Application of Triboacoustic Emission to Control the Friction Surface Quality

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As is known, many performance properties of the friction surface areas, such as contour area of the contact, oil carrying capacity, abrasive ability, friction coefficient, conformability, etc., are determined by the parts microgeometry of the machine friction couples often expressed by the profile elements height and width. However, the traditional roughness evaluation method using diamond probe surface scanning gives the high-quality profilogram and the data on many parameters of surface microgeometry, while it still has a number of disadvantages, including high costs of profilometers, relatively time-consuming measurements, sophistication of maintenance, high sensitivity to various contaminants on the surface.
The article presents description of elaborated methods and instruments for acoustic emission quality testers of friction surface areas. The main advantages and spheres of application for the diagnostic system promptly identifying the defects on the heavy-duty surfaces of the machine parts are given and the advantages of multiagent data collection system are presented.

Keywords: *Diagnostic system, microgeometry, roughness, surface layers defects, profilograph, acoustic emission, probe method, signal amplitude, profilogram.*

1. INTRODUCTION

It is well known that microgeometry of working surfaces contains the information of machinery parts performance characteristics, including the information of oil absorption, attrition wear, wear type, defects and stress concentrators presence in contact area etc. Therefore, roughness is one of the main of the part's characteristics which are indicated practically in all the drawings. Despite the existence of conventional methods of roughness control [1-3], the new procedures for microgeometry assessment, based on cutting edge science, are developed [4], or the old procedures [5] are improved, which are not widely used in engineering but of potential for solution of the actual problems faced by modern industry. In particular, those which enable the implementation of workpieces processing adaptable technologies, or equipment for efficient diagnostics of surface defects [6. 7].

Nano-structurized coating laboratory in Samara State Technical University develops the instruments and rapid methodologies to monitor the roughness, which are based on registration and processing of the acoustic emission (AE) [8] signals generated by the friction over the measuring probe surface. This principle, which has not been standardized in Russia yet, was the basis for the development of piezoelectric profilometers, the first being developed in our country about seven decades ago in Leningrad Institute of Fine Mechanics and Optics. Today, the profilometers with piezoelectric transformers based on barium titanate are manufactured by many leading companies in the instrument engineering sphere.

2. APPLICATION OF METHOD FOR ROUGHNESS ACOUSTIC EMISSION CONTROL IN MANUFAC–TURING PROCESS OF MACHINE PARTS

Samara State Technical University puts forward an idea to process the AE signal generated by the friction over the processed surface of the probe pressed to the surface with the specified load and moving about it with the specified speed. The method of roughness evaluation has the following stages.

1. The controlled surface of a part is touched by a probe with the specified speed and with pressing the probe to the surface. Here we may have several alternatives. The first alternative is that the probe is steadily moved over the fixed surface. The second alternative is that the surface is steadily moved around the fixed probe. The third option is that both the probe and the surface are fixed and moved relative to one another with the specified speed. The second alternative with the touching of the controlled surface provides an opportunity to control the surface roughness of a steadily moved part during its mechanical processing (sharpening, grinding, etc.) which is impossible with other methods.

2. The acoustically emitted electrical signal generated by the probe friction over the surface is received. If we explain the acoustic emission signal by the probe friction over the surface in physical terms, then the probe vibrates due to the part surface

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irregularities contacting the probe surface, which are recorded by the piezoelectric vibration acceleration sensor in the form of voltage spikes generated by the sensor. Along with that, the amplitudes of probe vibrations and the associated voltage spikes generated by the sensor increase together with the speed of relative movement of probe over the surface and the height of the irregularities. This distinctively differs the suggested method from the existing probe measurement methods as it controls the roughness over the cylindrical surfaces of the fast rotating parts. The decrease in microroughness period results in more frequent contact of a probe with the irregularities and thus to the more number of the spikes generated by the sensor, that helps to evaluate the average width of profile elements by the time of acoustic emission signal movements.

