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Second Quarterly Progress Report

ULTRASONIC TEMPERATURE MEASURING DEVICE

by

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ABSTRACT

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During the second quarter, work proceeded on room and elevated temperature ultrasonic measurements and analysis, on radiation capsule design, on analyzing and estimating radiation effects in refractory sensor wires, on planning for the radiation experiments in the Babcock & Wilcox test reactor, and on measurements essential to the design and construction of the ultrasonic pulsing unit.

Molybdenum wire was ultrasonically tested up to 4500°R in a carbon atmosphere. To permit operation of Mo and other refractory wires up to 5000°R for extended periods of time, it will be necessary to minimize or prevent carbon reactions with the sensor wire. Several approaches to this problem have been considered.

To obtain the required temperature accuracy, ± 50°R, and spatial resolution, 1 to 3 inches, ultrasonic frequencies of the order of 1 megahertz have been considered. Such frequencies can be generated magnetostrictively or piezoelectrically, and the vibration modes may be extensional or shear (transverse or torsional). It appears that sensor performance can be improved by operating at these relatively high ultrasonic frequencies.

Author

I. SUMMARY

During the second quarter, work proceeded on the first four steps in the program.

Step I consists of room temperature preliminary ultrasonic measurements, and capsule design and test. Continuing room temperature experiments on attenuation in lead-in wires, adequate transmission was obtained through 90 ft of 0.040 in. dia Mo wire. The attenuation was about 0.2 db/ft at about 80 kilohertz.

The radiation test capsule will be an aluminum or stainless steel container about 1-3/4 in. dia x ~6 in. long, unheated and unmonitored acoustically.

Step II is the radiation experiment and analysis. The probability of transmutations has been calculated for W, T, Mo and Re, and appears to be negligibly small for the flux levels anticipated. Analysis is continuing, to determine the possible hazards in handling the wires after irradiation. Radiation effects in wires with melting points between 4500 and 5000^{o}R, such as Cb (Nb) and Ir, will also be analyzed.

Step III includes high temperature tests and analysis. Molybdenum was tested to about 2100^{o}R in vacuum to study annealing effects, and to 4500^{o}R in a carbon atmosphere to study carbiding. The ultrasonic sensor wire does not depend on the electrical insulating properties of any packing material in which it may be embedded (e.g., magnesia or beryllia). This offers distinct advantages over thermoelectric devices, in the range 4000 to 5000^{o}R or higher. However, carbon reactions with the sensor wire itself can destroy the validity of the velocity-temperature calibration.

There are several approaches to this problem, some of which are unique because the single ultrasonic sensor wire and neighboring materials need not satisfy electrical requirements.

Analysis of the ultrasonic sensor shows that the use of high frequencies, ~1 megahertz, will improve thermometry accuracy and permit more localized determinations of core temperature.

Step IV involves the design, construction and testing of automatic ultrasonic pulsing unit, the output of which will be a continuous function of temperature.

II. PROGRESS ON STEPS I, II, III AND IV

A. Room Temperature Preliminary Ultrasonic Measurements and Capsule Design and Test

Molybdenum is of interest both as a sensor wire and as a lead-in wire to sensors of other materials. Using a double pulse system at 80 kilohertz, the attenuation of extensional waves at room temperature was found to be about 0.2 db/ft in Mo of 0.040 in. dia ($d/\lambda = 0.02$). Echoes could be resolved from the end of this Mo for lead-in lengths up to nearly 100 ft.

In the event that a future radiation test requires acoustic monitoring of sensor wires during irradiation in a pool type reactor, some lead-in wires may be partly submerged under water. Therefore, the attenuating effects of water on pulse transmission in a submerged wire were also investigated. Again using 0.040 in. dia Mo wire, the effect of water was found to be negligible for a lead-in length of 25 ft (no decrease in signal level was observed at 80 kilohertz.) This is to be expected. The acoustic extensional waves propagating in the thin wire produce particle vibration in the wire parallel to the wire axis. This vibration mode appears as a shear (or transverse) wave to the water. Since a liquid cannot support a shear wave, no acoustic extensional wave energy can be transferred to the water. Similarly, if the wire supported torsional waves, this energy would not be coupled out either. (In the literature, the terms extensional, dilatational, and compressional are used synonymously to express the thin wire velocity $\sqrt{E/\rho}$. Some authors also call this the longitudinal velocity but this term is preferably reserved for bulk materials, of diameter much greater than wavelength, where the longitudinal velocity is $V_L = \sqrt{E(1-\sigma)/(1+\sigma)(1-2\sigma)\rho}$, where E = Young's modulus, ρ = density and σ = Poisson's ratio).

