Thermocouple Probes

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The talk by Professor W. J. Fry on thermocouple probes was not recorded. The following is a synopsis of the presented paper.

THE SHORT WAVELENGTHS characteristic of ultrasound in liquid media in the frequency range above one megacycle per second require probes of very small size if the structure of field distributions, generated, for example, by focusing irradiators, is to be determined and if "point" values for the acoustic field variables are to be measured. In addition, very small probes designed for routine rapid field measurements are extremely useful especially if they can serve to determine absolute sound levels independently of any other calibration procedure. The thermocouple probe developed by the author and his associates at the Bioacoustics Laboratory realizes these desirable features.

It should be emphasized that the thermocouple probe which is the subject of this talk is completely different from other thermocouple probes which have been and are currently being used by other investigators to detect the presence of an acoustic field. All these other probes utilize essentially the "equilibrium" temperature rise principle—that is, the thermocouple junction detects the *maximum* temperature change produced by the sound field in a mass of absorbing material in which the thermocouple junction is imbedded. The value of this maximum temperature rise is thus dependent upon the size and shape of the absorbing mass and the field distribution within it. Since the mass is usually not less than about one millimeter in diameter, the minimum probe size is thus of the order of a millimeter in linear dimensions. Such probes interfere with the sound field, they are not capable of high accuracy, they cannot be used for absolute determinations of sound levels without previous calibration and their calibration is dependent upon the field configuration in which they are immersed.

By contrast, the thermocouple probe which has been developed at this laboratory does not suffer from these limitations. This probe consists of a thermocouple junction imbedded in an acoustic absorbing medium which closely matches in density and acoustic propagation velocity the values for these quantities characteristic of the medium in which the sound field exists. The method of operation consists of producing a pulse of sound with, for example, a rectangular envelope and observing the electrical output of the thermocouple in response to the initial time rate of the temperature rise of the absorbing medium (or in response to the temperature rise a short interval of time after the initiation of the pulse). This quantity is independent of the size, shape and configuration of the absorbing medium in the acoustic field. (This assumes that the transmission path of the sound in the absorbing medium is not so long that there is an appreciable reduction in sound level at the junction because of absorption along this transmission path.) This situation obtains since heat conduction processes are not involved in the determination of this initial time rate of temperature rise or the value of the temperature rise after a short interval.

We will now illustrate these ideas by describing the specific design of such a thermocouple probe which has proved extremely useful for studying the fields and determining the sound levels produced by focusing irradiators used in the research at this laboratory on the production of changes in the central nervous system by ultrasound. Fig. 1 is a photograph of such a probe. This type has been in use here for the past several years. The device consists of a fine thermocouple which can be seen in the photograph as a fine horizontal line lying along a diameter of the device. The thermocouple is constructed from 0.003″ diameter iron and constantan wires which are etched to a diameter of 0.0005″ in the neighborhood of the junction. The circular ring members support two thin (0.003″) polyethylene diaphrams which enclose a disc of an absorbing liquid such as, for example, castor oil. The ring opening is of such size as to permit the entire sound beam to pass through without reflection from the ring members. The particular probe shown in the photograph is fitted with a supporting bar which can be fastened to a positioning system. The thermocouple wires are supported from two Kovar seals which are soldered to one of the stainless steel rings. These Kovar seals constitute the electrical lead-throughs for the electrical connections. In order to reduce the effect of external shocks from breaking the thermocouple junction or wires, a short spring is incorporated in the constantan wire. The spring portion of the constantan wire lies beneath the stainless steel rings and is not visible by viewing through the membranes.

We have published an extensive analysis of the theory of operation of such thermocouple probes and have also indicated in the literature the type of experimental results which are obtained (Fry and Fry, 1954a; Ibid., 1954b). I would, however, like to discuss briefly several aspects of the theory of the operation of the device and also illustrate the type of response obtainable. As indicated previously, an electrical output voltage is produced in response to a short pulse of sound (for example, one second duration.) The duration of the pulse is chosen so that the effect of heat conduction processes in the absorbing material and the thermocouple wires are unimportant during the time of exposure of the probe to the sound. When a pulse of ultrasound falls on the probe the temperature change detected by the thermocouple junction is caused by two distinctly different mechanisms. One source of heat results from absorption of sound in the

