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The wear tribometer and digitalization of tribological tests data

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Properties

ABSTRACT

Purpose: The article deals with the modernization of the Amsler experimental machine. Modernization includes implementation of sensors for measuring the friction moment, the normal load and temperature; application of electronic components for measurement and graphical evaluation of tribological data.
Design/methodology/approach: In order to reach the goals further actions were provided: • Substitution and elimination of mechanical measuring unit with sensors and application of MATLAB/Simulink, • Implementation of computer for data processing and analyzing.
Findings: Records of tribological parameters were digitized using data acquisition card with MATLAB/Simulink and saved to a file processed in Matlab and transferred again to Simulink. To filter the records, the simulation scheme was designed in which low-pass filter was proposed by instrument FDA to monitor changes in the tribological characteristics. Applied modernization enables the increase of precision and effectiveness of measurements e.g. measurement of friction coefficient and temperature of lubricant and contacting tribopairs in the conditions of determined load. To change the sliding velocity the speed frequency converter was designed and connected.
Research limitations/implications: Analyzed modernization of the machine refers to pin on disc, disc-disc, block and disc unit sliding friction processes.
Practical implications: The possibilities of data processing and preserving in tribological research.
Originality/value: Designed and structurally modernized measuring system of the Amsler tribometer should ensure continuous recording of tribological characteristics in required output.
Results of this research can be used for study of contact fatigue and properties of lubricant, especially on friction pairs systems, sliding friction models, in extend given: • Selection of materials for friction pair elements, • Analysis of research on friction and materials under sliding and wear processes, • Lubricant selection for specified tribological system.
Keywords: Modernized tribotester; Sensor; Wear; Tribological properties

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1. Introduction

Tribology is an experiment-oriented branch of a complex, interdisciplinary science, in which testing plays a major role in the solution of technical problems, in the field as well as in the development of tribomaterials [1-3]. Tribology involves the recording of chemical, electronic and structural information from wear debris and surfaces [4]. Tribological problems are often complex and their understanding and solution rely on experimental data obtained from laboratory tests. Various test methods are used for this purpose, and the results are sensitive to the choice of test method and test conditions. Research in the field of tribology is associated with rapid transfer and applicability of the results of experimental tests into praxis. Among important factors accelerating tribological research the use of computer technology belongs. Tribological parameters of coatings (friction coefficient, normal load, temperature, etc.), especially their changes over time, must be continually analyzed with aim to predict the wear. Documenting and monitoring the tribological processes should be continuous. Automated checking systems for sensing and control of testing, improving the test methods and laboratory techniques are current challenge of tribology. Conventional measuring devices are based on mechanical principles, which are from a mechanical point of view interesting; but on the other hand; from the perspective of development they are obsolete.

The application of electronics is preferred and replaces the mechanics of devices. Modern devices are equipped by a digital output that can be further processed and archived in the computer, what saves time, money and storage space. Therefore, to process and analyse the tribological characteristics obtained by conventional twin discs Amsler tribometer the system Matlab/Simulink from MathWorks was applied.

Simulink as a block diagram environment for multidomain simulation and Model-Based Design supports simulation, automatic code generation, and continuous test and verification of embedded systems. Simulink provides a graphical editor, customizable block libraries, solvers and for modelling and simulating dynamic systems. Integrated with MATLAB, enables the incorporation of MATLAB algorithms into models and export simulation results to MATLAB for further analysis. The analysis of signals of tribological parameters was carried by design of appropriate filters parameters, and then filtering the records obtained during the tribological tests.

This work presents the integration of the MATLAB/Simulink system with data acquisition card (Humusoft) and also the application of advanced sensors at modernization of tribometer. Verification of modernized tribometer was carried out in the analysis of the tribological characteristics of thin hard coatings to study processes of contact fatigue with or without lubricant [5], [6].

