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D P HAMMOND

CULHAM LABORATORY
Abingdon Oxfordshire
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D P Hammond

Culham Laboratory, Abingdon, Oxon OX14 3DB, UK
(Euratom/UKAEA Fusion Association)

ABSTRACT

A method of measuring power density at a point in an energetic particle beam is described. The temperature rise of a short length of wire which is conduction-cooled at each end and directly irradiated by the beam is measured. By combining the electrical outputs of a number of detectors, a total power measurement is obtained. Factors determining the sensitivity and time constant of such a system are discussed and some experimental results are given.

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Introduction

In fusion experiments, injection of neutral hydrogen atom beams with energy in the range 10 - 100 keV and beam power of many kilowatts is frequently used. Thermal considerations restrict the beam pulse length to the order of a few seconds (Cole et al, 1973), and the conventional form of water-cooled beam stop can be unreliable when accurate, reproducible beam current measurements are required. If a direct electrical signal is taken from the beam stop, errors are caused by variations in the secondary emission coefficient due to the state of the emitting surface, the particle energy, and the presence of electric or magnetic fields. Also, the ratio of charged to neutral particles and the possible presence of slow ions add to the errors (Huizenga, 1968). A calorimetric measurement is more reliable, but, especially with large beam diameters, the long thermal time constant (typically some tens of seconds) of a device suitable for stopping high power beams can be troublesome.

Method

It is attractive in principle to intercept a small portion of the beam on a thin wire (Knyazyatov et al, 1964), the temperature of which is measured in some way to give an estimate of the power density averaged along the wire. If heat is lost from the wire principally by radiation, then the temperature which the wire reaches will be proportional to the one-fourth power of the beam power density and an insensitive device will result. However, if the wire is made short and mounted on heat sinks, conduction to the ends will be the dominant heat loss process. Referring to Fig.1, let a power density of W cals per unit area per second be incident on a wire of length 2ℓ and diameter d. Each end of the wire is maintained at constant temperature. Then, for an element of the wire of length dx :

$$W \cdot d(\ell - x) = \frac{K\pi d^2}{4} \cdot \frac{dT}{dx} \qquad \ldots\ldots \quad (I)$$

where x is the length of the wire measured from one end, K is the thermal conductivity of the material of the wire and dT is the temperature difference across the length dx. Then the temperature at a point along the wire, obtained by integrating equation (I), is :

$$T = \frac{4W}{K\pi d}\left(\ell x - \frac{x^2}{2}\right)$$

and the central temperature, at $x = \ell$ is

$$T = \frac{2W\ell^2}{K\pi d} \; . \qquad \ldots\ldots (II)$$

A closely analogous case is discussed by Carslaw and Jaeger (ref.4) and their results may be used to estimate the thermal time constant, τ, of the system as

$$\tau \simeq \frac{0.5\,\ell^2}{2k} \; , \qquad \ldots\ldots (III)$$

where k is the thermal diffusivity. A convenient way of measuring the central temperature is to make the wire into a thermocouple with the junction at the centre.

Chromel-alumel themocouples were mounted as shown in Fig.2 and ten such assemblies were fixed to a conventional water-cooled copper calorimeter of diameter 17 cm. The thermocouples were insulated from the upper plate and their outputs were connected in series to give a measure of total power over the surface. The system was irradiated by a beam of protons and neutral hydrogen atoms of energies up to 15 keV with a mean power density of 5.7 Watts/cm^2. Substituting appropriate values in (II) and (III), the average junction temperature was estimated to be 6°C and the output of the array should reach an equilibrium level of 2.3 mV with a time constant of 300 ms, for the dimensions and materials quoted.

The thermocouples were calibrated by comparison with the conventional calorimeter on which they were mounted and a sensitivity of 1.93 mV.secs/Kjoule was measured.

The array output is shown in the oscillograph trace Fig.3(a), together with a direct electrical signal (b), and is in reasonable agreement with the predicted values.

Conclusion

It is shown that a fast-acting calorimeter for high power beam measurement can be made from an array of small conduction-cooled thermocouple detectors.

