DESIGNING SPACECRAFT SHIELDING FROM THE IMPACT OF METEOROIDS AND SPACE DEBRIS

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ABSTRACT

The paper considers designing one-layer and multi-layer spacecraft from the impact of high-velocity mechanical particles of natural (meteoroids) and artificial origin. In the cases under conciderations it is suggested to define threshold speed as a speed of collision of a particle with a thin obstacle when the object passing through such an obstacle destroys itself not less then into two fragments. Based on the results of the experiments carried out in the laboratory evaluation of the efficiency of different shielding variants some of which are presented in the report is made.

1. INTRODUCTION.

It is well-known that while in low - Earth orbit a spacecraft collides with particles a hundred times, but not all the particles damage it seriously. For instance, the "Solar Max" satellite had been for more than four years in orbit at the height of 570 km about 2m^2 of its multi-layer heat shield made of capton and 0,5 m^2 of aluminium shutters were removed and brought to Earth. Optical analysis revealed 1900 holes and dents with diameters of 40...30 mm. The particles, however did not damage the satellite as a whole.

Never the less, particles of orbital debris with the diameter from 0,5 mm to 2 cm are dangerous for a space station because the latest estimates show that the space debris density at the height of 500 km exceeds the distribution density of meteoric particles.

Collision of space debris with spacecraft structure parts is actually possible, therefore there is a problem of creating protection means, or shielding.

2. SPACECRAFT SHIELDS ANALYSIS

Spacecraft shielding may be traditional - by using one-layer shield (armour) with the thickness ultimately breakable through for a given impact. The more is collision velocity, the more is the armour thickness and consequently the armour mass, because the estimated velocity is the maximum collision velocity.

