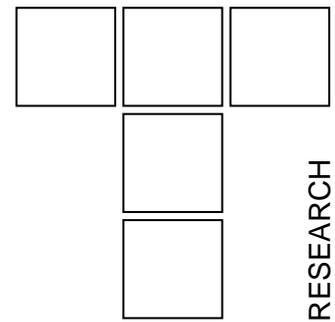


Tribological Processes of the Mechanisms of Free Motion of Impulsive Friction Variators



Free motion mechanism (FMM) of the impulsive variators is one vital part in power transmitting of impulsive lever variators which oscillating motion of external envelope (coulisse) converted in rotation movement of the output shaft. The elements of mechanism of free motion are exposed to friction and wear during the work, which may be extremely intensive in some cases. The paper analyzes the tribological processes on elements of free motion mechanism of impulsive friction variators with special report on wear of tribomechanical system: the external envelope (coulisse) - roller and roller - shaft (star).

Keywords: impulsive variators, free motion mechanism (FMM), tribological processes, wear,

1. INTRODUCTION

Unlike other ways of transmission, energy does not transmit continuously, but in the form of periodic impulses. This transmitter makes two types of movements. Rotating motion with constant angular velocity of input shaft transforms into oscillatory motion of elements on the output shaft. Then the oscillatory movement by the mechanisms of free motion (FMM) transform into rotation movement of the output shaft. To reduce the problems caused by delays in transmission or an uneven speed during the construction several fit of transformational mechanisms and (FMM) are connecting together. These mechanisms have been rotated in relation to one another for the $\Delta\varphi$ angle.

$$\Delta\varphi = \frac{360^\circ}{n}$$

n introduce - number of fit of the mechanisms.

(FMM) with impulsive variations, converts oscillating motion of the coulisse into rotating movement of output shaft [1]. Its consist of three main parts:

- exterior ring (the coulisse)
- input shaft (star), and
- rollers.

2. TRIBOMECHANICAL SYSTEMS IN FMM

According to its structure (FMM) belongs to a higher hierarchical class of the tribomechanical systems, because they can be subdivided in several basic tribomechanical systems [2, 3].

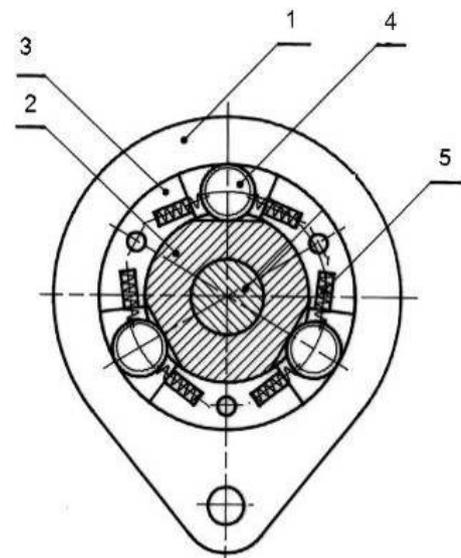


Figure 1. Free motion mechanism (FMM)
1 - coulisse, 2 - shaft, 3 - cylinder carrier,
4 - cylinder, 5 - spring

In FMM with impulsive variations (Figure 1), we distinguish the following tribomechanical systems:

- coulisse - roller,
- coulisse - cylinder carrier,
- coulisse - cylinder carrier (side contact),
- coulisse - capsule (side contact),

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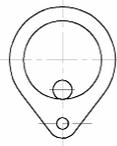
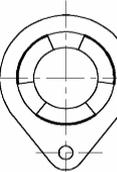
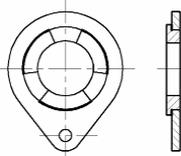
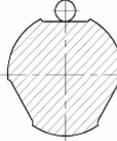
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- roller - shaft,
- roller - compression spring,
- roller - capsule (side contact),
- roller - cylinder carrier (side contact)

Table 1 shows an appearance of tribomechanical systems and their basic types of movement that appears. Following items affects on development of the tribologic processes in the contact zones of FMM:

- elements material quality,
- production technology of the contact surfaces,
- termochemical kind of processing,
- load of elements in contact,
- quality of lubricants and cooling liquids.

