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INITIAL EXPENDABLE TURBOJET PROTOTYPE TESTING EXPIRIENCES

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1. Introduction

Expendable turbojets, typically in thrust range from 40 to 400 daN, are used in target drones and missiles. Because of their usage they are designed to be simple and cheap rather to have some challenged performances according to [1],[2] and [3]. Also, because of their applications they are not requiring rigorous certifications as turbojets for man applications. Usually they are certificated together with the system in which they are installed. This paper is presenting experiences with initial prototype testing. At the moment when designed engine is produced and when some of component or subsystem testing are finished, we have to start with the very first tests. The point is that we will have to check performance of the engine which has to be running for the first time. If everything is fine during the first test and the results are very similar to expecting values it will be perfect. But usually in the engineering world it will not be the case. More than this we have to solve many small issues until we can run the prototype engine with confidence. On the other hand these days time for development is very limited, it is expected that such engine is ready for serial production in 12 to 18 months and consequently it is very important to accurately understand possible problems during initial testing. If we make wrong conclusions it will delay assigned development time and possibly come in position that development went to wrong direction. Technical papers usually describe achieved results but without complete picture of problem which they have to overcome in order to achieve development goals. With such motivation the material discussed at this paper describes what had to done to make prototype engine to run correctly and refers to the turbojet engine TJE-200 at the EDePro company.

2. Engine description

Turbojet engine TJE-200 consists of three stage axial compressor, through flow combustor with 12 centrifugal atomizers and single stage axial turbine, cross section of the engine is shown at Fig. 1. Maximum thrust is 185 daN and maximum rpm is 39450. The specific fuel consumption of the engine is 1.35 kg/danh. The maximum diameter of the engine is 270mm, while dry weight is 35kg. The starting system is air impingement at turbine, ignition is made by electric spark plug. Lubrication is based on spill out oil or kerosene system. The engine has directly coupled electric generator with maximum electric power of 1.5kW. The generator is directly coupled to engine shaft by means of innovative self-designed magnetic coupling which was the best solution in terms of vibrations comparing to commercial elastic coupling solutions. The compressor rotors were produced by CNC machining from steel 17-4 PH, while stators were produced from investment casted aluminum alloy. The combustor liner was produced from 310 stainless steel, while turbine rotor and stator were produced by investment casting of Inconel 713C according to [4]. The engine was balanced with maximum unbalance of 2gmm. The compressor, combustor and turbine were designed by EDePro company developed software based on previous empirical and experimental data.

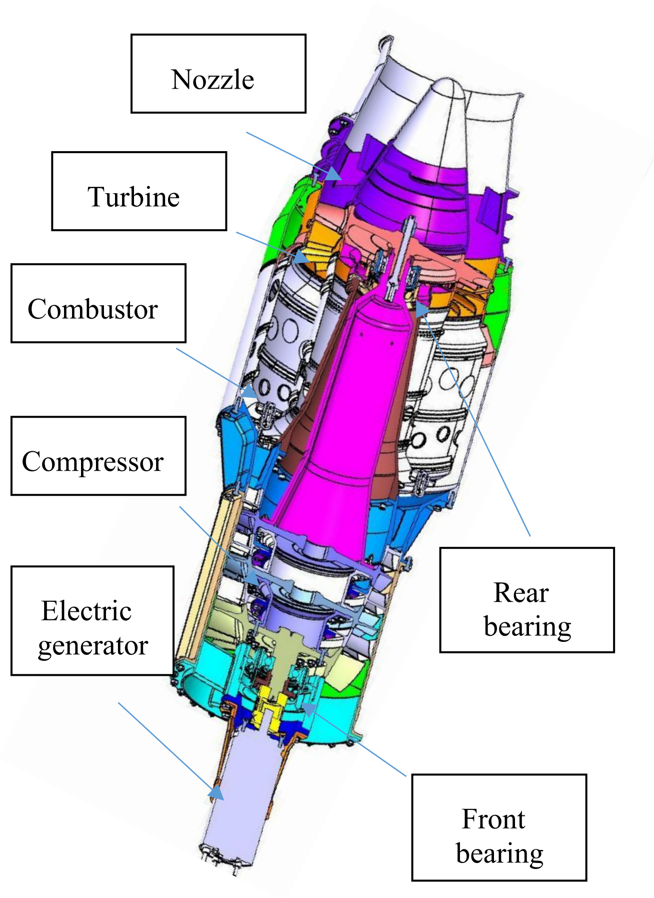

Fig. 1 Turbojet engine TJE-200 cut view

The engine rotor is supported at two elastic supports because the length of the shaft and rpm are not allowing rigid supports, according to [5] and [6]. Previous rotordynamic tests were performed to verify design and estimate the value of rotor displacement during operation. Photo from rotordynamic tests is shown at the Fig. 2.

