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THERMOSTABLE SCINTILLATION DETECTOR

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A design of a scintillation detector of ionizing radiation based on a Tl-activated NaI single or polycrystal is proposed. The detector is equipped with a unique compensator of inconsistent variations of the axial dimensions of the scintillator and its container.

The development of novel design solutions is the traditional method for improving crystalline scintillation detectors. This makes it possible to eliminate a number of problems, including inconsistency of thermally induced variations of linear dimensions of the individual components of detectors. In such a manner a number of thermostable designs of scintillation detectors have been developed [1-3] in which leading thermal variations of the axial dimensions of the crystals with respect to thermally induced variations of the axial dimensions of the containers are compensated by means of elastic gaskets or various spring devices. There is no need to describe the operation of these compensators in this article, since they have long been in use and do not differ much from one another. It should be noted that, despite the ability to compensate inconsistent thermally induced variations in the length of the crystal and the container, these devices have a number of shortcomings. The main one is a decrease in their shock resistance. The reason lies in the fact that compenstors based on the use of elastic forces are not rigid. In the case of an axial shock, the crystal of the detector can separate from the glass of the exit window and, by compressing the compensator, move away from the exit window of the detector. After the detector comes to rest, the system cannot recover. The optical contact between the crystal and the glass of the exit window remains destroyed. In a number of cases, dust from the light-reflecting coating enters the crystal–exit window glass unit. In practice, after an axial shock, such a detector always fails.

In what follows, we propose a design of a compensator of inconsistent thermally induced variations of the axial dimensions of the container and the crystal of a detector whose height can be changed only by thermal action, which is inversely proportional to temperature and completely independent of axial compression. The compensator is absolutely rigid with respect to axial compression. Deformable and spring elements are not mandatory and perform ancillary functions and by no means affect the basic rigidity of the compensator (Fig. 1). The detector consists of a crystal 1 mounted inside a container 2 on two centering rings 3 and 4. The gap between the container and the crystal 1 is filled with light-reflecting powder 5. At its exit end the crystal 1 is optically coupled to the exit window 6. The compensator of inconsistent thermally induced variations of the axial dimensions of the crystal 1 and the container 2 is located on the side opposite of the exit window 6 of the detector and consists of several outer rings 7, several inner rings 8, a metal disk 9, and a spring 10. The compensator consists of pairs of outer 7 and inner rings 8 connected by conical surfaces. The outer rings 7 are made of the same metal as the container 2, and the inner rings 8 are made of a material whose thermal linear expansion coefficient (TLEC) is much smaller than that of the material of the container 2. The disk 9 of the compensator is made of the same material as the outer rings 7. When heated, rings 7, which are made of a material [1] whose TLEC is greater than that of the material of the inner rings 8, increase their dimensions more intensely than the inner rings. In this case, the inner rings 8 move into the outer rings 7, which results in a decrease in their total height. Upon cooling, the process proceeds in the reverse direction. When compressed, the outer rings 7 push out the inner rings 8. The total height of these rings in this case increases. The geometric parameters of the conic rings 7 and 8 of the compensator and their

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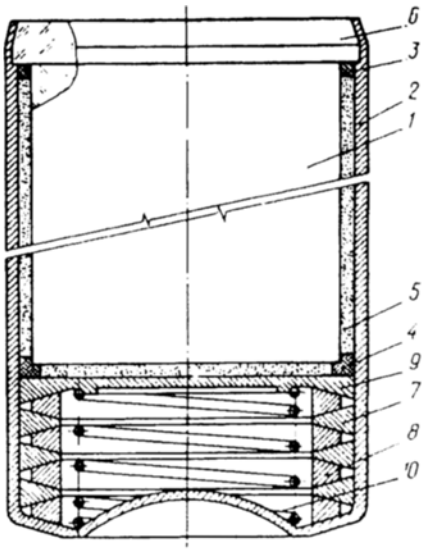


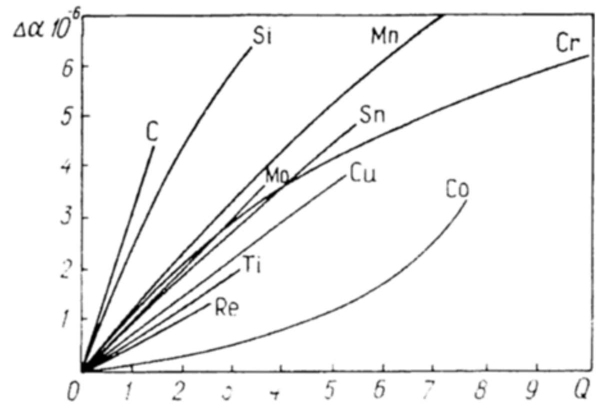


Fig. 1. Detector.

