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# A Method of Studying Temperature Distribution in Depth of Surface Layers of Rubbing Elements

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The aim of the study was to develop a new method of recording temperature fields within thin surface layers of friction pairs' elements. The materials under study were steel, titanium and aluminum alloy as well as silica glass and sapphire. When studying temperature distribution in depth of the bodies in contact the pin-on-disc geometry was used. Testing regimes were as follows: the sliding velocity was varied within 10 – 80 m/s range, the nominal pressure was 0.06 – 0.5 MPa. Experiments were carried out using a setup realizing optical-electron scanning technique and comprising a high-speed friction machine and a system for temperature field recording. The latter consists of an optical-electron transducer, a monitor, a video tape-recorder, an amplifier, a device of image brightness oscillogram forming and a digital storage oscillograph.

*Keywords*: friction, temperature, temperature distribution, surface layers.

## 1. INTRODUCTION

Fast-running thermal processes on actual contact spots are among the main factors governing the nature of solid wear and its rate. This is the reason why heat problems hold an important position in tribology. They were pioneered by Blok [1] who has highlighted the flash temperature concept and paved the way for further research in this field.

Regularities of thermal processes have been best studied theoretically [2 – 4]. Experimental investigations are rather complex, that's why they deal mainly with measuring maximum temperature in the friction zone. Numerous methods and means of direct temperature measurements (e.g. thermocouples, photocells, thermal indicators) either average the measured variable over the contact area or introduce errors in the process under investigation.

A technique described by Quinn and Winer [5] has been developed to study thermal effects in the contact between bodies one of which is transparent. It provides data on the dimensions, shape and maximum temperature of local heat sources.

However, a precise estimate of the temperature by the comparison of photographed colors of the heated reference material and contact spots depends, as the authors pointed, on exposure time during filming and quality of the photos made.

Quick-response photoelectric pyrometers are advantageous as to the recording temperature flashes whose duration is microseconds [6] although they are inapplicable in recording temperature distribution both over a single contact spot and in depth of rubbing bodies. So, the problem deserves a comprehensive study.

## 2. EXPERIMENTAL

### 2.1. Test geometry

The pin-on-disc geometry was used when measuring temperature distribution in depth of rubbing bodies (Fig. 1, a). In this case a sapphire plate 1 mm thick or a glass one 3 mm thick having rectangular section contact the flat surface of a rotating metallic or glass disc 7 mm thick and 180 mm in diameter.