2. Possibilities of evaluation of wear behaviour

The prime factor in necessitating a wide range of tribometers is the variety of wearing contacts occurring in the real situations that need to be simulated. Wear occurs under conditions of pure sliding, pure rolling, combined rolling and sliding, impact, abrasion, erosion and cavitation. Each form of wearing movement requires a specially designed tribometer.

The existing designs of tribometers for dry and partially lubricated sliding contacts are largely based on arbitrary choises or convenience. In some situations it might be desirable to design a new type of tribometer dedicated to specific tests. The fundamental question is, what constitutes a good tribometer or what are the basic requirements for good tribometer? The design of any tribometer should ensure sufficient mechanical rigidity to prevent vibration when there is a rapidly varying friction force and to allow accurate measurement of wear. Contact load can be applied either hydraulically, pneumatically, by a spring or by a hanging weight [7].

Basic requirements for laboratory tests are to model the conditions of the experiment the way, that the heat and mechanical actions on the surface layers in the area of friction surfaces were the most consistently to working conditions of friction pairs.

Nowadays, there is demand to evaluate tribological performance of new engineering materials using different techniques. PVD thin hard coatings belong to group of progressive materials [5],[8],[9],[10] with wide technical applications. This determines the activities associated with the development of new types of tribometer [11], not only to study wear on macro, but also on micro and nanolevel. In the area of research the trend is the application of tribometers with recording the friction coefficient, signalizing the first failure of thin hard coatings, using sensors for the pressure, temperature, acoustic emission (e.g. microtribometers, nanotribometers).

Methodology for testing of wear resistance should be selected with respect to the dominant type and the prevailing conditions of wear.

Laboratory tests allow evaluation of the influence only some of the basic parameters on character and intensity of wear process. Their advantage is usually simple sample preparation, defined basic conditions of the experiment and shorter trial period. A serious shortcoming is difficult transferability of acquired data into the conditions of operation of a particular machine or device.

Model-based testing allows better to simulate working conditions for construction elements. However, it is time consuming and expensive. In practice, therefore, model-based testing is primarily selected for verifying the lifetime of important design nodes for large-scale and mass production.

Operational tests, which run directly on production equipment, enable to monitor the process of wear in real terms. They give a basis for predicting lifetime of specific devices or their important parts. However, they are time-consuming, especially in the case of low intensities wear and are often influenced by the variation of operating parameters.

There is a wide variation in tribometer design and technology.

One of possible way to increase the effectiveness of conducting research is improvement, extension of possibilities of existing tribotesters [12].

3. Implementation of elements of the measuring chain

Implementation of elements of the measuring chain has been applied by substitution of the mechanical force-measuring system (normal force) by the C9B force transducer, friction torque sensor and non-contact infrared temperature the Optris CT sensor, thus improving the quality of scanning and digitizing the input and output data processed by the data acquisition card with MATLAB software.

The Amsler machine allows the study of tribological behaviour of friction pairs under the surface (disc and shapedrounded plate test) and linear contacts (two discs test, disc and block test) in conditions of dry, wet and boundary friction. Machine allows direct reading and plotting the friction torque under the various sizes of the normal load. Advantage is simple preparation of samples.

To change the sliding velocity, the speed frequency converter with continuously variable speed in the range 50 up to 350 rpm was designed and connected (Fig. 1). Adjustment of tensioning mechanism of loading spring was implemented without using special tools.

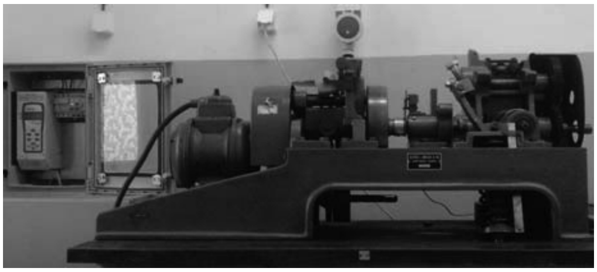


Fig. 1. View on modernized Amsler machine

Design and selection of sensors has been implemented with respect to parameters of tribometer, distribution of inputs and outputs of A/D converter. Variability of sensors is diverse in shape and size. Introducing the components of high quality and precision in sensor production, their working range of accuracy is from 0.03% to 0.25%.

