Development of test base for debugging of propulsion and power systems of feed and energy systems operating on hydrogen fuel and problems of accident protection

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Difficulties of development of rocket engines operating on hydrogen fuel cover determination of characteristics of the most intensive assemblies and units of the propulsion system, effective protection channels development and also methods of diagnostics of the engine technical state, operation conditions imitation and accident protection.

The main characteristics of NIICHIMMASH test base being presented include the system of test facilities and liquid hydrogen production with annual capacity at the amount of up to 800 t of liquid hydrogen per year, and the so called rocket-space equipment meant for debugging of its engines and propulsion systems.

Use coefficient of liquid hydrogen in manufacturing systems and test facilities is increased from 0.3 to 0.6–0.7 due to adoption of vapors utilization technology and drainage hydrogen blowouts, return of liquid hydrogen residues during tests to the stationary storage tanks, and cold technology process optimization and filling of cryogenic tanks.

The following problems of accident protection of hydrogen fuel tests, propulsion systems and their complex during stand tests with imitation of different effecting factors of hydrodynamics, temperature and environment vacuum, position of test object and others are solved.

Emergency situation during tests on hydrogen fuel can be caused by:

- condensation and accumulation of air or oxygen crystals in liquid hydrogen;
- explosion or flammable mixtures formations during hydrogen leakages or its blowouts into the environment.

In the first case, as a rule the emergency situation appears when hydrogen system is used repeatedly, or in the second case when hydrogen and oxygen tanks are destroyed simultaneously and components blowouts appear during the tests. Test safety is provided by different methods based on improved requirements for leak tightness of systems, hazardous concentration of hydrogen control, excluding hydrogen and air contact in communications and using of systems of hydrogen blowouts burning up.

In standard conditions, mixtures of hydrogen with air or oxygen turn out to be mixtures with quasi-equilibrium composition for ignition of which the external energy source is required. Minimum energy and body temperature causing self-ignition of the mixture is equal to 0.02 mJ and 700 K respectively [1].

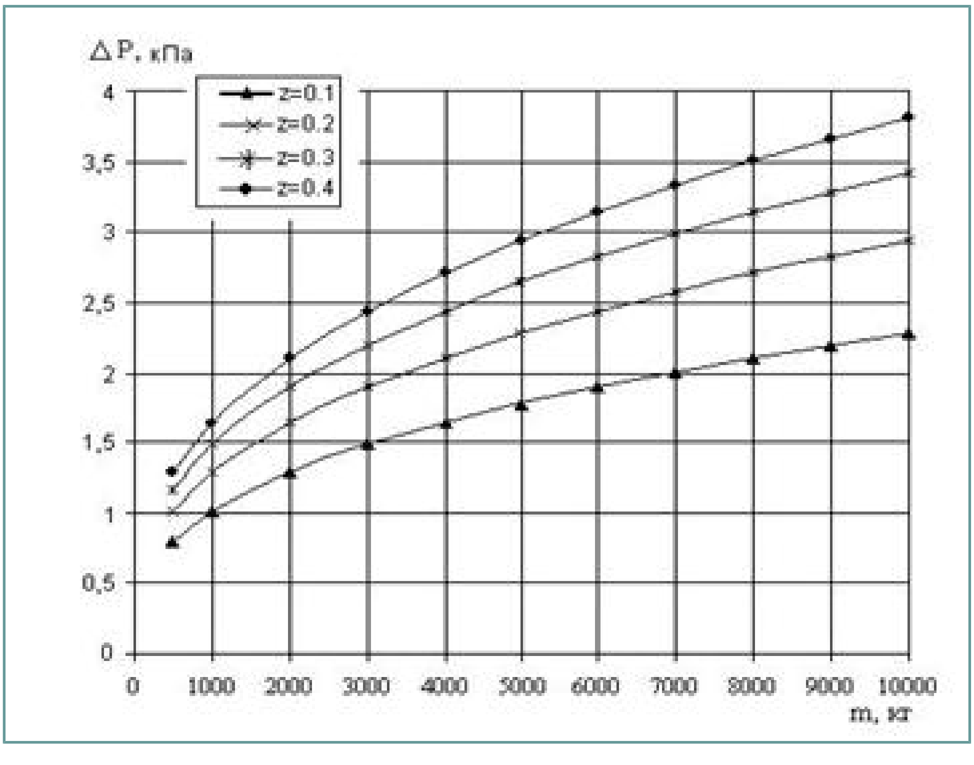
The most dangerous thing due to its consequences is the detonation (explosion) of hydrogen mixtures for appearance of which the appropriate initial source is required along with the presence of combustible mixture. During the test operation, hydrogen blowouts with flow rates more than 0.5 kg/s burn up, and hydrogen with less flow rates is discharged into the atmosphere by means of ballasting with inert gas – nitrogen.