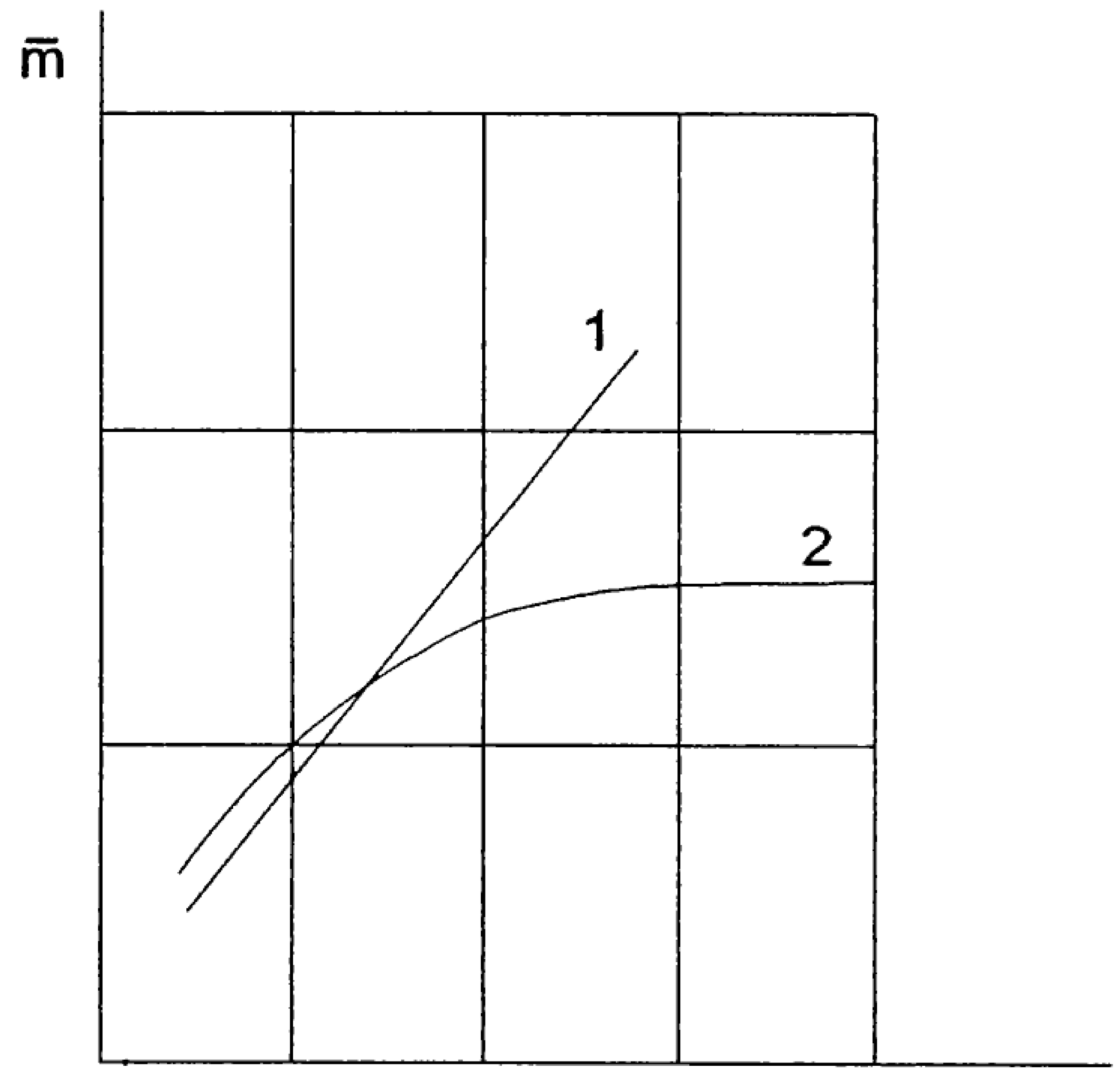

Fig.1. Mass characteristics for one-layer (1) and two-layer (2) shielding.

Some authors suggest multi-layer variants of shielding a spacecraft from high-velocity particles meteoric matter. This shielding design is efficient for collision velocities when the "screening effect" is in operation. It is possible to select such screen thickness that will make a high-velocity particle break into fragments and even melt and evaporate (at higher velocities). In the latter case it is assumed that a spacecraft part experiences the impulse load of gaseous matter of the particle and the impact of screen fragments. However this process is achieved at the collision velocities over 15 km/s, that is, it can be taken into account in designing shielding only from meteoric particles.