3. The acoustic emission signal is amplified and transformed into the electric one proportionate to the roughness value for the controlled surface, and then this signal is transferred to a recording or displaying device. To evaluate the irregularities of the rough surfaces the signal may not be amplified since the acoustic emission signal generated by the sensor may have high values sufficient for further processing. The acoustic emission signal is transformed into the electric signal proportionate to the roughness parameters in the following way. First, calibration dependence of acoustic emission signal amplitude on the surface roughness at the specified values of surface pressing force and probe movement speed is empirically obtained. Reference roughness specimens are used for calibration, and the range of reference roughness specimens should cover the range of the measured roughness values. Empirically obtained data is approximated (for example, with the least square method) as a continuous function in the coordinates "acoustic emission signal amplitude - roughness". Then the obtained function is used as the above mentioned calibration dependence.

4. The average value of Tae movement time for acoustic emission signal is found, and the average roughness of RSm elements width is evaluated as the product of a linear speed of probe movement over the surface v and acoustic emission signal time, i.e. RSm= v[m/s]·Tae[s]·106[µm]. The correctness of this expression is determined by the fact that every peak of acoustic emission signal is the result of probe top contact with a single irregularity on the touched surface. Thus, the calculated value sm characterizes the distance between the neighboring irregularity peaks, which generate the acoustic emission impulses when contacting the probe.

A device to implement the method (Figure 1) consists of a case (1) with the probe vibration sensor inside, which consists of a flexible element (2) (made from, for example, spring steel 65G) with the piezoelement (3) (for example, PKGS-00LD) bonded on it. Probe (4) is an angularly sharpened rod (for example, at 60□) inserted into the slot of the flexible element (2). To stabilize the pressing force of the probe to the touched surface there is a spring (5) inserted into the inner case cavity and closed with a cover (6) of the case. The signal from the piezoelement (3) goes via wire (7) to the input of the electronic unit (8). From the electronic unit, the signal is transmitted to the input of the recording device (9) connected (for example, by a USB port) to a displaying device (10) (for example, a personal computer).

The case is a hollow part with the probe vibration sensor inside. The case is to protect the probe vibration sensor from the mechanical damages and contamination. The outer form of the case is selected by the device application sphere (for example, the cylindrical form is for grasping by a hand, the form of a rectangular parallelepiped is to be clamped in a lathe toolholder, Morse taper is to be put in a broach holder in a numerical control machine).

The probe has the form of a rod and is made from metal (for example, brass) with less hardness than the touched surface to prevent its damage (scratches).

Standard compact sensors (for example, shock pick-up or vibration acceleration sensor) transforming the mechanical vibration intensity into the alternating electric signal are used as piezoelements.

