RT&A, No 2 (73)
Volume 18, June 2023

Use of tribodiagnostics in practice

Pavol Mikuš[1] Alena Breznická[2]

•

Faculty of Special Technology, Alexander Dubček University of Trenčín,
Ku kyselke 469, 911 06, Trenčín, Slovakia[1,2]
pavol.mikus@tnuni.sk
alena.breznicka@tnuni.sk

Abstract

Tribodiagnostics deals with the problems of lubrication, friction and analysis of oils in technical fluids. Based on the results of parameter monitoring and chemical analysis of the oil, it is possible to determine the impending failure of the entire system very accurately. Today, this relatively young field of technical diagnostics is gradually becoming very viable and its results are fully in line with classical vibroacoustic diagnostics or thermodiagnostics. It is used in all mechanical systems containing oil systems. This is one of the methods of non-disassembly technical diagnostics, which is based on the knowledge that the lubricant after a certain period of use in the lubrication system reflects the condition of the equipment and the conditions in which this equipment was operated.

Keywords: Tribodiagnostics, lubrication fluid, oil, friction

1. Introduction

The growing demand for vehicles forces us to think about ensuring a high level of operational reliability, which should be close to the inherent reliability, which is ensured by optimal use, maintenance, repairs, etc. For the maintenance to be technically and economically optimal, it is also necessary to optimize the technical diagnostics, resp. also a significant part of it - tribodiagnostics. The term tribology (from the Greek TRIBOS - friction and logos - science) is historically very old and has probably existed since the beginnings of written history. Examples of the development of wheels, bearings, friction surfaces, etc. are documented. Already in the early civilizations (Archimedes) and also the targeted scientific development of tribology has a relatively long history (15th century), when the foundations of the law come from Leonardo da Vinci. Important scientists who dealt with tribology were e.g. Lavoisier, Leibnitz, Tower, Reynolds, Stribeck and others [2].

2. Tribotechnical systems

From a narrower point of view, tribology is a science and practice that deals with the behavior of contacting surfaces in motion, or in an attempt to move relative to each other (sliding, rolling, rotating, impact, oscillating, flow of gases, liquids, etc.). When the surfaces interact with each other, there is resistance to movement and friction. At the same time, the engineering observation of friction has a predominantly phenomenological character, since it uses in particular its external manifestations, effects in the field of contact and effects on the environment. Generally speaking, there are generally two basic areas of research and application of tribology:

- the field of man-made artificial technical tribological systems,
- the area of natural tribological systems (e.g. human locomotor system - joints, plant roots, etc.),

An approximation of the sizes and dimensions in which tri-diagnostics is performed in the area of vehicle groups is shown in Fig. 1 and Fig. 2.

Both artificial and natural tribological systems include at least two, but usually four, system elements, namely a basic friction body, a counter-acting friction body, an Interfacial Medium and an Ambient Medium.

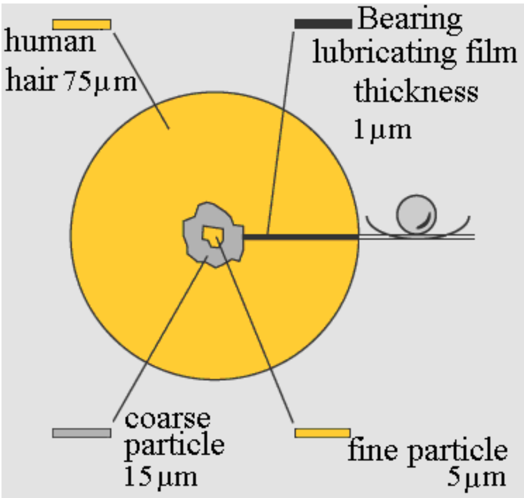

Figure 1: *An example of the size of the lubricating film and wear particles in the field of tribodiagnostics*

