Metrol. Meas. Syst., Vol. XVII (2010), No. 2, pp. 271-278

PAN
POLSKA AKADEMIA NAUK

METROLOGY AND MEASUREMENT SYSTEMS
Index 330930, ISSN 0860-8229
www.metrology.pg.gda.pl

THE USE OF SURFACE ASPERITIES ANALYSIS TO INVESTIGATE WEAR OF BODIES IN CONTACT ON EXAMPLE OF BRAKE ELEMENTS

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Abstract

The use of surface analysis to investigate brake elements shows how a pair in contact works and wears out during regular operation. The main purpose of this paper is to describe the asperities from initial state to a moment when further use of the drum and shoe is not possible. Between exchange of vital brake elements a truck with total mass exceeding 3.5 tons can cover as many as 300 000 kilometres. Use of brakes during the first 1000 kilometres after maintenance should be rather gentle with possibly intensive use of engine brake installed in the truck itself, because if this rule is not adhered to it may lead to a significant decrease of the braking force and on the surface of the pair in contact a layer will appear that is not possible to wear off and that will make it impossible to stop a truck using brakes. In that condition the shoe should be immediately replaced and the drum should be remachined (by turning) to a repair dimension. In the paper the condition and analysis of a surface after different course of exploitation was presented.

Keywords: brake system, surface wear, surface topography.

1. Introduction

More and more quality control divisions and research places are equipped with measuring devices capable of performing very precise inspection of machining goods. When these investigations are connected with personal safety and a point of view vital for quality and reliability, every manufacturing company does its best to ensure a proper production process. Tests made on brake lining make it possible to exclude damages caused by high temperature, dynamic loads and too low wear resistance. The aim of a project performed at the Division of Metrology and Measurement Systems of Poznan University of Technology was to show how a frictional surface on the lining and on the brake drum wears out after a certain number of braking cycles. In the experiment, the lining and brake drum installed on axles made by SAF-HOLLAND were used, dedicated for utility vehicles with allowable axle load even up to 9 tons.

During a conventional exploitation process of a truck, the lining and brake drum can easily cover up to 300 000 kilometres. Wear during that period of time does not influence the braking process in a negative way. It is only during the wearing-in process of the lining and brake drum over a distance of no more than a thousand kilometres that braking should be performed more gently, with possibly maximum use of the engine brake installed in a truck-tractor. Cases where braking during the first step of truck exploitation is done violently are connected with overheating of materials in contact and may cause vitrification of brake lining. This phenomenon will further result in an increase of brake lining surface hardness, what effects in losing braking ability and becomes dangerous for both the user of the vehicle and other traffic participants, to say nothing about additional repair costs.

Article history: received on Feb. 15, 2010; accepted on May 26, 2010; available online on Jun. 16, 2010.

Surface topography plays a significant role, having a decisive influence on basic tribological properties as well as sealing conditions, fatigue limit, heat and electrical conductivity, friction, strain, stiffness of connections and position accuracy but also esthetic feature (appearance). The contact character of two surfaces is determined to a large scale by their asperities. For this reason the real contact surface is smaller than the nominal one. In practical cases there are three types of relation between the surface and surroundings: two-bodies contact (direct contact of two solids), three-bodies contact (contact of two solids through a lubricating medium) and one-body contact (influence of the environment on a solid). In all these cases, knowing the surface characteristics enables a prediction of its behavior.

2. Research procedure

The construction of a typical SAF drum brake is shown in Fig. 1. Brake shoes are backward strutted in the brake drum direction by means of a pivot shaft with cam, pressure is caused by a pneumatic brake actuator located on inner side of the axle. In most modern vehicles automatic controllers of the braking force are used, adjusting the distance between the drum and lining as it wears down. The appearance of an axle after covering 250 000 kilometres is presented in Fig. 2.

Fig. 1. Typical SAF drum brake with 9-tons capacity [1].

Fig. 2. Vehicle axle after 250 000 kilometres.

For research purposes samples of the lining and drum brake after various distances and different wear were used. The first investigated sample was a new drum brake, where both drum and lining had no distance covered. The next sample had 80 thousand kilometres distance covered and it showed vitrification marks described above and it was unfit for use.

Two following samples had the distance covered equal to 230 000 and 250 000 km respectively and they were exposed to normal exploitation. The distance covered has been read out from the ABS system which supports the driver work and increases the work safety. The samples have been examined in the laboratory of the Division of Metrology and Measurement System ITM of Poznan University of Technology after precise verification of data of the vehicle and its distance covered. The measurements has been performed using a white light interferometer Veeco NT1100 which allows non-contact measurements of the surface. Surface images allow to observe the wear process of frictional elements as a function of the distance covered.

3. Optical profiler

Many devices which are applied in the metrology of surface use phase detection systems as the fundamental part of their measurement system. Especially it concerns the interferometer with a single beam, as well as heterodyne interferometers. Based on definition, the interferometer is an optical device which splits the light beam coming out from the source into two separated beams which, after passing different distances interfere constructively or destructively in order to obtain an image. One of the beams is reflected from the sample's surface and the second one from the reference surface.

