IAC-04-IAF-S.2.06

NEW PROPELLANT IGNITION SYSTEM IN LV "SOYUZ" ROCKET ENGINE CHAMBERS

Igor Yu. Fatuev, Anatoly A.Ganin

NPO Energomash named after academician V.P.Glushko,
Russia, 141400, Khimky, Moscow area, Burdenko str., 1,
tel: (095) 573-00-38, fax: (095) 251-75-04, e-mail: energo@online.ru

With reference to sustainers of the "Soyuz" LV it is discussed a problem of replacement of existing pyrotechnic ignition system of propellant in chambers for a chemical system, that allows to improve essentially operating performances of the launch-vehicle and to increase safety at preparation for launch.

The complex of design-development work is conducted at the choice of the optimum design solutions for an ignition system.

The scheme of the engine with a new ignition system has designed and the optimum cyclogramme of commands to aggregates of an ignition system to ensure a reliable engine start-up is determined by analysis.

The capability of use of main assemblies of an ignition system from other engines is determined.

The unique design of a unit of an hypergolic fuel feed to the steering chamber, ensuring gimbaling of the chamber on a given angle, has designed.

12 fire tests of 3 engines with a chemical ignition system, which has confirmed reliable ignition of propellant with smoothly varying pressure rise, are conducted.

The conducted volume of theoretical and experimental works allows to introduce an engines with a chemical ignition system in operation in a structure of the "Soyuz" launch-vehicle.

A base space launch-vehicle ensuring fulfilment of the federal space program of Russia, including delivery of the manned and cargo spacecrafts to International Space Station, is the "Soyuz" launch-vehicle and its modifications (fig. 1).

Fig.1. "Soyuz" launch-vehicle.

Thus the first and second stages of this launch-vehicle are assembled on a packet scheme, i.e. the engines of first and second stage are started simultaneously on ground and work during flight given time according to the mission profile.

RD-107, RD-108 engines are used as sustainers of the first and second stages.

The RD-107, RD-108 engines (fig. 2) represent four main chamber design with a feed of two (RD-107) or four (RD-108) of steering chambers from the main turbopump unit.

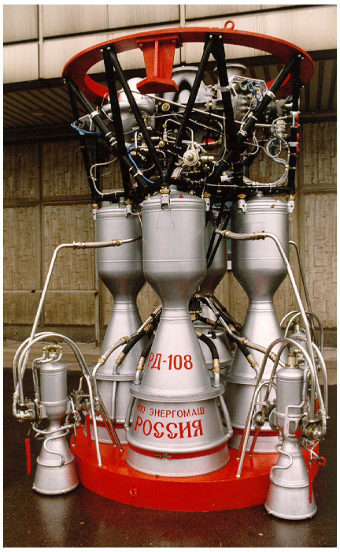

Fig.2. RD-108 engine.

4 RD-107 engines and 1 RD-108 engine are used totally at launch-vehicle.

Thus, ignition of propellant simultaneously in 32 chambers of engines first and second stages is provided at launch of “Soyuz” LV.

The pyrotechnic ignition system representing the explosive charge, installed in a firing cavity of the chamber with the help of a wooden support at preparation of the launch-vehicle for launch, is used in the existing design.

Reliable enough in itself pyrotechnic ignition system in the given specific application (large quantity of chambers) is dependent on quality of works conducted by launch team at a launching pad.

The damages both supports and units of their attachment to chambers during installation process, failure of integrity of electrocables are possible at removal of a service cabin etc.

Any of similar defects, if it will not be detected in proper time and is eliminated, can result in violation of conditions of inflaming in one or several chambers up to an ignition delay from the own pyrocartridge and inflaming from a plume of the neighboring chamber.

The similar phenomena are invalid, since can result in disastrous consequences at launch.

With the purpose of exception of a capability of a appearance of similar phenomena it is offered to exchange on these engines a pyrotechnic ignition system on chemical one, similar with used in more modern RD-170, RD-120, RD-180 engines.

The system of hypergolic ignition (fig. 3) represents the leakproof pipeline, restricted by membranes of free outbreak, between which there is hypergolic fuel self-ignited with oxygen, and the start tank with main fuel. Main fuel is displaced from start tank by nitrogen. In turn, the membranes break by pressure of main fuel, and hypergolic fuel is displaced in chambers, appropriate aggregates of an automatics and pipelines.