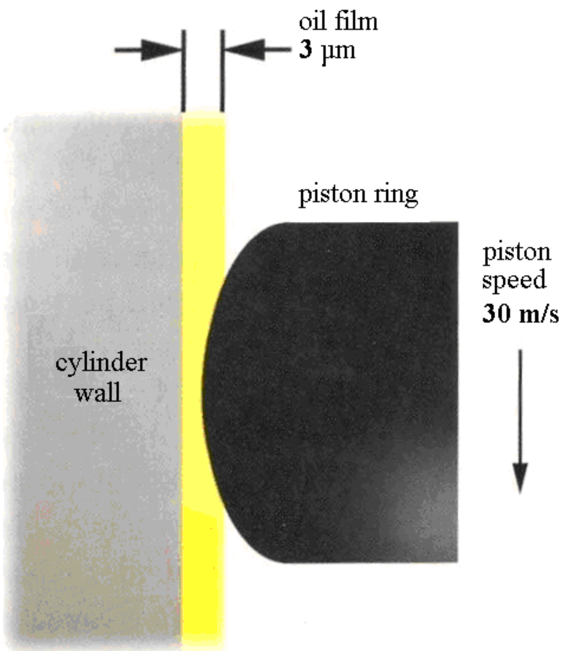

Figure 2: *Example of an oil film size for an internal combustion engine*

The Tribotechnical System (TTS) generally includes relationships between the following variables:

- Input Variables:
    - desirable,
    - undesirable (disturbing).

- Output Variables:
    - useful variables,
    - loss variables.

Undesirable - interfering input variables negatively affect the values of usable and lossy output variables. The role of TTS in practice is the conversion of input variables such as input torque, input speed, type of input movement, resp. in the case of several different movements, their sequence also includes, for technically usable output variables e.g. output torque, output speed and output movement. While the two contacting surfaces are part of each TTS, the interfacial medium and the surrounding medium may be absent from the system if it is a process taking place e.g. in a vacuum. Open systems are those where the base body is in contact in time with a different type of contact body or with several different bodies, e.g. when transporting materials or machining. Closed TTSs are those where the contacting bodies meet repeatedly. In addition to the other features of the tribological process mentioned above, when comparing open and closed systems, the ability of the system to function properly depends on:

- in the case of open TTS only for wear of the base body,
- in the case of closed TTS for wear of the base and opposing body [4].

3. Tribological load and interaction

The tribological load in tribotechnical systems is caused by the already mentioned input and disturbing variables, more precisely by their influence on the structure of the tribotechnical system. Tribological loading includes contact, kinematic, dynamic and thermal processes. A tribological load is a contact load of a base surface in the solid phase by another surface, which may be in the solid, liquid or gaseous phase, with relative relative movement of the two surfaces. This is done with the help of real contact surfaces. Plastic deformation and wear can cause a change in the size of individual real contact surfaces during the tribological process. Mechanical energy dissipates by friction, i.e. they dissipate and are converted into thermal energy, which affects the rate of wear. The nominal or apparent surface is decisive for lubrication when the two contact surfaces are not in direct contact and there is a sufficient amount of lubricant between them. With mixed lubrication, the lubrication parameter Λ is equal:

$$\Lambda = \frac{h_{\min}}{\left(R_{q1}^2 + R_{q2}^2\right)^{1/2}} \tag{1}$$

where h_{min} is minimum thickness of lubricating layer (μm), R_{q1} root mean square deviation of the base body surface profile (μm), R_{q2} mean square deviation of the surface profile of the opposing body (μm).

In the range 1 ≤ Λ <5, in the case of limit friction (lubrication) Λ <1 and in the case of dry friction, when both bodies are in direct contact, whether partial or complete, the boundary or real contact surfaces have a decisive influence. If there is direct contact between the friction surfaces, there will also be interactions between atoms / molecules and mechanical interactions at the locations of the real contact surfaces and in the affected area close below the surface of both bodies. This gradually leads to elastic and finally to plastic contact deformations and the creation of real contact surfaces. The type of interaction that occurs depends mainly on the state of lubrication. If it is a sufficiently lubricated contact, then atomic / molecular interactions are insignificant compared to mechanical interactions.