Table 1. Tribomechanical systems in FMM

	Tribomechanical system		Type of movement
	name	style	
1	coulisse - roller		rolling with sliding
2	coulisse - cylinder carrier		sliding
3	coulisse - cylinder carrier (side)	 	sliding
4	roller - shaft		rolling with sliding

Specific construction of FMM, complex operational conditions and a large number of influential factors causes that different kinds of friction occurs on FMM. Process that resists to relative motion of the object is used for the primary function and purpose of the transmitters. Friction in the FMM consists of: rolling friction with sliding, sliding friction, friction in the lubricant. Mutual complex connection makes difficult to analyze any kind of friction. Rolling friction with sliding occurs in process of wedging

the cylinder with external and internal envelope. It is partly caused by sliding in the triboelement contact zone and also with appearance of flexible hysteresis. Flexible hysteresis is caused by the deformation of loaded triboelements (rollers, external and internal envelope). Where by the resulting work of unload is only partially used for the motion and rest of it goes into heat. Sliding friction occurs in external envelope (coulisse) contact with the cylinder carrier. Under normal conditions of exploitation sliding friction in tribomechanical systems FMM is negligible compared to other types of friction. Friction and friction losses increases with increase of rotation number in FMM, viscosity and excess of the oil in contact [4, 5, 11, 12].

The following tribomechanical systems had biggest impact:

- coulisse - roller,
- coulisse - cylinder carrier,
- coulisse - cylinder carrier (side contact),
- roller - shaft (star).

On the elements of tribomechanical systems FMM can arise different kinds of wear and damages. On particular FMM may occur several types of wear but it is always the dominant one and it determines the future direction of development of the tribologic processes and finally lifetime of the FMM or pulse variator as its part. Which forms of wear occurs and which will be dominant depends on many factors: exploitation, construction, etc.

Determining the participation of certain types of wear in total wear of whole gear is very difficult. Visual quantification performs on the basis of appearance of the worn surfaces. The main criteria of working ability of cylindrical FMM impulse gear mechanisms is ability to wedge without traction and maintain the contact strength of most loading elements. FMM with cylindrical rollers gets out of order due to fatigue breakage and wear of the working surfaces star. FMM with an eccentric roller lost working ability due to destruction of the cylinder surface.

Breakage and wear may be limited by increasing the hardness of the material cylinder, stars and envelopes through thermal treatment, using insertion of hard alloys, reducing the roughness of contact surfaces, increasing the accuracy during production the cylinders, entire mechanism as well as its assembly.

3. DESCRIPTION OF EXPERIMENTS

Experimental testing of the power carrier impulse lever variator, with four types of transformation mechanisms and the FMM are conducted on specially made test table (figure 2).

Tested gear (2) was connected with the (1) driving aggregate over belted gear (4), (electric motor P=0.55 KN, n=2880 rpm). The brake disc was set on the output shaft of variator (6) that rotates in a magnetic field, of the electrical brakes (7) and thus made permanent load of the gear [8, 10].

Special measurement system was designed for tribometrical testing of the tribomechanical system FMM impulse lever, friction variator. The main components of that system are mentioned below:

- test table,
- device for analysis and measurement of surface roughness, TALYSURF 6,
- a device for wear measuring OPTON (ZEISS).

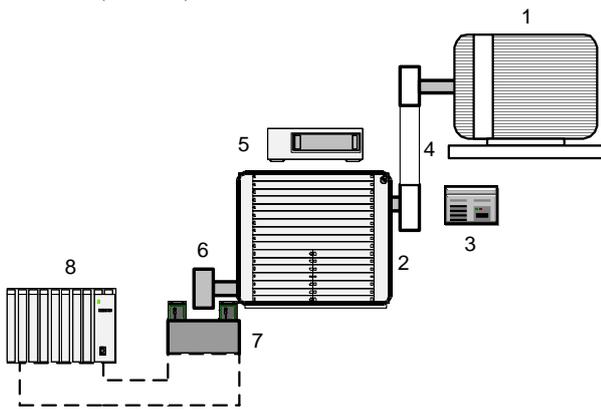


Figure 2. Schematic diagram of the test table

It was selected operational regime of the tested gear. The loading of the variator output shaft were achieved with brakes. Thus defined working conditions with a known geometry of the contact. After establishing the selected operational regime, carrier is put into operation a certain number of hours, then disassembly and measurement of the parameters of roughness and wear were performed. Tribomechanical systems of tested FMM (Table 1) where tribological processes are most affecting on the functioning of the mechanism and which changes were followed in the process of wear are:

- coulisse - roller,
- shaft - roller.

Changing the diameter of the hole on the coulisse $\Delta D = D_i - D_0$ (Figure 3), were measured on the computerized measurement device Opton (ZEISS). Measurement results are shown in Table 2.

