SPACECRAFT FUEL SYSTEM VITALITY IN METEOROID AND MANMADE DEBRIS ENVIRONMENT

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ABSTRACT

Requirements of high effectiveness and economical feedback of space systems make actual problem of their high vitality under influence of space debris. Treating vitality of any object as probability that it will not fail at the result of external influence allowed to develop model of fuel system vitality and to estimate its value.

1. INTRODUCTION

One of the major requirements to modern and prospective space systems is their high vitality under influence of space factors. Among them are meteoroids and manmade hypervelocity particles (HP),which are dangerous for space vehicles (SV) because of their high penetrating ability. As the amount of debris in outer space increases, the problem becomes more actual.

That makes to treat vitality as one of criteria being under use while SV designing. As one of the most vulnerable systems of SV, fuel system (FS) influences considerably on its vitality.

The purpose of the present article is to suggest some results on the problem of FS vitality estimation. The following models were developed:

- the model of FS elements, hit by hypervelocity particles, failures;
- the model of FS vitality.

2. ELEMENTS FAILURE

Crashing mechanism of FS elements filled by gas, similar to that of thin plates, is well—studied. If an element contains liquid, then high pressure is induced in fluid by impact. The liquid pressure loads element's walls, often being the reason of structural ('catastrophic') damage (Ref.1).

As experiments with natural fuel tanks are expensive, it is sensible to analyse interaction of projectile with thin plate adjacent to liquid as an approach to the problem. For experiments plates made of alloys being under use in space technology (D16T & AMg6) were used .Steel projectiles with diameter up to 11 mm were shot from powder gun.

Using experimental results, relations were achieved for determination the critical impact velocity v*, which induces catastrophic failure of the plate

$$v^* = \alpha\delta m^{-5/12}, \qquad (1)$$

where δ is plate's thickness, m - projectile's mass , α - empirical constant.

Comparing received data with formerly published results proved that the relations may be used for approximate determination of the critical impact velocity for natural fuel tanks. So, for steel tank of 360 mm diameter parameter $\alpha \approx 0.45 \cdot 10^6\ s^{-1}\ g^{5/12}$.

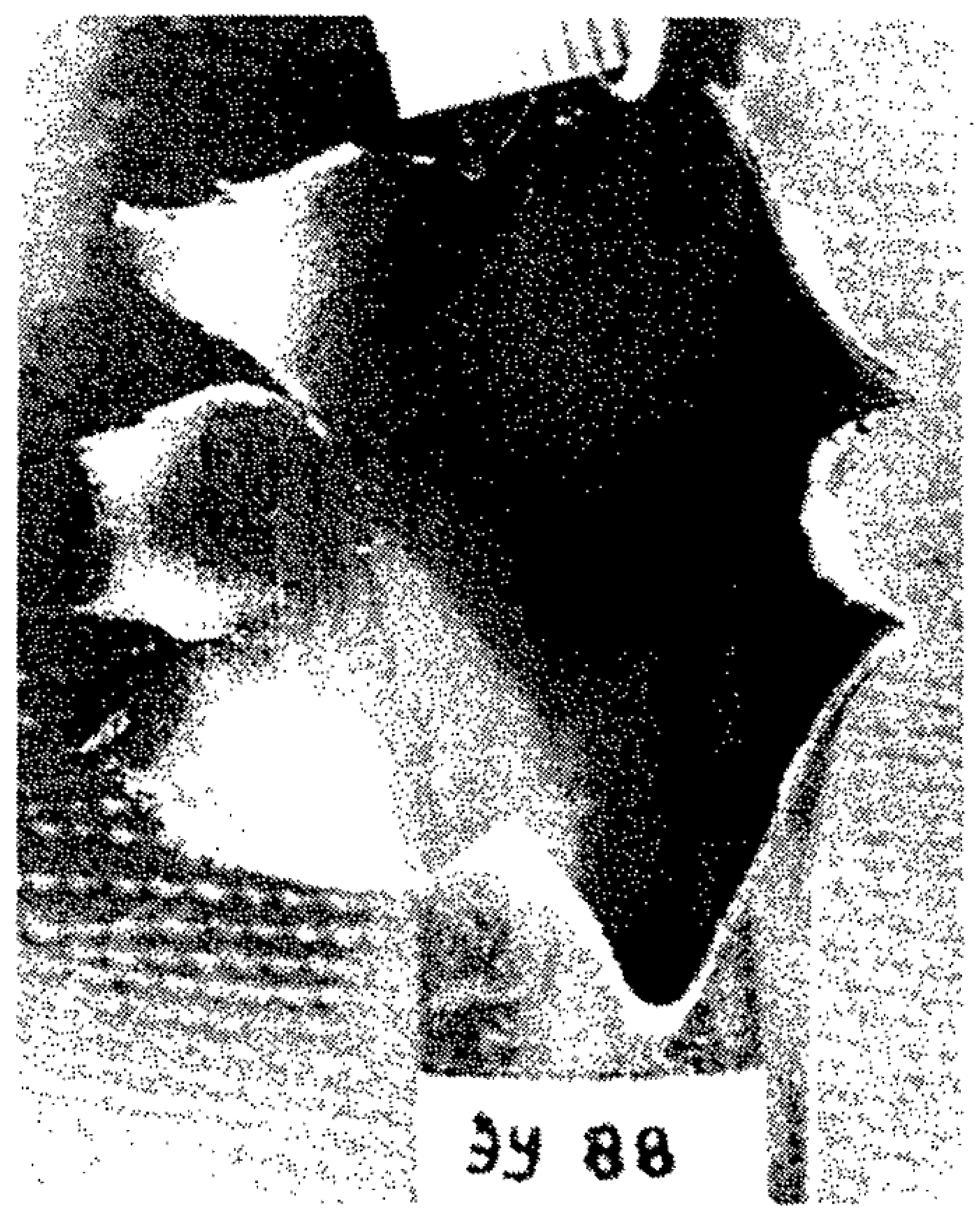

Figure1.Damage of aluminium pipe (d=16mm,δ=1mm) by steel HP (d=4.75 mm, v=1980 m/s)

