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Calibration features of a thermoelectric detector using pulsed laser exposure

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The work is devoted to the peculiarities of conducting calibration procedures for thermoelectric detectors via setting a pulsed laser load. Thermoelectric detectors and their sensitive elements based on Cr and GeTe crystallites were studied. A laser diode with a radiation power of up to 30 watts was used as a radiation source. A high-speed photodiode was used to assess the overall sensitivity of the sensor. The aspects of performing calibration procedures described in the work make it possible to obtain volt-watt characteristics for various sensitive elements and determine the degree of reliability of the values of heat fluxes produced by them when used in a pulsed gas dynamic experiment.

Keywords: thermoelectric detector, thermal EMF, pulsed laser diode, photodiode, calibration.

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Measurements of the surface temperature and the heat flux play an important role in heat transfer studies. Terrestrial experimental facilities (e.g., shock tubes) provide an opportunity to simulate various shock-wave processes in gas dynamics that proceed in actual spacecraft flight conditions. It is crucial for such studies to obtain reliable values of heat flux to the surface of the model under examination, which is made difficult by the high values of specific enthalpy in the incoming gas flow (several tens of MJ/kg) and short time intervals of operation of the facility (less than several hundreds and tens of μs) [1]. In other words, the model is subjected to a sudden strong thermal load on a very short measurement time scale. Experiments with a thermal load produced by a laser with a known output power are carried out to calibrate sensors to such conditions [2]. The laser calibration method is the best suited for pulsed gas-dynamic processes, since it allows one to supply the required heat flux to a sensor within a very short time. The used radiation power value is fixed and may be adjusted rapidly during calibration. The resulting volt–watt characteristic of the sensor is used for its subsequent application in the corresponding gas flow regimes: short time intervals and high temperature loads [3].

The present study is a continuation of [4] and is focused on the issue of calibration of thermoelectric detectors (TDs) with various sensitive elements that were proven to remain efficient in intense pulsed gas-dynamic flows [5–7]. The sensitive TD layer is a tilted condensed film formed on a heat-conducting dielectric substrate via vacuum oblique deposition. Owing to thermal motion, charge carriers produce a potential difference between the upper and lower boundaries of the layer, which is recorded in the experiment [8].

A laser diode with a radiation wavelength of 970 nm was used as a radiation source in the calibration stand; a pulsed operating mode was set at a radiation power in excess of 10 W. A high-speed photodiode with a time resolution of 5 ns was introduced into the optical circuit to monitor the response time of the sensor and the signal rise times.

The presented features of calibration procedures allow us to obtain volt–watt TD characteristics that help characterize more accurately the thermal processes accompanying high-intensity shock-wave interactions in a pulsed gas-dynamic experiment. When calibrating TDs, one needs to determine both the linearity range of sensors and their speed performance. Complete data on the frequency characteristics of the radiation source setting the thermal load are needed for this purpose. The circuit with a high-speed SFH203P photodiode operating in the current generator mode (Fig. 1, *a*) was used to estimate the time needed for the diode laser to reach the specified operating parameters.

The assembled system records changes in the luminous flux magnitude with a time resolution finer than 100 ns. The oscilloscope records illustrate the frequency characteristics of the laser load (solid curve in Fig. 2, *a*) that were used in further calibration of the sensors. The leading-edge time, which reflects the characteristic parameters of a radiation pulse from the laser diode, is on the order of 3 μs.

The signal generator produces control pulses for the laser diode (dashed curve in Fig. 2, *a*). Next, laser radiation in the form of a parallel beam (solid curve in Fig. 2, *a*) with its intensity repeating periodically the pulse shape of this control signal is fed into the optical circuit (Fig. 3).