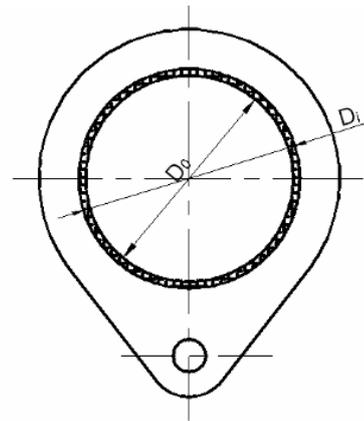


Figure 3. Coulisse

Table 2. Coulisse hole diameter changing ΔD , mm

Element name	Operational time h					
	7	35	80	170	300	
Coulisse	1	0,0058	0,0130	0,0168	0,0243	0,0397
	2	0,0089	0,0160	0,0190	0,0261	0,0381
	3	0,0070	0,0163	0,0230	0,0265	0,0327
	4	0,0083	0,0150	0,0182	0,0257	0,0375



Figure 4. Appearance of wear coulisse

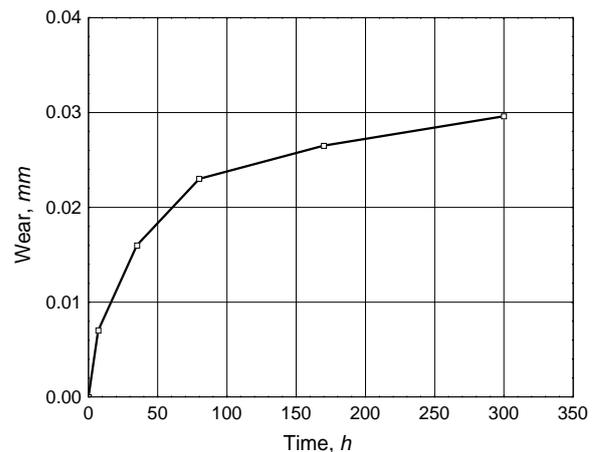


Figure 5. Curve of coulisse wear

Measuring shaft (stars) wear, was performed at the measuring device OPTON, figure 6. Table 3 give the measured values of the shaft wear.

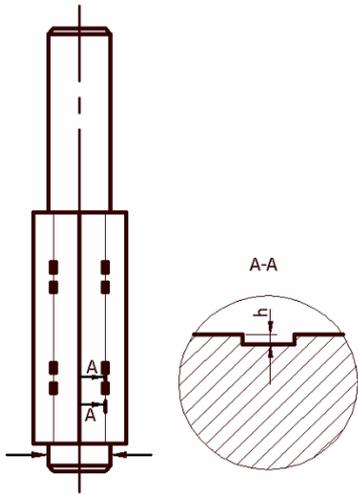


Figure 6. Places of measuring shaft wear

Table 3. Values of shaft wear, h, mm

Operational time, <i>h</i>				
7	35	80	170	300
0,0032	0,0040	0,0063	0,0162	0,0439
0,0026	0,0037	0,0067	0,0164	0,0420
0,0028	0,0042	0,0068	0,0178	0,0455

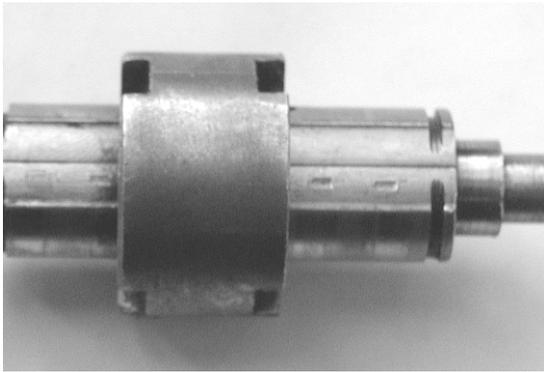


Figure 7. Appearance of wear cylinder shaft

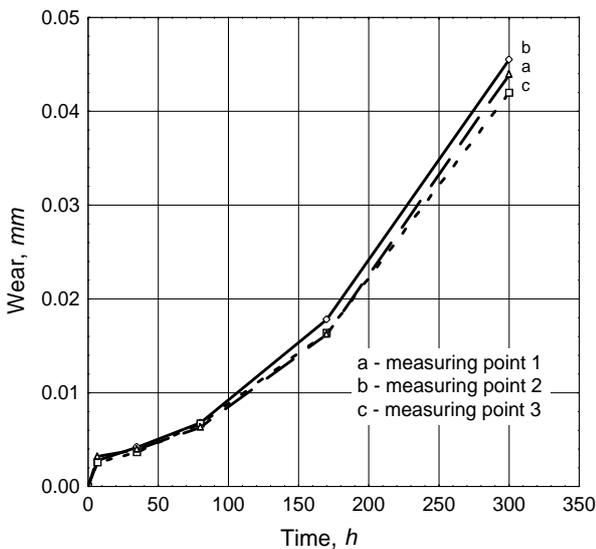


Figure 8. Curves of shaft wear (star)

