TRIBOLOGY FOR CONSTRUCTION AND MAINTANANCE OF MACHINES AND TECHNICAL DEVICES

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Abstract

A significance of tribology for construction and maintenance of machines, particularly in motorization, is discussed in the paper. Examples on negative and positive effects of friction are given. An attention has been paid to opportunities of preventing negative friction effects, based on tibological knowledge which should be used not only in an operation process of technical equipment but also in the phase of their design. A close relationship between the development of tribology, a safety level and economics of machines operation, especially motor vehicles, is emphasized. The DT-12 Scania internal-combustion engine as an example of complex tribological system, the Audi Q7 car AL 420-6A six extension automatic gear transmission as an example of complex tribological system, the rolling friction power as a vehicle driving power, economical effect of 15W/40 oil replacement with OW/30 oil, the logical model of piston – cylinder set in a dynamic state are presented in the paper.

Keywords: *tribology, combustion engine, machines construction and operation*

1. Introduction

A term "tribology" has originated from two Greek words: tribos – friction and logos – science. In most general terms you can say that tribology is the science dealing with problems of friction, wear and tear and lubrication which reduces friction and wearing out of solid bodies surfaces moving towards each other – components of machines or other technical devices. The tribology as a science has been formally formed in 1966 as a result of British experts' works (led by Sir H.P. Jost and the then Minister of Education and Science Sir F.P. Bowden – well-known for physics and tribology), assessing the condition of lubricating technology in Great Britain. They proposed to teach tribology defining it as "science and technology referring to lubricated surfaces, mutually impacting on each other, being in motion to each other, and practical issues related to them". Formerly the specific branches of tribology had been included into various disciplines of science, e.g. the problems of dry friction had been a discipline of physics, boundary friction - of physical chemistry, lubrication – a discipline of oil products technology, wear – of machines technology.

Knowledge about friction, in its long history involved such names as Aristotle, Leonardo da Vinci, Amontons, Coulomb, Reynolds and many others, developed into tribology, it is in one way doomed to further development, both in a research as well as a methodological respect; its importance will grow, especially with reference to construction and operation of machines. The development in constructing of machines still will be aimed at increasing of reliability and durability of machines and also their ergonomics and economics. Due to exhausting natural resources, including oil, the necessity of prospecting for new ways to reduce wastes of energy, including fuel consumption by vehicle engines, is still of a great importance. Therefore, there will be still two basic problems of the greatest importance for the researchers dealing with tribology and for operators of transport means: 1) Reduction of waste of energy used to overcome friction, 2) Increase of resistance to wear resulted from friction. The endeavour to resolve these problems in more and more detail and accuracy inspires to practice subtle research methods "in micro scale" and even "in nano scale".

2. Effects of friction to machine elements

The reliability and durability of machines during their life cycle are determined by intensity of wear and tear processes resulted from friction. Huge costs are absorbed by support and maintenance of machines, worn out parts replacement and losses resulted from machine damage stoppages. Therefore the basic operations of engineering industry consisting in manufacturing of new types of technical units with higher and higher technical and economical performances is related to a large extend with the necessity to reduce the resistance of friction and to enhance the resistance to wear out of a machine parts (tibological nodal points). The produced machines and technical equipment should achieve very high energy efficiency. The factor of energy efficiency describes among the others resistances of friction. In modern equipment, meantime, a large part of energy is being wasted e.g. in cars even up to 20% of engine power is wasted in order to overcome friction and in an aircraft piston engine up to 10%.

Most of the modern machines and technical equipment, e.g. motor vehicles are complex sets of tibological systems where you can distinguish elementary tibological systems creating simply a simple nodal of friction, called often a rubbing pair (sleeve–journal, cam-tappet, bearing ball-race, etc.). One of the more complex tibological systems is an internal-combustion engine of a motor vehicle which can serve here as an example (Fig.1).

