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An Apparatus for Measuring the Thermal Conductivity of Cast Insulation Materials

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well-received broadcast station (800 kHz, 50 kW) was tuned in using a pocket radio, and recorded via microphone on one channel of a two-channel tape recorder while the seismic signal was recorded on the second channel. Simultaneously, using a similar radio and tape recorder at a base station, the same radio transmission was recorded, but a constant 30 Hz tone from an oscillator was recorded in place of the seismic signal, to calibrate the radio transmission record.

To use the data, analogue displays of the signals recorded at the field sites and the base station were prepared, using a two-channel strip-chart recorder. By trial, it was found that using a 600 Hz bandpass filter on the radio playback signals adequately reduced recorder pen chatter while retaining characteristic details of the audio waveforms necessary to correlate them. Representative records taken at two field sites and at the base station are shown in Fig. 1. The vertical lines at *A* and *B* mark corresponding points on the radio playback traces, chosen for convenience with respect to important features of the seismic traces. The elapsed time between instants *A* and *B* was found to be 1.30 s, by counting cycles of the 30 Hz reference signal.

To minimize costs, we used the least expensive radios and recorders we could purchase. In consequence, the audio quality of the reception and recording was usually quite poor. Nevertheless, there was no difficulty in correlating the analogue traces as described. Speech records provided the most distinctive and useful patterns, while monotonous music was the least satisfactory. A peak detector circuit was tested as a replacement for the 600 Hz filter, with good results, and this approach will be developed in future work with the method. For the calibrating frequency it may be convenient to use the ac power line frequency, either directly or reduced by a divide-by-*n* digital circuit. Similar circuits could be used to generate calibration pulses from the broadcast station carrier wave.

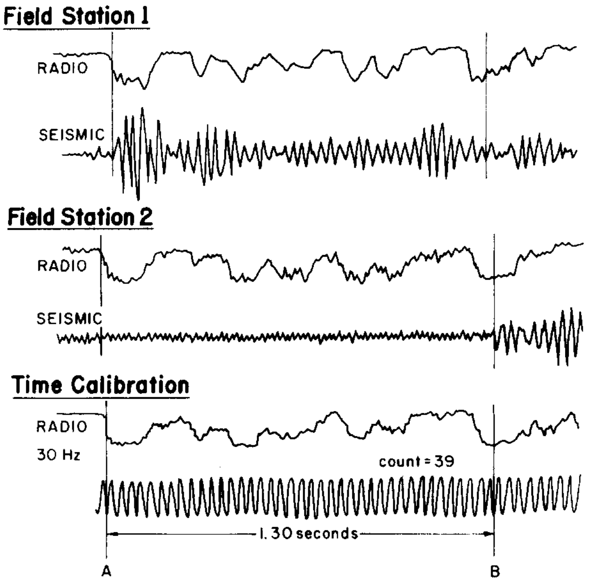

FIG. 1. Strip chart records of tape recordings made at two field stations and the time base station, allowing correlation of the radio voice signal traces as shown.

[1] D. A. Lapierre, M.Sc. Thesis, McGill University, Montreal, Canada, 1978.

An apparatus for measuring the thermal conductivity of cast insulation materials

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A steady-state apparatus has been developed for measuring the thermal conductivity of cast materials. The design has employed a novel thermal symmetry arrangement which can permit total electrical isolation of the test material from its surroundings.

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Thermal conductivity can be measured using a variety of transient and steady-state techniques.[1] Each technique or configuration has its own particular advantages and limitations, and none is universally accepted. The requirements imposed by cast materials are unusual, because of their impact on apparatus maintenance. The purpose of this note is to describe the preliminary design and evaluation of a steady-state apparatus for measuring the thermal conductivity of cast insulations. In addition, modifications of that apparatus will be discussed which enable it to measure the thermal conductivity of cast explosive materials, while maintaining total electrical isolation.