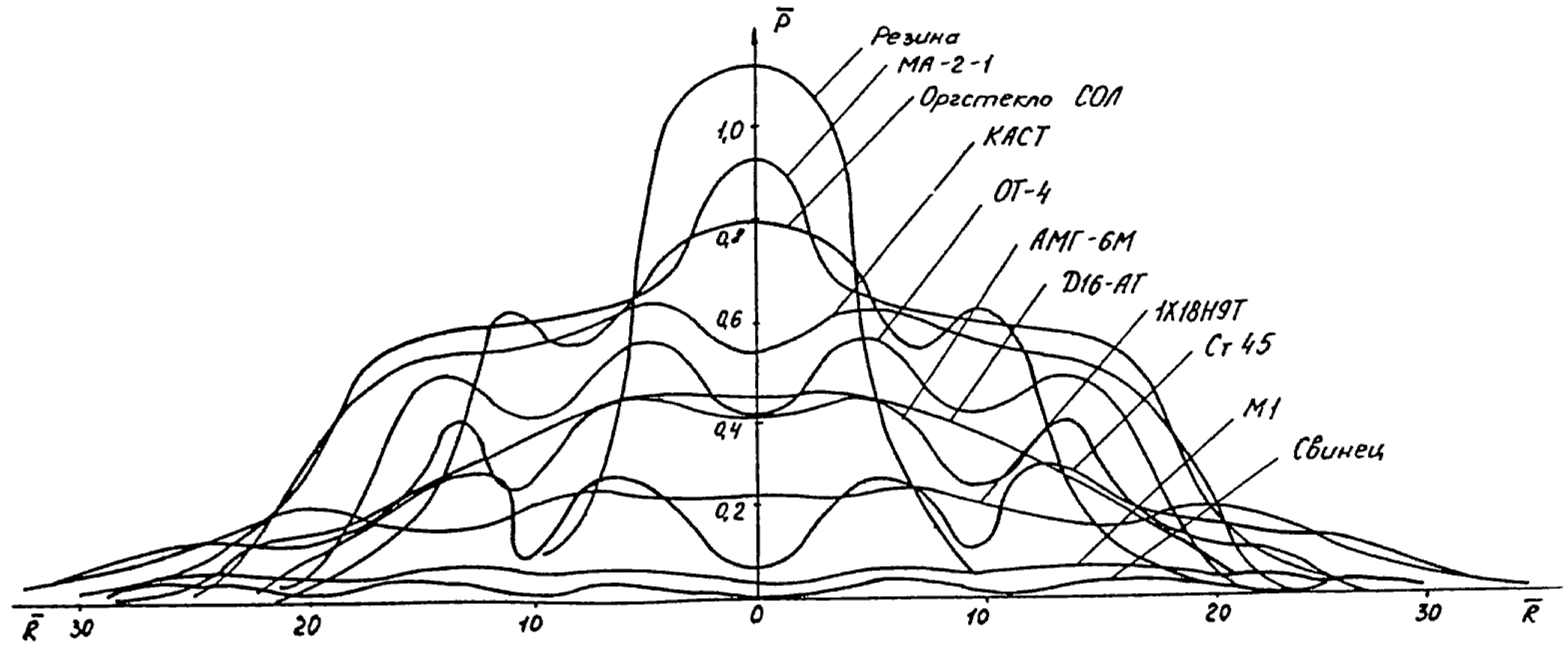

Fig. 2. relative penetration depth of particle fragments

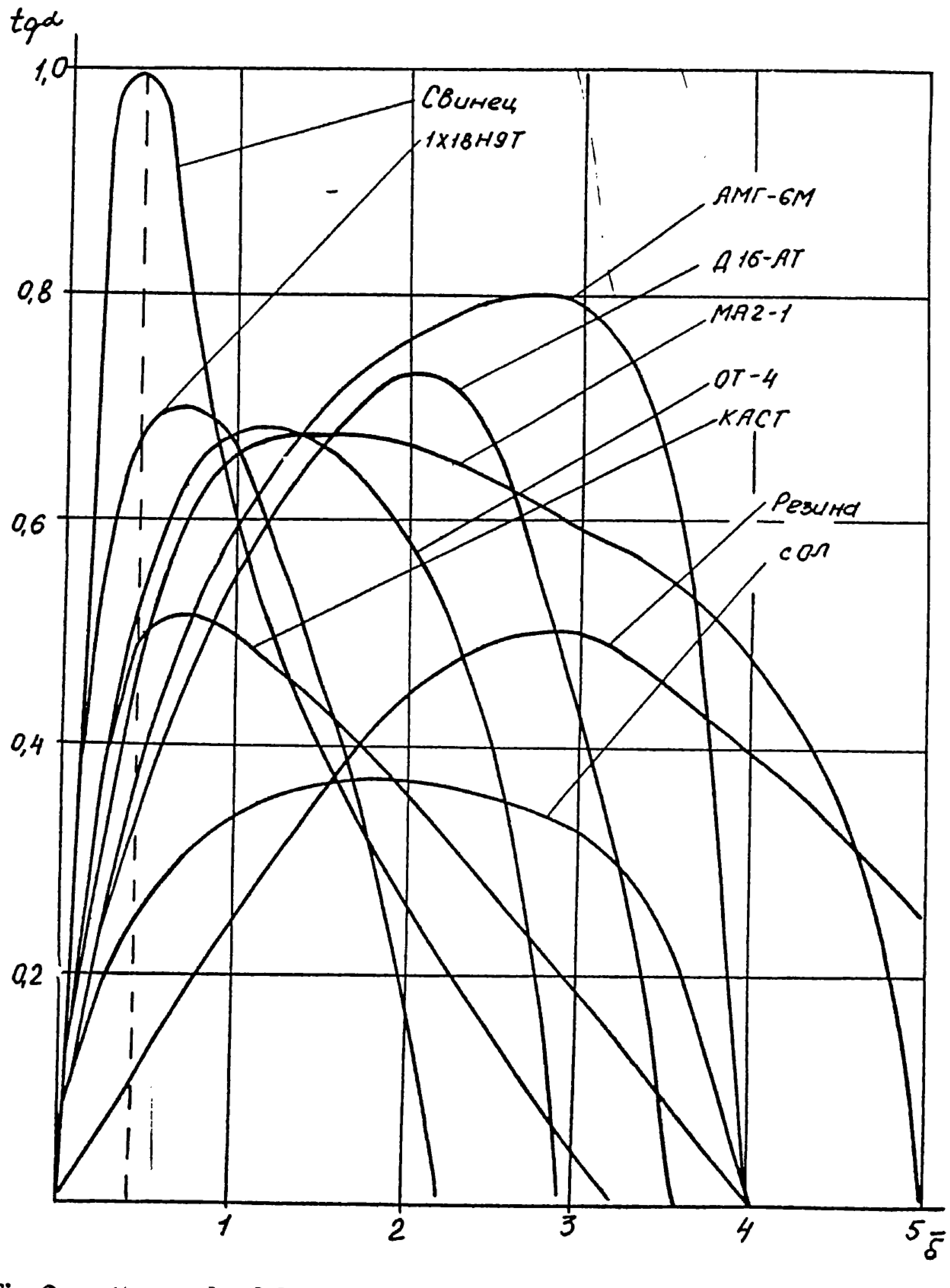

Fig. 3. scatter angle of the particle fragments and the screen fragments

High-velocity collision of a spacecraft with the field of space debris fragments is assumed to take place at the velocity less than 15 km/s. This calls for new approaches to the selection of shielding design.
Figure 1 gives the qualitative picture of dependence of mass characteristics m (mass per unit area) for one-layer (1) and two-layer (2) shielding of the collision velocity. The analysis reveals that at the velocity lower that the threshold velocity (V_{nop}), the mass of one-layer shielding may be less than the mass of two-layer shielding. But as the velocity exceeds the threshold velocity, two-layer shielding will have a smaller mass. Besides, it is possible to decelerate the threshold velocity through previous crushing of high-velocity particles by means of a special layer.

By threshold velocity we mean the collision velocity of a particle with a thin obstacle if the particle while passing the obstacle breaks into no less than two fragments.

This velocity V_{nop} is determined from the formula

$$V_{nop}=(2.6-\bar{\rho}\bar{\delta}^{0.11})\frac{1}{\sqrt{\bar{\rho}}} \quad (1)$$

where $\bar{\rho}=\rho_э /\rho_o ; \quad \bar{\delta}= \delta_э / d_o \quad (2)$

$\rho_э$, $\rho_э$- density and thickness of the screen; δ_o, d_o - density and average diameter of the particle.

While designing one-layer shielding we can use the formula to determine the ultimate thickness of the obstacle $\delta_т$ (mm)

$$\delta_n = K_1 \bar{p} \quad (3)$$

where $\bar{p}=1,8\rho_o^{2/3}(V_o/\rho_1 H_1)^{1/3}$

Here, the coefficient $k=1.5....1.8$; $\bar{p}$ is the crater depth in material at its semi-infinite thickness, V_o - the estimated collision velocity, ρ_0 - particle density, ρ_1 - density of the obstacle material, from Brennell.

The mass per unit area is determined by-the mass ensures the safety of a spacecraft structure part from the impact of high-velocity particle.