Fig. 1. DT-12 Scania internal-combustion engine as an example of complex tibologicalal system

It is a thermal engine generating mechanical energy thanks to thermal energy produced in a process of liquid fuel burning. Among the all thermal engines, just the internal-combustion engine, powering a car or another vehicle, achieves the highest general effectiveness, however it amounts to only 0,3 – 0,4 for elder types and around 0,5 for new ones. According to a superficial analysis of energy balance, even up to 30% of energy obtained from fuel may be needed to overcome various sorts of resistance relevant to friction process. As you can see in Fig. 1 and 2, as an example, the presented tibological systems are characterized by huge quantity of elements moving towards each other and rubbing against each other.

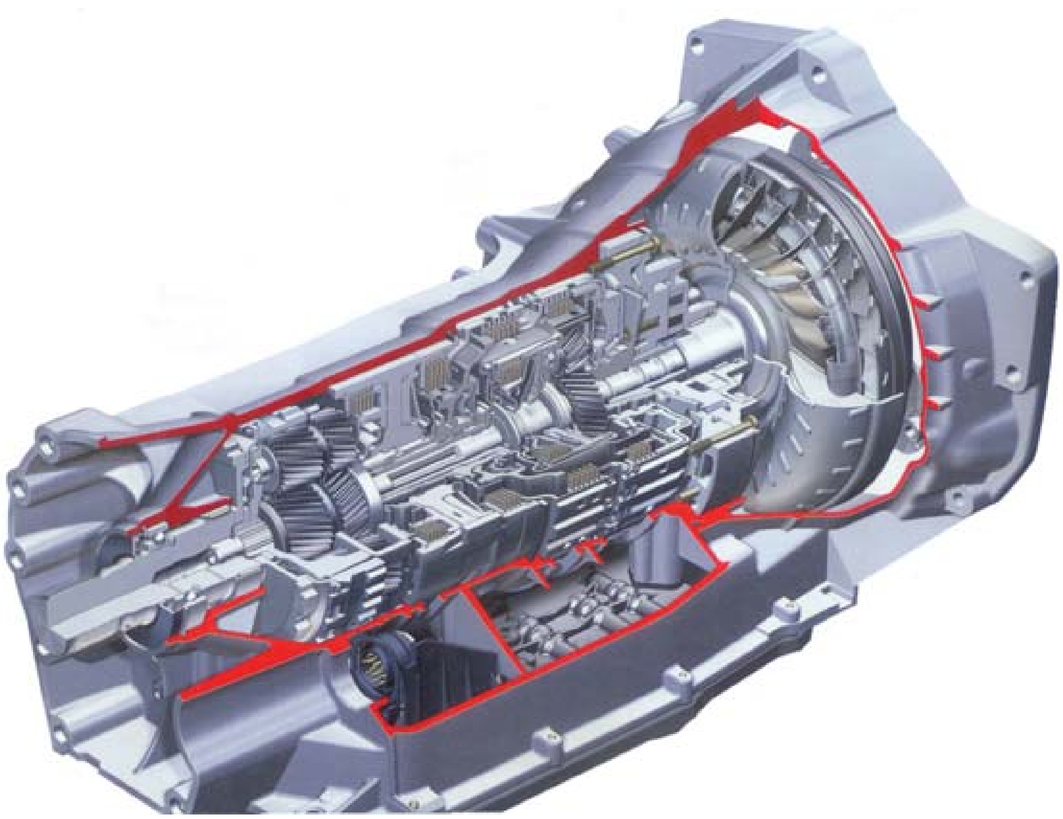

Fig. 2. Audi Q7 car AL 420-6A six extension automatic gear transmission as an example of complex tibological system

In the end only between ten and twenty percent of energy delivered to engine in the form of fuel reaches the road wheels, where also, a part of that energy is wasted due to friction resistance (apart from the necessary resistance of a wheel rolling on a road surface, without which a car drive would not be possible). As you can see, the value of ratio between the energy received at vehicle road wheels (driving) to the energy entering an engine in fuel is very low and in no case we can allow to its further reduce, e.g. by using low quality maintenance materials (fuel, lubricants, hydraulic liquids, etc.), or in result of bad technical condition of a vehicle. In fact, the key issue is to provide such co-operation conditions of individual tibological nodal points and an engine, as a complex tibological system, to be as small as possible and the intensity of wear and tear processes minimized. We will come to similar situation while analyzing work of every less or more complex tibological system.