Estimation FS pipes damage size was carried out in accordance with results of experiments on water filled tubes made of aluminium alloys and steel. In all the tests pipes were punctured through with the

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entrance wall damage looking like hole with small adjacent cracks. The exit wall damage was larger and its size increased considerably when HP velocity grew (Fig. 1).

The critical energy of projectile, inducing catastrophic failure, was estimated.

3. VITALITY MODELS

As the main characteristic of vitality of an object (SV, its system or element) we shall use the probability, that it will not fail at the result of external influence. This probability is a function of parameters of the object, of external factors and time. We'll call such the function a vitality function (Ref. 2).

FS element's failure is result of two events: hit of hypervelocity particle in vulnerable region of the element and its conditional failure. Vulnerable region of an element may be determined as part of element's surface, within borders of which element 's wall can be punctured by particle. Equations for estimating the probability of hitting hypervelocity particle into vulnerable regions of some elements were achieved.

The way of determination conditional probability of element's failure is different for cases of instantaneous and progressive failures.

For the elements (such as units of FS automatic) that, having been hit by hypervelocity particle, fail instantaneously, conditional failure probability is equal to 1. For the elements with progressive failure (such as gas cylinders, fuel tanks, pipes) failure takes place after some parameter Z exits range of workability Q. So, conditional probability of failure may be expressed by the next formula:

$$R_c = P(Z \notin Q) \qquad (2)$$

To describe behaviour of parameter Z, mathematical models had been worked out.

E.g. for gas vessel we have:

$$R_c = P(p \geq p^*);$$

$$p\,(t) = p_0\,(1+Bt)^{-2k/(k+1)}\,;$$

$$B = 0.8\,(k-1)\,C\,M\,S\;\;T_0^{0.5} / 2V\,;$$

$$M = [2/(k+1)]^{(k+1)/2(k-1)}\;(k/C)^{0.5},$$

where p is gas pressure, p^*, p_0 - its critical and initial values, t-time, S - area of hole in the vessel, T_0 – gas initial temperature, V - vessel volume, k = 1.4, C = 279 J/(kg K).

Then, if we know FS structure and vitality of elements, the problem of estimating FS vitality is similar to that of estimating system reliability and can be solved with the help of different methods, such as fault trees methods, network reliability methods, etc.

The latter proved to be very efficient for estimating reliability of the systems with complex structure. To use these methods , we need to represent FS as one or more directed networks, their branches reliability values being equal to that of system elements vitality functions . Finally we can determine vitality of the system as two-terminal network reliability (Fig.2.).

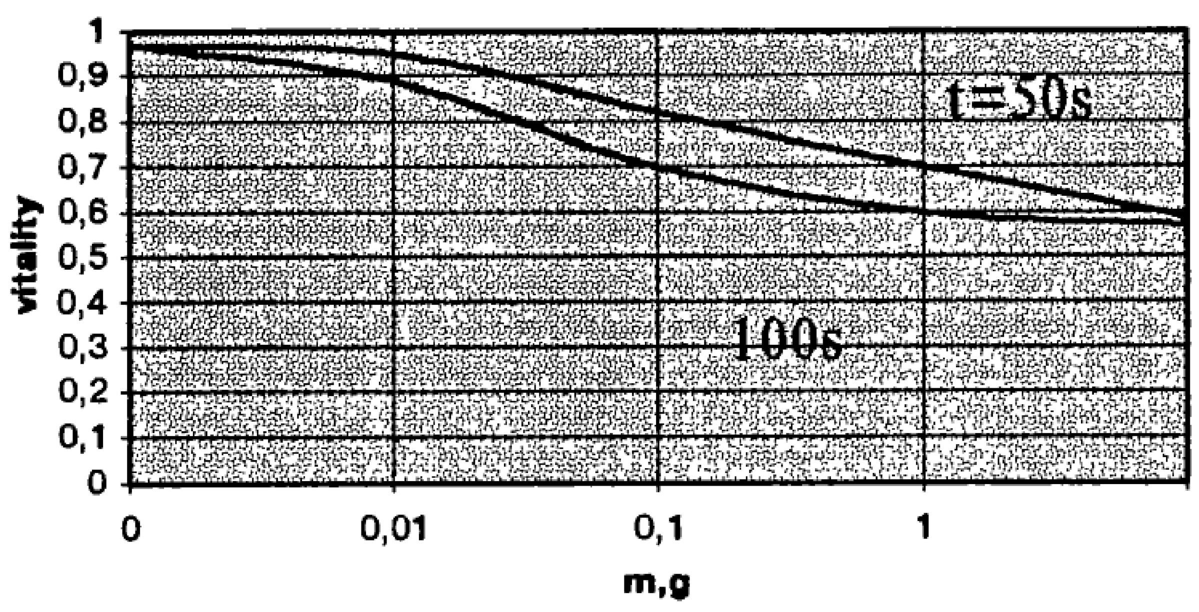

Figure 2. Vitality as the function of steel HP upon mass and time (HP velocity equals 3 km/s)

4. REFERENCES

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