WO_2 was verified. On the base of equilibrium diagram of the Co – WC might be said that in the second coating γ phase could be detected i.e. a solid solution combined W and C compounds in Co. Not clearly defined was the metallic W presence that would have been created by author [4] resulting from WC decomposition in flow of plasma gas to C and W oxides.

CONCLUSION

The AMDRY 927 coating (WC + 12% Co) with the interlayer is very dense almost without pores indication. With respect to a low resistance of WC in oxidizing atmosphere at increased temperatures the coating is not suitable for those parts made of superalloys when their operation above temperatures of 540 °C is needed.

Literature

1. MATEJKA, D. - BENKO, B.: Plasma Spraying of Metall and Cermet Powders, Bratislava, ALFA 1988.
2. AMBROŽ, O. - KAŠPAR, J.: Thermal Coatings and Their Industrial Applications. SNTL Praha 1990.
3. POŠTRKOVÁ, E.: Characterisations of Double-layer Coatings NiAl + (Al2O3+13 %TiO2). Thesis. Bratislava 1998.
4. DEMIDENKO, L. M.: Vysokoogneupornyje kompozicionnyje pokrytija. Metallurgija, Moskva 1979

AN AUTOMATED SYSTEM FOR THE EVALUATION OF THE COMPLEXITY AND THE PREDICTION OF LABOUR INPUT OF FITTING AND ASSEMBLY OPERATIONS

Ivo Hlavatý, Sergej Nikolajevic Pasynkov, Alexander Ivanovic Korshunov

Abstract

The article is about a task of creating of an automated system for the evaluation of the complexity and the prediction of labour input of fitting and assembly operations, which used for manufacturing of machine-building item.

Key words

constructive - technological complexity, technological alteration, automated system

As a rule, products of engineering plants are complex items. For their design engineering and manufacturing, a large volume of design documentation is required. In order to raise their competitiveness, the plants constantly expand the spectrum of products, which naturally leads to an increase in the volume of preproduction.

In this connection, solving the problem of making-up the product range of an engineering plant is rather complicated and at the same time, it is currently central. An adequate evaluation of labour input and production costs that are necessary for manufacturing an item is one of the main requirements for efficient and effective planning the production activity of an engineering plant.

In specialists' opinion, the operations referring to machining and fitting-assembly operations are the most labour-consuming in machine-building because they are performed manually 60-80% and require significant inputs of manual labor and high level of proficiency from workers. Increased labour input of fitting-assembly operations appreciably increases the general labour input in machinery manufacturing and substantially impairs economic indicators of the plant operation, which is caused by an increase in the in-process storage of expensive completed parts and elements. This, in its turn, increases the cost of the work-in-progress inventory and decreases the efficiency of the working capital use.

DEVELOPMENT OF AN AUTOMATED SYSTEM

Thus, the quality improvement and the increase of labour productivity of fitting-assembly operations are very important for the enhancement of the efficiency of an engineering plant. In this connection, the evaluation of the labour input of fitting-assembly operations at early stages of the life cycle of a machine-building item including the step of decision-making on its manufacturing is one of the currently central problems. The task of prediction of the labour input in machining a machinery part is resolved based on the use of the constructive-technological complexity [1].

Since the design documentation package has been developed, the determination of the labour input of the fitting-assembly operations for a certain production type is carried out based on the differentiated or extended norms. The prediction of the labour input and production costs for a machine-building item at early stages of its life cycle in the absence of the developed design documentation is very often difficult due to the absence of respective methods or their insufficient development.

The necessity to improve the efficiency of the engineering and manufacture of new items requires that up-to-date automated systems for the technological preparation of the production process will be introduced. At present, active work in this sphere has resulted in the creation of automated systems or program modules, one of the functions of which is resolving the task of norm setting and cost fixing [2].