Wilkins[2] has presented many of the design details for this apparatus, including thermal modeling, error analysis and evaluation of results. The apparatus is

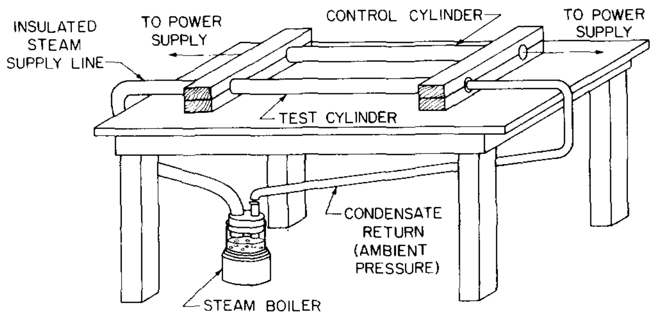

FIG. 1. Schematic diagram of thermal conductivity apparatus.

shown schematically in Fig. 1. The design is based on the principle that two cylinders with identical external dimensions and surfaces will experience the same heat transfer rates when their surface temperatures are the same. By measuring the heating rate to one cylinder, the steady-state heat flux through the material in the other cylinder was known. Two identical pipes with outside diameters of 5.43 cm (5.08 cm ID's) were mounted between supports as shown. Exposed pipe lengths were 76 cm, and the end supports were made of wood. The pipe axes were parallel and 25 cm apart. One pipe has been designated the test cylinder and the other was the control cylinder. The test cylinder contained the cast insulation, while the control cylinder contained an 0.7-mm-diam. nichrome heater wire. The heater wire was attached to silver plated, Teflon insulated, copper leads and held in place in the control cylinder by micarta end plugs.

A cross section view of the test cylinder is shown schematically in Fig. 2. The coaxially mounted central copper tube was supplied saturated steam from a closed loop beaker system. Pressure was measured at the tube inlet and outlet and both were sufficiently close to ambient pressure to permit an ambient pressure assumption in estimating steam temperature (maximum error was estimated to be 0.03 °C). The estimated heat transfer coefficient between the steam and the copper tube was on the order of 20,000 W/m^{2}C, permitting the surface temperature of the inner copper tube (1.28 cm OD, 0.98 cm ID) to be assumed equal to the steam saturation temperature to within 0.01 °C. The annular region between the outer copper pipe and the inner copper tube contained the test material. The outer copper pipe surface temperature was measured using four copper-constantan thermocouples (four thermocouples were mounted identically on the control cylinder, as well, to insure thermal symmetry). The outer surface temperature of the test cylinder was established by the environment and the control cylinder was heated (by varying the voltage across the nichrome wire) until its outer surface temperature matched the surface temperature of the test cylinder.

The test apparatus was placed on a table in a room, and care was taken to be sure that the symmetry plane of the apparatus was a symmetry plane for the table and a nominal symmetry plane for the room. A typical test took between 3 and 4 h, due primarily to the time required to control manually the outer surface temperature of the control cylinder.

Accuracy of the apparatus was established using a test material whose thermal conductivity was known. The material used was silica-filled ethylene propylene dien monomer (EPDM), which is a neoprene rubber used as solid propellant rocket motor insulation. The thermal conductivity of EPDM has been reported[3] as 0.234 W/m K which is considered the upper acceptable limit for any batch of that insulation. Deviations of that value can occur due to mixture variations and temperature changes, but the test apparatus was expected to produce a similar value. Ten separate tests were conducted to measure the thermal conductivity of EPDM over a period of 6 months.

X-ray photographs of the test cylinder indicated that the EPDM had separated from the inner steam pipe during the curing process. Since EPDM was not an open pore material, the inner tube was not required and was removed during those tests. The steam was fed to the test cylinder by attaching short tube sections to each end of the EPDM. The inside surface of the EPDM was smoothed, and the new diameter was measured before the thermal conductivity tests were conducted.

Assuming steady-state, one-dimensional heat conduction, the thermal conductivity was related to the rate of electrical power consumption in the wire, $\dot{P}$, the steam temperature, T_s, the outer pipe surface temperature, T_0, the heater wire length, L, the outer diameter of the inner tube $D_{0,T}$ and the inner diameter of the outer pipe, $D_{i,P}$ by

$$\lambda = \frac{\dot{P}\,\ln(D_{i,P}/D_{0,T})}{2\pi L(T_s - T_0)} . \tag{1}$$

The measured thermal conductivity was 0.244 W/m K, with a standard deviation of 2.5%.

