Initial tests’ test plan

Twardowsky 2 propulsion

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1. **Introduction**Within this document, the test plan regarding initial qualification tests of the propulsion system will be presented. Initial qualification tests are understood as tests, that verify readiness of individual subsystems and its elements for functional tests in conditions specified within project requirements. Main goal of this testing phase is to make sure, that assumptions and calculations accepted during mechanical model creation are compliant with reality, particularly with regard to the stress calculation of components and the design of subsystems’ seals. After that phase of testing, the next step is to begin functional tests campaign which consists of cold flow and hot fire tests.

Obraz zawierający tekst, zrzut ekranu, Czcionka, linia

Opis wygenerowany automatycznie

Fig 1. General scheme of qualification test campaign

In order to make sure, that conducted tests will be performed in safe way in accordance with stated requirements, each must be performed in conformance with pre-prepared checklists or test sheets which later have to be stored as a prove, that test took place. For safety reasons, tests involving pyrotechnic materials (gunpowder or solid propellants) require particular attention in the procedure. The integration of pyrotechnic components must always take place under the control of a person experienced in this field.

Obraz zawierający tekst, diagram, Plan, linia

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Fig 2. Initial tests’ campaign

The initial tests consist of several steps, the defined sequence of which must be followed. In addition, due to the different functionality of the subsystems, each has to go through a different route in the verification process. The components and subsystems concerned by the initial tests are listed below:

* Tank
* Main valve
* Vent valve
* Plug assembly
* Combustion chamber

**2. Tank**

Due to its role in the propulsion system, tank is critical component when it comes to pressure and leakage proof testing procedures. Its durability is determined by the weakest spot in its structure, which is the weld that joints the tank body with its ends. Tank has been welded using simple TIG method, which was chosen for it accessibility and based on previous experiences in Twardowsky project, where welding technology was particularly problematic. Tank leakage test is included in test plan, due to possibility of leakages on weld itself, in case when it was manufactured without cleaning precautions. The test is important because there may be holes in the weld of such small dimensions that pressure tests utilizing water will not detect the leak due to the low compressibility of the medium. For this reason, the fact that the leak test is carried out using air, a compressible gas, is crucial. In the case of target engine operation or when performing cold flow and hot fire tests, the medium that will fill the tank will be partly in the gas phase, which can lead to uncontrolled leakage at the weld.

The test should take place with a gaseous medium, the pressure of which can be easily controlled once the tank is full and can reach maximum pressures in the region of 1 MPa. Carrying out leak tests with higher pressure gases is not recommended for reasons of test safety. A compressible gas, unlike an incompressible liquid (e.g. water), stores much more kinetic energy during compression, which, if the tank is destroyed, can lead to a risk to the life or health of the test participants. At the time of writing, it is assumed as standard, to use a compressor with a maximum operating pressure of 8 bar for this purpose. A compressor with such parameters has been used on numerous occasions during the tests of the Twardowsky 1 engine.

Then, when the tank is found to have passed the test, it should proceed to the pressure test stage. As required, pressure testing of any tank that is part of the rocket must pass the pressure test given a nominal design safety factor of 1.5. The tank's destruction safety factor is 2, but at the time of writing, no tank destruction test is assumed. The nominal tank pressure is 60 bar, so a pressure test must be carried out bringing the tank to a pressure of 90 bar with an accuracy equal to that of the available pressure indicator. For pressure testing the compressed medium is water, preferably demineralized water should be used here to reduce the risk of mineral deposition inside the tank. Water, as a liquid, is an incompressible medium which is preferred for pressure tests. Because of this fact, if a tank is damaged during the test, the kinetic energy that will be imparted to the debris will be much lower than if a gas-filled tank is destroyed. Nevertheless, special safety measures and personal protective equipment, such as safety goggles or protective headphones, must be observed here. According to the requirements set, the predefined pressure must be maintained for 2 times the maximum time allowed for the tank filling process, so the time during which the pressure must be maintained is 180 minutes. During this time, the pressure reading must be checked every 20-30 minutes or so and changes recorded. After this time has elapsed, or if a partial failure of the tank is detected, or if leaks are detected, the set pressure should be released completely before the test participants approach the tank. During the test, the tank should be immobilised and the bottoms protected against damage in case of weld rupture.

**3. Main valve**

Testing valves is more problematic and requires more steps, than in case of vessels’ tests. The valve qualification process consists of four stages:

* Static leakage test
* Static pressure proof test
* Dynamic test
* Dynamic pressure test

**3.1 Static leakage test**

Static leakage test is simple and similar to other leakage tests. In this case, the main goal of this test is to verify, weather the sealants for the main valve piston were chosen properly. The test should be performed, when the valve is in the closed position, using gaseous medium. As described in the Tank tests description, the standardized device to produce the pressure here is the compressor with maximal pressure of work of 8 bar. During this test, the valve assembly should be immobilized and nobody should stand in the axis of piston movement.