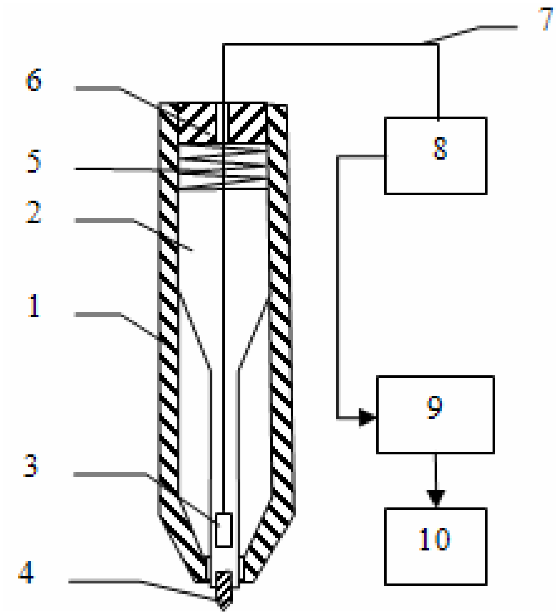


Figure 1. Schematic view of portable AE profilometer

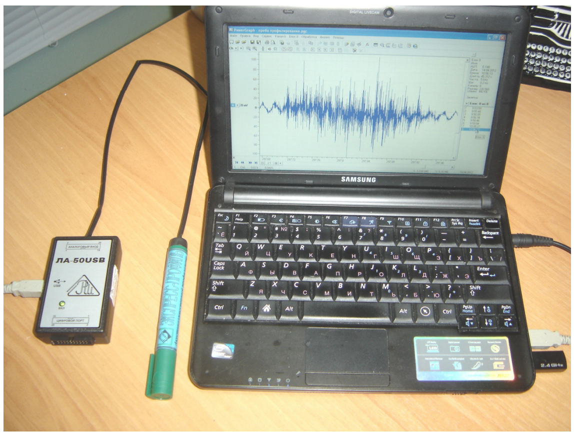


Figure 2. Prototype of acoustic emission profilometer

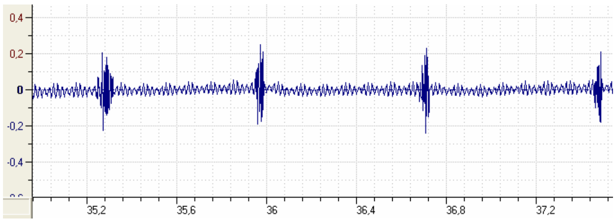
The electronic unit is designed to amplify and calibrate the probe vibration sensor signal and to switch on the power supply unit, amplifier and calibrating node. The calibrating node is designed to provide the proportionality of the electric signal, transmitted to the recording device, to the amplitude of the acoustic emission signals received while touching the surface. If the calibrating dependence is closer to the linear form, the calibrating unit function may be fulfilled by a divider made from a trimming resistor. In this case, the adjustment of the trimming resistor is aimed at reaching the match between the roughness values and the data of recording or displaying device.

Any standard recording device and voltmeter or a computer connected with the data collection system (for example, E14-140, E14-440, La-50USB, etc.) and equipped with the appropriate software (for example, ADCLab or PowerGraph) may be used as a recording or displaying device.

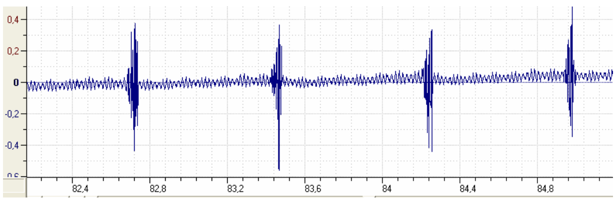
AE profilometer is designed in the form of a measuring probe head for the numerical control machines (Figure 3). This device is intended to be used in developing the adaptive technologies of surface finishing, for example, grinding, when the duration of surface sparking-out is determined by a factual surface smoothness defined by the current readings of AE profilometer rather than by the strict procedures.

Fig. 3. A production version of AE profilometer in the form of a measuring probe head for the numerical control machines

AE signal character at this profilometer application is shown in Figure 4, where it is clearly seen that the signal amplitudes grow with the surface roughness.



a



b

Fig. 4. AE signal generated by the friction of brass probe over the steel surface with the roughness R_a= 3.2 μm (a) and R_a= 6.3 μm (b).

3. APPLICATION OF THE ACOUSTIC EMISSION METHOD FOR ROUGHNESS CONTROL DURING THE OPERATION OF FRICTION COUPLE PARTS

Acoustic emission methods effectively identify the defects on the surface occurred during the exploitation of friction couple parts. For example, for a pair of wheels to be used on the roll surface no slid flats with the depth of more than 1 mm, no chips with the depth of more than 10 mm or length of more than 25 mm (for passenger carriages), no weld-on deposits of more than 0.5 mm, no cracks and other defects are allowed during the operation of a pair of wheels over the roll surfaces. To apply the acoustic emission method for prompt evaluation of car wheel roll surface quality, there is a need to face the following challenges. First of all, when scanning the surface the probe must not deform (scratch) it, that is why it is made from the less hard (and with less lifetime) material. Secondly, it is necessary to provide the continuous contact of the probe at high sliding speeds, therefore the pressing force of the probe should be increased and/or its weight can be reduced. However, the probe load is not an efficient way to provide the sensor sensitivity since it may result in quick wearing-out of the probe. Thirdly, the diagnostics should be performed over all width of the roll surface, which is a difficult task for typical probe methods. Fourthly, the diagnostics means must be easily integrated into the existing structures of the trucks and be simple, reliable and at the same time modern and science-intensive.