The analysis shows that at present, the automated systems used in the industry provide the standartization for the fitting-assembly operations in accordance with the technological process developed. The evaluation of such operations in the absence of the design documentation developed is carried out at a plant with the help of the methods that are based of the analog method. It leads to the subjectivity of evaluations obtained, the accuracy of which significantly depends on the qualification of a specialist, who carries out an evaluation. Thus, it is necessary to develop a method for prediction of the labour input of the fitting-assembly operations needed for manufacturing a machine-building item, which should be based on the analysis of the design documentation package for this particular item [3]. The constructive-technological complexity factor of a machine-building item is offered as the basis for developing the method.

The objects of the present research are the development of a method to determine the probable labour input of fitting-assembly operations, which will take into account the factors influencing the complexity and labour input of operations, and the creation of an automated system based on the method offered that will allow determining the probable labour input of fitting-assembly operations.

In order to reach the above object, it is necessary to resolve the following problems:

The investigation of the influence of the constructive-technological complexity of items on the effectiveness of fitting-assembly operations.

The development of a method for the formation of the constructive-technological complexity factor for fitting-assembly operations.

The investigation of the factors that influence the constructive-technological complexity and labour input of fitting-assembly operations; the obtaining of their numerical evaluations.

The development of a method for the determination of the probable labour input of fitting-assembly operations.

The development of algorithms for the determination of the probable labour input of fitting-assembly operations.

The development of an automated system for the determination of the probable labour input of fitting-assembly operations.

The approbation of the method and the automated system developed under the manufacture conditions.

