FORMATION OF LIGHT-REFLECTING POWDER SHELLS FOR SCINTILLATION CRYSTALS WITH A COMPLICATED SHAPE

V. I. Mel'nik and B. V. Grinev

UDC 539.1.074.3

Technical means for mechanized formation of light-reflecting powder shells of scintillation crystals with a complicated shape that is close to conical are unknown at present. Below, we suggest a design for such technical facilities, a technology for assembling detectors with their aid, and the selection of the operational parameters of the assembly.

The problem of the formation of light-reflecting powder shells of crystalline scintillators (ionizing radiation detectors) falls into the category of those that have undergone intense development. As far as crystals of cylindrical and prismatic shapes are concerned, i.e., those having a fixed cross section, a variety of techniques and facilities exist at present [1-4] that permit one to mechanize almost fully the operation of the formation of light-reflecting powder shells and even to create the necessary conditions for its automation. The situation is less satisfactory with respect to crystals of a complicated shape, in particular, one that is close to conical, with a broken-line or curvilinear generatrix. There is a practical need for such detectors, because in some cases the use of complicated shapes in the constructions of scintillators makes it possible to optimize the collection of light and thus to increase the yield of light and other parameters of the detector, scintillation block, or modules assembled on their basis.

In the present paper we propose a method for assembling a detector with a conical scintillator and technical means for implementing the method. Such a detector is virtually of traditional design and differs only by the shape of the scintillator. It consists (see Fig. 1) of a crystal 1, an output window, centering rings 2 (lower) and 3 (upper), a container 4, consisting in turn of a cone 5 and a shaped ring 6 welded together, the lid of the container with an elastic gasket inside, and the conical part 7 and the end face part of the light-reflecting shell (positions not designated by digits are not shown in the figure).

The available methods do not make it possible to form the conical part of a uniformly dense light-reflecting shell.

The essence of the method proposed here is that at the start of the assembly the container of the detector is placed vertically and set into rotation. Then, during rotation the powder for the light-reflecting shell is distributed over the inner surfaces of the container with the help of a screw conveyer that also rotates. The speed of rotation of the container is selected so as to prevent spontaneous motion of the powder on the container walls either downward or upward. After the powder had been distributed over the inner surface of the container, the crystal, preliminarily set into rotation with an angular velocity equal to that of the container, is pressed into the latter. The output-window unit is the last to be assembled.

The facility for assembling the detector (Fig. 1) includes: clamps 8 and 9 provided with a rotational drive (not shown) for fixing the container 4 in a vertical position and setting it in rotation about its symmetry axis; a guide 10 for centering the removable instrument 11 (Fig. 1a) and the removable lower centering element 12 (Fig. 1b); a unit 13 for centering, moving axially, and setting into rotation the instrument 11 or the upper centering element 14; the unit is provided with a block for uniaxial loading and with axial and rotational drives (not shown). The worm instrument 11 consists, in turn, of a shaft 15, a ring 16, and a screw coil 17. The shaft 15 is made hollow with a blind cavity 18 open from above and through holes 19 in the walls 20. The cavity 18 is used as a container

Institute of Single Crystals, Academy of Sciences of Ukraine, Kharkov. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 68, No. 2, pp. 263-270, March-April, 1995. Original article submitted July 10, 1992; revision submitted June 20, 1994.

