Available online at www.sciencedirect.com
ScienceDirect
Measurement 40 (2007) 28–35
Measurement
www.elsevier.com/locate/measurement

The infrared measurement of form deviations of machine parts in motion

Stanisław Adamczak, Tadeusz Orzechowski *, Tomasz L. Stańczyk

Kielce University of Technology, Mechatronics and Machinery Design, Al. 1000–lecia PP 7, 25-314 Kielce, Poland

Received 18 April 2005; received in revised form 4 May 2006; accepted 9 May 2006
Available online 16 May 2006

Abstract

The thermovision method was applied to assess the type and quality of friction between the mating surfaces of an automotive drum brake. The thermal field on the outer surface of a drum was analysed to determine roundness and waviness profiles of the elements in motion. In the experiment, the distribution of temperature was measured along the outer circumference of the drum employing the infrared technique. The results were compared with those obtained for the inner surface of the drum measured with a Taylor–Hobson Talyrond 73 precise measurement device. The analysis shows that a temperature signal can be used to assess the geometrical structure of machine parts in motion.

Keywords: Thermovision; Form deviation; Temperature; Drum; Brake

1. Introduction

Form deviations of machine elements in motion greatly affect their dynamics and the accuracy of the motion transfer. These deviations are mainly due to errors occurring during the product manufacturing process. Producers are obliged to meet product standards defining what errors are allowable. If defective products are manufactured, the limits must have been exceeded. Products with excessive form errors are rejected during initial or final quality inspection.

Another cause of form deviations is the operational wear of mating elements. The wear depends on a number of factors, yet the most important is temperature. According to Brayan [1,2], the factors affecting the thermal conditions and temperature-dependent production errors, for instance, in machine tools, are classified into six groups: heat produced in the cutting process, energy lost in the mechanical system, the cooling system, change in the room temperature, operation of the machine tool, and the thermal memory effect. The other major factors include the methods of lubrication, cooling, servicing, etc.

Proper temperature is essential for satisfactory performance and reliable operation of devices. An increase or decrease in temperature causes a rise in the drift and operational tolerance of machine parts, which leads to deviations from pre-determined operational parameters and excessive wear. If the temperature is too high, considerable stresses are

* Corresponding author. Tel.: +4841 34 24 334/294; fax: +4841 34 24 340.
E-mail address: todek@tu.kielce.pl (T. Orzechowski).

0263-2241/$ - see front matter
doi:10.1016/j.measurement.2006.05.004

observed. They result in the material failure, cracks, fatigue or creeping. In order to prevent unfavourable thermal phenomena, it is necessary to apply additional cooling systems responsible for temperature stabilization. These extra units, however, make the device more complicated and expensive. It should be mentioned that the impact of changeable thermal conditions on the operation of a device can be reduced at the design stage [3,4].

To assure proper performance of a machine, it is essential to monitor the operational conditions of mating surfaces. Classic techniques of metrological measurement can be employed for the purpose, yet of great disadvantage is the necessity to periodically switch-off or even partly dismantle the machine. The information about the state of a device can be obtained also by using non-destructive methods such as the vibro-acoustic or thermal analysis [5,6]. Today's engineering industry requires that the operational conditions as well as the geometrical structure of mating elements should be controlled continuously. If heat is released on mating surfaces, it is enough to study the temperature field, as it provides us with all the necessary information, also that on the geometry of the elements in contact.

The aim of the study was to present the relationship between the thermal field and roundness and waviness profiles.

2. Subject matter and methodology

In the experiment, automotive drum brakes were analysed employing an inertial test stand. It was necessary to model the mass per vehicle wheel. A revolving mass and a brake drum were attached to the same shaft. The simulation involved bringing the two elements up to a certain initial speed. The braking process began, when the engine driving the shaft was switched-off. As the drum was not covered, the whole braking operation could be easily observed. Depending on the requirements, it is possible to register a number of characteristic parameters, e.g., braking torque, pressure in the braking system, pressure forces on the brake pedal, etc.

The temperature on the outer surface of the drum registered by a thermovision camera was a signal to be analysed in order to assess, for example, the form accuracy of the drum elements. The infrared technique was employed to measure the temperature resulting from the radiation emitted by an object. Moreover, no interference occurs between the sensor and the analysed element, which is the main advantage of this technique. The observation can be carried out from a considerable distance, provided that adequate optical systems are used.

The software that the thermovision camera is equipped with makes it possible to calculate temperature for all points of an element surface basing on measurements of the intensity of infrared radiation. The emission is recorded as colour images forming a thermal map – a thermograph. Different colours and shades indicate different intensity of radiation, and therefore, different temperature.

The radiation that is recorded by the camera is actually not only the radiation emitted by the observed object but also the radiation reflected by other sources situated in the object vicinity. Furthermore, before it reaches the scanner, the radiation is attenuated by the atmosphere and, at the same time, amplified by the gas emission. All the above mentioned factors should be taken into account, if the object temperature is to be determined properly. This parameter is calculated basing on the infrared radiation intensity measured at a given point of the surface. The relationship between the intensity of the radiation emitted by object $I_{ob.}$ and that reaching the scanner I_c is represented by the following simplified formula [8]:

$$I_c(\lambda) \cong I_{ob}(\lambda)\tau(\lambda) + \tau(\lambda)[1 - \varepsilon(\lambda)]I_s(\lambda) + [1 - \tau(\lambda)]I_a(\lambda), \tag{1}$$

where τ – coefficient of atmosphere transmittance–transmissivity, ε – object emission factor–emissivity, λ – wavelength, I_s – intensity of the radiation emitted by the objects located in the vicinity, I_a – intensity of the radiation emitted by the atmosphere.

Eq. (1) takes account of the corrections necessary for the proper determining of temperature. In the experiment, it was essential to correct the emissivity of the outer surface of the drum, $\varepsilon = \varepsilon(\lambda)$. It was dependent on the properties of the object surface as well as the wavelength of radiation registered by the detector of the thermovision camera applied. The impact of the other factors was negligible.

The Swedish AGEMA Thermovision® 900LW camera used for the measurements is capable of registering radiation in a spectral range of 8–12 μm, the operational temperature being from −30 °C to 1500 °C. The device sensitivity at 30 °C is 0.08 °C. A thermal image of an object consists of 136 lines, 272 points each. When revolving elements such as wheels, spindles, etc. are analysed, the scanner