Acknowledgements

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References

1. H C Cole et al, 1973. Rev.Sci.Instrum.44 no.8, 1024-1028.

2. W Huizenga, 1968. Nucl.Inst.Methods, 63, 109-113.

3. A S Knyazyatov et al, 1964. Pribory i Tekhnika Eksperimenta, 46-48.

4. H S Carslaw and J C Jaeger, 1959. "Conduction of Heat in Solids" (Oxford, Clarendon Press,p130).

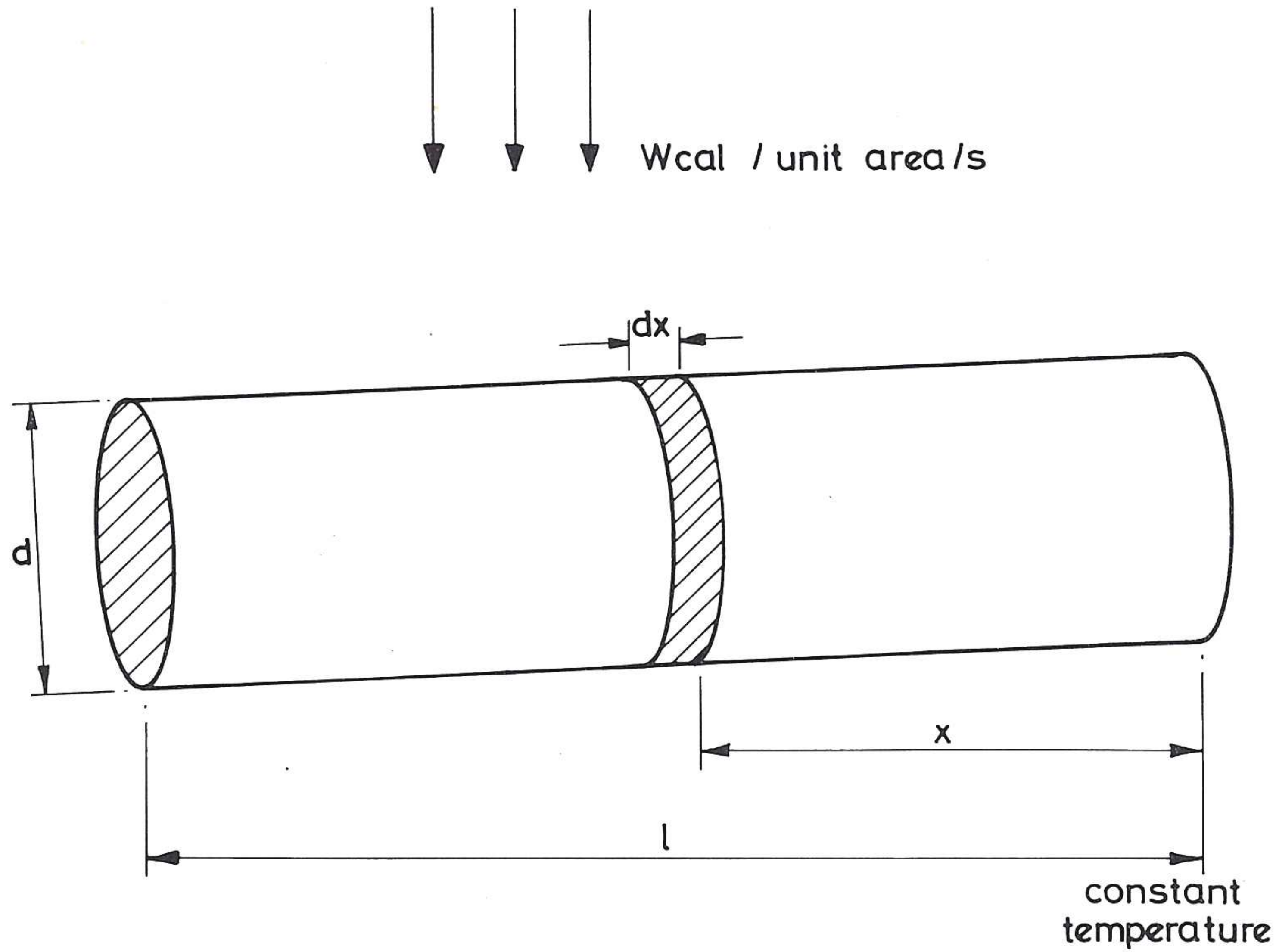

Fig. 1 Sketch of basic system.