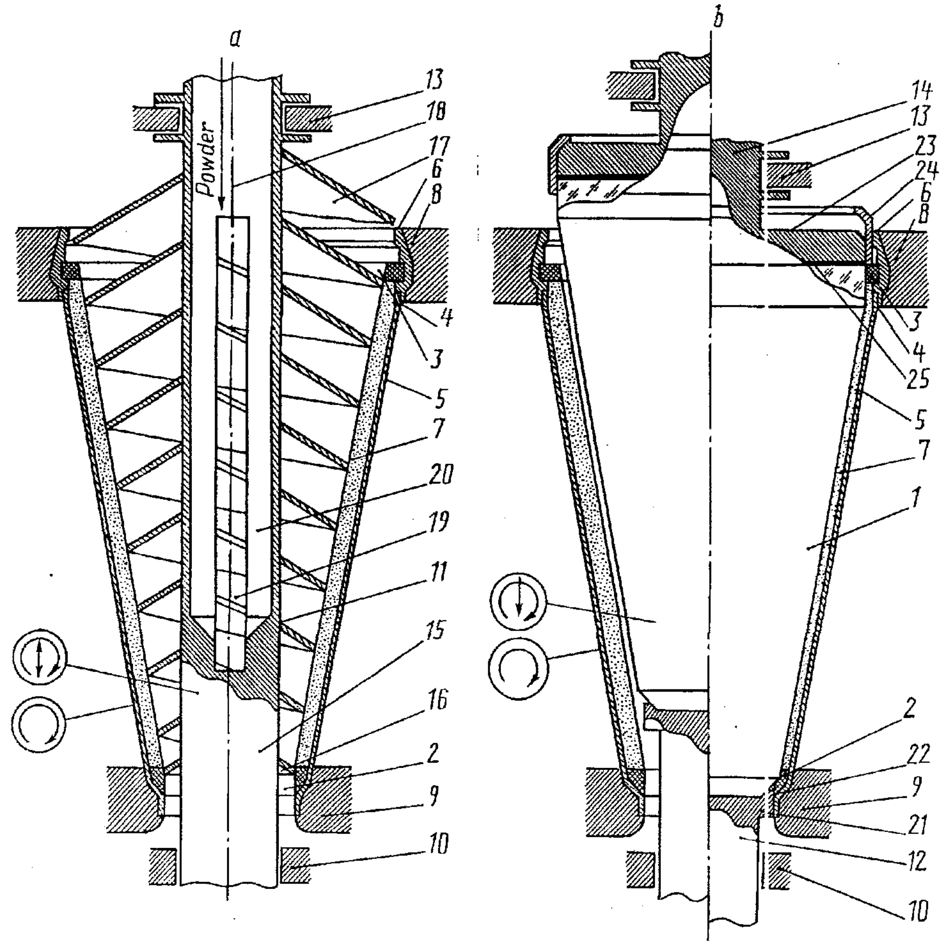

Fig. 1. A device for assembling a detector shown in the states of formation of a light-reflecting powder shell (a) and insertion of the crystal into the container (b).

accommodating the powder for the light-reflecting shell. The ring 16 is secured in the lower part of the shaft 15 below the level of the cavity 18; with the facility being in the operative state, it is located inside the centering ring 2 of the detector with a slight tightness not impeding free rotation. In such a state the ring 16 fully overlaps the space between the shaft 15 and the lower centering ring 2 of the detector. The screw coil 17 joins in its lower part with the ring 16, it has a variable radius over its height, and in the operative state of the facility it is located inside the container 4 with a fixed gap. The through holes 19 in the walls 20 of the hollow shaft 15 are made at the level of the screw coil 17 and are meant for extracting the powder for the light-reflecting shell from the cavity 18 of the shaft 15 onto the loops of this coil. The lower centering element 12 is a spring-loaded (from below, not shown in the figure) vertical shaft with a centering tray 21 on the upper end face. The tray 21 itself has a peripheral centering collar 22 that is also oriented upward. The upper centering element 14 has a tray 23 in its lower part and a peripheral centering collar that is oriented downward and is made in the form of a separate, axially mobile piece, namely, a ring 24 encircling the tray 23 with a minimum clearance.

In designing the detector and the facility for its assembly, the shape of the crystal 1, the thickness of the cone part 7 of the light-reflecting shell in the states directly before and after the pressing of the crystal 1, the geometry of the centering rings 2, 3 and the instrument 11, and the high-speed regimes of the assembly of the detector must necessarily be correlated. In this case the following requirements must be met:

1) in assembling the detector, the powder should not fall spontaneously or be ejected upward along the inner surface of the container 4 (at the time after the withdrawal of the instrument 11 and before the time of full insertion of the crystal 1 in the container);

2) the necessary degree of compaction of the powder should be attained.