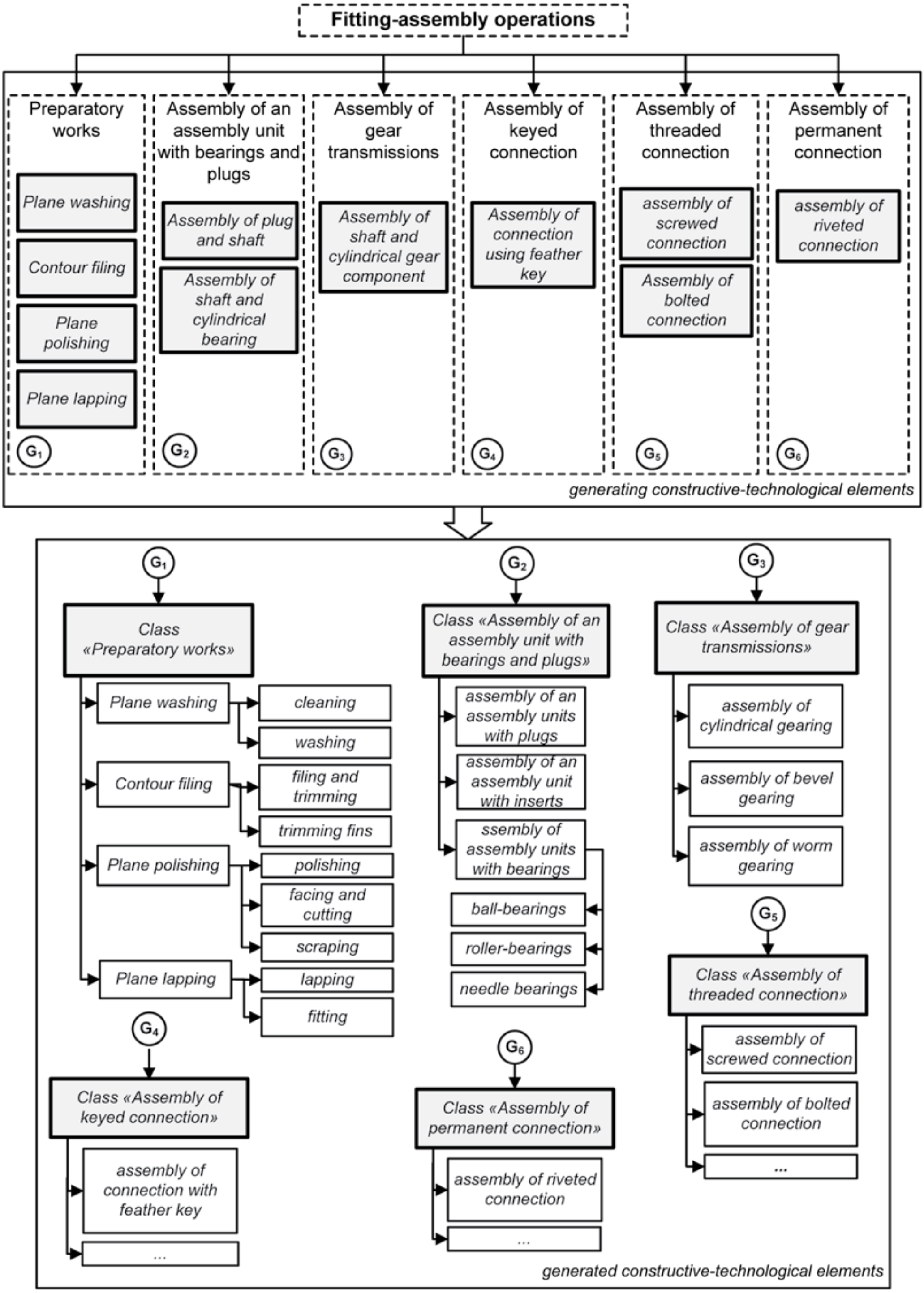


Fig. 1: Classifier of fitting-assembly operations

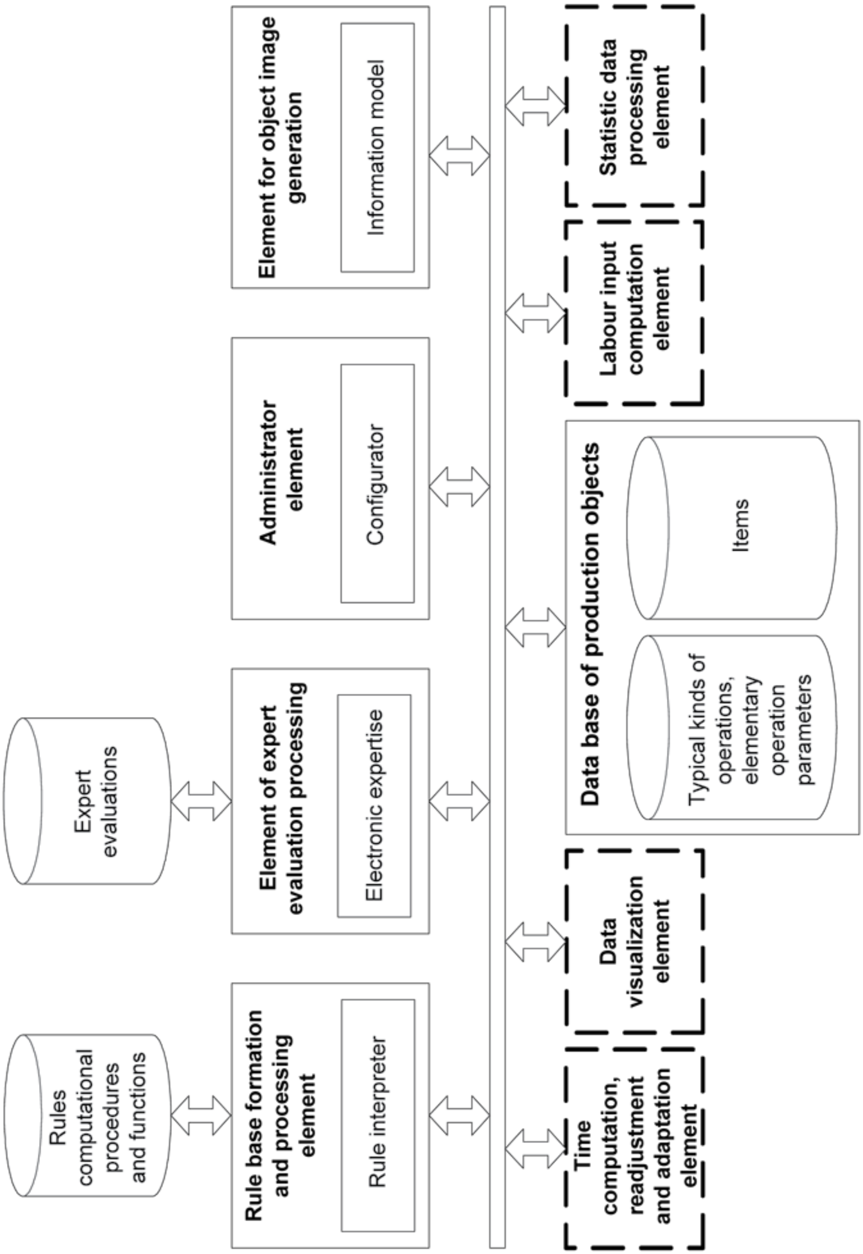


Fig. 2: The automated system structure

In accordance with a general model for the formation of the constructive-technological complexity that is used as the main element in the formation of an information model for a particular fitting-assembly operation, an elementary operation is singled out and the type of an aggregate function is determined, which takes into account the structure and the volume of carried-out elementary operations and their parameters. The elementary operations are combined into separate classes. In each class, generating elements providing the formation of generated elements are singled out. (Figure 1).

CONCLUSION

At present, the formation of generating elements for the classes of elementary operations and the numerical evaluation of their parameters are carried out. The formation algorithms for the information model of fitting-assembly operations are developed based on the singled-out elementary operations. Based on the model, the evaluation algorithms for the constructive-technological complexity and laubour-input of an operation are also being developed. Based on the obtained results, the designing of the structure (Figure 2) and the specifying of the modules are conducted for the developed automated system for the evaluation of the complexity and for the prediction of labour input of fitting-assembly operations.

Literature

1. PASYNKOV S.N., KORSHUNOV A.I.: Determination of labour input of manufacturing of machine-building items with the use of modern automated systems for technological preproduction. // The significance of research in the process of preparation of competitive specialists for plants of the Udmurt Republic: proceedings of research-methodological conference, Votkinski branch of Izhevsk State Technical University (May 10 – 11, 2006) – Izhevsk: Izd-vo IzhGTU, - 2006 – P. 194-197.