Besides the wear a friction may cause an overheating of co-operating parts. To rub your hands on each other is enough to understand, that a great part of friction energy is transformed into heat. Car brakes could be a practical and meaningful example from the area of technology, confirming the above observation (Fig. 3).

Fig. 3. A brake shoe – disc, tibologicalal system

It happened not to one driver to see a brake disc heat up until it was red-hot, when a brake plunger got stuck (e.g. in result of seize up resulted from too small clearance in a brake cylinder or because of impurity which got inside). Even completely efficient brakes, if often and violently used, generate enormous quantity of heat – what is easy to check by touching a brake disc with your hand. Even if the wear out is slight, high temperature reduces frictional properties of the brake lining materials and contributes to weakening of durability of metal used to make a brake drum or a disc. Another example may refer to the co-operation between the internal-combustion engine cylinder sliding surface and a piston ring. When a piston ring slides inside the engine cylinder, too high temperature resulting from poor cooling (e.g. a dirty engine, limited inflow of air, malfunctions of a thermostat, etc.) may result in weakening of engine oil anti wear out properties, what next can lead to increased wear out of a piston ring and a cylinder sliding surface.

The above examples briefly explain negative effects of friction. However, under some circumstances there are certain benefits, which predominate and friction is desirable, e.g. in the car brakes, mentioned above. Without friction we could not drive a car with wheel drive at all, they would be skidding (Fig. 4.).

Fig.4. Rolling friction power as a vehicle driving power

Similar examples of desirable friction effects can be mentioned many times more, the ones connected with a driver's duties, while driving a car for instance. If there would not be friction, we could not walk and even we would have difficulties with standing still. In most cases however the minimizing of friction negative effects is concerned, especially in use of machines and technical equipment. **The tibological wear out and the generated friction heat seem to be just the most important factors decreasing durability and operation reliability of the most machines and technical equipment.**

3. Prevention of friction negative results

Based on current tibological knowledge you can resolve many, existing in operating practice, problems connected with friction. However, straight majority of excessive tibological wear cases refer to structural miscalculations or wrong selection of materials. Designers often are not able to predict responsibilities and conditions the tibological nodes of designed machine are to work. As a result of that, the tibological nodes work under conditions they should not do. The most often error is a wrong combining and selection of materials for sliding nodes, inappropriate shape, too large or too small assembly clearance, etc. The result can be a seizing of the tibological node. The attempts to seek new better lubricating substances will not resolve the problem at the time because the reason of difficulties lays somewhere else. As an example when selecting the materials for sliding nodes you should take into consideration a fact of more or less susceptibility to adhesion. The inclination to adhere of two various metals, i.e. easiness to form transitional lattice is influenced by similarity of their crystallographic arrangement and differences of lattice constant values. Major differences of these features mainly prevent from adhesion. In steels the susceptibility to adhesion is favored by the increase of ferrite or austenite (retained) content. A substantial susceptibility to adhesion with constant is displayed among others by: Ba, Ti, Cr, Co, Ni, Mo, Cu, Al, Zn and Mg, whereas Sn, Sb, Bi, Cd, Pb, In are characterized by a small susceptibility. In this context it should be said, that Mr. Babbit had a lot of luck while arranging chemical composition of his bearing alloy and after all having no full knowledge to that. At present however, the era of lead bearings is about to be finished due to ecological considerations. Intensive research are carried out aiming at introducing by 2009 lead-free sliding bearings.

Inappropriate shape, e.g. lack of required circularity, too high surface roughness and too small clearance can be a reason of seizure of the mentioned before brake piston or another precise pair, e.g. a forcing element of injection in-line pump of a self-ignition engine. The effect of such a state of affairs may be not only an excessive fuel consumption but even a drastic, damage to the injection pump. Therefore a workmanship precision of tibological node elements as well as their periodical diagnostics and maintenance are so important. There are also such cases, when too small surface roughness is not required due to possibility of micro lost motion. Especially, it refers to tibological nodes determined as "nominally immovable", e.g. all screw or riveted joints. The easiness to appear of micro lost motions with simultaneous moisture and oxygen availability, favours the wear appearance called fretting. This is a drastic kind of fatigue wear combined with corrosive and abrasive wear appearance. In such cases, it is advantageous to maintain substantial friction between "nominally" motionless surfaces or to use non-metallic spacers. Depending on a kind of tibological node, there can be various ways to avoid fretting. Sometimes, an advantageous one can be to use an appropriate lubricant in order to achieve minimum friction coefficient.

