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Protection of orbital station optics against high-speed damaging elements

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ABSTRACT

Various protection of optical devices, arranged in the orbital stations against "space debris" and probable terrorist acts in space are examined in the paper. The materials, transparent in visible spectrum and applied for development of transparent armor, are given. Variants and prospects for creation of new materials intended to protect optical devices in space are considered.

1. Introduction

In recent years the problem, connected with protection of orbital stations against ballistic exposure to "space debris", primarily to the components of the worked-out space vehicles, is widely discussed in scientific literature and internet [1,2]. A rich variety of information is available in literature about distribution of space debris in orbits, in accordance with size and mass and the number of the objects being tracked [3]. But this information is contradictory and unreliable. Yet, all the sources are of the opinion that space debris presents a real threat for orbital stations [4], and its amount will be increasing owing to active exploitation of the near-Earth space environment and mutual collision of the space debris objects and particles (Kessler syndrome). Every year the number of public and private companies engaged into space activity is increasing and we are to be ready to counteract to "space terrorism".

Today, the space debris control is limited to periodic discussion of the problem on different international commissions and committees, debris monitoring with optical and radar techniques, project development for the earth orbit to be cleaned. Literature and patent sources include a considerable amount of information about the methods intended for protection of space vehicles against collisions with high-velocity damaging elements. In most cases these are protective shields based on physical principles [2,5,6].

Information about the implemented constructions and introduced effective engineering solutions is not available in press.

It should be noted that such constructions are not suitable for protection of optical devices installed in space vehicles, because they cause screening of the pupil of the optical system.

2. Protecting optical devices

It should be noted that today broad experience has been compiled in development of materials and structures for light armor protection, including materials which are transparent in optical range. These materials are applied for protection against high-velocity bullets and fragments with surface density not exceeding 50–80 kg/m^2. Constructions made of non-transparent materials can be used for protection of mechanic and electronic components of the optical devices, while constructions of transparent materials are used for protection directly of optical components.

A variety of armor constructions, protecting against high-velocity damaging elements (that will be “space debris“) one can divide into the following groups:

1. Textile armor (fibres of kevlar, tvaron. тварон, dainema дайнема etc.);
2. Metallic armor (steel, aluminum, titanium, and different alloys);
3. Ceramic armor (corundum, boron carbide, silicon carbide etc.);
4. Organoplastic armor (composite armor based on aramid fibres or long polyethylene);
5. Combined multilayer armor (metallic-textile-organoplastic etc.);
6. Transparent armor.

Transparent armor is intended primarily for direct protection of optical elements when in use in space object. This armor should possess maximal transmission in operating optical range, not introduce aberrations (wavefront aberrations) into operation of optical system and provide the required (the given) protection level against high-velocity damaging elements. Today, the choice of such materials is small.

Inorganic glass and transparent polymers (organic glass) are

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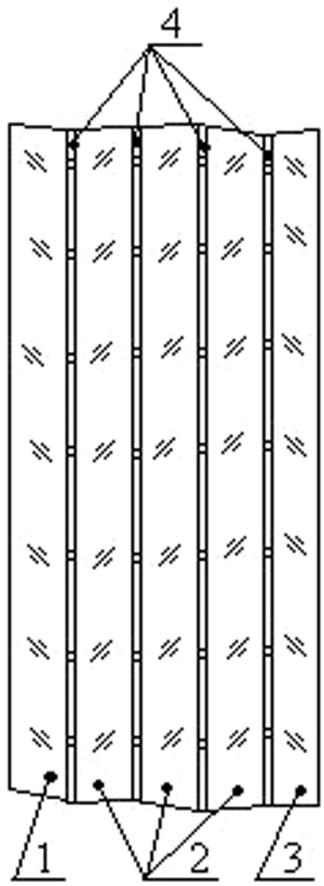

Fig. 1. Circuit of a standard multilayer transparent armor. 1 – very hard facing layer, 2 – glass layers, 3 – polycarbonate layer, 4 – clear adhesive..

extensively applied as the materials for manufacturing the transparent armor. But transparent ceramic solids: leucosapphire (single-crystal colorless aluminum oxide Al_2O_3), polycrystalline aluminum oxynitride Al23O27N5 (ALON), magnesium-aluminum spinel MgAl2O4 [7] possess higher protective properties.