Measuring cylinder wear (a measure $\phi 6$) was performed by micrometer with prism TESAMASTER, measuring range from 0 to 25 mm measurement accuracy ± 0.001 mm. Change the cylinder diameter $\Delta d = d_0 - d_i$, is given in table 4, with:

d_0 - cylinder diameter measurements before the start operational,

d_i - cylinder diameter value measured after a certain number of working hours of, FMM or variator.

Table 4 Changing of the cylinder diameter Δd ,mm

Element name	Operational time <i>h</i>				
	7	35	80	170	300
cylinder	0,0028	0,0086	0,0110	0,0187	0,0410

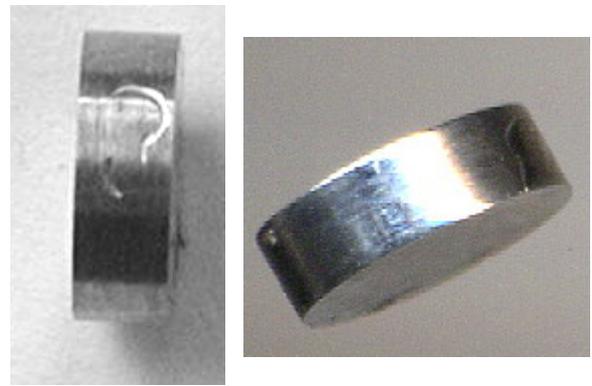


Figure 9. Appearance of wear cylinder

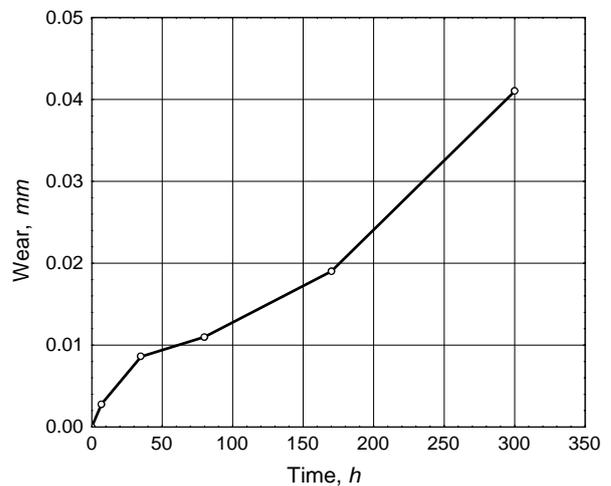


Figure 10. Curve of cylinder wear

Figure 11 shows coulisse from the exploitation on which is not implemented adequate thermochemical processing. Coulisse was withdrawn from work after approximately 10 hours.

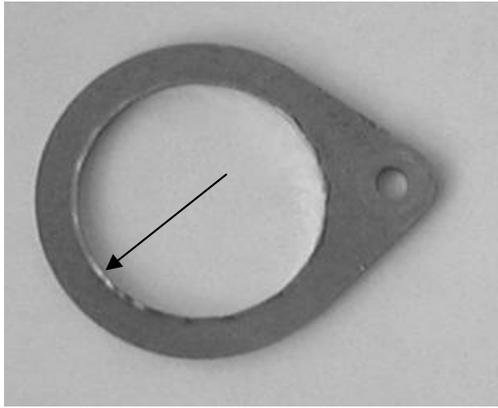


Figure 11. Deformity coulis caused by poor thermochemical processing

The images from 12 to 14 show the changes of the relevant parameter curves for observed elements roughness for tribomechanic systems of FMM impulse variators.