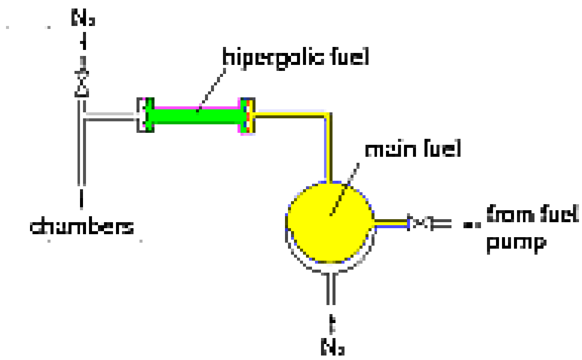

Fig.3. Simplified scheme of system of hypergolic ignition.

The conducted analysis has shown, that for the given type of engines the system of hypergolic ignition of propellant of RD-120 engine (sustainer of a second stage of “Zenit” LV) can be used.

The similar use of existing and serially produced units allows essentially to lower technical risk, cost and terms of implantation of a system of hypergolic ignition in RD-107/108 engines.

The feed of hypergolic fuel in the main chamber of RD-107/108 engines conducts through four special pins, brazed instead of nominal pins in a power ring of the firing face bottom on peripherals of the mixing head (fig. 4).

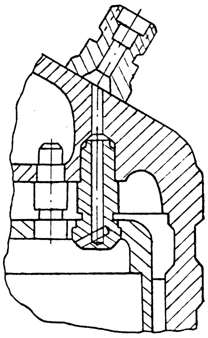

Fig.4. The feed of hepergolic fuel into main combustion chamber.

The pins have a through channel with a gauged hole, through which hypergolic fuel moves in the combustion chamber under a angle of 45° to a plane of the firing bottom.

Four unions (pipe connections) are welded on a power ring above pins. The lines of hypergolic fuel for submission it in the combustion chamber join to this unions.

The feed of hypergolic fuel to the steering chamber (fig. 5) is conducted through the bimetallic union (pipe connection), welded to a wall of the lower part of chamber near to the mixing head.

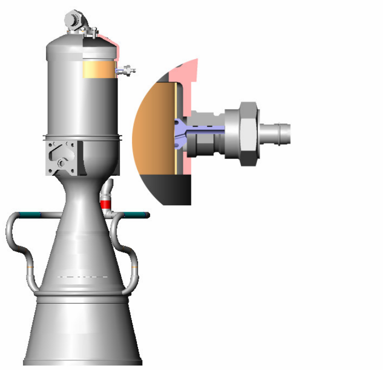

Fig.5. General view of steering chamber with union of hypergolic fuel feed.

The output calibration hole of the bimetallic union (pipe connection) is directed to the throat cross-section of the chamber under angle of 20° to a plane of the firing face bottom.

Taking into account necessity of ensuring of gimbaling of steering chambers on angle ±45° the new design of a unit of fuel feed in the steering chamber (fig. 6) was designed and tested in a structure of the engine.

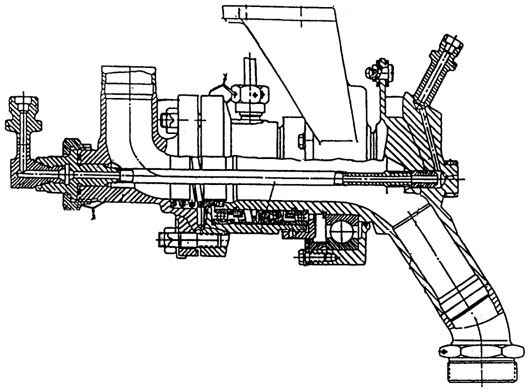

Fig.6. Unit of hypergolic fuel feed into steering chamber

The pipeline of hypergolic fuel is located in internal cavity of a unit of main fuel feed. By one end this pipeline is hard-mounted on an exit pipe of a trunnion of a unit of feed and is connected to the output union (pipe connection) ensuring an feed of hypergolic fuel, and after its ending - feed of main fuel.

Other end of the pipeline of hypergolic fuel is freely located in a directing hole of a flange of a unit of feed and performs movement on a given angle in this hole at gimbaling of the steering chamber.

9 tests of two RD-108 engines and 3 tests of one RD-107 engine together with steering aggregates were conducted totally.

The tests were conducted in a broad band of change of external conditions at engine input, in particular on temperature of an oxidizer from -168,3°C up to -179,3°C, temperature of fuel from -42°C up to +40°C, on pressure of oxidizer from 3,61 kgf /cm^2 up to 5,2 kgf /cm^2, pressure of fuel from 2,99 kgf /cm^2 up to 3,7 kgf /cm^2.

For an estimation of possible influence of the main fuel flowrate through a feed line of hypergolic fuel after its inflaming with oxygen the values of pressure in chambers from 90% up to 105% and mixture ratio from 2,0 up to 2,85 are varied at all engine operation modes during tests.

