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Note

Development of a Millisecond Pulse-Heating Apparatus[1]

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A millisecond pulse-heating apparatus is presently under development at the Harbin Institute of Technology (HIT). The design is based on systems previously developed both at NIST (U.S.A.) [1, 2] and IMGC (Italy) [3] for the measurement of several thermophysical properties with millisecond time resolution. The apparatus uses rapid resistive self-heating of a strip-shaped specimen from room temperature to a pre-chosen maximum temperature. Power is furnished by a subsecond-duration electrical current pulse through the specimen. Simultaneous measurements are carried out for several quantities. The maximum current is up to 2000 A. Experiments are performed on strip-shaped specimens with the following typical dimensions: 80 mm in length, 10 mm in width, and 1 mm in thickness. The specimen is contained in a large vacuum chamber (bigger than 300 mm in both diameter and height) whose inner wall is coated with a nonreflecting paint. A special designed high-speed pyrometer will be used to measure the temperature of the specimen through one of two quartz windows of the chamber. The heat capacity, the electrical resistivity, the total hemispherical emissivity, and normal spectral emissivity of the specimen are measured by using this apparatus for various materials.

KEY WORDS: dynamic measurement; high-speed pyrometer; pulse-heating method; thermophysical properties.

1. INTRODUCTION

In the last thirty years, pulse-heating techniques have become accepted methods for the accurate measurement of several thermophysical properties (heat capacity, electrical resistivity, total hemispherical emissivity, and

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spectral emissivity, etc.) of electrical conductors in the high temperature range [1–3]. Now several pulse-heating apparatus have been developed in some countries such as the U.S.A., Italy, etc. A millisecond pulse-heating apparatus is presently under development at the Harbin Institute of Technology (HIT). The design is based on systems previously developed both at NIST (U.S.A.) and IMGC (Italy) for the measurement of several thermophysical properties with millisecond time resolution. The first stage of our project was the development of an apparatus capable of fast and accurate properties measurements of the sample. This paper gives a description of the experimental setup.

2. MEASUREMENT TECHNIQUE

The measurement technique is similar to the technique developed at IMGC, which is a high-speed version of an integrating sphere reflectometer of the comparison type (Fig. 1) [4, 5]. The radiance temperature on one side of the strip is measured by a high-speed pyrometer. A modulated beam generated by a laser diode is reflected by the other side of the strip facing the sphere. The reflected beam is collected by the integrating sphere, transmitted through the optic fiber and measured by a silicon detector placed outside of the experimental chamber, in order to replace the detector conveniently. The typical dimensions of the integrating sphere is: 80 mm in diameter and 2 mm in thickness. The measurement technique is not

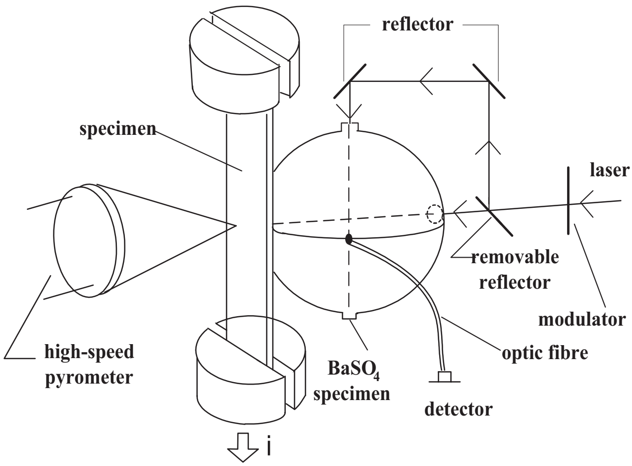

Fig. 1. Schematic of pulse-heating experiments using strip specimens and an integrating sphere.

absolute and requires therefore an appropriate reflectivity reference standard to take into account different factors (including the geometry of the integrating sphere and possible imperfections in its internal coating). This is done in a separate calibration experiment using reflectors placed in an appropriate holder to reflect the collimated beam to a $BaSO_4$ specimen (Fig. 1) and measuring the silicon detector output for all the temperatures of interest in these experiments. In the calibration experiment, the removable reflector is set at an appropriate degree, so the collimated beam is directed toward the reference specimen. In the practical measurement, we control the reflector to direct the collimated beam toward the measured specimen.

A numerical lock-in technique is used to discriminate between the reflected modulated beam and the radiation emitted by the specimen itself at high temperature. The modulation frequency of the laser diode is 1 kHz, and the output of the integrating sphere detector is recorded with a 16-bit data acquisition system operating at 100 kHz. Each modulation is defined by 100 data points, and the changes in the amplitude of each modulation are directly related to reflectivity changes of the specimen.

3. MEASUREMENT SYSTEM

The millisecond pulse-heating apparatus consists of an electric power circuit, associated measuring and control circuits, and various components and instrument.

3.1. Pulse Power Circuit and Experimental Chamber

The pulse power circuit includes the specimen in series with a battery bank (12 V), a standard resistor, and a high speed switching system. The heating rate of the specimen and the shape of the current pulse are controlled by increasing or decreasing the number of batteries of the battery bank. The switching system is computer operated through MOSFET drivers and is opened and closed in sequence with a predetermined time interval.

The experimental chamber contains the specimen, the integrating sphere, the clamping electrodes, an expansion joint, voltage probes, and other auxiliary components. The inner wall of the chamber is coated with a non-reflecting paint. The focussing of the pyrometer on the specimen is achieved through a porthole with a fused-silica window. On the other side of the chamber there is another window so the modulated beam can reach the specimen. An expansion joint allows expansion of the specimen in the lower direction. The chamber is designed for conducting experiments with the specimen in vacuum using a turbo-molecular vacuum pump. The specimen is a strip of the following nominal dimensions: 80 mm in length, 10 mm in width, and 1 mm in thickness.

3.2. High-Speed Pyrometer

The temperature of the specimen during a pulse experiment is measured with a high-speed pyrometer designed and constructed specifically for this apparatus on the basis of the multi-wavelength pyrometer that has been constructed in cooperation between HIT and University of Rome "Tor Vergata" [6]. It operates at a fixed distance from the target (300 mm). The response time of the pyrometer is less than 5 μs, and the pyrometer covers a temperature range from 1000 to 4000 K using an auto-ranging feature. Pyrometer auto-ranging is accomplished by inserting three amplifiers connected in series between the pyrometer signal output and the data acquisition system, and each amplifier output signal is recorded with the data acquisition system. One of them is selected and analyzed by appropriate software after the experiment.

3.3. Digital Data Acquisition System

Electrical signals from the pyrometer as well as those corresponding to the current through and the voltage across the specimen are recorded as a function of time. This is accomplished through the use of a 16-bit data acquisition system capable of one measurement every 10 μs. It consists of a sample and hold array and a high speed A/D converter. The data acquisition system is controlled by a PC.

4. CONCLUSION

The development of a millisecond pulse-heating apparatus is aimed at the measurement of thermophysical properties for military and space materials. In the present stage, the experimental apparatus has been constructed and measurements are performed on various materials such as niobium, tungsten, etc. The experimental results will be published in a later paper.

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