Various modifications were carried out on the double pulse ultrasonic temperature measuring device in order to facilitate the forthcoming high temperature and radiation tests. Some of these modifications were suggested by E. A. Thorne of the Atomic Energy Establishment, Winfrith, England, during his visit to Parametrics, Inc., in November 1965.

In order to increase the signal levels and produce a "clean" pulse the previous magnetostrictive nickel tube was replaced by a seamless, 0.0775 in. dia, 0.0026 to 0.0027 in. wall thickness, nickel 205 tube. When this small diameter, thin walled seamless tubing was used in the system the quality of the signal improved significantly.

To attenuate the pulse which propagates toward the pad (see Figure 1, First Quarterly Progress Report) it has been common practice to run the magnetostrictive tube back several feet and terminate it in an absorbing material such as rubber. To avoid excessive length, it is convenient to coil the tube. In the present case, this thin walled tube was coiled around a 6 in. dia mandrel without creasing the tube.

Thorne demonstrated that by controlling the solder joint between the lead-in wire and the nickel tube, joint reflections can be cancelled. This technique is an alternative to using an impedance matching section, between the transducer and lead-in, and avoids one joint.

Various modifications were carried out in order to make the equipment sturdier and to more effectively shield the system. The connector between the pulsing unit and the external amplifier is now a multi-pin type (Amphenol MS 3102A-22-18P) and all other connectors are now shielded.

A new set of transmitting and receiving coils were constructed in order to increase the signal level, and reduce pulse length. The new coils are wound on a spindle that is half as wide as the coils they replaced. This can produce a narrower pulse since the excited area on the magnetostrictive tube is reduced by 50%. These new coils are enclosed in a shielded capsule.

The result of these modifications is that with the same lead-in wire the received signal level has increased by 20 db.

In order to get reproducible results from sensor to sensor it is desirable to reproduce the kink in each sample. A jig has been constructed to do this. To kink a sensor wire without shearing off the sensor length the area to be kinked must be at a temperature above the ductile-brittle transition temperature. This temperature is shown in Table I for several materials of interest.[1]

[1] Schwartzberg, F. R., et al, Ductile-Brittle Transition in the Refractory Metals, DMIC Report 114 (June 1959).

Table I

Ductile-Brittle Transition Temperatures

Element	Transition Temperature for Recrystallized Metal, °C	Lattice
Tantalum	$\leq$ -195	BCC
Molybdenum	-30 to 25	BCC
Tungsten	150 to 315	BCC
Rhenium	None[2] or <25[3]	HCP

Of the metals in Table I, the only material with a ductile-brittle transition temperature above room temperature is tungsten. Using the kinking jig we have successfully kinked a heated tungsten wire without damaging the sensor.

The capsule for containing unheated, acoustically unmonitored sensor wires during irradiation in the Babcock & Wilcox test reactor will be completed next quarter. It will be tubular, about 1-3/4 in. dia x 6 in. long, of aluminum or stainless steel.

B. Radiation Experiment and Analysis

The radiation experiment scheduled for the early part of 1966 will include room temperature irradiation of a number of candidate sensor wires. To determine radiation effects, the sound velocity will be measured as a function of temperature, and compared with velocity in an unirradiated wire. Sound velocities will be measured before and after irradiation. Temperatures will be measured in several ways, such as thermocouple, pyrometer, calibrated thin wires, and sound velocity in the inert gas environment of helium or argon.

(2) Sims, C. T., "Properties of Rhenium," pp. 23-35, p. 26, in B. W. Gonser, Rhenium, Elsevier Publ. Co., Amsterdam and New York (1962).

(3) Gaines, G. B., "Rhenium in Electronics," pp. 140-148, Table I, p. 141, in B. W. Gonser, op. cit.

The probability of transmutations in W, Ta, Mo and Re have been computed for the flux anticipated in the Babcock & Wilcox test reactor. Such effects are expected to be negligible.

Calculations will also be made of the activities expected in these wires after irradiation. Also, radiation effects in other wires of melting points in the range 4500 to 5000°R, such as Cb (Nb) and Ir, will also be estimated.

