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THE ROLE OF TRIBOLOGY IN IMPROVING THE PERFORMANCE OF MACHINERY SYSTEMS

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Abstract: *Tribology, as a multidisciplinary scientific field that studies friction, wear and lubrication, has a key role in improving the performance of modern machine systems. Effective management of tribological processes contributes to increasing energy efficiency, extending the service life of components, reducing maintenance costs and improving system reliability. In this paper, the basic tribological phenomena are analyzed, with special reference to the performance of machine systems, as well as the connection between friction, wear and energy losses. Some of the current advances in tribological systems and what lubricants and lubrication represent for a machine element are also presented. The aim of the work is to point out the importance of integrating tribological principles into the design and exploitation of machine systems, as well as the potential benefits that such an approach brings in terms of performance, sustainability and economy.*

Keywords: *tribology, friction, wear, lubrication, machine systems, efficiency.*

1. INTRODUCTION

In modern engineering, the development of mechanical systems is constantly being pursued. Machine element systems are generally more reliable, efficient and long-lasting. One of the key factors that directly affects these characteristics is tribology - a scientific discipline that studies the phenomena of friction, wear and lubrication between contact surfaces in relative motion. Tribology is the science and technique of surfaces in contact and relative motion and related activities. [1] Although the presence of friction has been known since the earliest stages of technological development, only with the development of modern research methods did it become clear how complex and important tribological processes are for the functioning of technical systems. In mechanical systems, friction and wear are the main causes of energy loss, damage to parts, and reduced operating efficiency. With the correct application of tribological principles, we contribute to a significant reduction of all or at least a good part of the negative effects, but also to extend the working life of the equipment and reduce maintenance costs. In addition, in an era when more and more attention is paid to environmental protection, tribology plays an important role in the development of technologies that contribute to the reduction of energy consumption and harmful gas emissions.

This paper aims to show the basic principles of tribology, its importance in machine systems, as well as the ways in which tribological solutions can contribute to improving the performance of technical devices and plants. Special emphasis is

placed on practical applications in industry, modern materials and lubricants, as well as on the latest trends in this area.

Finally, in the conclusion, the key findings of the work are summarized and the need for continued investment in tribological research and its application as a basis for reliable and efficient operation of machine systems is emphasized.

2. TRIBOLOGY AND PERFORMANCE OF MACHINE SYSTEMS

Tribology has a direct impact on the performance of machine systems, because it deals with the analysis of interactions between surfaces in contact that are in relative motion. In practice, these interactions determine how efficiently and long-term a particular system can function. Basic tribological phenomena - friction, wear and lubrication - affect several key aspects of the operation of machine assemblies: power transmission efficiency, reliability, dimensional stability and overall energy consumption. Friction occurs at all contacts where there is relative motion - in bearings, sliding joints, gears, pistons and other components. Although some level of friction is required (eg to transmit torque), most friction in mechanical systems is a loss of energy in the form of heat. By reducing friction using adequate lubricants, surface treatments and constructive solutions, the overall energy efficiency of the system can be significantly increased. By using tribologically optimized solutions, machine systems can run longer, with less downtime and reduced maintenance costs. This increases overall productivity, which is especially important in industrial production, where any work stoppage means direct financial losses. Tribology makes it possible to reduce total costs through lower consumption of spare parts, lubricants and energy. On the other hand, when we talk about the efficiency of maintenance of machine systems, it should be mentioned that it is one of the most important factors for achieving high reliability, longevity and reducing exploitation costs. In this context, tribology plays a key role because it allows a better understanding and control of the processes that lead to mechanical damage, failures and performance reduction of machine parts. Traditional maintenance methods, based on the regular replacement of parts at certain time intervals (preventive maintenance), are increasingly being replaced by a predictive approach, which uses real measurements and analyzes to predict failures. Tribological analysis - especially the analysis of lubricants and examination of the state of the contact surfaces - plays a central role in this process. As an example, we can take oil analysis, which allows detecting the presence of metal particles that indicate the wear of certain parts.