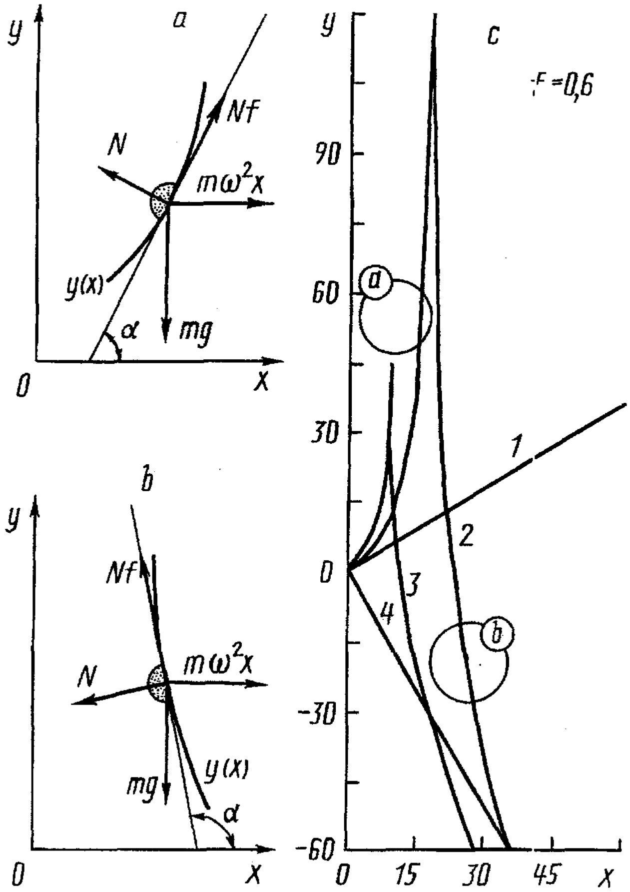

Fig. 2. Computational schemes (a, b) for two critical equilibrium positions of a powder particle of a light-reflecting shell on a generatrix of the inner surface of the container and graphs (c) of the critical generatrices corresponding to an angular velocity of the container equal to zero (1), 15 sec^{-1} (2), 20 sec^{-1} (3), and infinity (4). x, y, mm.

Let us consider the first requirement. Suppose that $y(x)$ is the generatrix of the inner surface of the container 4 (of the surface of revolution). Since the symmetry axis of the inner surface and the very rotational axis of the container coincide in the process of assembly (see Fig. 1), the domain of definition of the function $y(x)$ is $x \in [x_{out}, x_{inn}]$, where x_{out} and x_{inn} are the minimum and maximum radii of the inner surface of the container, measured between the sites for the centering rings 2 and 3, i.e., at the level of the side part 7 of the light-reflecting shell. As regards the generatrix $y(x)$, we can make one of the following two assumptions: its form is known, for example, from the conditions of the optimum design of the detector based on its performance figures; its form is unknown. In the latter case only x_{out} and x_{inn} are assigned, while the function $y(x)$ itself and the regimes of assembly, in particular, the rotational speed ω of the container 4, or, better, the boundary values ω_{out} and ω_{inn} in the possible range of this speed, are to be determined.

Let us consider this case. We consider $y(x)$ to be either a monotonically increasing, a monotonically decreasing, or a piecewise assigned function consisting only of monotonically increasing or only of monotonically decreasing portions. Other versions are excluded by reason of impracticability of assembly. Since in the case of the piecewise representation of the generatrix $y(x)$ each of its fragments can be studied separately, we shall omit this version from consideration in what follows. From the viewpoint of the statement of the problem, several situations are possible:

1) a particle of mass m is located on an ascending generatrix, adheres to it by its weight and friction forces, and attains the critical equilibrium state with respect to its motion downward (the friction force is directed upward, see Fig. 2a);