The interference intensity along the vertical scanning direction is collected by a CCD detector and called a correlogram. Subsequently the data are sent to a microprocessor which, based on an algorithm, calculates the coherence peak. From the data obtained from the correlogram we are able to calculate roughness parameters [2].

Interferometry uses frequently the surface method in order to obtain information about roughness, in which topography is calculated from a set of interference fringes. However, occasionally profilometric solutions which are using an optical follower, are also used. The individual interferometer methods depend on the system and the modification in the interferometer that has been applied in the device. A review of a different kind of interferometers used in metrology is presented by Schmit and Creath [3].

Modern interferometers are very complex systems. First of all they use white light, whose advantages are presented by Wyant and Creath [4], whereas Schmit showed the theoretical foundations of principle of operation of the white light interferometer [5]. One of the most important advantages of using white light is the possibility of measurement of surface discontinuity like a deep fault or a high step, which is indistinguishable for an interferometer which uses monochrome light. The most popular interferometric measurement techniques are phase-shifting interferometry PSI, vertical-scanning interferometry VSI and enhanced vertical-scanning interferometry. PSI uses a monochrome light source and generally is applied to the analysis of a very flat surface, because this method is characterized by sub-nanometre resolution. On the other hand it suffers from phase-ambiguity problems, which limited the usability of PSI to surface discontinuities not higher than $\lambda/4$, where λ is the wavelength of the light used. Besides, a monochrome light source limits the use of the PSI to ranges where continuous fringes can be obtained. In order to overcome this difficulty a new technique called Multiple Wavelength Interferometry (MWI) has been developed and it has extended high-difference limitation successfully. In this method two wavelengths are selected, which allows to increase the dynamic range and at the same time to keep the same resolution. Further increase of the dynamic range is possible when white light is applied (VSI).

Interferometers and microscopes are combined with interferometric microscopy. Through that connection very good resolution and a significant vertical range can be obtained. The interferometer is responsible for scanning on a nano scale, and the microscope head is placed on a micro scale giving a vertical range even above one millimetre. The origin of this technique comes from microdensimetric interferometric fringe analysis of which an example is the FECO method. Its description might be found in Hodgkinson [6], Ratajczyk and Dobosz [7] articles. The FECO, short form of Fringes of Equal Chromatic Order, is a multi-beam interferometer. This kind of fringes is formed when a collimated white light beam is reflected many times from two surfaces, of which the first is the surface of the sample and the second one is a super-smooth reference surface. The light beam after reflection is split by a prism. On this basis, among other things a scanning interferometer FACO [8] was constructed and this construction is acknowledged as a modern interferometric microscopy ancestor.

Nowadays an interferometric microscope in English-language articles is treated as an optical profilometer which operates like a white light interferometer with a microscopic objective which increases the vertical range. Calling this device a profilometer might be misleading, since during the measurement process the fragment of surface is collected as opposed to acquiring individual profile in profilometer. During the operation of this kind of measurement system, the lower beam splitter is used to create a correlogram of each point of the surface, which is next collected by a CCD array. By moving the objective a vertical range point can be found where interference has a maximum value . By monitoring of the position of the objective at the maximum of the interference value, a topographic surface map is created. The principle of vertical scanning is shown in Fig. 3.

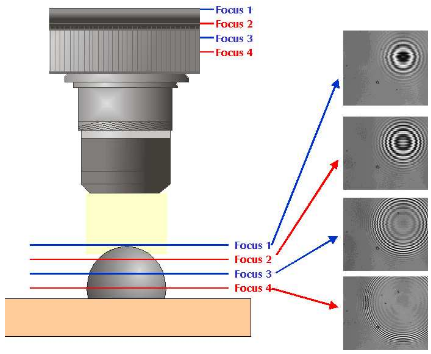

Fig. 3. Principle of vertical scanning in interferometry.

Depending on the objective and field of view (FOV**)** used, in one scan a surface of up to 50 mm x 50 mm can be analysed. Analysis of the area is possible by applying stitching scans, thanks to this option the methodology of this measurement may be compared to a multiprofilometer. The accuracy of stitching scans in the VSI causes a major error when this method is applied, what can be compared to difficulties in accuracy of connection of profiles in a multiprofilometer. Errors occurring during stitching can deform the proper image of the measured surface as a whole [9].

4. Results and discussion

In order to compare results obtained after a definite number of brake cycles, values of the amplitude of parameters of topography (*Sa*, *St*) have been taken into account. In Fig. 4 and Fig. 5 topographic surface images of drum and lining are presented as new elements and after 250 thousand kilometres of covered distance.

