A METHOD FOR DETERMINING ULTRAHIGH TEMPERATURES

V. N. Bogomolov and I. I. Zakharkin

UDC 536.5.55

The problem of determining high and ultrahigh temperatures is urgent in connection with mastering the technology of new high-power energy sources. The known methods of measuring temperatures by using thermocouples, ultrasound, or optical devices can either be used only over limited temperature ranges or are very difficult to apply in practice. The present article describes a method of determining temperature based on the phenomenon of rethermalization of neutrons. The neutron is used as an agent interacting with the hot medium. When neutrons are scattered by atoms of a hot medium there is a change in their energy spectrum which is uniquely related to the kinetic temperature of the medium. In principle there is no apparent upper limit of the temperatures which can be measured by this method.

Let us consider briefly the physical bases of the method. It is known that the energy distribution of the neutron flux density in a sufficiently large volume of moderator containing a neutron source is close to the state of thermodynamic equilibrium with the medium. When the temperature of the medium changes there is a corresponding change in the neutron energy spectrum. The relation between the temperature of the medium and that of the Maxwellian neutron distribution has been rather well developed. Fleck and Meisterl [1] described a favorable attempt to use a linear relation between the temperature of a neutron gas and that of the moderator in the core of a pulsed reactor to determine the temperature of the moderator during the development of a power pulse of the reactor.

The modification of the method described below permits the measurement of the temperature of a gas stream outside the core of a power assembly and consists in the following. Far from the boundary between two adjoining media having different temperatures, equilibrium neutron spectra are established with corresponding temperatures of the neutron gas. Close to the boundary between the media the neutron spectra reflect the transient relaxation of the temperature of the neutron gas. By observing the behavior of the neutron energy flux in one of the media far from and close to the boundary it is possible to draw an unambiguous conclusion about the temperature of the other medium. It should be noted that the requirement of equilibrium energy exchange processes between neutrons and atoms of the medium is not necessary, since even for incomplete exchange of energy between neutrons and the atoms of the medium it is possible to obtain sufficient information about the temperature of the medium. Naturally the effect of hardening of the neutron spectrum will be greater with increasing density and volume of the medium whose temperature is being measured.

To use this method next to a gas stream (through appropriate thermal insulation) it is necessary to have available a moderator block at a relatively low temperature. The moderator block may contain a neutron source or be irradiated by neutrons leaking from the core. Neutrons thermalized in the moderator block pass from the block into the gas stream where they are scattered by the atoms of the gas and gain energy.

At a point in the block close to the boundary with the gaseous medium the neutron flux will have a harder energy spectrum than at a point well inside the block. The hardening of the neutron spectrum can be determined by using a thermal-neutron detector shielded, for example, by a gadolinium jacket. Thus, the moderating block is a source of thermal neutrons directed into the gaseous medium and serves as a thermal shield for the neutron detector which measures the hardening of the neutron spectrum.

In our proposed scheme for determining the temperature the thermal neutrons are detected by the scalar (integrated over the angles) flux. In addition, the detector is located inside the moderating medium, and therefore the required neutron source strength will be 2-3 orders of magnitude lower than in the scheme using a collimated beam of neutrons described in [2]. Estimates show that by using a standard neutron detector with a counting efficiency of ~ 0.1 for thermal neutrons, a source strength of $\sim 10^7$ neutrons/sec in a $40 \times 40 \times 40$ cm moderator block, for example beryllium, is sufficient for the purposes described. The average neutron flux

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 3, pp. 8-11, May-June, 1979. Original article submitted April 27, 1978.

0021-8944/79/2003-0266$07.50

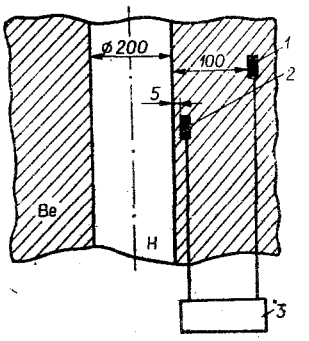

Fig. 1

density in the prism is $\sim 10^5$ neutrons/cm^2 · sec, which is sufficient for the operation of a detector in both current and pulsed regimes. The operating procedure is determined by the choice of circuit, the geometry of the relative position of the neutron source and detectors, and the requirements for the dynamic characteristics of the measuring system.

To determine the sensitivity of the proposed method for measuring the temperature of a gas, calculations were performed for the model shown schematically in Fig. 1 (1 and 2 are neutron detectors sensitive to the shape of the thermal portion of the spectrum, and 3 is the measuring unit). It was assumed that an infinite block of beryllium contains an infinitely long cylindrical cavity 200 mm in diameter filled with hydrogen having a density of 10^{21} nuclei/cm^3. The temperature of the beryllium was assumed constant and equal to 300°K, and the temperature of the hydrogen was 300, 1300, 2000, and 5000°K. The neutron energy spectra in beryllium were calculated at these four hydrogen temperatures at various distances from the boundary of the cavity. The neutron spectrum was calculated in the 0-0.67 eV energy range by a 15-group program in the P_1 approximation of the spherical harmonics method [3]. The scattering of neutrons in beryllium was treated by the crystal model, and in hydrogen within the framework of the gas model. The distribution of neutron sources in the thermal energy region was assumed space-independent.