C. <u>High Temperature Tests and Analysis</u>

Molybdenum has been tested ultrasonically at ~80 kilohertz up to 2100°R in vacuum, and up to 4500°R in a carbon resistance furnace. Negligible increase in attenuation was observed, in agreement with other independent ultrasonic tests in metals up to their melting points. Carbiding prevented testing bare Mo to higher temperatures.

To avoid or minimize carbiding in future tests, several approaches are being considered. In one metallic shielding system, the thin wire will be placed in a Ta tubular shield and pressurized He will flow over the wire at a low flow rate. The effect of this will be to keep the carbon from contacting the wire while not removing enough heat to affect the temperature measurement. This technique has been used effectively with thermocouples.(4) The advantage of this system is that it is a simple way to prevent carbiding of the sensor when tested in a graphite resistance oven, and may be applicable to practical installations.

The use of sensor and sheath materials in which the carbide reaction has gone to completion (i.e., carbides of refractory materials) will also be considered.

In addition to the Ta shield, a zirconium diboride (ZrB_2) shield also will be considered. This material is reported to be stable in the presence of carbon and may be satisfactory for long term use. ZrB_2 can be applied to Ta tubing using plasma spray techniques, yielding a composite shield material.

It is desirable to avoid contact with carbon. Partial isolation of the sensor wire may be accomplished with tubes or powders of MgO or BeO. Note that these materials need not be electrically insulating at 5000°R; they need merely reduce the rate of flow of carbon to the sensor.

Hall and Spooner[4] conclude that BeO is the only suitable electrical insulator for use at 4100°R. They point out that the use of BeO at 4100°R is marginal, and that 3900°R is a more realistic maximum. As acoustic isolators and partial barriers to carbon contamination, powders should be usable to their melting or eutectic points, which in some cases are over 5000°R.

Still another approach is to choose a metallic wire that does not carbide. There are few candidates, but rhenium is one. The eutectic formed by rhenium and carbon melts at ~5000°R, whereas pure rhenium melts at 6200°R. Below 5000°R, there is some dissolving of carbon into rhenium, causing some embrittlement. The effect of this embrittlement on sound velocity will be measured in future tests.

The thin wire feedthrough for the 7000°R radiant heating source (Figure 3, First Quarterly Progress Report) has been constructed and preliminary system tests have been conducted. These tests showed that the feedthrough will hold the vacuum required when operating this oven during 5000°R ultrasonic tests. Besides sealing for vacuum and pressure, the feedthrough neither introduces any reflections nor attenuates the signal. Commercially available feedthroughs such as Conax MHC-040-A-2-L and MHC-040-A-2-T have been obtained, and will be evaluated.

D. Construction and Testing of Pulser

To achieve core thermometry based on the principle that sound velocity is a function of temperature of a wire sensor, an important question arises concerning ultrasonic test frequency. Sensor design, following the techniques of Bell et al, would have to compromise the divergent requirements of high accuracy, ± 50°R, and localized readings, 1 to 3 in. However, at sufficiently high frequency, of the order of ~1 megahertz, and possibly up to 3 megahertz, the sensor length can be coiled in small reflectionless coils, to compress the kink to end distance. For example, with 0.020 in. dia wire coiled on an 0.020 in. dia mandrel about 6 in. of wire could conceivably be coiled in 50 turns to localize readings in a 1 in. long region. Low frequencies

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(4) Hall, B. F., Jr., and Spooner, N. F., Study of High Temperature Thermocouples. AFCRL 65-251 (March 1965) (AD 619 038); "Temperature Measurement in a Graphite Environment from 1600 to 2500°C," ISA Preprint No. 16. 13-3-64 (Oct. 12-15, 1964. Using argon, Hall and Spooner achieved a temperature of 4840°R for 2 hours without any effects of carbiding.

would be reflected by such tight coils, but high frequencies may be adequately transmitted. Upper limits on frequency are imposed by the sound attenuation characteristics of the wire.

Frequency selection involves transducer optimization with respect to frequency, materials (piezoelectric or magnetostrictive), mode of vibration (extensional or shear), size and shape. For a given transducer, the pulser will be designed to yield a pulse shape of optimum rise and fall times, and width.

The acoustic bandwidth of the lead-in and sensor wires also enters into transducer and pulser optimization, since this bandwidth imposes an upper limit on ultrasonic pulse frequency.

Circuitry design and construction for the automatic thin wire thermometer will depend on the results of the transducer optimization study now in progress.

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