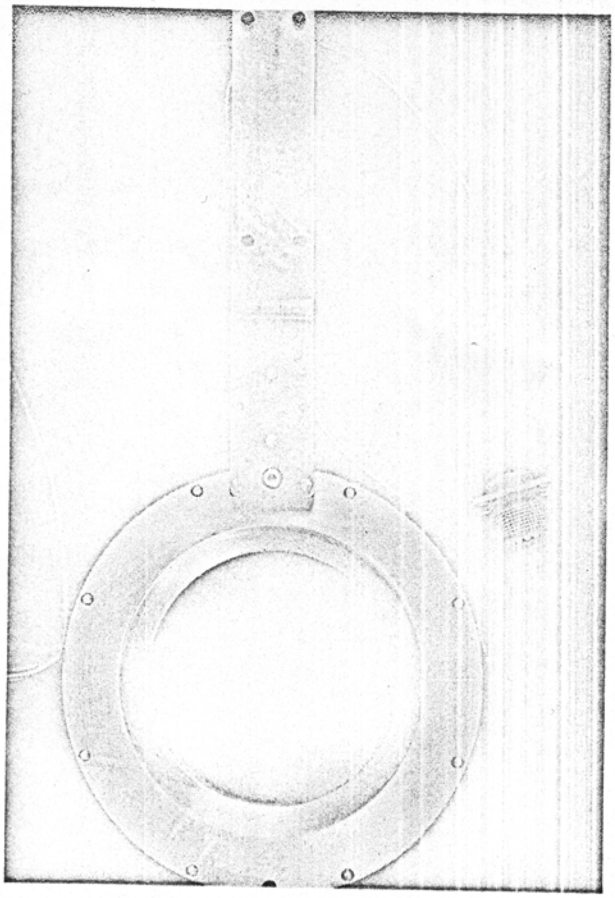

FIG. 1. A thermocouple probe, membrane window diameter three inches.

acoustic absorbing medium which surrounds the junction. The time rate of temperature increase is proportional to the absorption coefficient and the square of the acoustic pressure amplitude. A readily derived theoretical formula relates the acoustic pressure amplitude to the time rate of temperature rise, the acoustic pressure absorption coefficient, and the heat capacity per unit volume of the absorbing medium. The second heat source, which contributes to the temperature rise, results from the action of viscous forces between the wires and the imbedding medium. The viscous action is caused by relative motion between the wires and the liquid. This contribution to the temperature rise, which is proportional to the square of the particle velocity amplitude, would, of course, be absent if the wires were not present. The viscous source of heat is localized to the immediate neighborhood of the wires and junction and therefore the resulting temperature rise exhibits a rapid approach to an equilibrium value as compared with the rate of approach of the temperature change, resulting from acoustic absorption in the liquid medium, to its equilibrium value. When such a probe is subjected to a sound pulse of rectangular envelope of one second duration at a frequency of approximately one megacycle per second, the response recorded on a magnetic oscillograph is shown in Fig. 2. The

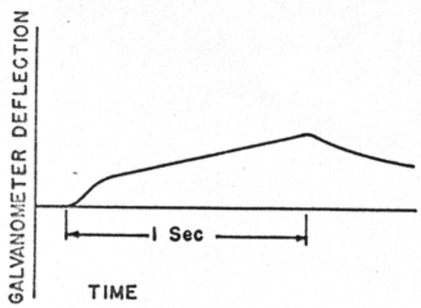

FIG. 2. Response of a thermocouple probe to a one-second pulse of 1.0 mc./s. ultrasound. The galvanometer deflection is proportional to the temperature rise at the junction.

initial rapid rise is caused by the viscous force action. The subsequent slow rise results from absorption in the acoustic absorbing medium in which the thermocouple junction is imbedded.

It might be well to mention that another mechanism, in addition to the two just discussed, contributes to the temperature rise at the junction. This contribution results from a lag which occurs during each cycle of the acoustic disturbance in the heat conduction process at the liquid-wire boundary. The periodic transfer of heat at the fluid-metal boundary gives rise to a term in the function describing the periodic temperature change in the fluid which is not in phase with the pressure. Acoustic energy is thus transformed into heat. This mechanism contributes only about 1/1,000 of the heat contributed by the viscous mechanism for the probe construction which we have been using.

It should be pointed out that resolution of fine structure of a field as well as the accuracy with which absolute determinations of acoustic pressure amplitudes can be made are functions of the diameter of the thermocouple wires and the junction. Theoretical expressions have been derived which permit a choice of wire size to be made consistent with the required accuracy and resolution.

In summary, thermocouple probes which operate on the principle of the initial time rate of change of temperature in response to an acoustic pulse have proved extremely useful, at this laboratory, in studying complex sound fields at ultrasonic frequencies. These probes can be used for rapid determinations of acoustic field configurations, for adjusting and studying focusing irradiators of both the single and multibeam type, and for determining absolute sound levels of ultrasound fields without recourse to any other calibration procedure. The devices are rugged and are stable over long periods of time. This type of thermocouple probe is a precision instrument for use in the ultrasonic frequency range in the neighborhood of one megacycle per second and above.

References

Fry, W. J. and R. B. Fry. 1954a. Determination of absolute sound levels and acoustic absorption coefficients by thermocouple probes—theory. J. Acoust. Soc. Am. *26:* 294–310.

Fry, W. J. and R. B. Fry. 1954b. Determination of absolute sound levels and acoustic absorption coefficients by thermocouple probes—experiment. J. Acoust. Soc. Am. *26:* 311–317.