Selection of sensors and devices is based on the requirement of change of measured quantity into electrical one [13], [14].

For measurement of the friction torque and for graphic recording the sensor with output, resolution of <0.01 (Megatron) was applied. To record the normal force without distortion, attachment and ensuring the transmission of load from the compression spring without being affected by bending moment, the sensor was designed with special holder and pad (Figs. 2 and 3).

Fig. 2. Sensor with designed holder

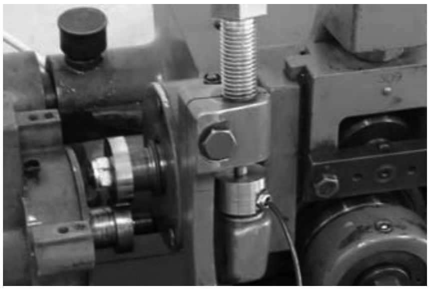


Fig. 3. Sensor with holder mounted on the tribometer

Data recording (forces, friction torque and temperature) and their storage were carried out using the MATLAB/Simulink system [15]. Records of force and friction torque are linked. The friction coefficient is calculated automatically according to the equation:

$$\mu = M_t / F_N .\ r \qquad (1)$$

where:
F_N - normal force [N]
μ - friction coefficient
r -radius of sample [m]
M_t - friction moment [Nm]

The temperature under which the tribological measurements are carried out is an important factor. Changing the temperature, the lubricant viscosity varies i.e. value of friction coefficient is depending on the temperature. Therefore it is advisable to analyze the temperature load in frictional systems in terms of triboreactions. Acquisition and evaluation of the temperature in the friction system is required continuously for all measurements of tribotechnical systems in practice and also in research.

There are two types of temperature, i.e. bulk temperature and the frictional temperature rise. The bulk temperature is usually the temperature imposed on the specimen by external heating or refrigeration and this temperature should closely follow the temperatures found in the practical problem. The range of temperatures studied extends from cryogenic temperatures of a few degrees K to 1500 K or more in high temperature tests on ceramic materials. Frictional temperature rises are significant for almost all kinds of tribological tests apart from small amplitude fretting. These temperature rises can range from -1K to several hundred K where temperature is limited by the melting point of the worn material. In general, frictional temperature rises during the simulation experiments should be maintained at the same level as those found in practical problems [7].

For temperature measurement the visible and infrared area of electromagnetic radiation, from 0, 33 μm to 30 μm is used, what corresponds to the range of measured temperatures from -40 °C to 10 000°C.

For temperature measurement the infrared sensor OPTRIS CT (Figs. 4 and 5) was selected, which records the surface temperature of the object without contact (measuring range: -40 to +900 ° C, system accuracy ± 1 °C, temperature resolution: 0.1°C,digital interface: USB, RS232, RS485). The surface temperature is determined by the emitted infrared radiation. Easily accessible programming key and illuminated display allows easy operation of the device.

Fig. 4. Infrared temperature sensor Optris CT

The non-contact temperature sensing method for rotating specimens extends the possibilities of research of tribocontact applying the infrared sensing of rotating specimens with specific coverage of scanned areas and record. Algorithm of continuous measurement of recorded signal enables the record with various intervals according to user requirements.

The advantages of non-contact temperature measurement are:

- negligible influence of measuring technique on measured object,
- possibility to measure quick temperature changes on objects (in dependence on type of sensor),
- by optics and added mechanics possibility to realize line or surface representations of surface temperature (e.g. thermovision).