To address these issues, it was suggested to use a metal brush with soft steel or brass nap (wire with the diameter of 0.15 mm) as a probe. The width and the profile of brush nap are determined by the profile and the width of car wheel roll surface. Along with that, a flat probe is formed by a wide row of evenly distributed wires. Brush pressing force is specified to be small (up to 5 N). At the same time, in the context of wheel lubrication, the nap wearing-out speed does not exceed the permissible value. To transform the acoustic emission signals into the electric signal, a miniature piezoelement PKGS-00LD attached to the reverse side of the brush was used. Every wire serves as a probe scanning the surface. If one or several wires appear on the defective area, this impacts the overall background of the registered signal.

To identify the acoustic emission sensor sensitivity, the experiments were carried out with the cylindrical samples having different surfaces, including 1) a sample with roughness Ra=10 μm referred to as the surface of new wheels; 2) a sample with chips of up to 1 mm (accepted defect); 3) a sample being the same as the previous one but with one defect modeling cross crack with the depth of 1 mm left by a sharped chisel. The diameter of the samples was 25 mm. The rotation frequency is 950 min-1, which corresponds to the linear speed of about 4.5 km/h. The experiments were aimed at evaluating the spectrum of the received signal.

The obtained spectra show the visible differences in the sphere of higher frequencies closer to 1350 Hz matching the frequency of probe nap contact against the irregularities rather than in the sphere of sample rotation frequency.

It was suggested to use a distributed multiagent wireless sensor network as measuring data collection and processing system. Each sensor-agent consists of the following structural modules: primary transducer; matching amplifier; analog-to-digital converter; microcontroller; wireless data transmission module.

Figure 5 shows a schematic diagram of wireless diagnostics data collection and processing sensor-agent.

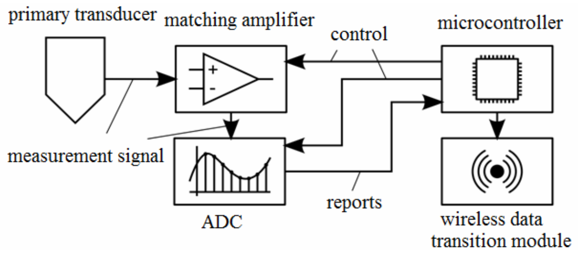


Figure 5. Structural scheme of wireless diagnostics data collection and processing sensor-agent.

The measuring signal received from the primary transducer, passes through the matching amplifier and gets into the analog-to-digital converter. The amplification coefficient of the matching amplifier and the signal sampling frequency are controlled by the microcontroller. The microcontroller collects the discrete time signal reports from the analog-to-digital converter and processes them. To provide the communication for the sensor-agent within the collection and processing system, the wireless data transmission module is used. Wireless modules are supposed to organize the mesh topology of interaction between the structural components of the system, that will provide the significant increase of maximum data transmission distance and ensure the communication of "each-with-each" type. The sensor-agents with the wireless communication for information interaction simplify the introduction of the analyzed technology since there is no need to install wired infrastructure covering all nodes of data collection.

The described technology of rail transport diagnostics collects and processes many measuring flows which are interconnected with each other. For example, the frequency characteristics of signals received from the flatcar wheels have the components which are determined by the profile of railroad bed, power plant vibrations, flatcar wear and many other factors, as well as the qualitative characteristics of these wheels. Thus, there is a need to carry out a comprehensive analysis of the measured parameters. In this case, when processing the information at the central unit, it is necessary to organize the continuous transfer of the measuring time reports from the sensor-agents to the processing system. However, with the wireless communication as the means to transmit the data flows, there arises an issue on a limited number of wireless protocol channels. Typically, the number of transmitting channels of standardized wireless protocols is limited with a several dozen thereof. Therefore, it is suggested to use a multiagent principle of data processing, when the diagnostic information flows are processed inside the sensor-agent media through their interaction with each other. As a result of data processing, each sensor-agent gets an aggregated data about the mechanism conditions, this information presents specific value importance with prior defined patterns. The described patterns are the structure determining the methods of aggregation and mutual analysis of diagnostic data, as well as the importance degree dependence on the specific values. The importance of processing results determines the need to keep logs on the server and/or to notify the managing personnel.