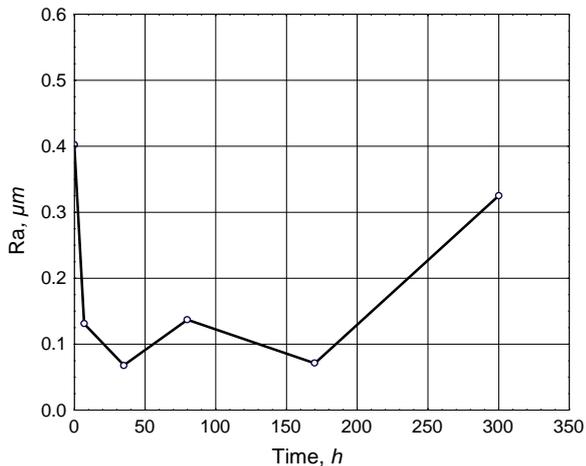


Figure 12. Change parameter Ra surfaces of coulis

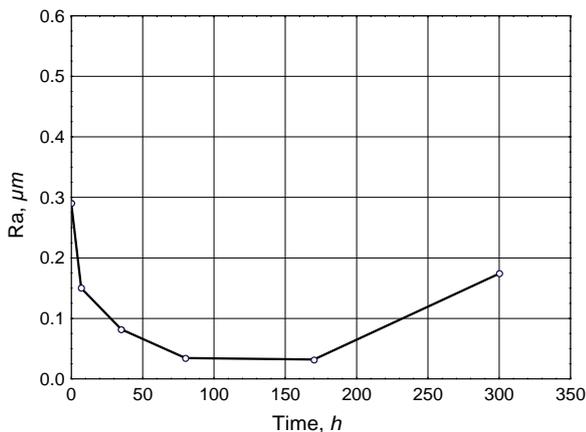


Figure 13. Change parameter Ra surfaces of cylinder

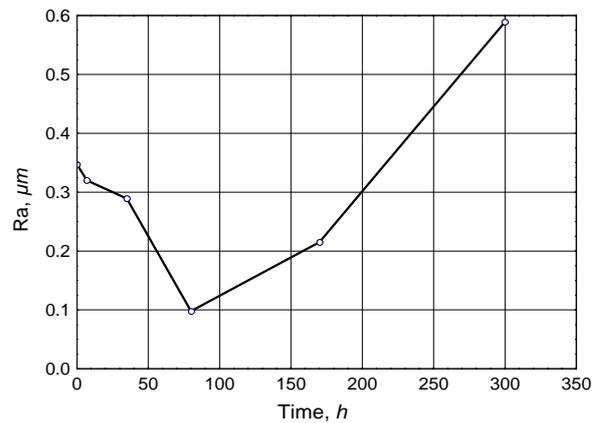


Figure 14. Change parameter Ra surfaces of shaft

4. THE ANALYSIS OF THE RESULTS

Elements of FMM during the operation are exposed to frequent changes of load and strong fatigue within materials of the entire system. The presence of cyclic strain fields causes appearance of fatigue in FMM, appearance of micro cracks, craters, as well as large plastic deformation, which can cause permanent damage and mechanism failure. Wear types of the observed tribomechanical system elements (cylinder, coulis, and shaft) are: adhesive, fatigue and abrasive wear.

In shaft (star), the prevailing form of wear is fatigue wear (pitting) with a pronounced process of plastic deformation of the contact surface, which is a direct consequence of contact of the elements with different hardness (shaft 48 HRC, roller 62HRC), in conditions of high normal pressures, strains [10, 11].

Due to the relative movement of the cylinder over the shaft and large specific pressures that follows the process of wedging it comes to increasing plastic deformation of surface layers and to the appearance and increasing of micro defects in it. After the certain number of operational cycles or load cycles separation of small pieces of material from the surface may appear, which can cause increased abrasive wear on this elements. In order to reduce the intensity of fatigue wear it is desirable that the contact surface of the elements had the finest quality of surface.

The adhesive wear that appears in the zone of contact roller - shaft and roller - coulis preceded the destruction of lubricant layer, because of too high load during the wedging. That situation leads to increased contact pressure and temperature witch caused plastic deformation and appearance of scoring at the contact surfaces. Coulis appears as a critical part in the movement and power transfer. During the operational it is exposed to cyclic

loadings followed by frequent strikes due to unbalanced rotations of the external shaft. Oil film in contact of coulisse with roller and roller carrier is destroyed during the wedging process. As a result of that, increased wear in combination with material fatigue and very frequent gear overload leads to coulisse failure.

If we observe the curves, of wear and roughness parameters, we can notice that smoothly work period of the surface, for most elements starts after about 50 operational hours. Then normal wear process begins. Start work smoothly period characterized the changing of the surface topography, because of transition technological topography in the experimental one. This process follows the sudden change in the roughness parameters, roughness peaks were taken and the profile becomes more unify. Due to high local loads, which are necessary for power transmission and friction motion, becomes changing roughness obtained after finishing contact surfaces.