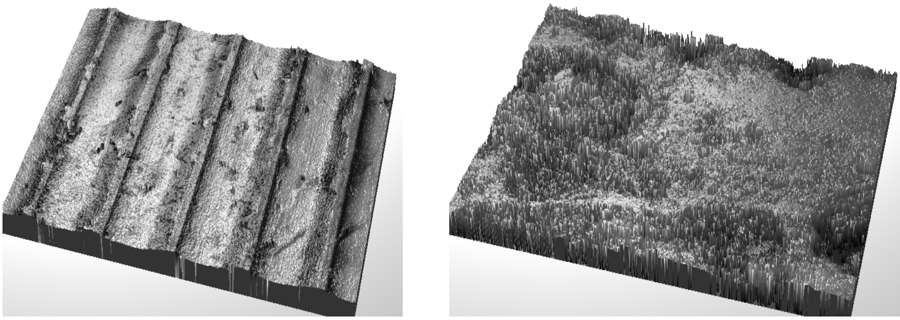

Fig. 4. Brake drum (left) and lining (right), 0 kilometres of covered distance.

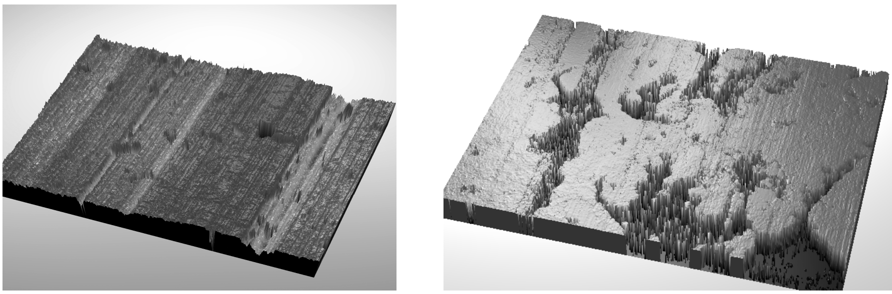

Fig. 5. Brake drum (left) and lining (right) after 250 000 kilometres of covered distance.

Images show how much the roughness of surface has been changed. The drum has totally lost its original periodic character of roughness, moreover areas have appeared in which the surface was almost fully wiped out. An analogous situation is observed with lining where on the predominant part of the surface distinct contact tracks were visible. Selected amplitude parameters of surface stereometry are presented in Table 1.

Table 1. Parameters of roughness of brake element surfaces.

Drum 0:	**Drum 250:**	**Lining 0:**	**Lining 250:**
Sa: 3.10 µm	Sa: 3.40 µm	Sa: 7.49 µm	Sa: 1.76 µm
St: 62.90 µm	St: 104.80 µm	St: 109.47 µm	St: 150.41 µm

Parameter value Sa for a drum not only has not decreased but it has even slightly increased. The change of the character of roughness from periodic to random proves that during contact of the parts of the brake, pieces of material have been removed. In addition, the value of the height of the maximum roughness has increased. In the case of lining, the average height roughness has decreased significantly, what can be observed in Fig. 5. The value of the maximum height of roughness has risen, what is additional proof that pieces of the material have been removed from the surface. In summary, both elements (especially the drum) are still in a condition good enough to be used for further thousands of kilometres before replacement will be necessary.

In Fig. 6 the surface of the brake drum after verification is presented. This is a surface with only 80 thousand kilometres of covered distance. However inappropriate braking especially in the initial phase of operation resulted in the change of surface character and sharp worsening of its performance.

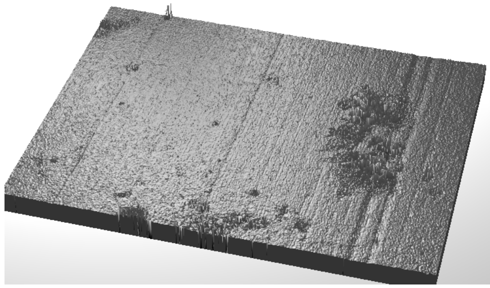

Fig. 6. Brake drum after vitrification, 80 thousands of kilometres of covered distance.

The average height of roughness has also changed meaningfully – the value of parameter *Sa* decreased to 0.55 µm. The maximal height in comparison to the height of a new drum is only marginally lower (*St* is 58.2 µm) what indicates that the deepest valley which still exists on the surface did not participate in the contact and its depth did not change during work. However the capacity of braking of the whole surface is minimal and for safety reasons it cannot be further used.

5. Conclusions

In summary, our investigation showed undoubtedly that the wear process of lining and drum can be described and understood better. A sample which has never been used is characterized by a uniform surface, on the brake drum we are able to detect periodic marks of the machining lathe. This example of lining evidently shows that parameter *Sa* together with distance covered by the vehicle decreases many times faster than in the case of the drum. It proves that this element is worn out first. Increase of the *St* parameter shows that during the operation a decrement in material occurs. The significant changes of temperature which occur during the operation of the vehicle have a big influence on the phenomenon described above. In a sample, after vitrification caused by wrong setting of the brake (the investigation displayed that the braking force was too small), on the drum surface the value of parameters *Sa* decreased sevenfold. This case shows unequivocally that replacement would be necessary or reboring of the drum to the next repair size which is allowed by the brake elements producer.

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