A diffuse scattering element in the form of a 4-mm-thick plate made of milky polymethyl methacrylate is mounted

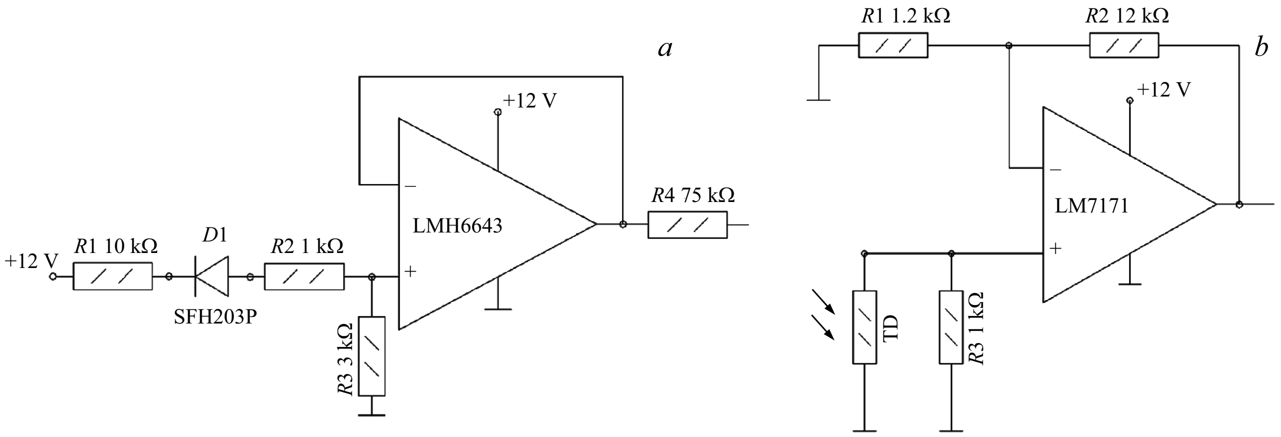

Figure 1. *a* — Circuit diagram of the sensor recording laser radiation parameters with a high-speed SFH203P photodiode operating in the current generator mode with a repeater via an LMH6643 operational amplifier. *b* — Circuit diagram of the ten-fold signal amplifier from a thermoelectric detector utilizing an LM7171 operational amplifier.