The most dangerous tests are those of propulsion systems on hydrogen fuel for there may be cases of depressurization of fuel supply system along with the engine failure, and also the explosion of hydrogen and oxygen channels. Therefore the firing test of propulsion system is always carried out while special safety actions are carried out.

Cold tests of the propulsion systems must precede the firing tests in order to check out the system confunction. There must be systems of components overflow and additional tanks charging in the tanks of the propulsion systems. The propulsion system must be equipped with warning systems of fire-explosion preventing, which provide control of the specified parameters of the engine, the propulsion system and stand systems and break of tests caused by their deviation from the given values [2].

According to the model of instantaneous event development the calculation of dangerous areas for test operation of rocket blocks was carried out, having liquid hydrogen in their fuel tanks at the amount from 1000 up to 10000 kg. In the given calculations excessive pressure was supposed to be in the area of the shock wave equal to 2kPa 1100m away from test stand (the area of dwelling zone) under which the second degree of safety was realized with the partial destruction (less than 50 per cent) of buildings and construction glazing.

In the figure below Dependence of the shock wave ΔP on hydrogen blowout explosion (m_B) under different values of hydrogen coefficient in the explosion of blown hydrogen (z). z dependence mixture of hydrogen with air or oxygen; under kriteri Reynolds Re>>Reкр zmax = 0.42. At the same time the accident statistics shows that the events preceding the explosion happen rather slowly and that allows to counteract the development of accident situation, and the hydrogen use coefficient in the explosion in most cases does not exceed the value of z = 0.02−0.1. With respect to the facts stated forth above, z can be equal to 0.02−0.1 − for open test stands, and equal to 0.3−0.5 − for closed test stands.



With respect to the adoption of developed measures of safety in the test stand and propulsion system and calculation carried out, particularly in 1991, the inter-branch expert board on the safety made the decision of possibility of carrying out of cold and firing tests of propulsion systems of rocket blocks at NIICHIMMASH test stand with fuel tank filling with liquid hydrogen at the amount of 2700 kg. Along with degree of risk equal to 10^{-4} (1 failure for 10000 tests) the second degree of safety was provided 1100 m away from the test stand.

When during the test the value of z = 0.1 is realized, the question can be considered about tests to be carried out of propulsion systems of the advanced rocket blocks with fuel tank filling at the amount of up to 6500 kg under additional safety measures fulfillment (adoption of non-inertial systems of hydrogen leaks control, effective channels of safety systems and etc.) and counteracting of emergency situation [3].

The main results are as follows:

- debugging of series of oxygen-hydrogen rocket engines (11D56, 11D57, RD-410, RD-0120, KVD1 and etc.), rocket blocks "R" of complex "№ 1-L3", "C" of complex "Energiya-Buran", 12KRB of complex "GSLV" (India) and power systems of power-supply systems with hydrogen fuel elements of lunar spaceship of complex "№ 1-L3" and orbital spaceship "Buran";
- of research and development works under the optimization of filling modes, supercooling, non-drainage storage of liquid hydrogen in the stationary and on-board systems of test stands and etc.

Prospects of development and modernization of test complex for fulfillment of the Federal Space Program of Russia during 2006−2015 are examined:

- Hydrogen production with adoption of hydrogen production systems out of natural gas (reducing of energy expenditure and the product cost by 1.5−2 times) and transport vehicles for delivery of liquid hydrogen to the space ports;
- Test stands for debugging of the advanced engines, upper-stage rocket "KVTK" and their systems for the new generation launch vehicle "Angara-A5" and power-propulsion systems of rocket-space systems with hydrogen fuel use.

Scientific and technical potential of NIICHIMMASH along with performing tasks under debugging and rocket-space techniques with hydrogen fuel use allows to solve many problems of adoption of new technologies using hydrogen in the sector of the national economy (energy sector, transportation industry, metallurgy and etc.) [4].

Thus the examined principles, methods and means of accident protection of tests can be used under creating and debugging of propulsion systems and adoption of the technology of hydrogen use in the energy sector and in transportation industry.

References

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