The essence of the "screening effect": a particle flying at a velocity exceeding threshold velocity is crushed (when colliding with a thin obstacle) into small fragments, the thickness of the obstacle being no less than a fragment size. The more is collision velocity, the less is the size of fragments. This effect enables us to design a lighter shielding (as compared to armouring).

This two-layer shielding consists of a screen and an armour removed from each other at some distance. The velocity is estimated as such one at thick the particle is not destroyed on the screen and reaches an element of a spacecraft structure only if it decelerates.

3. EXPERIMENTAL RESULTS ANALYSIS

While designing two-layer shielding it is essential to determined the material and thickness of the screen; the distance between the screen and the armour; the material and thickness of the armour.

The screening material must possess good crushing properties and good decelerating properties (the velocity after passing the screen must be as low as possible). The screening material should not break into fragments which might break through the structure parts.

Some screens (plates) 1 mm thick, made of more than twenty material, were tested. The best results revealed the dependencies of the relative penetration depth p of particle fragments and the barrier fragments against the distance R from the particle collision axis analysis of the maximum penetration into the screening structure and comparison of mass characteristics allow to give preference to materials D16AT and AMr6M.

Let us notate as the scatter angle of the particle fragments and the screen fragments. Fig.3 gives the correlation of tgα to the screen thickness. These correlations are obtained as a result of a great number of experiments with collision velocities 3...7 km/s and allow us to determine the screen thickness.

Of great importance is the distance from the screen to the second shielding (armouring) layer. When the screen is positioned close to the structure, the group impact of the particle fragments and screen fragments on the small area of the structure in likely. This may lead to greater damage. Consequently the distance between the layers of two - layer shielding may be determined by means of the scatter angle of the fragments.