4. Wear

Wear can be characterized as an increasing loss of material from the surface of the solid phase upon interaction and relative motion with the solid phase body, liquid or gas. Wear of two rigid bodies occurs in direct contact, ie. in case of insufficient thickness of lubricating film, or in case of absence of lubricant. Wear is manifested by the release of particles from the surface of the material of one or both bodies in frictional contact. Wear can be caused by several mechanisms, the following four being the most important of them:

- surface fatigue,
- abrasion,
- adhesion,
- tribochemical reaction or erosion [1].

5. Tribotechnical diagnostics

Tribotechnical diagnostics is a set of methods and means of checking the technical condition (diagnosis, localization, prognosis, or genesis) of usually complex, closed friction moving joints of mechanical systems using lubricating media (oils, greases, greases, etc.) hydrau -lic liquids and. i. It organically combines the measurement, evaluation and forecasting of parameters and characteristics of processes taking place in a given facility. The results of the analyzes are used to perform the following tasks:

1. Monitoring the condition, trend and mode of wear of machinery based on, e.g. determination of the content of abrasions, resp. abrasion metals in the lubricant, while the decisive factor is mainly the trend of measured values.

2. Determination of the service life of the lubricant by determining the degree of its degradation by chemical reactions, products of thermal-oxidation processes, internal contamination, external impurities, etc. Increased number of impurities, e.g. in oil it not only means greater wear of the lubricated parts, but the contained deposits can clog the lubrication holes and grooves. The service life of the lubricant is expressed by a set of relatively objectively determined indicators.

3. Determination of optimal times for changing individual lubricants. The importance of this task is currently increasing with the rising price of lubricants and cost-saving measures.

By fulfilling the above tasks, we can get an overview of the technical condition of the relevant mechanical system, the aging and deterioration of the lubricant, wear of functional parts of the machine, or. about the location of excessive wear, which is usually the cause of failures and sometimes system crashes. Analytical data on the lubricant provide, in addition to diagnostic information, also prognostic information and make it possible to predict and also prevent accident situations. Lubricant analysis makes it possible to very sensitively determine the wear rate of the system as a function of time, resp. in real time, provides additional control options, e.g. filtration systems, tightness of cooling systems, etc. In addition to the requirement of complexity, tribotechnical diagnostics must meet the condition of correct selection of the necessary tribodiagnostic methods, their simplicity, speed and unambiguous responses to the state (mode) of system wear and further usability of the lubricant. In terms of use, depending on the complexity of the technique, the organizational level, the traffic intensity, the instrumentation and the personnel possibilities, the methods of tribotechnical diagnostics can be divided as follows:

- Simple methods and tests - express methods (speed methods).
- Standard methods and tests - according to STN EN.
- Special methods and tests - tribodiagnostic methods.

From the point of view of the essence and physico-chemical principles, the methods of tribodiagnostics can be divided into:

- Methods for determining the concentration of abrasive metals.
- Methods for evaluating the morphology and distribution of abrasive particles.
- Methods for determining the physico - chemical properties of a lubricant [5,6].