The estimation of character of inflaming of propellant was made under the readings of narrow range pressure transducers, which were installed directly ahead of injectors of main and steering chambers.

The charts of typical change of parameters in a system of hypergolic fuel at an engine start-up are shown in a fig. 7.

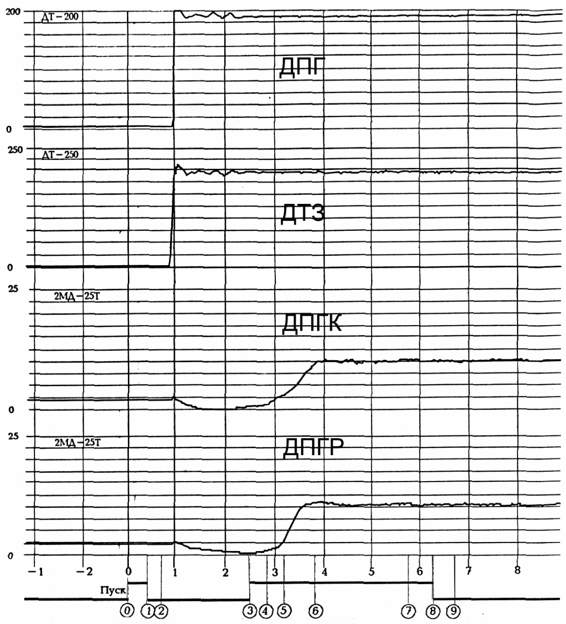

Fig.7. Change of parameters in hypergolic fuel system at engine start-up.

Thus the following designations are used:
ДПГК - pressure of fuel in front of the main chambers;
ДПГР - pressure of fuel in front of units of feed of steering chambers;
ДПГ - pressure of hypergolic fuel in front of branch to chambers;
ДТЗ - pressure of fuel in front of the pipeline of start.

The cyclogramme of commands is designated as follows:
0 - command to open the valve of an oxidizer;
1 - opening of the valve of an oxidizer on a preliminary mode;
2 - pressurization of a start tank;
3 - opening of valve of fuel;
4 - 6 - beginning of entry of hypergolic fuel in separate chambers;
5 - disconnection of ПРМ КДПГ contacts;
7 - 9 - inflaming of main fuel in separate chambers;
8 - closing of the КД1 relay contacts.

Through 0,8 sec after “Launch” command (opening of valve of oxidizer) the command on pressurization of a start tank was given, thus pressure of fuel behind a start tank (ДТЗ parameter) reached the maximum value during 0,2-0,25 sec. To this time the membranes of pipelines of start were broken (through 0,03-0,05 sec after a command on pressurization of start tank) and hypergolic fuel went to branch on combustion chambers. The moment of entry of hypergolic fuel in this segment of a line was determined by the beginning of growth of ДПГ parameter, which took place through 0,1 sec after of a beginning of intensive growth of ДТЗ parameter.

The filling of pipelines of hypergolic fuel feed to engine chambers was accompanied by lowering of pressure on ДПГК and ДПГР parameters with its subsequent growth at the approach of hypergolic fuel to units with increased hydraulic resistance (orifices at inputs in chambers).

The estimation of times of hypergolic fuel entry in firing cavities of chambers was made under the readings of thermocouples installed on supports at distance of 400 mm from the face bottom of a mixing head for the main chamber and 165 mm for the steering chamber.

The times of hypergolic fuel entry in the main and steering chambers of RD-107 engine were in range of 2,96-4,0 sec (from “Launch” command) and 2,98-3,3 sec accordingly. For RD-108 engine these times were 3,59-3,96 sec and 2,9-3,81 sec accordingly.

The comprehensive analysis of times of entry and response times of КД1 pneumatic relay, which controls achievement of 0,25 kgf /cm^2 pressure in the first chamber, has shown, that the indicated times do not exceed the bounds of statistics of engine tests with a pyrotechnic ignition system. Dispersion of time of inflaming of propellant in a complete set of engine chambers is close to statistical value.

In the whole character of pressure variation in chambers displays, that the process of inflaming of the main propellant occurs smoothly.

The process of an reaching a preliminary mode of the RD-107 engine is determined, first of all, by change of balance allocated and consumed powers of the turbopump unit on time.

The application of a system of hypergolic ignition does not influence practically the qualitative and quantitative characteristics of powers balance, therefore changes of the main parameters describing a preliminary mode engine reaching, obeys to legitimacies implemented in engines with a pyrotechnic ignition system.