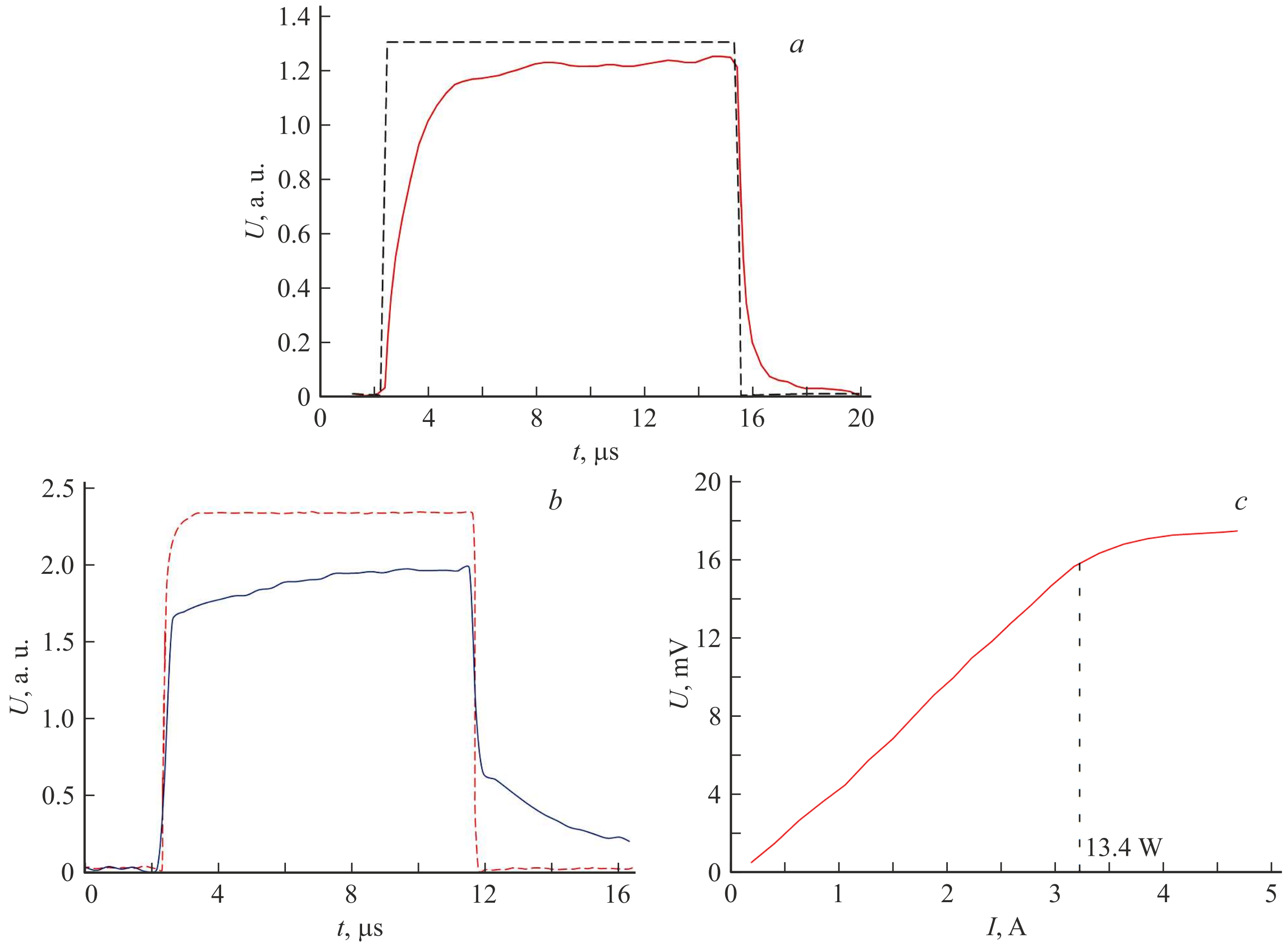

Figure 2. *a* — Time dependences of the photodiode voltage and the current generator voltage. Dashed curve — control current pulse of the laser diode; solid curve — photodiode signal revealing the characteristics of an incoming laser pulse. *b* — Time dependences of the thermoelectric sensor voltage (solid curve) and the photodiode voltage (dashed curve). *c* — Dependence of amplitude values of the TD potential difference on the laser module current.

at a distance of 90 mm from the collimator. This scattering optical element is needed due to the emergence of a speckle structure. Owing to this effect, generated laser radiation may have a highly non-uniform intensity density profile.