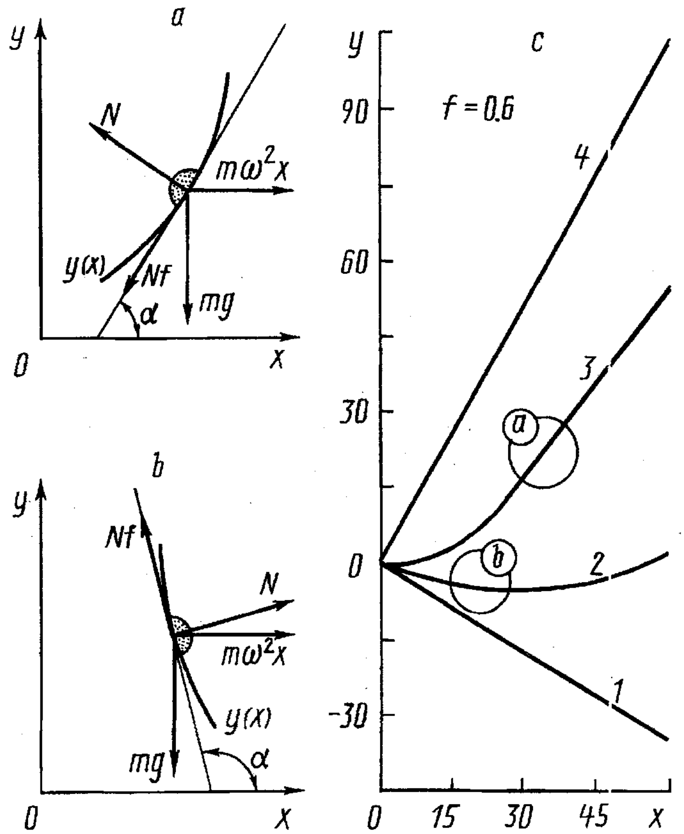

Fig. 3. Calculational schemes (a, b) for two critical equilibrium positions of a powder particle of a light-reflecting shell on a generatrix of the container surface in contact with it and graphs (c) of the critical generatrices corresponding to an angular velocity of the container equal to zero (1), 5 $\sec^{-1}$ (2), 15 $\sec^{-1}$ (3), and infinity (4).

2) the particle is located under a descending generatrix, adheres to it due to the centropetal and friction forces, and attains the critical equilibrium state with respect to its motion downward (the friction force is directed upward, see Fig. 2b);

3) the particle is located on an ascending generatrix, adheres to it by its own weight and friction forces, and attains the critical equilibrium state with respect to its motion upward (the friction force is directed downward, Fig. 3a);

4) the particle is located on a descending generatrix, adheres to it by its own weight and friction forces, and attains the critical equilibrium state with respect to its motion downward (the friction force is directed upward, Fig. 3b).

The second and fourth versions of the position of the particle on a generatrix have no practical application for the proposed concrete implementation of the means of assembly of detectors, but are not devoid of applied value and will also be considered in what follows.

The equilibrium condition for a powder particle for situations 1 and 2 (here and below, the upper signs), 3 and 4 (the lower signs) is

$$\pm Nf + m\omega^2 x \cos\alpha - mg \sin\alpha = 0\,, \quad N - mg\cos\alpha - m\omega^2 x \sin\alpha = 0\,. \tag{1}$$

From the system of equations (1) it follows that for all $x > 0$ (the negative domain of the argument has no physical meaning), the first derivative of $y(x)$ has the form

$$\dot{y} = \frac{\omega^2 x \pm gf}{g \mp \omega^2 fx}\,. \tag{2}$$

Having integrated Eq. (2), we obtain equations for the critical generatrices:

$$y = \frac{-g(1+f^2)}{\omega^2 f^2} \ln \left| x \mp \frac{g}{\omega^2 f} \right| \mp \frac{1}{f} \left(x \mp \frac{g}{\omega^2 f} \right) + C, \tag{3}$$

where C is the integration constant, which can be found from the condition $x = x_{out}$, $y = 0$. Several examples of critical generatrices are given in Figs. 2c and 3c. The space between two critical generatrices (the first downward, the second upward) contains an infinite number of generatrices that can be selected as actual ones, i.e., those laid down in the design of detectors. Here it should be kept in mind that the first derivative of a generatrix must also lie in the space between the critical values of the derivatives calculated from expression (2). Proceeding from an analysis of expression (2) for the first derivative, it can easily be seen that as $\omega \to 0$ the critical generatrix transforms into the straight line $y = fx + C$ for the first version of the statement of the problem (Fig. 2c, curve 1) and into the straight line $y = -fx + C$ for the fourth version (Fig. 3c, curve 1). When $\omega \to \infty$, the critical generatrices also acquire a linear form: $y = -x/f + C$ for the second version of the statement of the problem (Fig. 2c, curve 4) and $y = x/f + C$ for the third version of it (Fig. 3c, curve 4). In the case of intermediate values of the angular velocity $0 < \omega < \infty$, function (3) corresponding to the first and second versions of the statement of the problem undergoes a discontinuity at the point $x = g/\omega^2 f$ (Fig. 2c, curves 2 and 3). The ascending branches of these curves, for example, the fragment a on curve 2, correspond to the first version of the statement of the problem (Fig. 2a), while the descending branches (e.g., the fragment b on curve 2) correspond to the second version of it (Fig. 2b). Function (3) corresponding to the third and fourth versions of the statement of the problem has a minimum at the point $x = gf/\omega^2$ (Fig. 3c, curves 2 and 3). The ascending branches of curves 2 and 3, in particular the fragment a, correspond to the third version of the statement of the problem (Fig. 3a); the descending branches, in particular the fragment b of curve 2, correspond to the fourth version (Fig. 3b).