2. BÍLIK, Jozef, TITTEL, Viktor, BABICOVÁ, Ľudmila: The analysis of production technology and material properties of chassis part from high strenght steel. In: Hutnik- Wiadomosci Hutnicze. – ISSN 1230-3534. – Nr 8 (2009), s. 562-565
3. BOŽEK, P., ONDRIGA, M.: Contribution to increasing ergonomic comfort. In: Innovative technologies in welding and NDT: Prospective technologies and materials for technical applications. International Conference, 3.-4.12.2009, Kálnica. - Trnava: Inweld Consulting, 2009. - ISBN 978-80-970321-0-4. - S. 72-81
4. NAŠČÁK, Ľ., HRČKOVÁ, M.: An educational program management fundamentals continuous dynamical systems / Lubomir Naščák, Mary Hrčková. In: Informatics in school and in practice: Proceedings 4th International Conference: 16 to 18 September 2008, Ruzomberok: Faculty of Catholic University in Ruzomberok, 2008th - ISBN 978-80-8084-362-5. - S. 221-224
5. PASYNKOV, S.N., KORSHUNOV A.I.: Development of an automated system for the evaluation of the complexity and probable labour input of fitting-assembly operations.// Modern technologies in machine-building and motor car construction. Proceedings of scientific and technical conference. – Izhevsk: IzhGTU, - 2005 – P. 42-43.
6. KRALIK, M. - SOUCEK, J. - PAVLOV, A. I: Implementation of the design of assembly processes on the computer. In: discrete manufacturing automation, Sozopol 1990th
7. SHARIN, YU.S., YAKIMOVICH, B.A., TOLMACHOV V.G., KORSHUNOV A.I.: Theory of complexity. – Izhevsk: Izd-vo IzhGTU, 1999. – 132 p. (Izhevsk: printing-house of Izhevsk State Technical University

Alexander Dubček
University of Trenčín
ISSN 1337-6047
9 771337 604001 01