Generally the transparent armor includes three components (Fig. 1):

1) surface layer, immediately taking impacts and blocking the penetration of the damaging elements;
2) power block, absorbing the basic impact energy;
3) rear surface, absorbing the impact energy and blocking the spread of the secondary glass fragments.

Based on the layers functions the strength and viscoelastic properties of the layer-built composition components (silicate and organic glass, and adhesive materials) are matched.

Transparent armor, being conceptually a composite construction can be singled out as a special class of ballistic materials.

Blanks with imparted mechanical properties and heat resistance are sticked together with a transparent elastic polymer film (e.g. butyral resin) and warmed, or with a sizing connective, solidifying under ultraviolet light. In this way one obtains a heterogeneous multilayer structure with high resistance to shock loads and with ability to confine fragments. Depending on the number of layers one distinguishes triplex (tree layers), pentaplex (five layers) and polyplex (more than five layers).

Under impact with such a structure, even if the attacking element hangs in the outer layer of composition, the elastic wave, propagating from the impact point toward the interior with high velocity, and reflected back through deeper layers, will cause its destruction. In this case, the higher is the impact energy, the larger the velocity of cracks propagation will be [8]. The more durable is the glass, the more energy of the attacking element will be spent for its destruction. That is why strengthening of glass is of decisive importance when developing the effective transparent armor.

Table 1
Strength of plate silicate glass (versus its state).

Glass state	Limit of the bending short-time strength, MPa
Raw glass	30–80
Hardened	
Air hardening	120–180
Liquid hardening	200–400
Ionic exchange	300–700
Etching	1000–1700
Combined method	1700–2700

In spite of the very high theoretical strength of the silicate glass, determined by strong chemical bonds, its real strength is hundred times lower and mainly dependent on the surface plate state. Invisible for eye cracks, scratches, microcracks emerging in production, shipment and storage will be the stress concentrators and sources for fast cracks extension even under small loads. Hence, the methods to strengthen glasses are directed to the elimination of the surface defects (chemical etching), or to generation of high compression stresses in the glass surface layers (thermal hardening, ionic exchange), which compensate tensile stresses under static and dynamic loads and block the cracks extension. Combined methods to strengthen silicate glasses are particularly effective (Table 1) [8].

A continuous crack network is being formed as a result of the hardened glass fracture, which makes the product nontransparent and plenty of small fragments is formed. Application of hardened glass for space is very limited because of these fragments to be thrown by impact into space.

Selection of the transparent armor composition is based on the protective properties and weight restrictions given by the customer on the one hand, and starting material and technologies available, on the other hand. E.g. a shockproof polycarbonate, applied for sticking the rear layer is not produced in Russia. Domestic adhesive films are not available; our experts have to apply the import ones.

Manufacture of the lightweight armor requires the glass to be hardened, and the curved surface requires equipment for the glass bending. All these requirements make the products more expensive (depending on the dimensions and shapes complexity).

Thickness and shape of the transparent armor influence substantially the optical values. Though today optical transmission is standardized for the glass to have shielding properties, one should take into account that increase in the product thickness from 15 to 60 mm decreases optical transmission (depending on the composition material) from 80 to 85 to 50–60%. The curved surface shape causes unwanted optical distortions (aberrations), particularly in the edge zones, in this case with increase in the armor thickness, such distortions will be increased. This makes observation more difficult and application of optoelectronic devices less effective.

All these reasons force the customer and producer to find the ways for the costs and quality to be optimally matched. It is also difficult to compare the data about the armored glass thickness, because specifications relative to foreign shielding products and their classification are established by national standards, e.g. German DIN V 5229 (shielding classes), American NIJ classes MPSA-HPS-SPSA-33HPS-ASHPR) and UL 752, British BSI (classes G0-G3), Italian UNI 9187 (APS/A - APS/F).

Table 2 [8] gives the obtained limits of thickness and estimated weight of 1 m^2 composition in line with the Russian classification in State Standard P 51136-2008"Multilayer protective glass".