The most widespread and at the same time the most accessible method of determining the amount of wear of machine elements is a method based on measuring the characteristic sizes of machine elements with measuring devices before and after exploitation or testing. It should be said that the method is applicable only for measurements of larger absolute values of wear of machine elements. [2]

Proper selection and regular monitoring of lubricant quality is key to maintaining the tribological characteristics of components. Lubricants not only reduce friction and wear, but also play a role in heat dissipation, corrosion protection and cleaning of contact surfaces. By using high-quality lubricants and automated lubrication systems, the period between service interventions can be significantly extended. Jakovljević (2012) points out that proper tribological control significantly extends service intervals and reduces the probability of downtime, thereby increasing machine availability and work safety. [3]

Prof. In his doctoral dissertation, Skulić talks about the types of lubricants, where he says that according to their function, two basic groups of lubricants are distinguished: structural and technical lubricants. Structural lubricants are considered as an element of machine construction, the selection of which is made during the design of machines or devices

simultaneously with the selection of other materials and other parameters of parts exposed to friction and wear. Technological lubricants are applied during metal processing by cutting and deforming with the aim of lubricating and cooling the tool and the material being processed. The choice of these lubricants is made when defining the technological process itself. [4]

2.1 The relationship between friction, wear and energy losses

In mechanical systems, friction and wear are two basic tribological phenomena that directly affect energy efficiency, operational reliability and overall performance. Their interconnection has significant technical and economic consequences, because friction leads to energy losses, and wear leads to degradation of parts and additional maintenance costs.

Friction is the resistance that occurs when two surfaces move relative to each other. In most technical systems, especially those that work in continuous mode (eg motors, bearings, gearboxes), part of the mechanical energy is converted into heat due to friction, which represents a direct energy loss between certain machine elements.

According to Rabinowicz, losses caused by friction make up about 10-20% of the total energy consumption in industry, while in transport that figure can be even higher. Increased friction leads to higher consumption of fuel or electricity, and additional wear and tear causes more frequent breakdowns and increased maintenance costs. [5]

Some examples can be a piston-engine system where 20% of the total energy can be lost to friction between the piston and the cylinder, but also gears and bearings, where friction decreases as well as the transfer rate of useful power, while the need for cooling increases. Reducing friction with the help of adequate lubricants, more precise tolerances and better materials can significantly increase energy efficiency. The combination of friction and wear often creates a chain reaction. And it can be friction that causes local heating, increased temperature accelerates material wear, but wear also creates particles that further increase friction and worsen lubrication and further increase energy losses. That is why it is important to identify and control these phenomena early through tribological analysis and optimization of design, materials and lubricants.

Tribological characteristics - such as the coefficient of friction, wear resistance, lubricant properties and surface microgeometry - determine how the surfaces will behave during operation: efficiency, reliability, service life.

Bhushan states that even small shifts in tribological performance can have a significant impact on maintenance intervals, reduced downtime and the overall economic viability of the system. [6]

2.2 Damage to machine elements

Damage to machine elements is one of the key problems in the operation of technical systems, as it directly affects the safety, reliability and functionality of machines. In most cases, damage is the result of long-term loading, unfavorable working conditions, inadequate lubrication or improper maintenance. Tribology, through the understanding of friction and wear processes, provides a tool for timely recognition and prevention of these damages. One of the more complex optimization tasks is the optimization of gear transmissions due to the properties of the mathematical model that describes its behavior. This is because a large number of factors affecting their functioning must be taken into account and their influence is described in complex mathematical expressions. [7]

When we talk about the factors that influence the occurrence of damage, we must certainly mention one of the most common ones that we

encounter. It is about using a low-quality lubricant that does not create a sufficiently protected layer. On the other hand, overloading of machine elements, as well as materials of low hardness, improperly treated surfaces, impurities, impurities in the environment can also lead to damage. In this connection, some of the damage prevention within tribology should be mentioned. When we talk about prevention, we can talk about analyzing the components that are in contact with the machine, but also the use of advanced treatments, the use of optimal lubricants that correspond to certain working conditions or the development of a self-lubrication system.