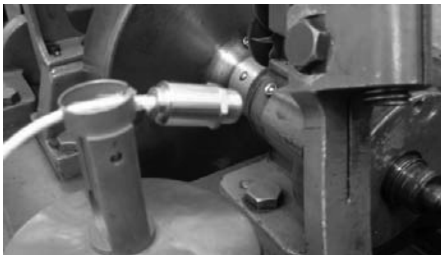


Fig. 5. Application of temperature sensor on tribometer

Fig. 6. Amplifier Clip IG 301

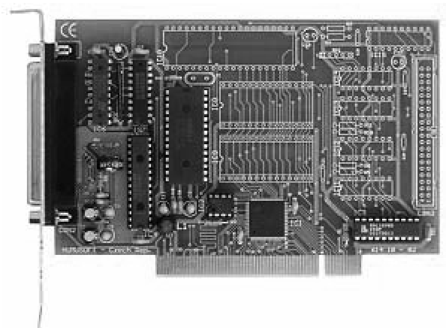


Fig. 7. A/D converter

To amplify signals, the IG amplifier 301 (Fig. 6) was used. The amplified signal at the input of the computer was transmitted via A/D converter (Fig. 7), where analogue signal was changed into digital signal processable by the computer itself and software MATLAB/Simulink.

The advantage of simulation and modelling softwares is visualization of examined parameters in real time.

Real Time Toolbox in the surroundings of software MATLAB/Simulink enables the work with external analogue and digital signals obtained by sensors.

The complete research unit includes also a universal recorder unit supported by computer with application MATLAB/Simulink software. Fig. 8, presents block scheme of data processing of tribological characteristics [16], [17].

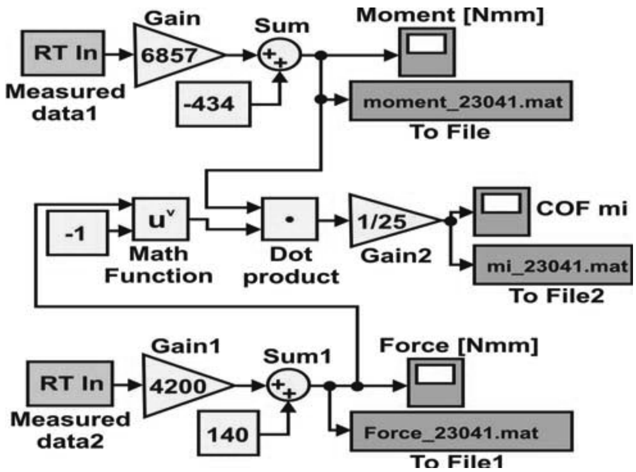


Fig. 8. Data Processing of tribological characteristics

4. Examples of application of modernized machine at temperature measurement

For temperature measurement two methods were applied [18]:

- non-contact sensor Irtec Rayomatic
- infrared camera FLIR ThermaCAM type E.

Processing and analysis of signals were carried out on the tribological characteristics (friction coefficient and temperature) obtained from the experimental research of the contact fatigue by twin-disc tribometer Amsler.

The friction pair consisted of two rotating discs, one disc with a multilayer (CrN-TiN/x3) 3 µm and counterpart made of material according to Slovak Standard 14220 (1,7131, 16MnCr5, tempered and carburized), lubricated with oil PP30.

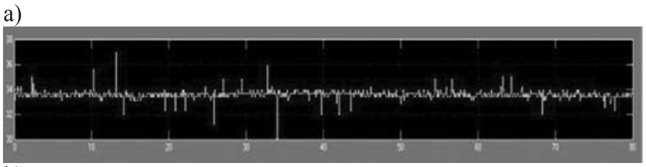
Using a FIR filter, the changes in the course of the friction coefficient and temperature were analyzed depending on the defined period of time. Example of filtering the temperature is shown in Fig. 9 [19].

Record of temperature (Fig. 9) shows a relatively low deviation of the mean value at the beginning of the recording.

Studying the tribological characteristics (friction coefficient and temperature), the significant changes were not observed and the records show a relatively constant course. Filtering out by low pass filter, the temperature (Fig. 9a) shows no significant changes and was relatively constant.