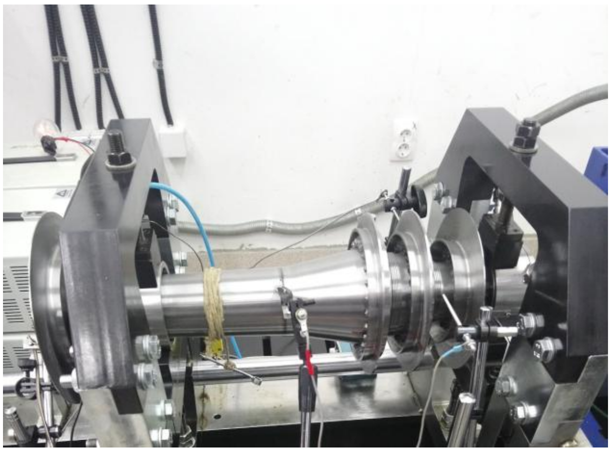

Fig. 2 Dummy rotor at rotordynamic test stand

3. Engine first tests

The first engine test shown the compressor surge issues during the starting approximately around 50% of the maximum rpm. In order to clarify the nature of the problem next test was done without nozzle. That test was successful with engine performances as expected. The position of the working line at the compressor map was in the expected range so the conclusion was that the problem was due to exhaust nozzle. Actually, the shape of the initial exhaust nozzle was dictated by some structural analysis results which shown that there are possible natural frequencies in the working range. After second analysis it was concluded that there is no force which could excite nozzle at desired frequency and that it will be almost impossible to satisfy required shape and pressure drop of the nozzle and to avoid such natural frequencies. The next tests were made without exhaust nozzle to verify mechanical behavior of the engine until the new designed nozzle was produced, as shown at the Fig. 3. The working lines without nozzle, with nozzle without central body and with final design nozzle are shown at the Fig. 4.

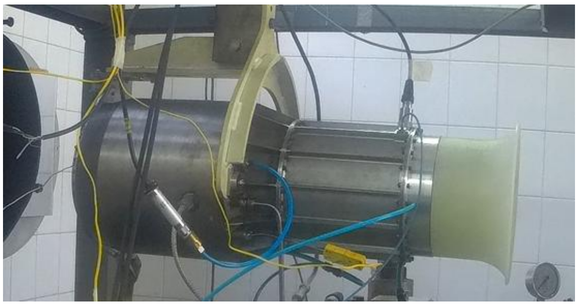

Fig. 3. TJE-200 at test without nozzle

The second issue during the first engine runs were increased level of vibrations during starts. Because the tests of rotordynamics which were done before engine tests it was obvious that increased vibrations are possibly due to some contacts between rotor and casing. After disassembling it was evident that there were contact between PTFE seals positions at compressor stators and compressor shaft. Because the compressor stators were assembled as two half's due to assembling it was very difficult to ensure the correct gap. As a solution, the radial gap was increased. No any contacts were detected in the following tests.

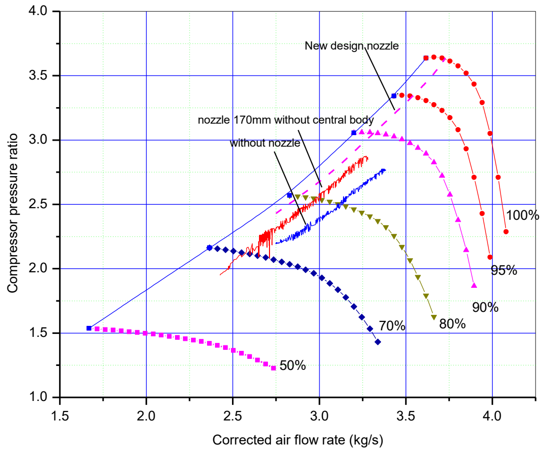

Fig. 4. Different working lines for different nozzles

The third problem during initial testing was related to electric generator caused vibrations. The first tests were carried out without electric generator which is directly coupled with engine shaft. Initial solution was to use the elastic commercial coupling. Although the coupling was factory balanced the increased vibrations were encountered. The reason was that the engine is supported at two elastic supports and when elastic coupling was connected to the shaft it was driven out of axis and it was producing undesirable unbalance. The problem was solved with innovative solution. Since that power and torque which have to be transferred by coupling are small (1.5kW and 0.35Nm) we introduced self-designed magnetic coupling. One part of the coupling is at the engine shaft and another at the generator shaft, with axial gap of around 1.5mm. The logic was simple, if the generator is not in direct contact with engine shaft it will not be able to produce vibrations. More than this, the engine can be balanced together with magnetic coupling.

The fourth major problem was related to the turbine stator vanes overheating. After most of the tests engine was disassembled in order to check component conditions. When the overheating problem was noticed at the turbine stator vane leading edge the small analysis was made. As the efficiency of the engine was ok it was concluded that overheating is consequence of non-uniform temperature field at the combustor exit. It was difficult to conclude at which regime it is dominant, starting or working. However, the actions were made to minimize that effect: the small pipes were introduced in each second dilution hole to enhance mixing (but with minimum effect on pressure drop) and the pressure swirl atomizers were replaced with smaller one in order to minimize droplet size especially during starting. After these changes no overheating issues were noticed.