**3.2 Static pressure proof test**  
After it is confirmed, that the system passed the leakage test, the static pressure proof test should be performed. This test is designed to verify the correctness of the strength simulations of the valve components in the closed position. The test should be carried out at 1.5 times the nominal pressure of the oxidiser in the tank, so the set pressure should be 90 bar. The pressure should be set from the inlet port side with the valve piston in the closed position. The purpose of the test is to verify that the valve can also be used during the entire filling and pressurizing period, so, as in case of tank pressure test, the pressure should be maintained over a period of 180 minutes. Pressure drops during this time should be periodically recorded. As is the case with all pressure tests, here too water should be used as the working medium.

**3.3 Dynamic test**

The dynamic test of the valve verifies the ability of the valve to change state between closed and open positions. In order to correctly verify the valve operation, at least 5 tests must be carried out for each of the following operating scenarios:

- switching from closed to open position

- switching from open to closed position

- switching from closed to open position and then switching to closed position after approx. 2 seconds

Dynamic tests take place without pressure load. The tests corresponding to all the scenarios listed should be carried out with the system fully integrated. The two pyrotechnic charges (also not activated during the test) should be elaborated in order to verify the risk of damage to the charge during deceleration of the piston movement.

After each test corresponding to the last mentioned scenario, the leaktightness of the valve in the final closed position should additionally be checked.

**3.4 Dynamic pressure test**

After confirming the valve's ability to operate under unloaded conditions, proceed to performance tests under conditions corresponding to the operating conditions. It is worth mentioning here that the geometry of the main valve piston has been selected in such a way that the pressure of the fluid flowing through the valve generates a force in the direction of the piston movement when it opens. In this context, a pressure value equal to the nominal pressure, i.e. 60 bar, was considered as the worst case of operation during the opening of the valve under pressure. At this pressure, therefore, dynamic tests should be carried out under the valve load. In order to correctly verify the valve operation, at least 5 tests must be carried out for each of the following operating scenario:

- switching from closed to open position

The tests corresponding to this scenario should be carried out with the system fully integrated. The two pyrotechnic charges (also not activated during the test) should be elaborated in order to verify the risk of damage to the charge during deceleration of the piston movement.

**4. Vent valve**

The vent valve used in the engine design is a COTS ACL brand valve, model E170BBL15. Despite the manufacturer's assurance of the valve's correct operating conditions, additional validation of the valve's operation must be performed. For this purpose, a leakage test and a pressure test of the closed valve position should be carried out. Both tests should be carried out at 2 times the maximum time allowed for filling and pressurising the oxidiser in the tank. Thus, the load for both tests should be held for a period of 180 minutes, with pressure drop values being read cyclically over time during this time. Particular attention should be paid here to the application of the load on the inlet side of the valve. The leak test should be carried out using an air compressor at a maximum pressure of approx. 1 MPa. As with the other leakage tests, it is recommended that the test is carried out using a compressor at a maximum operating pressure of around 8 bar, as was the case with the Twardowsky rocket engine leakage tests. In contrast, the valve pressure test should be carried out at the nominal oxidiser pressure, i.e. 60 bar, using water as the working medium.

**5. Plug assembly**

In case of plug assembly, a leak test and pressure test should be carried out. Due to the design, both tests should be carried out in the 'swirl injector' configuration of the plug assembly, replacing the injectors themselves with plugs. For practical reasons, the plugs should be sealed by flat washers on the outlet side of the adaptor plate, allowing the system to be sealed without disintegrating the system. The leak test should be carried out using the recommended air compressor at a maximum pressure of 8 bar. The initial pressure test, should be carried out at 45 bar, which is 1.5 times the pressure difference between the expected tank pressure and the engine combustion chamber pressure. The load for both tests should be maintained at 2 times the engine operating time. Thus, the load should be applied over a period of about 20 seconds, with the final pressure noted after this period. The first pressure test here is at a lower pressure than the nominal pressure due to the conditions of the plug during the first cold flow test. Once first cold flow test has taken place, a second pressure test should be carried out by applying a pressure of 90 bar over the same period of time. This procedure is due to the fact that the plug has a relatively low safety factor and its destruction will stop the test campaign by prohibiting functional tests.

**6. Combustion chamber**

Tests related to the combustion chamber must be performed under conditions different from those for other pressure vessels. This is related to the anisotropicity of the carbon-phenol composite used to construct the chamber and the fact that the combustion chamber bodies are manufactured in the association's workshop. The required burst safety factor of the combustion chamber in this case is 3. Pressure tests in this case should be carried out to a load factor of 2. Therefore, pressure tests in this case should be carried out using a load of 80 bar, due to the maximum expected pressure in the chamber combustion equal to 40 bar when working in the configuration with a swirl injector. Leakage tests should be carried out using the recommended air compressor at a pressure of 8 bar. Both the pressure test and the leakage test should involve applying a load for 20 seconds and noting the final pressure. However, after the pressure test, the tightness test should be performed again to verify that there was no damage to the combustion chamber body during the pressure test. Such tests should be performed each time for each newly manufactured combustion chamber in order to qualify the component for further testing. If finances and time allow, it is also recommended to perform a combustion chamber burst test to determine the actual burst safety factor. However, there is a risk of destruction of test components (including test plugs).

**7. Revision**

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| 1 | Bartosz Hyży | 2023-12-10 |
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