Fig. 2. Effect of alloying on TLEC value ($\Delta\alpha$, K^{-1}) of Invar alloy (Q, content of elements, wt.%).

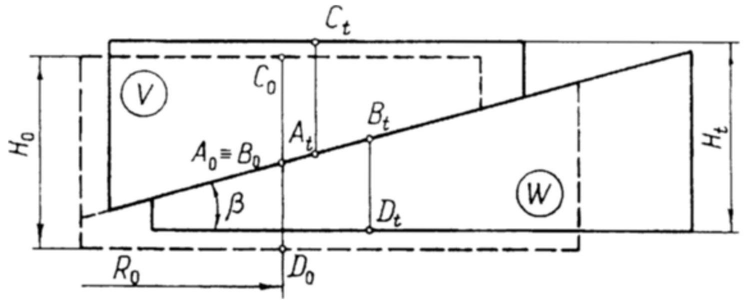


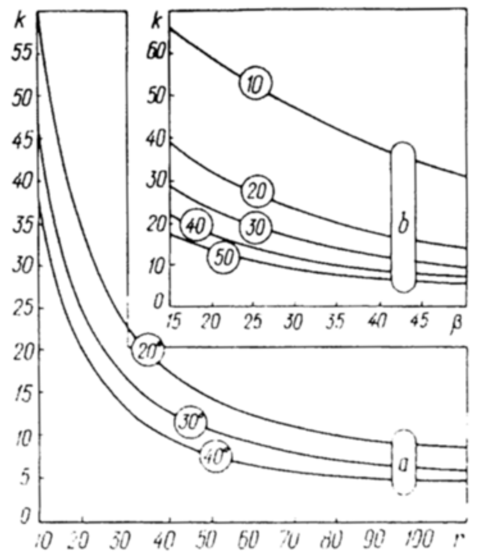
Fig. 3. Diagram of element of the compensator of inconsistent thermally induced variations in the length of the crystal and the container of the detector.

material are chosen to ensure that thermally induced variations in the height of the compensator and the difference in variations in the lengths of the container 2 and the crystal 1 are always equal in magnitude and opposite in sign.

Invar alloys are the most suitable material for the inner rings 8, since they have one of the lowest TLECs of most metal alloys. Inasmuch as the TLECs of the rings 7 and 8 of the compensator and the geometry of the rings must be correlated it should be possible to vary the TLEC value of at least one group of rings. In fact, we must select the material of the inner rings 8. The choice can be simplified if one turns to the data (Fig. 2) on the effect of the components on the TLEC of Invar-group ferronickel alloys [4].

Figure 3 presents a diagram of a compensator element. Here V is a fragment of the radial cross-section of an inner ring, and W is a fragment of the radial cross-section of an outer ring. It is assumed that in the process of variation of their temperature (heating) both rings (fragments of cross-sections V and W) do not lose contact with one another, i.e., a point A belonging to fragment W is always in contact with fragment W, and a point B belonging to the fragment W is always in contact with the fragment V. The initial temperature state of the compensator elements is indicated in Fig. 3 by the subscript 0, and the final one by the subscript t. Hence, A_0 and A_t are nothing more than the same point A on the conic surface of the inner ring (fragment V) in the initial and final temperature states, respectively. The same holds also for point B.

Let us denote the height of the two fragments of the cross-sections of both of rings as H_0 in the initial state, and as H_t in the final state. We denote the temperature difference of the initial and final states as Δt and



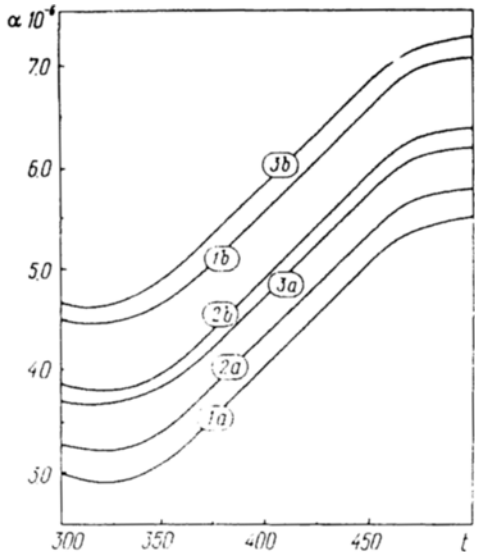


Fig. 4. Dependence of the number of pairs (*k*) of contacting conic surfaces of the compensator rings of the detector (NaI(Tl) crystal 250 mm in length) on the geometrical parameters of its construction elements: a) radius of the crystal base (*r*, mm) for values of the angle (*β*, deg) at the base of conic surfaces of the compensator rings of 20, 30, and 40 deg; b) on the angle *β* for values of the radius of the crystal base of 10, 20, 30, 40, and 50 mm.