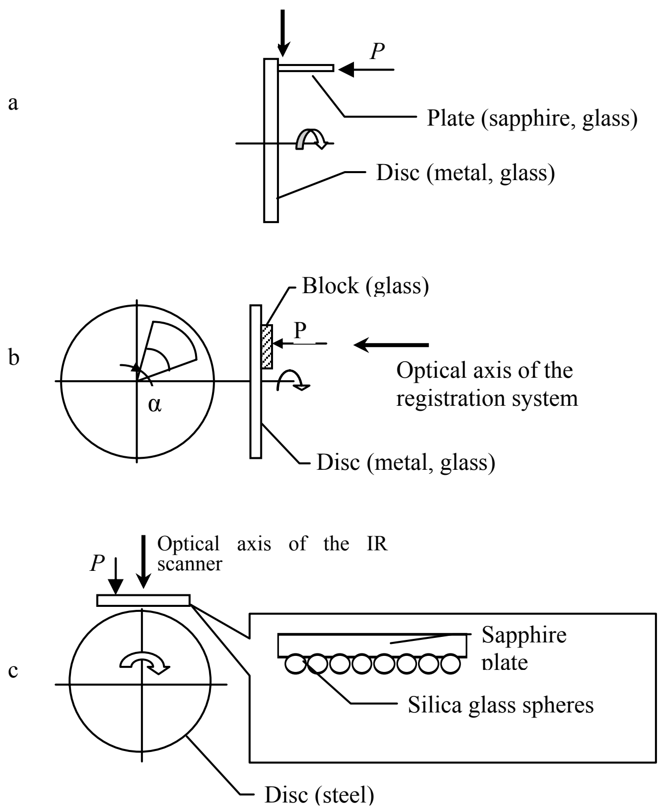


**Fig. 1.** Test geometry

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When determining flash temperature and average surface temperature we used the geometry similar to that realized in disc brakes, i.e. a block shaped as a circular sector contacted the flat surface of the disc (Fig. 1, b). Specimens with different values of α angle were tested that allowed us to study friction pairs having overlapping factor within 0.08 – 0.33 range. The block was made of a material with low heat conductivity (silica glass 5 mm thick) while discs for rotating specimens 180 mm in diameter and 7 mm thick were made of different metals (steel, titanium, and aluminum) and silica glass. The same contact geometry was used to study heat dissipation from lateral surfaces of stationary specimens of various shapes. These specimens were made of silica glass and steel 1.5 mm thick and had equal areas of the surface being in contact with the counterbody. In these experiments the optical axis of the registering system was parallel to the disc rotation axis as it is shown in Fig. 1, b but the optical-electron transducer was placed form the side of the transparent disc which transmitted heat radiation from the contact zone.

When studying thermoelastic instability of friction contact the following geometry was used: the lateral surface of a steel disc – the surface formed by asperities of various height (a mono-layer of glass spheres having different diameter and fixed with glue on a sapphire plate) (Fig. 1, c).

## 2.2. Experimental set-up

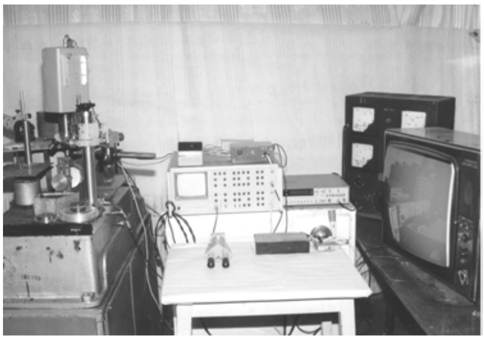
The developed set-up intended to study temperature fields in the friction zone realizes optical-electron scanning technique. The set-up consists of two main units, viz. a high-speed friction machine and a system of temperature field registration (Fig. 2). The friction machine allows sliding velocity to be smoothly varied within the 1 – 100 m/s range. Friction coefficient is recorded by strain gages connected to an amplifier TA-5 that transmits the signal to an oscillograph.

The temperature field registration system incorporates an optical-electron transducer (OET), a monitoring device (MD), a video tape-recorder (VTR), an amplifier (A), a device to form oscillograms of image brightness (DFO), and a digital oscillograph C9-8 (DO).

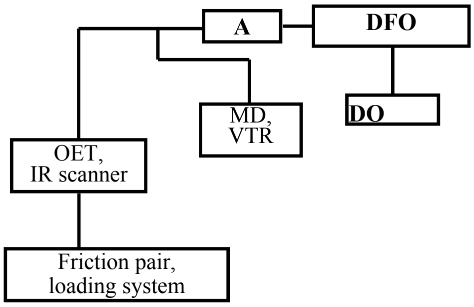
The optical-electron transducer comprises a turret head, an accessory lense (magnification 4 – 25×) fastened to the head so that to adjust it in the vertical direction, and a TV camera KTP-62 whose optical axis coincides with that of the lense. The transducer is locked to a special rack which makes it possible to move it in vertical and horizontal directions and to rotate it through 90 deg.

The monitoring device is a TV monitor with low frequency signal connected to the OET through an amplifying and commutating unit.