The comprehensive analysis of the diagnostic parameters is intended to trigger the exchange of the aggregated data inferred from the time reports after the processing between the sensor-agents. For the information to be exchanged, the interaction interface for the sensor-agents is provided with the tools to publish the data aggregation services, as well as their application. The data aggregation services give the sensor-agents an opportunity to request the information necessary for the comprehensive analysis of the indicators in accordance with the processed pattern. Figure 6 shows an information-logic model of multiagent technology for data collection and processing.

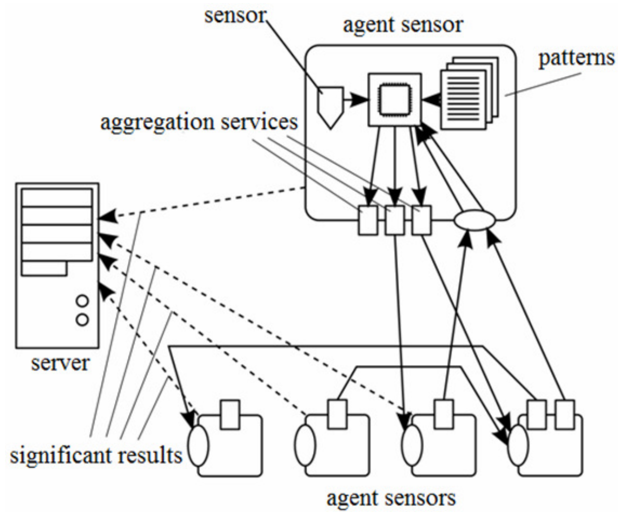


Figure 6. Information-logic model of multiagent technology for data collection and processing

4. CONCLUSION

Practically important application of acoustic emission control consists in prompt assessment of workpieces surfaces smoothness either during machining, or after that. Such control enables the approach to solution of the adaptive technology development issue when feedback between the current parameters of machined surface quality and machining process. However, the known ways of continuous control of surfaces quality during machining process, when acoustic emission sensor is connected to machined workpiece or cutting tool, are not available to provide high-accuracy measurement of the obtained roughness. The low cost of the acoustic sensor can be explained by the lower price for a piezoelement with an amplifier as compared to thereof for conventional electromagnetic transducer, and for a brush probe as against a diamond probe. Roughness comparison specimens are required only for factory calibration of the instrument. Acoustic emission profilometer by its cost is comparable with the simplest mechanical profilometers, and even in comparison to them it has the advantages regarding the prime cost. But the fundamental superiority of the proposed devices consists in the fact that they enable to estimate roughness when used on surfaces moving with high velocities (rotating part, bogie wheels, etc.), which allows to use them for solution of tasks set in the article, namely for the purpose of adaptive technologies development and instant monitoring of surface defects. Those tasks, nowadays, cannot be solved in practice by means of any other known profilography procedures. Thus, the described technology gives the solution for the diagnostics data collection and processing tasks with the implementation of sensor multiagent network.

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ПРИМЕНА ТРИБОАКУСТИЧНЕ ЕМИСИЈЕ ЗА КОНТРОЛУ КВАЛИТЕТА ТАРНИХ ПОВРШИНА

А. Гаљамов, И. Ибатулин

Познато је да су многа својства тарних површина, као што су контурна површина контакта, носивост уља, абразивност, коефицијент трења, прилагодљивост, итд., одређена микрогеометријом делова машине који остварују везу трењем, а што се изражава елементима профила као што су висина и ширина. Међутим, класичан метод евалуације храпавости скенирањем површине сондом са дијамантском главом даје квалитетан профилограм и податке о много параметара микрогеометрије површине, мада има и много недостатака као што су висока цена профилометара, релативно дуготрајна мерења, сложеност одржавања, велика осетљивост на различите контаминанте на површини. Чланак даје опис сложених метода и инструмената за квалитетну анализу акустичне емисије код тарних површина. Приказане су основне предности и области примене дијагностичког система, који брзо открива дефекте на машинским површинама са високим оптерећењем, као и мултиагентни систем за прикупљање података.