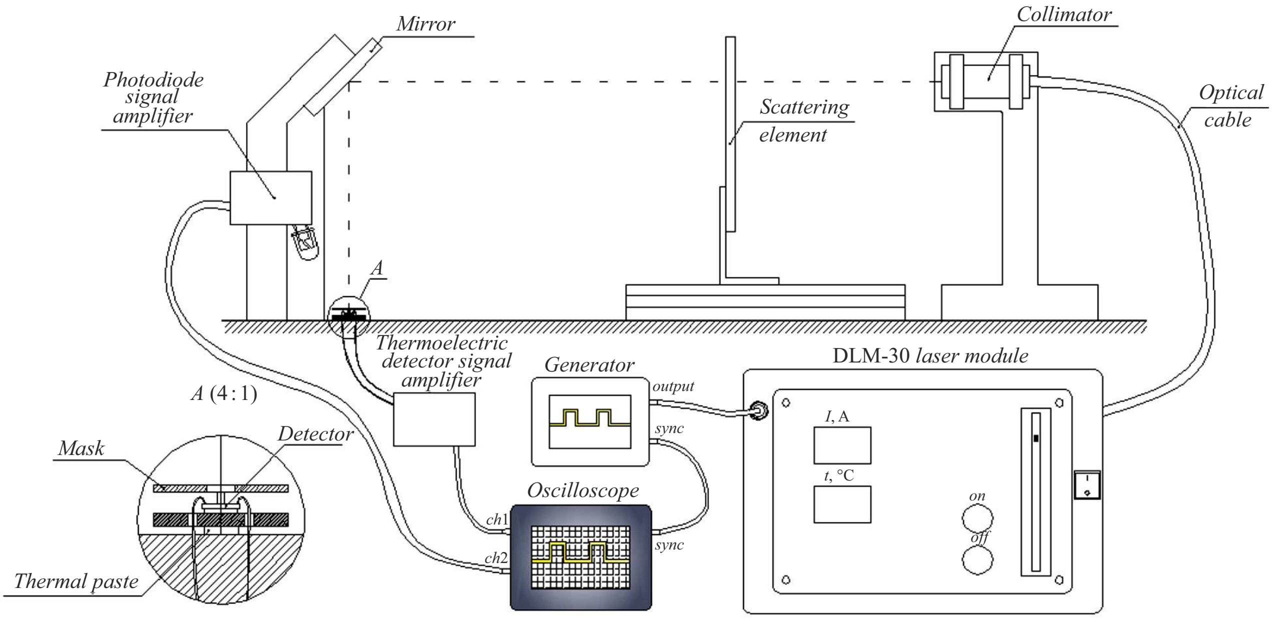

Figure 3. Diagram of the experiment on calibration of thermoelectric detectors with a laser load.

A mirror with a gold coating is mounted at a distance of 250 mm from the collimator to reflect the laser beam vertically downward. The examined sensor, which is a rectangular plate 14×5 mm in size with a thickness of 1.5 mm (the sensitive element dimensions are 5×5 mm, and its thickness is $< 0.3\,\mu$m), is mounted at a distance of 100 mm from the mirror. An anodized aluminum mask with an aperture 3 mm in diameter was fabricated for experiments. To measure TD signals, a 1 kΩ resistor was installed parallel to its output. The TD signal was fed to the oscilloscope through an operational amplifier with a ten-fold gain and a delay time of 42 ns (Fig. 1, *b*).

Figure 2, *b* presents the photodiode data (dashed curve) that reflect the rise/fall parameters of a laser radiation pulse arriving at the Cr-based TD. The dependence of amplitude values of the TD potential difference on the laser module current (i.e., on the intensity of laser radiation) is shown in Fig. 2, *c*. To verify the relation linearity, the laser radiation power was measured for each plot point with a Synrad Power Wizard 250 meter, and its value reaching the sensor was then recalculated. It can be seen that the readings of the Cr-based TD cease to be proportional to the incoming laser load and become nonlinear when the power exceeds 13.4 W (at a radiation flux density of approximately 53 W/cm^2). The observed value of thermal EMF produced by the TD corresponds to the distribution of charge carriers established between the upper and lower planes of the sensitive element. When a higher thermal load is applied, the thermal equilibrium of the TD structure is disrupted, and it starts to degrade [8]. Similar data were obtained for a TD based on GeTe films. The circuit used for signal measurement in this case was similar to the one shown in Fig. 1, *b*, but a hundred-fold gain was set, since the signal from such structures turns out to be an order of magnitude weaker under the same thermal load [4].

Calibration experiments performed at the assembled stand revealed the following features of voltages generated by GeTe- and Cr-based TD sensitive elements under a pulsed laser load:

— all elements produce a signal proportional to absorbed laser radiation;

— the obtained data correspond to the model of thermal EMF generation in a sensitive TD layer due to the difference between temperatures at its front and back surfaces (see [4–7] for details).

In contrast to [4], blackening of the surface of elements was not performed, since we were interested in the time resolution of fronts of the output signal. A photodiode with a high temporal resolution, which made it possible to determine the rise/fall times of laser pulses, was used for this purpose. The TD signal delay, which was found to be shorter than a microsecond in our experiments, is due to the thickness of the sensitive element and the onset of thermal relaxation in it. Higher values of the time response of sensors to thermal load are due both to the absorption of radiation by the sensor substrate and the generation of thermal EMF in the reverse direction and to the degree of blackness of the upper surface of the sensitive element.

The assembled stand will be used in further experiments aimed at refining the thermal EMF parameters in the case of shorter and more intense laser pulses. The obtained data should make it possible to determine the TD operating modes under high thermal loads.

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Conflict of interest

The authors declare that they have no conflict of interest.

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