In most cases, when analyzing various tibological problems, we must apply a quantitative approach, not only a qualitative one. For instance, in designing the already mentioned car brakes, it is necessary to have knowledge how effectively they will brake the vehicle. The effectiveness is determined by the value of friction force between the brake shoe material and brake disc (or brake drum). However, a braking distance depends on the friction force between the vehicle wheel tire and a road surface. For the same vehicle moving with the same speed along the same road, the friction coefficient depends on passing condition of a road surface, mainly determined by weather conditions. Due to that, the sliding friction coefficient of the "braked" wheel on a road surface may be different by two orders of value (and even more). We should realize that while braking on wet and slippery (e.g. ice-covered) surface.

To depart for a while from the issues referred only to motorization, the diametrically different examples are huge turbines and generators used in power plants. Though, the friction in bearings of these machines is low, mainly due to apply initial hydrostatic lubrication prior a shaft is set in motion and hydraulic lubrication is „produced", huge mass of these equipment cause that waste of power to overcome the friction are high, after all. In this case, even minor reduction of friction may lead to substantial reduction of energy waste.

An effective way to reduce energy waste resulted from friction is to apply better and better, and correctly selected to equipment operation conditions, lubricants. To apply the principle: **for very high relative speeds – not very high (selected) viscosity of oil with optimal lubricity**, is understandable for tribologists and needs no explanation – it is enough to be cognizant of the dependence of friction coefficient in a specific tibological node, e.g. slide bearing, on the Hersey-Stribeck number.

$$\mu = f(\frac{\eta \cdot n}{p_{sr}}), \tag{1}$$

where:

η - oil dynamic viscosity [Pa*s],
n - rotations of shaft neck in the sleeve of slide bearing [1/s],
$p_{śr}$ - average individual pressure in a bearing [N/m^2].

The situation presented on Fig. 5 may be an example of advantages resulted from less viscosity engine oil use.

The fast and effective protection of an engine against an excessive wear out is possible due to easiness of oil inflow to its most remote tibological nodes. In result, a better durability of an engine and direct economies are obtained in the form of smaller fuel consumption. The multi-seasonal, synthetic engine oils, produced at present, enable to achieve such an effect. These oils having quite low viscosity are characterized by a very high (WL) viscosity index, that is essential invariability of viscosity in a temperature function and excellent anti-wear out and anti-seizure properties thanks to an appropriate package of refining supplements contained in.

It is necessary to remember however, that capabilities to load every tibological node are limited, irrespective of the used lubricant substance's quality. Both mineral and synthetic oils are made up of coal, hydrogen and oxygen atoms. Such chemical constitution determines the limit of applicability of these substances, mainly due to chemical stability it possess under high temperature, e.g. in an internal-combustion engine. Both mineral and synthetics oils undergo oxidation in the presence of air (oxygen). In result of that they take on the nature of acid and attack the material of lubricated surface. In the final phase of the process oxidation polimolecular products of high viscosity are formed, of similar consistency to rubber. Such dark brown substance can be watched e.g. in car gearboxes operated for a long period without low quality oil change. Chemical stability of oil can be enhanced with special anti-oxidizing additions, what happens in a refinery in a blending process. The effectiveness of these additions is currently very good but after all limited. Moreover, it was found an oil decomposition could happen even without access to oxygen. Appropriate quality of all maintenance liquids depends not only on their composition but also on effective ways of protection against environmental pollution.