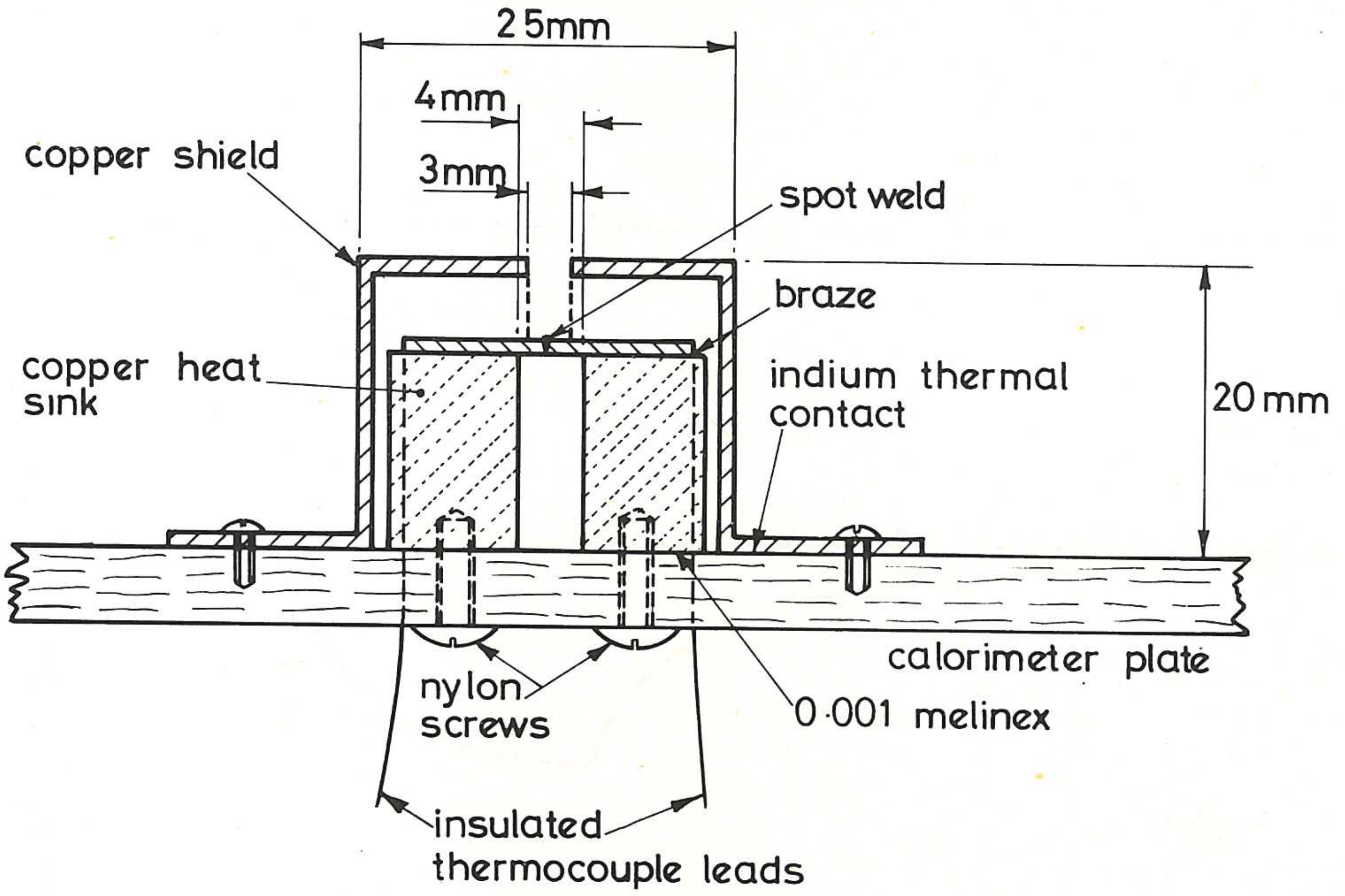

Fig. 2 A thermocouple assembly.