5. Ferrography

The detection of wear of oil-lubricated mechanical systems is based on the knowledge that the oil after a certain period of operation reflects the technical condition of the mechanical system and the operating conditions. This multidimensional information is carried by metal abrasion, which is dispersed in the oil and which, after quantification by a suitable method, allows indirect monitoring of the wear regime and mechanical changes in the system in which the oil is used. From the detected amount of metal abrasion, the intensity of the increase in the number of particles, the shape, morphology, size and material composition of particles and wear fragments, certain conclusions can be drawn - if the increase in abrasion and other parameters are systematic and compared with the nominal values determined for a given mechanical system (determined by calculation, long-term monitoring, etc.), it can be relatively reliably judged to be a normal course of wear without an increased risk of system failure. A sudden increase in the number of metal particles and the finding of particles of shapes characteristic of abnormal wear mechanisms signal an extraordinary event. From the size and shape of the particles, the growth rate, their number, morphology and other parameters, the severity of the disorder and the urgency of corrective action can be inferred. An important diagnostic circumstance is the ability to locate the site of increased abrasion and incipient disorders. According to the material composition of the metal abrasion, it is possible to determine the friction pair in which there is a sharp increase in wear. For these purposes, a suitable method is ferrography, based on the separation of solid metallic and non-metallic particles contained in the oil filling of lubrication systems of machines and equipment from the actual oil. Describes trapped particles (especially ferromagnetic) and assigns them to individual wear mechanisms; allows you to detect an impending machine failure. Abrasive particles can be divided according to their composition, size and other characteristics using this method. The separation takes place in a ferrograph, Fig. 3 - a sample of the examined lubricant flows down an inclined pad, which is placed in a magnetic field. The largest ferromagnetic particles settle at the beginning of the substrate and then the particles settle according to their magnetic properties, composition, size and shape. With this method it is possible to distinguish the shape of particles, their origin, place of origin (location of wear), morphology, etc. Ferrography is focused on the analysis of ferromagnetic abrasives in a lubricant using a magnetic field. It is a technique for separating metallic (and non-metallic) substances from used oil. In the ferrographic analysis, a diluted sample of oil is drained over an inclined transparent substrate (foil), under which a strong magnet is placed. The inclination of the substrate causes a particle size distribution along the transparent substrate due to the gradient (variable force) of the magnetic field. At the beginning, larger particles are captured (>15 micrometers) and the closer the film is to the magnet, the smaller particles are captured (<5 micrometers, or at the end up to 1-2 micrometers). After passing the oil sample, the oil is washed away with a suitable solvent (technical gasoline) and the particles are fixed on a transparent support with a transparent varnish, thus obtaining the so-called Ferrogram. Ferrogram allows to assess particle size, ratio of large particles (10-100 micrometers) to small particles, morphological (shape) characteristics of particles, etc. Based on the observation of particles on a special bichromatic microscope (combination of metallographic and biological microscopes - reflected as well as transmitted light is used), the wear regime of the mechanical system can be determined.