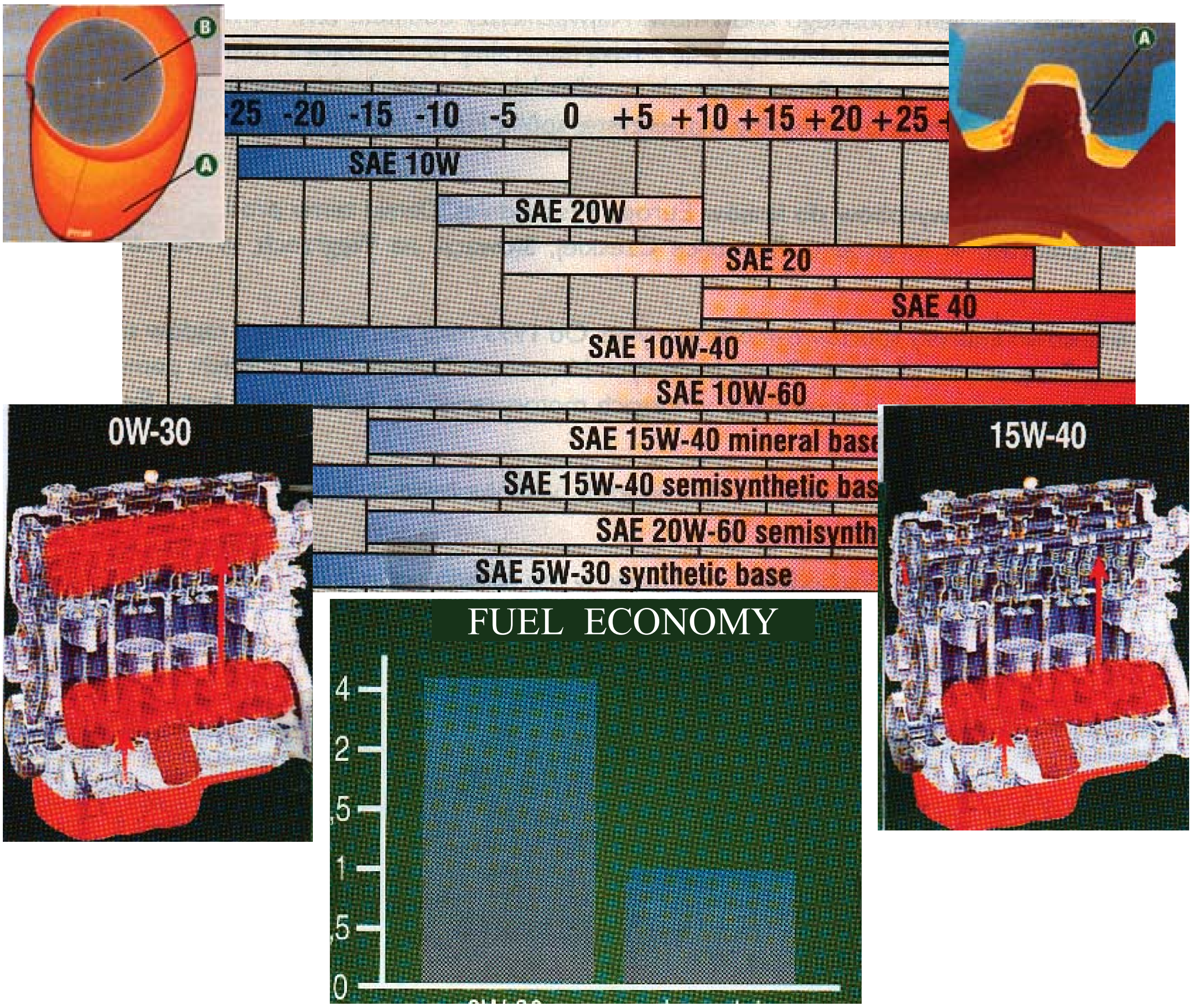

Fig. 5. Economical effect of 15W/40 oil replacement with OW/30 oil

Because of incomplete effectiveness of these protections , one of the most common and intensively proceeding tibological wear out course of action is an abrasive wear as a result of functioning of various origin hard grains ("abradants"). Such wear takes place also in case of lubricated tibological nodes, in spite of employing high accuracy and effectiveness filters. As an example, hard particles of dust, which are sucked in together with air-fuel mixture through a carburettor to cylinders by a car engine, make a serious problem.