Visualization of characteristics and use of FIR filters simplify the interpretation of results in research of friction and wear in real time. For filtering the records (signals) in real time, the block scheme in Simulink was designed with lowpass and highpass FIR filters.

a)



b)

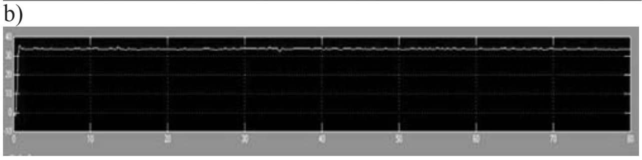


Fig. 9. Temperature - analysis of signal, a) Course of temperature, b) Filter of LP type

Comparative temperature measurements carried out by thermal imaging camera and using software ThermaCAM QuickView allows identification of temperature fields (i.e. isothermal display) but the record of temperature is usually in a short time interval [20], [21].

Monitoring of tribological processes for documenting of triboprocesses should be continual, what at temperature recording by thermovision camera may not always be effective, particularly in terms of contact fatigue.

The designed algorithm of continuous measurement of recorded signal allows the recording in interval of 0, 1 sec to 60 min, respectively multiples of 24 hours. The signals for improved identification of recorded variables were filtered using FDA tool. Exemplary record of alternation of temperature during the friction process with the use of lubricant is presented in Fig. 10.

Thermovision devices enable:

- Measuring of temperature in one point,
- Visualization of minimum and maximum temperature,
- Visualization of places with the same temperature,
- Videorecord of all images and data.

Fig. 10. The temperature recording by infrared camera FLIR ThermaCAM type E

There is possibility of change of research unit to the one adjust to liquid lubricant environment test. Lower working element then is equipped with adequate clamping ring allowing hold required volume of such lubricant.

The design of testing and simulating devices requires: simplicity of preparation and implementation of testing, low costs for tests, accelerated character of tribological process, satisfactory reproducibility and accuracy of test results.

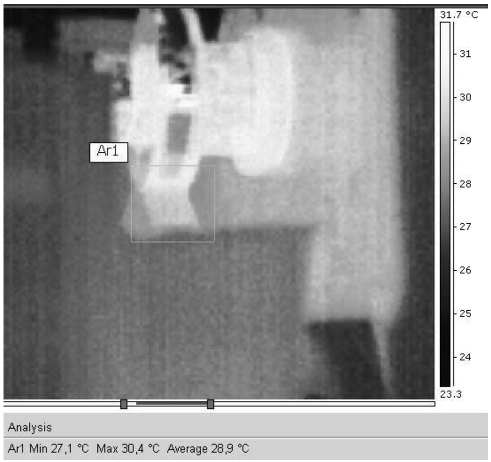


Fig. 11. Temperature measured by infrared camera

Modernization of Amsler tribometer with sensors and utilization of system MATLAB enable the automated data processing and process visualization during tribological tests.

Equipped with computer system Amsler machine enables actions as:

- Data visualization,
- Data processing,
- Data logging and management.

Introduced improvements allowed the realization of modernization assumption, therefore observation and recording of changes that are to take place, in following parameters:

- Friction surface temperature and the temperature of lubricant,
- Moment of friction,
- Friction path.

Possibilities of laboratory tests using modernized tribometer Amsler allow testing of the wear resistance of materials and also the temperature measurement and preservation of digitized data that can be processed into the desired output graphically.

5. Conclusions

- Modernized tribometer is useful to study the complex wear and tribological data. The fatigue wear tests modelling the rolling of two discs with or without slipping can be carried out.
- Modernization of Amsler tribometer was carried out by application of sensors (force, friction moment and temperature). Simultaneously, change of sliding speed with regulation was ensured.

- Application of system MATLAB/Simulink enables to digitalize, analyze and preserve the tribological data.

To study wear processes, the challenge in modernizing tribometer is analysis of sound recording.

Realized activities on the device have been associated with research of duplex PVD coatings in terms of contact fatigue [5,6].

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