The calculation showed that at high hydrogen temperatures the neutron energy spectrum in beryllium close to the cavity boundary is appreciably hardened, but at distances $\geqslant 100$ mm from the boundary the spectrum corresponds to the equilibrium spectrum in beryllium. By using the spectra obtained, the ratios of the reaction rates of two neutron detectors with $\sim 1/v$ reaction cross sections placed in the beryllium at distances of 5 and 100 mm from the cavity boundary were calculated. Both detectors contained 0.15 mm thick gadolinium filters. The ratios of the reaction rates were found to be 1.00, 2.10, 3.35, and 5.50 for hydrogen temperatures of 300, 1300, 2000, and 5000°K, respectively. In the 2000-5000°K temperature range the sensitivity of the method in the present example is $\sim 7\%$ of the change of the detector readings for each 100°K change in hydrogen temperature, which shows a rather high sensitivity. The universally recognized accuracy of such calculations within the framework of the model assumed is not worse than 15% [4], and according to our estimates is $\sim 10\%$. It should be noted that the material of the moderator block can also be graphite, beryllium oxide, or metal hydrides. The sensitivity obtained in the example considered is not maximum, but can be increased by a more appropriate choice of detector and filter. This is the subject of a special investigation.

The practical application of the method requires the calculation of neutron spectra at various gas temperatures and densities for the chosen size and shape of the moderator block. If the density of the gas is known from independent measurements, the required temperature can be determined from the readings of the two detectors by using the spectra calculated for that density. The presence of two detectors in the block eliminates the effect of variations of the neutron source strength if this source is neutron leakage from the core. The practicable average linear dimensions of the moderator block are 100-500 mm, depending on the kind of moderator. The practical utilization of the method discussed requires performing additional investigations to substantiate the basic parameters of this type of thermometer, and to overcome a number of technical difficulties.

However, the main advantage of the method – the absence of an apparent limit of measurable temperatures – makes it attractive for practical use over the main range of ultrahigh temperatures.

The authors thank G. A. Ilyasova and M. Ya. Bankrashkova for their kind assistance in calculating the neutron energy spectra.

LITERATURE CITED

1. C. M. Fleck and J. Meisterl, "The behavior of the neutron temperature during a power pulse," Atomkernenergie, 13, No. 6 (1968).
2. L. B. Luganskii, L. P. Pitaevskii, and V. B. Fiks, "Slow-neutron diagnostics of dense plasma," Pisma Zh. Tekh. Fiz., 2, 57 (1976).
3. G. I. Marchuk, V. F. Turchin, V. V. Smelov, and G. A. Ilyasova, "Methods for calculating slow neutron spectra," At. Energ., 13, 534 (1962).
4. J. R. Beyster and J. M. Neil, "Thermal neutron spectra," in: Slow Neutron Spectra [Russian translation], Atomizdat, Moscow (1971).

DETERMINATION OF THE PARAMETERS OF PARTICLES SUSPENDED IN TWO-PHASE MEDIA BY MEANS OF PENETRATING RADIATION

A. G. Borovoi

UDC 621.384

Determination of the concentration, size, and internal structure of microscopic particles suspended in two-phase media by means of contactless methods constitutes an important technological problem. If the particle sizes are on the order of the wavelength of light, methods based on light scattering by particles are widely used for this purpose. The most direct method consists in observing the optical signal scattered by an individual particle [1]. There are also several methods where the total signal from a large number of particles is recorded, but, in this case, multiple rescattering of light on particles must be negligible [2, 3]. At the same time, the complex relationship between the scattering amplitude and the refraction index, the shape of particles, etc., as well as the increasing background of multiply scattered light with greater thickness of the scattering layer, restrict the scope of application of such methods and make other measurement methods desirable, e.g., in the case of instrument calibration. Our aim is to point out the advisability of investigating two-phase media by means of penetrating radiation, which has been used successfully for radiation flaw detection [4] and for inspecting the composition and density of matter [5]. We shall mention the most important advantages of the proposed method. First, the interaction between individual particles and nonrefracted radiation is described by simple expressions, which makes the interpretation of results much easier. Second, in using the most informative scheme whereby scattering media are investigated "by transillumination," the background of multiply scattered radiation with a low information content (or, to borrow a term from radiation protection physics, the build-up factor [6]) increases with an increase in the scattering layer thickness much more slowly than it does for light. This makes it possible to use radiation methods for investigating "optically dense" two-phase media. We shall consider below the possibility of determining the distribution function of particle sizes by measuring the radiation attenuation as a function of the linear coefficient of attenuation inside the particles.

Consider the attenuation of a collimated radiation beam with the flux density I_0 which is incident perpendicularly to a uniform layer of a two-phase medium whose thickness is d. We assume that the linear attenuation factor of the liquid or the gas μ_0 is constant. We denote by the function $\mu_i(\mathbf{r}-\mathbf{r}_i)$ the difference between the linear factor inside the i-th particle and the value of μ_0, where $\mathbf{r}_i$ is the position of the center of the i-th particle, while the function $\mu_i(\mathbf{r})$ determines the internal structure of the i-th particle; it vanishes at distances larger than the particle size. For a fixed configuration of scattering particles, we write the density of the flux attenuated in conformity to the radiation exponential at the point $\boldsymbol{\rho} = (x, y)$ in the $z = d$ plane bounding the layer in the following form:

Tomsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 3, pp. 11-14, May-June, 1979. Original article submitted January 9, 1978.

0021-8944/79/2003-0268 $07.50