The effective air filters, changed according to a car producer's recommendations, substantially improve the situation, but in spite of that, a certain small portion of dust gets inside the engine. Similar things happen with an inflow of "polluted" diesel oil to precise pairs of a self-ignition engine fuel injection system or an inflow of "polluted" liquid in various systems and hydraulic drives.

4. Summary

Some minimum level of tibological wear out is therefore unavoidable. The point is to minimize that wear out by complying with all rules of appropriate operation included among the others in instructions manual and maintenance for machines and technical equipment. The rules of appropriate and modern operation of these equipment arise largely due to the development of tribology. In future this relationship will increase. The research aspect of tribology and scientific explanation of tibological phenomena and processes become more and more important. The tibological research being carried out in our times are aimed first of all at finding the basic mechanisms of friction, tear out and lubricating.

Without full knowledge on wearing out mechanisms we cannot predict tear out values of the specific tibological node. In recent years series of new wear out models and efforts to program values of various tibological nodes tear off.

The construction engineers and operators still have no got precisely defined and unified analytical methods for predicting tear out values of various tibological nodes. It partially results from the fact, that under real conditions, various kinds and forms of wearing out impact on themselves, and the influence of environment is often unpredictable. The friction process is infinitely complex in its nature since mechanical, electric, magnetic and other phenomena happen simultaneously. These phenomena happen or appear on various levels of material structure and must be considered in a various geometric scale: macro or molecular, and even sub-molecular. Some must be noticed in millionth parts of a second, other require long-standing research and observations. A recognition of these phenomena and processes requires subtle and very much advanced research methods, considering the complexity of tibological issues and its deep relationship with physics and chemistry. Some research methods applied so far, e.g. isotopic or vibratory-acoustic, are not sufficiently exact and they can be applied rather to signal of certain critical states. Other methods of machine elements wear out assessment are based on „post factum" examining, i.e. the friction process is halted and accumulated results of the process on worn out elements are observed (after dismantling – that is, disrupting the whole process).

Many factors are unnoticeable by a researcher at that time, because the final effect observed by him is a result of combination, superposition and synergy of various impacts under determined conditions of machines works (tibological node). The point is about the development of such research methods, which would allow to carry out research in the entire complexity of the course of processes and phenomena, happening in outer layers „in situ" – during friction process, without disrupting it, in a chosen scale (macro, micro and nano). There are better and better possibilities to carry out such research (scanning microscopy, tunnel microscopy, electrochemical scanning tunnel microscopy, micro and nannotribometry, spectrophotometry). The development and implementation of these methods in tibological research may result in transposing on development in the field of computerized systems enabling to monitor changes of tibological processes during a machine use and thanks to that appropriate reaction of a user or automatic control system – the same way as existing and used successfully in motorization the ABS systems or the Lambda probes. Before it happens, yet the necessary is ability to interpret correctly the results of research, to work out detailed models of specific friction nodes wear out and to develop suitable automatic signal recording and sending systems, adequate to applied measuring techniques.

The brief description of tribology relationships with construction and operation of machines, seems to substantiate to sufficient degree the thesis proposed in the introduction on inevitability and necessity to develop tribology. Tribology is the field of knowledge which determines proper designing and constructing of machines and their further operating.

It is not possible to analyse properly any operated systems, which in fact, are tibological systems, without the knowledge on tibological processes happening in the system and results caused by these processes.

In order to explain these relationships lets use at the end, a certain simple tibological system, e.g. a precise hydraulic pair consisting of a plunger and a bush (a piston – T and a cylinder – C). A liquid (where small particles of pollutants can be present - Z) is transferred in the system (e.g. a fuel – P). A presence of these pollutants may be a reason to precise pair's abrasive materials wear out. A logical model of such TPZC system in a dynamic state is presented on the figure below (Fig.6.).