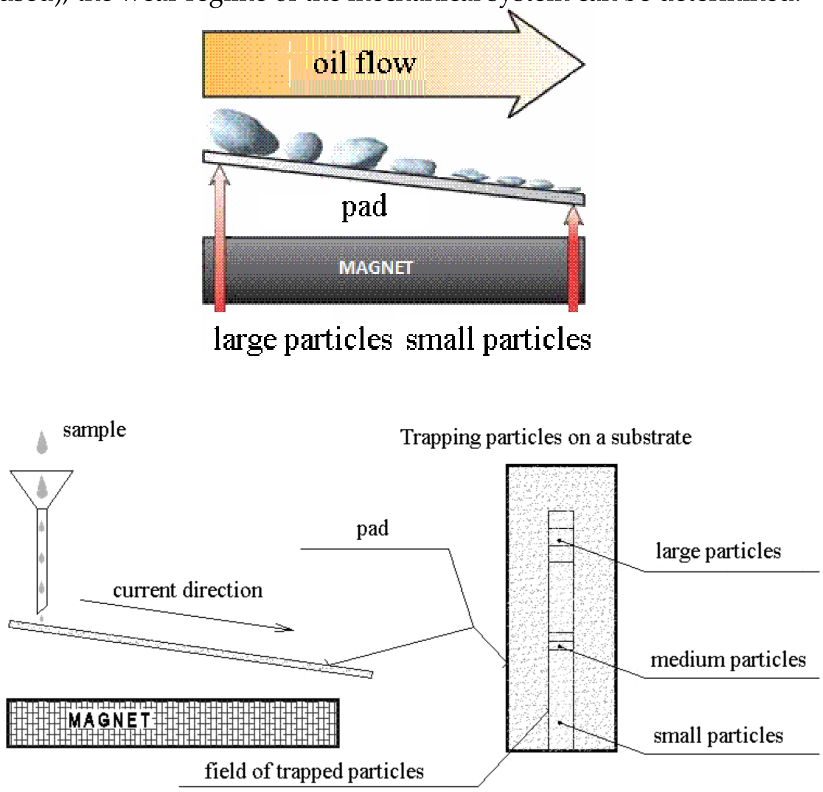

Figure 3: *Schematic of a ferrograph and the principle of ferrographic analysis*

The operating conditions, in particular the efficiency of the air filter, the presence of water in the oil and the overall care of the technical staff for the equipment, shall be clearly indicated at the end of the sedimentation trace on the ferrogram. Image analysis can be used for quantitative evaluation of ferrograms. In Fig. 4 and Fig. 5 are particles isolated from oil filters.

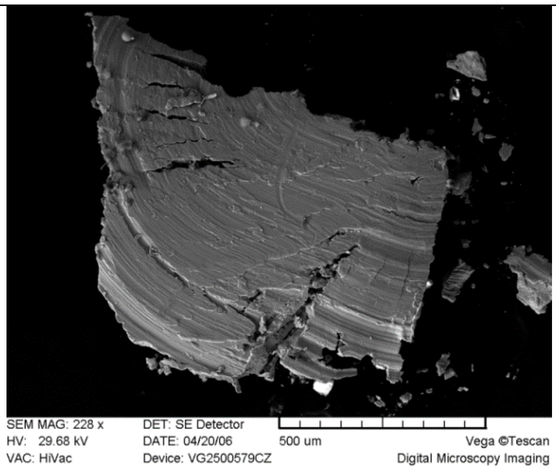

Figure 4: *Particles from oil filters*

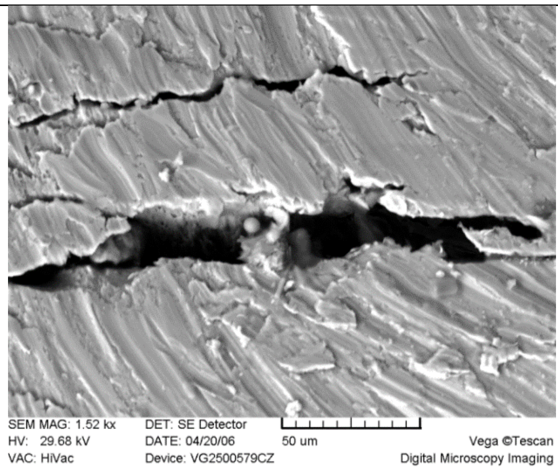

Figure 5: *Particles from oil filters*

Fig. 4 shows laminar particles where traces of abrasive wear due to high pressures at the contact of the friction surfaces are visible and incipient cracks are visible in the edge portions. In Fig. 5 is a spheroid artifact typical of fatigue wear. The ball is formed by the slow growth of a fatigue crack extending into the oil-soaked surface [7].