The fact that the measured thermal conductivity is approximately 5% greater than the specification value indicates that a small systematic error is present. Three possible error sources were considered: (1) End heat losses; (2) Interfacial thermal resistance effects; and (3) The error introduced by removing the inner tube. The end effects were considered the primary error source, because analyses showed that as much as a 10% increase in measured thermal conductivity could result

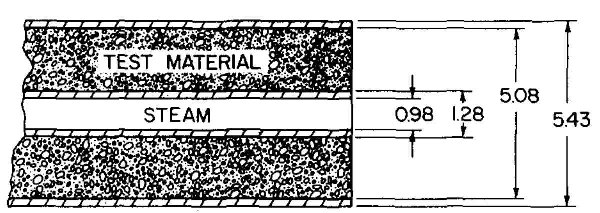

FIG. 2. Partial cross-section of the test cylinder, showing test material location and copper pipe dimensions.

from axial heat flow out uninsulated ends. The interfacial resistance between the two copper cylinder surfaces and the test material was only half as important (only one interface) for the EPDM as in other tests, but that effect must always produce a lower effective thermal conductivity, rather than the higher value measured here. Similarly, the tube removal resulted in no more than a one to two percent uncertainty in diameter and that error should not have exceeded the diameteral uncertainty.

Two other insulation materials, designated HTPB and SIPB, which were peculiar to the Jet Propulsion Laboratory solid rocket motor program were also tested. They represented an additional fifty tests and the inner and outer cylinders were both present. The mean thermal conductivity values for the HTPB and SIPB were 0.1214 W/m K and 0.1135 W/m K, respectively. While no standard measurement data are available for those materials, the measured values were consistent with the observed performance of those materials in the test program. Currently, the authors are awaiting verification of those data by the National Bureau of Standards.

The results of these preliminary tests have been very encouraging. The small standard deviation for measurements taken over a relatively long time interval indicates that the system behaves very reproducibly. An optimum sized apparatus can be developed which has a predictable end loss correction, combined with a convenient test cylinder size, in terms of casting requirements and accuracy.

The system can be modified readily for investigating temperature dependent thermal conductivity or the thermal conductivity of explosive materials. Different insulation temperatures can be examined by either using a pressurized steam system or by using heating fluids with different boiling temperatures—thereby varying T_s and the mean insulation temperature. The test cylinder can be isolated electrically for measurements of explosives if the thermocouple temperature transducers are removed and the surface temperature of the two cylinders are monitored using an infrared scanning system.

This work represents one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract NAS7-100, sponsored by the National Aeronautics and Space Administration. The authors would like to thank Robert L. Ray for his assistance in performing these experiments, and Warren L. Dowler and Richard L. Bailey for their suggestions and support.

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[1] R. P. Tye, *Thermal Conductivity* (Academic, London, 1969), Vols. 1 and 2.
[2] C. A. Wilkins, Masters Thesis, California State University, Northridge (1980).
[3] Thermal conductivity specification provided by Thiokol/Wasatch Division, using the guarded hot plate method. Data available as specification STW4-1506, 26 May 1977.

A goniometer for cutting single crystals

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A simple, compact and robust goniometer is described which is suitable for aligning and cutting metal single crystals with a slow speed saw.

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This goniometer was designed for the orientation and the cutting of metal single crystals with a slow speed saw. The principle of operation is shown in Fig. 1. The relative rotation of two wedges of angle α gives an angular range of 0 to 2α, while rotating the crystal in the top wedge brings the desired plane parallel to the saw and perpendicular to the x-ray beam. The crystal is first aligned by Laue diffraction with the arm clamped to the x-ray generator. It is then transferred to the slow speed saw.

The advantages of this device are that it is compact and light but extremely robust; and it has a high precision even though small, because a 180° relative rotation of the wedges corresponds (for $\alpha = 23°$) to a range of 0° to 46° and hence a 0.2° precision can be obtained without a vernier scale. (The choice of angular range will be determined by the crystal structure, the planes required and the crystalline orientation of the ingot.) The disadvantage is that the rotations are not simply related to the angles measured by a Greninger chart.[1] However these equations are derived below, and in practice the use of a small programmable calculator bypasses this difficulty.

The geometry of the goniometer is shown in Fig. 2. A, B, C and D lie in the plane of the photographic plate