If the equation of the generatrix $y(x)$ and, consequently, the equation of the first derivative $\dot{y}(x)$ are specified (including the boundaries of the domain of definition x_{out} and x_{inn}) by the initial conditions, then, using expression (2), we can solve the inverse problem, i.e., determine the range of the angular velocity ω (squared) within which the equilibrium condition (1) for a powder particle will be fulfilled for any $x \in [x_{out}, x_{inn}]$:

$$\frac{g(\dot{y}(x) - f)}{x(1 + f\dot{y}(x))} < \omega^2 < \frac{g(\dot{y}(x) + f)}{x(1 - f\dot{y}(x))}. \tag{4}$$

The practical importance of inequality (4) is evident. We only note that to implement the technique, it is insufficient that condition (4) be fulfilled for the interface of the powder and the container material. If the coefficient of internal friction of the powder of the light-reflecting shell turns out to be smaller than the corresponding coefficient for the pair of powder and container material, it is necessary to verify condition (4) for the powder itself and to select a value for the angular velocity ω that would satisfy both conditions.

The degree to which the powder of the light-reflecting shell is packed in its conical part 7 is determined by the thickness ratio of the light-reflecting layer before the pressing of the crystal 1 (Fig. 1b, left side) and after its pressing (Fig. 1b, right side). The necessary degree of compaction is achieved by matching the dimensions of the elements of the detector and the instrument 11.

The technological process of assembly of the detector proceeds as follows. At the beginning, the rings 2 and 3 are placed and fixed, for example with adhesive, inside the container 4 without the lid (Fig. 1). Then, with the aid of the clamps 8 and 9 the container 4 is fixed in a vertical position and set in motion. Then, using the guide 10 and the unit 13, the worm instrument 11 is put inside the container 4 coaxially with it and so that the ring 16 of the instrument 11 is located at the level of the lower centering ring 2. After this, the instrument 11 is set in motion in the same direction as the container 4 but with a somewhat different angular velocity. Then, the amount of powder needed to form the conical part 7 of the light-reflecting shell of the detector is filled into the cavity 18 of the shaft 15. From the through holes 19 in the walls 20 of the shaft 15 the powder is brought by rotation from the cavity of the shaft 15 to the surface of the screw coil 17 of the worm instrument 11 and then to the gap between the coil 17 and the cone 5 of the container. The ring 16 prevents leakage of powder outside the working zone. The powder falls down the surface of the cone 5 by gravity and is raised upward by the worm instrument 11. The powder falls only in the first stage until the angular velocity of its particles becomes equal to that of the parts of the container.

Moreover, equalization of the velocities is impeded by the instrument 11 itself, which rotates somewhat more slowly than the container 4. As soon as the powder is uniformly distributed over the inner surface of the cone 5, it ceases to interact with the coil 17 of the instrument 11 and, consequently, it gradually acquires an angular velocity equal to that of the container surfaces in contact with it. As a result, the centripetal forces acting on the powder particles and, correspondingly, the internal friction between the particles increase and, consequently, their fall stops. In this state, without stopping the rotational motion of the container, the instrument 11 is removed.