6. Results and discussion

The maintenance program is usually based on vibration monitoring, selected operating parameters and tribodiagnostics, which allows you to assess the specific condition of the equipment in real time. It is important that maintenance only applies to those parts or machines that really need it. The fault can be detected at the stage of occurrence and thus prevent more extensive damage, there are no unexpected outages and at the same time no unnecessary work is performed. Tribodiagnostics is based on regular sampling of lubricants (oils) from monitored machines and their analysis. With the help of tribodiagnostic analysis, we can determine both the condition of the oil itself and especially the condition of the monitored machine. The lubricating oil serves as a medium containing wear particle of the lubricated parts of the monitored machine. By analyzing these particles, we obtain important information about the mode of wear and events in the machine. It is very important to monitor the machine systematically and continuously from the beginning of the operational deployment and to obtain trends in the content of particles in the oil, resp. other tribodiagnostic parameters in the oil, as this information provides a reliable indication of changes in the wear regime and the actual technical condition. The second part of tribodiagnostics is the analysis of the oil itself, which we find out by changing its physico-chemical properties, as well as its pollution by foreign substances, e.g. water, mechanical pollution, chemical compounds. The basis of the success of tribodiagnostics is a correctly taken oil sample. The sample must be truly representative, ie. it must contain all substances in the proportion in which they occur in the lubrication system of the monitored machine. The optimal place for sampling is the return line, where the oil returns from the lubricated places to the oil tank. Some manufacturers already equip the machine (engine) with a sampling tap located just on the oil return line. Sampling must be performed while the machine is running, if possible, or shortly after it has stopped. Sampling containers (sample boxes) must be clean and dry. An important aspect of tribodiagnostics is the speed of response and the accuracy of the results. Regular samples should be analyzed quickly, based on the results of the diagnosis, the results are sent to the machine operator. Only the results of the analysis of the oil sample or the evaluation of the analysis with a recommendation for further action may be given in the relevant report. It depends on the system that suits the knowledge and experience of the workers.

7. Conclusion

This article briefly analyzes the crucial problems of friction and wear that occur during the operation of vehicles (especially vehicle combustion engine, transmissions, hydraulic systems, etc.), defined tribological unit as the smallest element where friction and wear take place. The tribological unit includes interactions of min. two friction surfaces, lubricant and environment. A separate part is devoted to the tribodiagnostic method of ferrography. This focuses on the detection of wear of oil-lubricated mechanical systems is based on the knowledge that the oil after a certain period of operation reflects the technical condition of the mechanical system and the operating conditions. There are still few such maintenance personnel who practically use and apply the current state of the art to identify the condition of the equipment based on the condition of the oil system. The introduction of new approaches to the care of means of production, technology, and processes enables the rational use of the results of analyzes for reliable and trouble-free operation. Proper treatment e.g. by filtering or adding the right additives will significantly affect the economy of operation. If the oil is still clean and properly maintained, it does not need to be changed. This will significantly reduce the environmental risk as well as increased environmental protection.

References

[1] Deters, L. *Springer Handbook of Mechanical Engineering*, Part B. [s.1.]: [s.n.], Tribology, 2009. ISBN 978-80-540-491.

[2] Stodola, J.: *Diagnostika bojových a speciálních vozidel.* Vysokoškolská učebnice U- 3086: Univerzita obrany Brno, 2005. ISBN 80-7231-017-8.

[3] Macian, V., Tormos, B., Olmeda, P., Montoro, L.: *Analytical Approach to Wear Rate Determination for Internal Combustion Engine Condition Monitoring Based on Oil Analysis.* Tribology International 36 (2003), p. 771-776.

[4] Krtička, F.: *Obrazová analýza částic v provozních hmotách a konstrukčních materiálech pro dopravní prostředky*. Dopravní fakulta Jana Pernera. Univerzita Pardubice, 2007.

[5] Leugner, L.: *The Practical Handbook of Machinery Lubrication.* Maintenance Technology International, 2005.

[6] Michael A. Taylor.: *Quantitative Measures for Shape and Size of Particles*, Powder Technology, 124 (2001), p. 94–100.

[7] Totten, E., G.: *Handbook of Lubrication and Tribology*. Volume I. Taylor&Francis Group, New York, 2006, ISBN 0-8493-2095-X.

[8] Leitner, B. (2020). The procedure of operational risks management in railway companies, In. Transport Means - Proceedings of the International Conference, Pages 57 - 622020 24th International Scientific Conference on Transport Means, Kaunas, ISSN 1822296X.