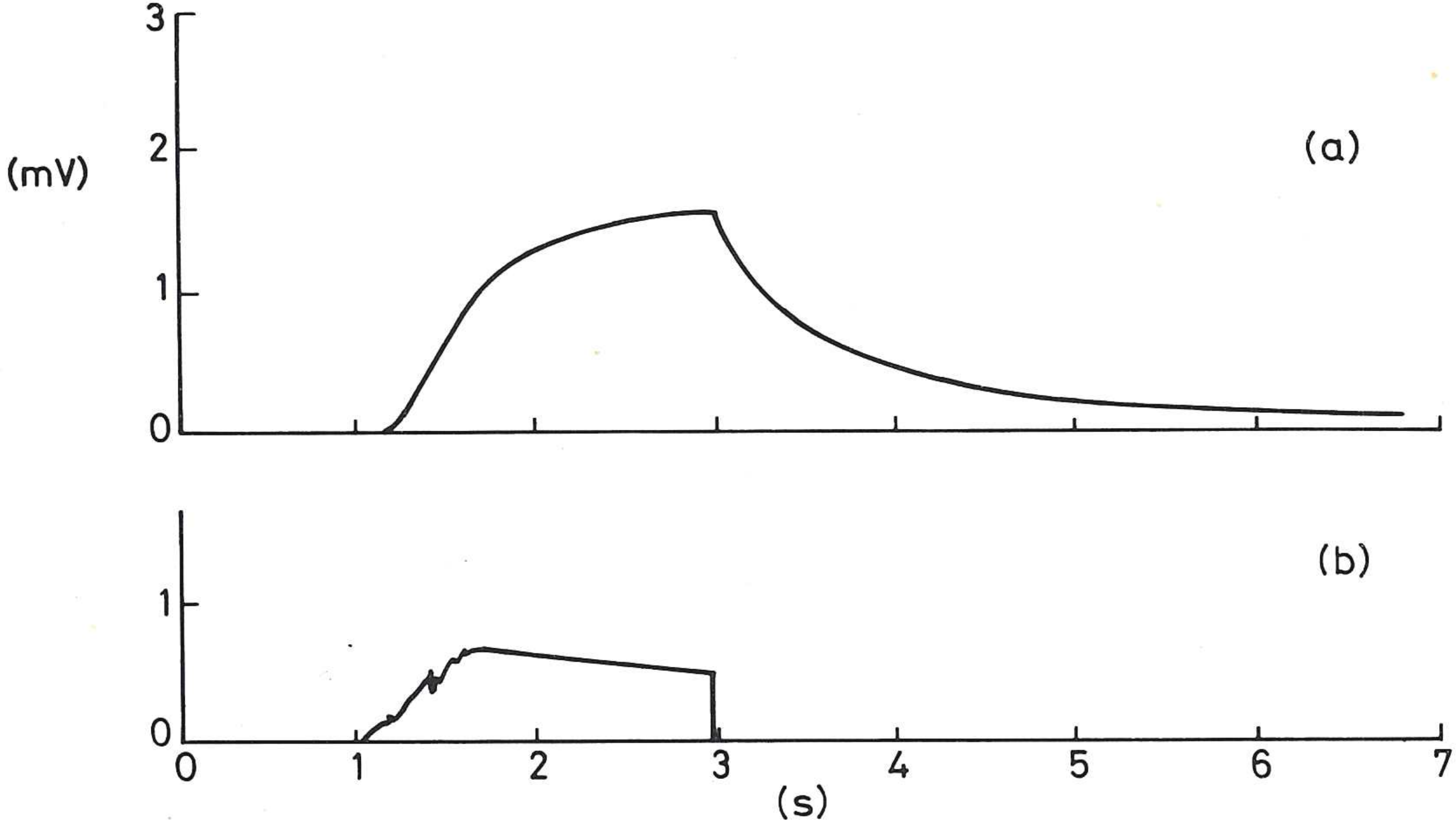

Fig. 3 Oscillograph traces of array output and direct electrical signal.