The fifth problem which is worth to mention was rear bearing temperature. The lubrication system is of spill-out type. It means that the oil is injected in the bearing and then spilled out into the main flow. In order to minimize the flow rate of the oil and consequently losses of the oil the minimum portion of the oil is required. It is maintained with system of valves which are opened and closed with desired frequency. The so-called secondary air of the engine is used to transport that oil into the main flow and it is shown at the Fig. 5 and Ref. 1.

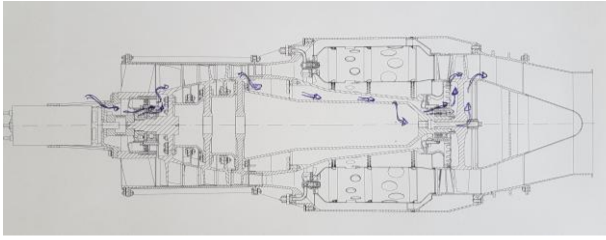

Fig. 5. Description of the secondary air flow

The point was that through rear bearing is passing the air taken from after the compressor which has temperature of around 180 ºC at the maximum rpm. Although bearing maximum temperature is declared as 250 ºC we wanted to keep that temperature below 150 ºC. Initially, very small amount of oil was injected (around 0.3g/s) and consequently the temperature of the bearing was always higher than temperature of incoming air. When the oil flow is increased to level of 1.5g/s the bearing temperature falls below air temperature. Again, since that oil is loosed it is more practical to use fuel for that purpose as in Ref. 2. The final solution is based on kerosene spill out system, small amount of fuel is injected into bearing area. Typically it increases specific fuel consumption for about 2-3% but avoiding any element in the lubrication system.

The summary of initial problems and corrections made are shown in the Table 1 and in the Fig. 6.

Table 1. Summary of the corrections

problem	*correction*
Compressor surge	Nozzle redesign
Increased vibration levels	Labyrinth seal gap correction
Electric generator increased vibration levels	Coupling redesign
Turbine stator vanes overheating	Corrected combustor dilution zone
Rear bearing temperature above desired limit	Corrected oil amount and lately switch to kerosene lubrication

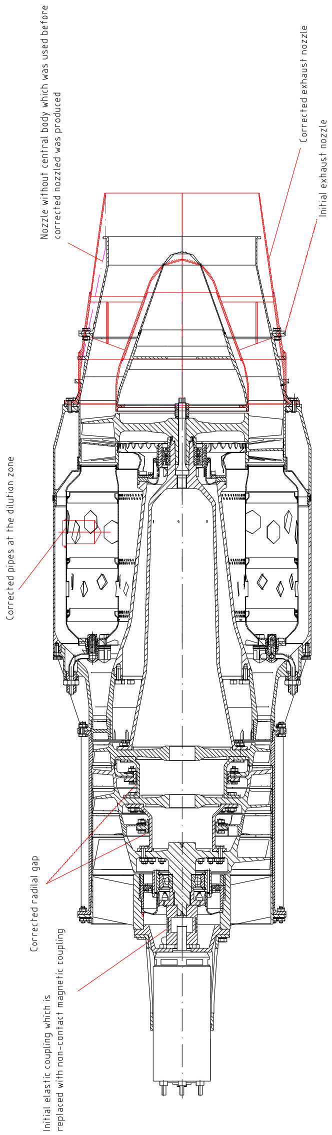

Fig. 6. *TJE-200 corrections during initial testing*

4. Conclusion

The initial engine testing is presented. The mentioned work was done from June to December 2018. i.e. in the period of six months. We have to underline that for one newly designed and produced engine engineers have to understand the behavior of the engine presented through measured data and through engine component conditions. It is very important to use knowledge, experience and logic to come to correct conclusion and perform appropriate action. Otherwise, wrong conclusions may drove to completely opposite side of solution causing loses of time allowed for certain project. The main contribution of these work is real now-how process in limited time line.

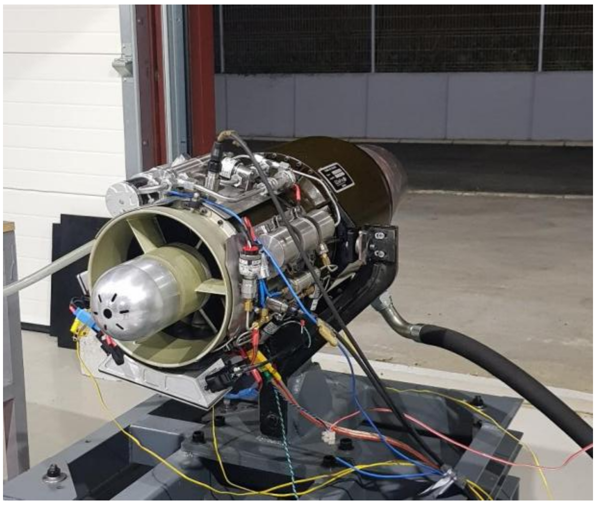

Fig. 7. Final version of the turbojet engine TJE-200 with subsystems at the test stand

Acknowledgments

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