The next stage (Fig. 1b) in the process of the assembly of the detector is the insertion of the guide 10 of the centering element 12. Since the element 12 is spring-loaded from below in the axial direction and is installed inside of the guide 10 with the possibility of both rotational and translational motion (in the direction of the symmetry axis of the container 4 and of the whole facility), it moves under the action of the axial spring to its upper position, for which its centering tray 21 is set above the level of the container 4. Then, with the help of the unit 13 the upper centering element is fixed. At this time the crystal 1 is already prepared for placement in the container 4. Then, using the axial drive of the centering element 14, it is raised as high as needed for it to be placed in the space between the trays 21 and 23. While this is being done, the coaxiality between the crystal and the elements 12 and 14 is strictly observed. To protect the polished plane of the output face of the crystal 1 from mechanical damage, it is covered with an elastic gasket 25 (Fig. 1b) made, for example, of polyfluoroethylene resin. After this, using the axial drive, the element 14 is lowered and the crystal is pressed between the centering trays 21 and 23. Now, its displacement relative to the elements 12 and 14 is impossible. In the axial direction this is prevented by the trays 21 and 23, and in the radial direction – by the peripheral collar 22 of the tray 21 and the bandage ring 24 of the tray 23. Now, the rotational drive of the centering element 14 is started and with its aid the entire system is set in motion, i.e., the element 14, crystal 1, element 12. At this time the gasket 25 operates as a friction clutch. Gradually, the speed of the crystal is brought up to that of the container and it is stabilized at this level. Then, using the uniaxial loading block overcoming the resistance of the axial spring of the centering element 12, the crystal is transferred into the container (Fig. 1b, left side). The crystal is inserted until its side surface fully contacts the powder of the light-reflecting shell powder distributed in the container. At this time the resistance to the insertion of the crystal into the container increases in jumpwise fashion, due to the start of powder pressing. This is the beginning of the stage of pressing of the crystal 1 into the container 4. The condition of pressing is regulated by the uniaxial loading block. As soon as the crystal is pressed into the container to the necessary depth (Fig. 1b, right side), the pressing is stopped, but the axial force is not removed. In this state all the rotational drives are disconnected and the piece (detector) is stopped. Then, the axial loading acting on the crystal from the side of the centering element 14 is removed, and the element 14 itself is moved upward. At this time, spontaneous partial rise of the crystal 1 by not more than the thickness of the centering rings 2 and 3 is possible. The probability of such a rise and its extent depend on the shape of the crystal and the magnitude of the forces of friction between it and the powder of the light-reflecting shell 7.

Having removed the gasket 25 and prepared the input end face of the crystal 1, we coat it with the material for optical binding of the output window glass with the crystal. The glass is installed using the same centering element 14 with its uniaxial loading block, the tray 23 and the bandage ring 24, and the gasket 25; the glass is centered relative to the container 4 and the crystal is pressed again to its former position. Then, keeping the crystal from spontaneously rising from the container, we raise the bandage ring 24 and pour adhesive into the gap formed between the glass and the shaped ring 6 of the container 4. After the adhesive hardens, the piece is removed from the facility, the end face of the light-reflecting shell is formed, and the input-window unit of the detector is assembled.

Conclusions. The proposed technical solution, so far the only one among those available, makes it possible to mechanize the assembly of detectors with a crystal of complicated shape (close to conical), guaranteeing the required uniformity in the distribution of the powder in the light-reflecting layer and the programmed degree of compaction of the powder.

NOTATION

f, coefficient of friction of a powder particle against the container surface; g, free-fall acceleration; m, mass of a particle; N, normal reaction; α, angle of slope of a tangent to a generatrix; ω, angular velocity of a particle.

REFERENCES

1. B. V. Grinev and A. N. Litichevskii, "A device for forming a light-reflecting shell in a scintillation detector," Patent 1626894 RF: MKI^5 G O1 T 1/202.
2. B. V. Grinev and A. N. Litichevskii, "A device for forming a light-reflecting shell in a scintillation detector," Patent 1715067 RF: MKI^5 G O1 T 1/202.
3. B. V. Grinev and V. I. Mel'nik, A scintillation detector, a means of assembling it, and a device for assembling a scintillation detector," Patent 1805410 RF: MKI^5 G O1 T 1/202.
4. V. I. Mel'nik, B. V. Grinev, and A. N. Litichevskii, "A means of forming a light-reflecting shell in a scintillation detector," Patent 1725648 RF: MKI^5 G O1 T 1/202.