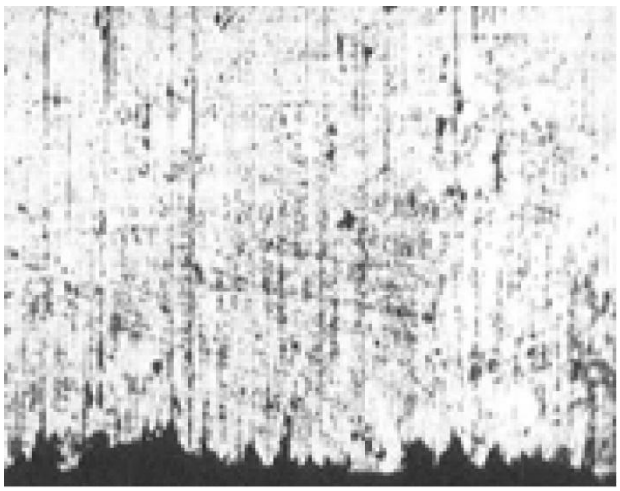

Figure 1. Wear due to contaminants [8]

Damage to machine elements is an inevitable part of exploitation, but with a proper understanding of tribological phenomena, they can be significantly slowed down, controlled or completely prevented. Through the selection of suitable materials, proper lubrication, quality processing and regular maintenance, it is possible to extend the working life of the components, increase the reliability of the machine and reduce the costs of repairs and downtime. Tribology thus becomes an indispensable tool for every engineer involved in the design, exploitation and maintenance of technical systems.

2.3 Techniques for improving tribological properties

The key to improving tribological properties is certainly in increasing efficiency, but also extending working life, as well as reducing maintenance costs. Today, a number of methods and techniques are used to control and optimize friction, wear and lubrication. When we talk about techniques and methods, we should mention several of their basic categories:

1. improvement of materials and surfaces,
2. optimization of lubrication,
3. construction solutions.

The surface of the material has a key influence on friction and wear. By introducing different treatments, it is possible to improve hardness, wear resistance and lubricant retention. Heat treatment, i.e. hardening, cementation, nitriding, increases hardness and resistance to wear. On the other hand, the application of protective layers (eg PVD, CVD, thermal spraying) is used to create thin, strong and smooth wear-resistant layers. As for polishing, sandblasting, superfinishing, they contribute to reducing roughness and improving contact properties.

Lubricants represent one of the key elements in tribological systems, because they have a direct impact on reducing friction, wear, heating and energy losses in machine components that are in relative motion. Proper use of lubricants not only extends the service life of machine parts, but also significantly improves their efficiency, reliability and economy. In modern engineering, the selection and application of lubricants are becoming more and more complex due to the specific requirements of various industries, the growing need for sustainability and the development of smart lubrication systems. When we talk about lubrication, we can say that it represents one of the most important aspects of tribology, because it enables the control of friction and wear between contact surfaces that are in relative motion. Proper lubrication not only reduces resistance and extends the life of machine parts, but also plays a key role in energy efficiency, safety and reliability of technical systems. Without lubrication, most machine elements would only work for a short time. Increased wear and tear,

which occurs even after a relatively short time due to inadequate lubrication, prevents longer operation of the machine, which must be stopped and repaired. [9]

3. CONCLUSION

Through the analysis of basic tribological phenomena, it is clear that friction and wear lead to significant energy losses, damage to components and reduction of overall performance. On the other hand, with appropriate techniques - such as surface treatments, selection of advanced materials, optimization of design and application of quality lubricants - it is possible to significantly reduce the negative effects of tribological processes. Of particular importance is the correct use of lubricants and developed lubrication systems, which enable reducing friction, extending the working life of parts and achieving better control reducing friction, extending the working life of parts and achieving better control over working conditions. Modern trends, including automated lubrication systems, biodegradable lubricants and digital monitoring of tribological parameters, further contribute to improving maintenance and overall system sustainability. Finally, it can be concluded that tribology is not only a field of theoretical importance, but a practical tool for optimization and improvement of technical solutions in all branches of industry. Investing in tribological research and its application brings multiple benefits: it increases reliability, reduces operational costs, saves energy and contributes to environmental protection.

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