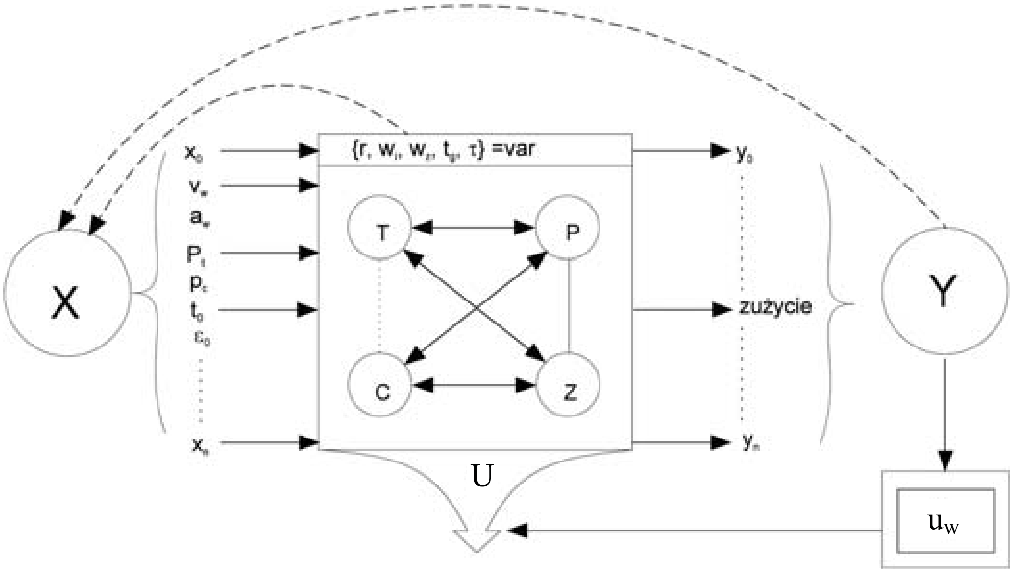

Fig. 6. A logical model of TPZC in a dynamic state : v_w –linear relative velocity of a precise pair piston a_w – acceleration of a precise pair piston, P_t – axial power impacting on a piston ,p_c –pressure of the liquid supplied to the system, t_o – temperature of the system environment ,t_g – temperature generated in the system ε_0 – concentrations of abrasive grains in hydraulic liquid, r –internal relations (interaction)between the system's elements, w_i – individual property of the system elements, w_z – team property of the system elements, τ – time

A knowledge of number of the system elements (i), their individual properties (w_i), team properties (w_z) and internal relations between them (r) is needed to describe every tibological system. Only at that time a structure of the tibological system can be identified S={i, w_i, w_z, r}. Moreover, the dominating internal relations (environment extortions) require to be determined and assessed, to determine in result, functional characteristics of system output –a tibological and a functional. In order to determine the optimal functional output the tibological processes should be thoroughly identified (Output Y). Meantime the authors of most publications concerning operation of technical equipment try to determine only functional output (U), forgetting completely about the need to identify tibological output (Y). Such analysing of the system is deprived of possibility to determine and assess reasons of anomalies in the way of system functions. In the case of hydraulic precise pairs T-C, mentioned here as an example, the parameter combining the system's answer, tibological and functional, is definitely its internal tightness changing in the function of time ($u_o \xrightarrow{\tau} u_w$) among others in result of inflow of pollutants presented in a liquid and causing the tibological node elements wear out.

A similar logical model should be constructed in every other case of analyzing any tibological system. In a structure of every tibological system, in result of internal interactions, some changes occur of the system elements properties and relations among them, which should be observed in research, to be able to find dominating reasons of obtaining (Y) specific values of tibological output determining a functional output (U). The methodology to carry out this type of research was presented by the author earlier, in papers [1, 2]. Individual research methodologies and subsequent phases of an analysis should be subordinated to the construction of tibological model. The scope of research as well as applied apparatus and measuring devices must enable to assess (X) constraints as well (w_i) individual and (w_z) group properties of examined (i) tibological system all elements, and also to assess $Y_0 \xrightarrow{u_0} U_0$ output zero function, and to find (r) dominating relation and $Y \xrightarrow{u_w} U$ output dominated function.

In TPZC system, provided as an example the output dominated function changes due to an existing dominating (r) relation what is the abrasive wear out of T-C precise pair elements resulted from an abrasive affect of mechanical pollutants present in hydraulic liquid. In result a decrease of $u_0 \rightarrow u_w$ internal precise pair leak tightness happens, therefore the system (device) hydraulic efficiency gets worse.

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