Fig. 5. Calculated temperature dependence of TLEC (α, K^{-1}) for the material of the inner rings of the compensator for NaI(Tl) crystals 250 mm in length: a) and b), crystal diameters of 50 and 100 m, respectively; 1, 2, and 3) angles at the base of contacting conic surfaces of the compensator rings of 25, 35, and 45 deg, respectively. *t*, K

consider it as positive if the final temperature state is characterized by a higher temperature than the initial one. Then the variation in the height

$$\Delta H = H_0 - H_t , \tag{1}$$

that the compensator element undergoes when its temperature varies by value Δt can be defined as

$$\Delta H = R_0 (\overline{\alpha}_2 - \overline{\alpha}_1) \tan\beta \, \Delta t - (\overline{\alpha}_1 A_0 C_0 + \overline{\alpha}_2 B_0 D_0) \, \Delta t , \tag{2}$$

where R_0 is the distance from the common symmetry axis of the compensator (not shown in Fig. 3), A_0C_0 is the height of fragment V in the initial temperature state measured at distance R_0, B_0D_0 is the height of fragment W in the initial temperature state measured at distance R_0, $\overline{\alpha}_1$ and $\overline{\alpha}_2$ are the mean TLEC values for the materials of the inner and outer rings, respectively (in the temperature range Δt), and β is the angle at the base of the conic surface along which the rings contact one another.

If R_0 is chosen to satisfy the condition $A_0C_0 = B_0D_0 = 1/2H_0$, expression (2) can be written in the form

$$\Delta H = R_0 (\overline{\alpha}_2 - \overline{\alpha}_1) \tan\beta \, \Delta t - \frac{1}{2} H_0 (\overline{\alpha}_2 + \overline{\alpha}_1) \, \Delta t . \tag{3}$$

The obtained relationship for evaluation of the variation in the height of the compensator is convenient from the viewpoint of analysis. An increase in ΔH is stimulated by an increase in:

a) the diameter of the compensator rings (through R_0);

b) the difference $(\overline{\alpha}_2 - \overline{\alpha}_1)$ between the TLECs of both rings in each pair;

c) the angle β at the base of the conic surface along which the compensator rings contact one another (cannot be greater than 0.5π minus 'he friction angle of the material of the outer ring over the material of the inner ring one).

If it appears in the process of calculation of the compensator that one pair of rings is insufficient for complete compensation of the inconsistency of thermally induced variations of the lengths of the detector crystal and its container, one should choose the necessary number of rings and adjust the value of β.

In a real detector the inner and outer rings of the compensator can each have one or two conic surfaces that take part in matching thermally induced variations of the dimensions of elements of the detector construction. Therefore, it is appropriate to use in calculations the quantity k, which is the number of pairs of conic surfaces. It is evident from Fig. 4 that for a fixed crystal length (250 mm) an increase in the raduis of its base, and therefore, in R_0, results in a decrease in the minimum number of pairs k. The quantity k also decreases with increasing β. It is clear that the smaller k, the shorter the entire detector. Therefore, the larger the crystal diameter, the more efficient the proposed design of the compensator. The above considerations hold for compensators with containers of AMTs alloy. Here we asume that the temperature detector is in the vicinity of 300 K.

Figure 5 presents temperature dependences of TLEC calculated using expression (3) for the material of the inner rings of the compensator for detectors with an NaI(Tl) scintillator with a length of 250 mm and diameters of 50 mm (curve a) and 100 mm (curve b). Three curves are drawn for each value of the crystal diameter, which are denoted by indices 1, 2, and 3 and correspond to angles β of 25, 35, and 45 deg and numbers of pairs k equal to 22, 16, and 12 (for the 50-mm-diameter crystal) and 12, 8, and 6 (for the 100-mm-diameter crystal). These dependences are used to select the material of the inner rings of the compensator. In the particular case most suitable are Invar alloys such as 38NK, 30NKD, 29NK, etc. [5].

The optical properties of the described detector design coincide completely with those of detectors without compensators. The vibration and shock resistances of the detector depend on the temperature in the same manner as a thermal action affects the strength parameters of the exit window unit and the crystal itself.

Thus, the proposed design of the detector as a whole and of the compensator of inconsistent thermally induced variations in the dimensions of the crystal and its container in particular has no analogs so far and makes it possible to solve successfully the problem of matching of the linear dimensions of its main components in the required temperature range without any sacrifice of rigidity and strength of the device.

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