At the beginning of the examination becomes an intensive removal of material from the surface what can be seen from the curves of wear. The most expressed peaks of roughness were taken away, so the profile becomes more equal and less rough. Roughness parameters reduced until the end of this period. This proves that the surface tends to become balanced in terms of topography. Period of normal wear begins after a start work smoothly period. Roughness parameters increase slightly, the surface had crossed in exploitation, and wear is settled. An exception is shaft with roughness parameters increases sharply to about 200 operational hours. The curves of wear shows increased wear, which is consistent with the previous, and if it continues this trend of increase wear, may be normal to expect a quick switch of normal to destructive wear.

5. CONCLUSION

The appearance of tribologic processes on contact surfaces of the tribomechanic elements of FMM impulse friction variators is one of the main causes of loss of accuracy and work reliability. During the operational of these tribomechanic systems as the inevitable occurrence of the process of rolling cylinder between envelopes, rolling resistance appears. It has very complex nature and must be observed in the context of all causes and factors that affect on that. The dominant mechanism of wear on elements of the observed tribomechanic system is fatigue, and also adhesive and abrasive wear [8].

Wear intensity on elements of the observed tribomechanic systems is a function of the large

number of influential factors such as types and quality of surface and thermochemical processing, the size of the normal load and speed of relative movement between the basic, critical tribomechanic carrier systems [8, 10].

To reduce the wear on contact surfaces of the tribomechanic basic elements of (FMM impulse friction variators) and extended operational life of gear it is necessary to consider: the selection of material for triboelements, improve the contact surface topography, consider the economic confirmation for production of the FMM elements with hard plate on contact surfaces. Classic cylindrical roller replaced with convex cylinder. Under the load convex cylinders are compressed and they have the same shape of contact surface as the cylindrical. Also their dispose of load is very well, even at very high loads. Cylindrical roller are exposed to high tension concentration on the edge, which makes them very exposed up margin pitting and short life time. Convex cylinders are less exposed to wear, and also compensate possible deviations in the phase of construction and producing, even in conditions of high tensions as in the FMM.

REFERENCES

- [1.] Мальцев В.Ф.: *Механические импульсные передачи*; "Машиностроение", Москва; 1978.
- [2.] Мальцев В.Ф., Луиза А. И., Медведев Е. А.: *К экспериментальному исследованию импульсных передач*, Передаточные механизмы; "Машиностроение", Москва; 1981.
- [3.] Кропп А.Е.: *Приводы машин с импульсными вариаторами*; "Машиностроение", Москва; 1988.
- [4.] Bi-min Zhang Newby, Manoj K. Chaudhury, *Friction in Adhesion, Langmuir*, Vol. 14, No. 17. 1998, pp. 4865-4872.
- [5.] Miloiu Gh., Dudita Fl.: *Transmisii mecanice moderne*; "Editura tehnica", Bucuresti; 1971.
- [6.] T. Pöschel, T. Schwager, N. V. Brilliantov: *Rolling friction of a hard cylinder on a viscous plane*, European Physical Journal B, Vol. 10 (July 1999), pp. 169-174.
- [7.] Takahiro Ito, Takuto Ogushi and Teru Hayashi: *Impulse-driven capsule by coil-induced magnetic field implementation*, Mechanism and Machine Theory, Volume 45, Issue 11, 2010, Pages 1642-1650

- [8.] Jovanović D., Tanasijević S.: *Mehanizam slobodnog hoda impulsnih varijatora, oblik i karakteristike*, KOD'04, Novi Sad, 2004.
- [9.] Jovanović D., Nedić B., Čupović M.: *Influence of the technological heritage on life cycle of machine elements*, 10th International Scientific Conference On Flexible Technologies, MMA2009, Novi Sad, 2009.
- [10.] Jovanović D.: *Tribološki procesi mehanizma slobodnog hoda impulsnih polužno - frikcionih varijatora*, magistarska teza, Mašinski fakultet, Kragujevac, 2005.
- [11.] Jovanović D, Tanasijević S.: *Uticaj habanja na promenu ugla zaklinjavanja mehanizma slobodnog hoda impulsnih polužnih varijatora*, IRMES'06, Banjaluka, 2006.
- [12.] Mihailidis Athanassios, Salpistis Christos, Panagiotidis Konstantinos, Sachanas Christos, Gatsios Stelios: *Wear of machine elements made from powder metallurgical tool steels*, Tribology in Industry, vol. 30, No. 1&2, pp. 40-46, 2008