The character of pressure variation in the main and steering chambers at main mode engine reaching is shown in a fig. 8 and 9 accordingly.

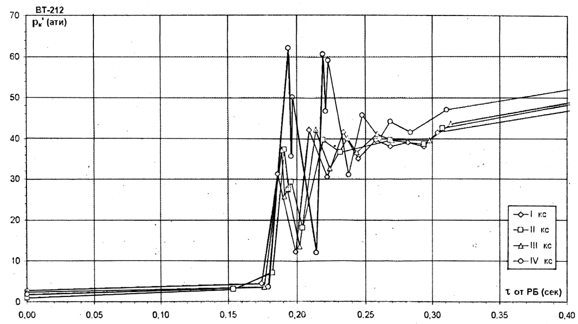

Fig.8. Change of pressure in engine' main chamber at main mode reaching.

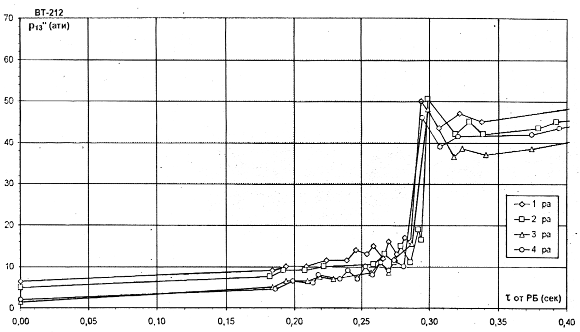

Fig.9. Change of pressure in engine' steering chamber at main mode reaching.

The main times describing dynamics of main mode engine reaching are shown in a fig. 10.

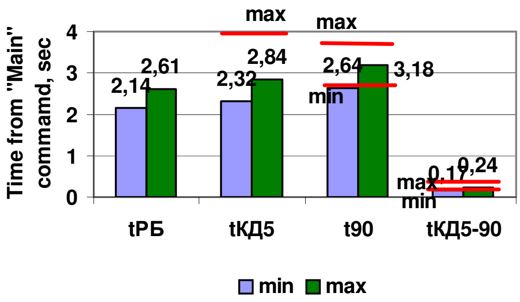

Fig.10. Main times, which describe engine start-up for main mode.

In the given figure the following designations (time from a command on engine transfer to the main mode) are used:

$\tau_{РБ}$ - rupture of a bolt of the pump of an oxidizer;

$\tau_{КД5}$ - operation of КД5 relay;

τ_{90} - achievement of 90% of thrust of a main mode;

$\tau_{КД5-90}$ - time of transition from the moment of a rupture of a bolt up to the moment of operation of КД5 relay.

The conducted analysis has shown, that it is not revealed of any features, bound with kerosene feed in engine chambers through a hypergolic ignition system.

The time frames of transients depend on test conditions and have no differences from the statistical data obtained during tests of engines with a pyrotechnic ignition system.

It is not marked of any features in behaviour of dynamic parameters on this segment of launch.

At all tests of RD-107, RD-108 engines with hypergolic ignition system, the working process in chambers of engines was steady.

The maximum values of parameters of vibro-pulsation mode in 400-8000 Hz frequency band have constituted ≈30g for vibroaccelerations on chambers, ≈0,4 kgf /cm^2 for oscillations of fuel pressure before injectors, 0,15 kgf /cm^2 for oscillations of oxidizer pressure before injectors of engine chambers, i.e. the additional feed of fuel in engine chambers through a hypergolic ignition system has not influenced practically on level of vibro-pulsation mode of combustion chambers.

The estimation of specific parameters on RD-107, RD-108 engines with hypergolic ignition system has shown, that the deviation of vacuum specific impulse of thrust, definited by results of measurements, from expected ones lies within the limits of deviation admitted for the engines - prototypes.

Conclusions.

1. The designed system of hypergolic ignition of propellant in chambers of RD-107, RD-108 engines has ensured at all tests reliable inflaming of propellant with smoothly varying pressure rise in the chamber.

2. Start-up, operation of engines on modes of preliminary, intermediate and main modes are conducted without rebukes with ensuring dynamic responses lying in statistical ranges of engines with a pyrotechnic ignition system.

3. The additional feed of fuel through a hypergolic ignition system in chambers of engines has not influenced on specific parameters, as well as on stability of working process in chambers.

4. The conducted volume of theoretical and experimental works allows to introduce RD-107, RD-108 engines with a chemical ignition system in operation in a structure of “Soyuz” launch-vehicle, that will allow to increase essentially its operating performances and safety of service on a launching pad at preparation for launch.