N90-17924

NASA NCTM WORKSHOP

January 17-19, 1989
Pasadena, California

Summary of Subsession II
(Dynamic Response for Thermal Control and Measurement and Fast Radiation Thermometry)

R. L. Shepard (ORNL) and A. Cezairliyan (NIST)

Two-Color Ratio Pyrometer Temperature Sensing for Dynamic Control of MEL

A preliminary evaluation was made by ORNL of a two-color ratio pyrometer (TCRP) for temperature control in the Modular Electromagnetic Levitation (MEL) experiment. A discussion was presented by Eric Spjut at the 1987 NASA Non-Contact Temperature Measurement Workshop (NASA Conf. Publ. 2503, pp. 182-213) in which he described the non-linear characteristic of the time response of TCPs. We replicated his model and results and note that the non-linear response behavior is minimized for small temperature steps at high temperatures. We then used the predicted response in a model for a proportional or integral feedback controller and predicted the control characteristics for heating and cooling a 5-mm diameter sphere of niobium at high (1500-2750 K) temperatures. The analysis shows that for a slow (25-ms) time response for a commercial TCRP, overshoots of several hundred kelvins will result from a 100-K decrease in the setpoint, and temperature tracking errors of 14 to 45 K will occur for control temperature ramps of 1000K/s. For a fast (<0.1 ms) time response, the overshoot and ramp response errors are largely eliminated.

Additional analysis should be performed and provisions for decreasing the TCRP response time should be employed before considering the TCRP as a sensing element for feedback heating control in the MEL experiment. Such a control system would also require the incorporation of an algorithm which describes the non-linear response characteristics of the TCRP, and probably the present and intended temperatures as well. In spite of many concerns about the universality of the TCRPs independence of the samples emissivity, the TCRP should be considered as a control sensor, but its unusual dynamic response must be recognized. An alternative approach might use only one channel as the control signal, normalized to the correct temperature at steady state by two-channel ratio.

Fast Radiation Thermometry

A review of the development and operation of millisecond and microsecond resolution radiation thermometers (pyrometers) at NIST - the National Institute of Standards and Technology (formerly National Bureau of Standards) was given at the First Non Contact Temperature Measurement Workshop in 1987.

In this session, progress made at NIST in fast pyrometry since the last Workshop was summarized. Special emphasis was placed in the development of the fast spatial scanning pyrometer. This pyrometer is capable of measuring the spectral radiance temperature at 1024 points along a straight line in the target field about every one millisecond. The pyrometer utilizes a self-scanning linear array of silicon photodiodes as a detector. The electrical signals are recorded with a digital oscilloscope every one microsecond (12 bits) and processed with a computer.

The preliminary tests indicate satisfactory stability and reproducibility. At 2000K, imprecision is about 1 K and estimated total uncertainty is 4 K. Work is in progress to further assess the operational characteristics of the pyrometer. It is expected that the spatial scanning pyrometer will become completely operational by the end of 1989.

The spatial scanning pyrometer will permit performance of experiments which have not previously been possible: (1) accurate determination of the temperature uniformity or nonuniformity in pulse-heated specimens in transient experiments. This pyrometer is likely to be very useful also in measurements of temperature distribution in specimens under steady-state conditions. The short scanning times will minimize the effect of some of the changing conditions and improve the diagnostic procedures.

NASA NCTM WORKSHOP
January 17-19, 1989

Summary Comments

R. L. Shepard (ORNL)

Noncontact temperature measurement science as applied to NASA materials research and space applications is a multi-dimensional problem. Such applications include (a) various materials: metals, semiconductors, insulators, and organics, (b) a spectrum of temperatures ranging from 300 to 3000 K, (c) properties such as solidification and crystallinity, and (d) spatial requirements including very fine detail, imaging, and mapping.