Heat radiation induced in the friction zone passes through the lens, than the TV camera generates electric signal. The latter is converted into high frequency signal and input into the MD forming a TV image of the contact zone. The image is recorded by the VTR. The DFO connected to the VTR output forms the image brightness distribution along two sections (for example, along and perpendicular the sliding direction). The distribution is displayed by the DO as signal measured in mV.



a




b

**Fig. 2.** Exterior view (a) and flow (b) of the experimental setup

When using the geometry shown in Fig. 1, a it is possible to determine temperature under the surfaces of both stationary and moving specimens. The temperature is measured along the marker line perpendicular to the sliding direction. The marker line can be moved lengthwise along the sliding line over the image of a contact site portion being examined (Fig. 3). In reality profiles of the mated surfaces are not seen since the resolution of the set-up with respect to linear dimensions is 5 μm that exceeds arithmetic average roughness by one or two orders of magnitude. Because of this we cannot determine is the marker positioned either at the center of a contact spot or between spots. A number of spots may be located in the section of the friction track selected by the marker; therefore the temperature averaged over these spots is registered.

To study the distribution of subsurface temperature across the friction track width, the optical-electron transducer was rotated through 90 deg so that its optical axis was parallel to the sliding velocity vector. The temperature was measured at a given depth under the surfaces of both specimens in various sections of the track selected by the marker, then temperature distribution across the track width was plotted.

The set-up was calibrated with an optical pyrometer. The latter was used as a standard radiation source and mounted in the visual field of the OET instead of the friction pair. Brightness temperature of the source was converted into real temperature with account for the reflection capacity of the materials under study.

The average surface temperature in the friction zone was determined using the geometry depicted in Fig. 1, b but the OET was replaced by a photodiode FD-119 inserted into a Dewar vessel and cooled to –196 °C.

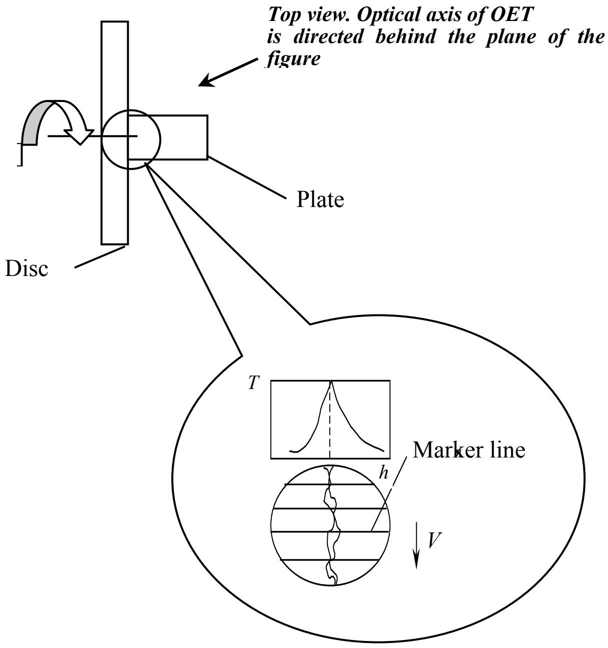



**Fig. 3.** Schematic diagram of subsurface temperature measurements

Heat radiation generated in the friction zone passes the lens and hits the photodiode which converts radiation energy into electric signal. The signal income to the input of the amplifier and then to the oscillograph. This devise is capable of measuring temperature exceeding the ambient temperature by 1 – 5 °C. the device was calibrated by the black body model. The device optical axis was made coincident with the geometric axis of the model. The lens was focus on the radiating surface. Then the model was heated (the temperature was measured with a thermocouple) and values of the photodiode output signal $U$ were recorded.

To study thermoelastic instability in the contact between a flat surface and the surface having a regular relief an IR scanner "TERMOVISION-470" ("AGEMA", Sweden) was equipped with an additional optical system. The scanner registers radiation within the 6 – 12 μm range that corresponds to the temperature range from –30 to 1500 °C.

## 4. CONCLUSIONS

An experimental method has been developed to study thermal processes occurring in mated materials at high-speed friction. The method makes it possible to determine both the temperature of local contact spots (flash temperature) and temperature distribution in depth of rubbing bodies.

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