It is clear that there is no universally applicable temperature measurement technique that can cover all the applications. Development of a wide choice of diverse techniques is essential in meeting the varied requirements. While research studies reported at this meeting provide many phenomena related to and useful in thermometry, each technique is strongly application dependent. Many of these applications require a specialized knowledge of the technique and of the application requirements to be successfully used in thermometry. Workshops such as this provide an essential vehicle for transporting such knowledge between the developer and the user, and in identifying applications for which no successful thermometry technique has been developed.

NASA is to be commended for supporting the workshop and the studies which were reported. These studies have produced several new and potentially useful thermometry techniques that were developed since the last workshop held in Washington in 1987. These new studies include surface modulation reflectance in semiconductors, UV laser fluorescence, Raman scattering, ellipsometry, and Johnson noise. A recurring theme was the application of multicolor radiation thermometry and its pros and cons, with some encouraging reports of success in some applications. Additional emphasis appears in the use of laser and fiber optic technology.

Problem areas reported at the meeting or inferred from the presentations include (a) accurate noncontact measurements at temperatures below about 1000 K, (b) inference of bulk temperatures from surface temperature measurements, (c) competing requirements for high temperature accuracy and fast response time, (d) application of discrete or large-area temperature determinations to thermal imaging, and (e) development of related techniques for calorimetry, phase identification, and crystallinity.

One specific application problem still remains unsolved. There does not appear to be any one radiometric method that can provide an accurate non-contact measurement of the surface temperature of a molten metal sphere without some knowledge or assumption about the metal's emissivity, the shape of the sphere, and its surface texture. The problem is compounded by two additional practical considerations: (a) the effects of the speed of response of the measurement system on the temperature control and (b) the occlusion of the radiation by window fogging. Four general methods have been proposed: (1) multicolor pyrometry, (2) brightness pyrometry supported by reflectance measurement, (3) brightness pyrometry supported by ellipsometry, and (4) very short wavelength ("high power of T") pyrometry. Each have been used successfully in some applications, but each has some limitations or implicit assumptions that limit its application to the temperature measurement of a molten metal drop. Multicolor pyrometry (1) is reported to be susceptible to large temperature errors if the functional relationship of emissivity to temperature or to wavelength is not simple, well-behaved, and continuous. It has however been used at Purdue, MIT, Georgia Institute of Technology, Vanderbilt, and Physical Sciences Inc. to provide good temperature accuracy in some applications. Laser reflectance (2) has been used by workers at Rice and JPL to obtain normal incidence emissivity for correcting brightness measurements, but its application to spherical, irregular, or rough surfaces presents some problems. Ellipsometry (3) has been used at Rice and Intersonics to correct brightness measurements with notable success, but it requires off-normal incidence and very smooth surfaces. Very short UV radiometry (4) minimizes the error in temperature due to an uncertainty in the emissivity, but is apparently difficult to implement in practice. Additional progress could be made in developing each of these techniques. Several (2 and 3) would profit from a variable wavelength laser that would encompass the effective wavelength of the brightness pyrometer. Each will be difficult to employ for measurement of a moving, pulsating, or dancing metal sphere. The laser reflectance technique now seems most likely to be used in near-term applications, but it might be coupled with one of the other methods (e.g., two-color ratio pyrometry) to reduce the temperature uncertainty and provide temperature control system signals.

A general problem in the NCTM program is the validation of data produced by various investigators, which highlights needs for test method, calibration, and material property standards. Calibration capabilities of the NIST were addressed by Barry Hillard, and materials properties were addressed by C. Y. Ho of Purdue. Test method standards do not appear to be well supported.

Particular problems for transfer of terrestial laboratory techniques to space applications include (a) miniaturization and remote operation of equipment, (b) interfacing of temperature sensors with control systems, and (c) management, storage, and transmission of copious amounts of data.

The workshop produced a sense of optimism about our abilities to measure temperatures in many exacting and difficult applications. It appears that the imminent problems to be faced in the NASA program are the engineering application of these techniques to the control and data production in specific space missions.