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VÝPOČET A OPTIMALIZÁCIA VENCA LOPATIEK PLYNOVEJ TURBÍNY EXPERIMENTÁLNEHO MOTORA

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Abstract

The thesis deals with the calculation and optimization of the stage of the gas turbine distributor vanes of an experimental engine. The aim is to create an experimental turboshaft engine by combination of the Saphir 5 auxiliary power unit and a free gas turbine with a gearbox, derived from the TS-21 turbine starter. Through calculations, it is necessary to determine the optimal geometric parameters and the resulting number of stator vanes in order to design a 3D model of the gas turbine stator shroud as a connecting element between the Saphir 5 and the free gas turbine, which consists only of the rotor blades. The results of the work and the evaluation consists of calculations of the thermodynamic circulation of Saphir 5 and calculations of gas turbines. It also contains the design of the stator ring of a free gas turbine, as an intermediate member or flange of two aggregates creating an experimental engine. The 3D model and optimization is created using the Creo 7.0 program, which are based on the calculation of the gas turbine itself. In the end, we will get to the answers and to the summary of the results that created the exact design of the experimental engine.

Keywords
gas turbine, free gas turbine with gearbox, auxiliary power unit, turboshaft engine, APU Saphir 5

1. Introduction

The topic of the calculation and optimization of the stator casing of the gas turbine distributor blades in an experimental engine, drawing from knowledge of aircraft power units, which has always interested me. Additionally, this topic captivated my interest in exploring the Saphir 5 auxiliary power unit and proposing a new experimental engine. The introduction to the issue discusses the possibilities of utilizing small turbine power units, which were once used as APU on aircraft but are now decommissioned. Given their non-operational status, there is potential for utilizing these turbine APUs as experimental engines with innovative features. Gas turbines are subject to high demands such as reliability, durability, and precision, as any damage or malfunction can adversely affect the investor's financial aspect. Requirements for gas turbines include small size, low weight, high reliability, long lifespan, high efficiency, among others. The goal of my thesis is to focus on the Saphir 5 auxiliary power unit, representing a turbine device known as an air generator. My aim is to transform this air generator into a turboshaft engine by integrating a free gas turbine with a gearbox from the TS-21 turbine starter, with the possibility of adding a propeller afterward. This would result in a small turboprop power unit. The free gas turbine consists only of a rotor casing without the stator casing of the distributor blades. However, to efficiently deliver hot gases before the rotor casing, it is necessary to integrate the stator casing into the system. The work consists of four chapters, each describing individual steps. The first chapter, titled "Current State of the Issue," discusses the theory of aircraft turbine power units, followed by the principles of turbine operation and its constituent parts. The second chapter deals with theoretical knowledge of the issue, focusing on turboshaft and turboprop power units, auxiliary power units, their functions, and classification. This chapter concludes with a focus on the Saphir 5 APU and its technical modifications. The third chapter comprises the practical part, including the methodology of work, the design of the experimental engine, and enhancements to the Saphir 5 schemes for implementing the new design and its functionality. The fourth chapter includes the calculation of the thermodynamic cycle of the Saphir 5 APU and subsequent calculation of parameters for three stages of gas turbines. These data serve as input values for designing the stator blades and, consequently, the stator casing of the free gas turbine, derived directly from the calculations. For this purpose, the Creo 7.0 software is used for 3D modeling of the structural components. After creating the stator casing model, the next step is a structural analysis using Creo 7.0 software. Upon completing the stator design, the thesis concludes with the description and evaluation of the results. Finally, the answers and final findings are provided.

2. Work methodology

Work methodology is an essential element of scientific or research efforts, which defines the sequence of steps and ways to achieve the goal. It consists of a systematic approach that aims to ensure reliable results. In connection with the work methodology, two main methods are used. The theoretical method of the work is based on the analysis of concepts and theory. The second method of work is the empirical method, which is based on experience, observations and analysis of real data [12].

In my diploma thesis, I used an archival form of data collection, such as renovated sources, especially book publications. I worked with measurements, with calculations and used software tools to make analysis and design. The methodology of my thesis consists of a literature search, with the help of which I created a comprehensive overview of available sources, such as book sources and internet publications. Another method, which is comparison, consists of evaluating and especially comparing relevant information and sources for the thesis. The collection of information was carried out through the method of information processing, with the help of which I systematically collected relevant data for individual areas of work.

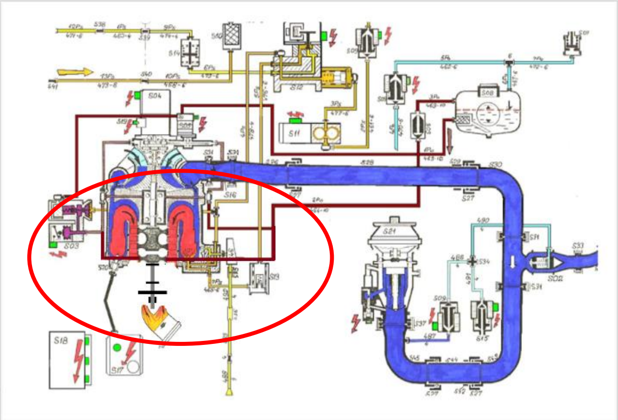

Figure 1. Scheme of free gas turbine and its new oil system [10]

The diagram shows the oil inlet and outlet, which must be secured from the outside. The proposed connection consists in the connection of the free gas turbine with the oil pump, which ensures the oil supply. The rest of the oil is then diverted back to the Saphir-5 oil return branch.

Subsequently, the oil from the return branch is transferred to the cleaner, where it is filtered and proceeds to the oil tank as a closed cycle. This system ensures constant lubrication and cooling of the free gas turbine with a reducer, which is effective for its long-term reliability.

The supply of the air system to the free gas turbine with a reducer is realized by taking air from the existing Saphir-5 air system and supplying it to the stator ring of the free gas turbine. In picture no. 2, the air intake is only partially shown due to limited space, but more detailed information about the air intake routing is shown by the red arrow.

This design eliminates the need for the original starter air system, allowing a maximum air intake of 25 kg/min for experimental turboshaft engine purposes [7].

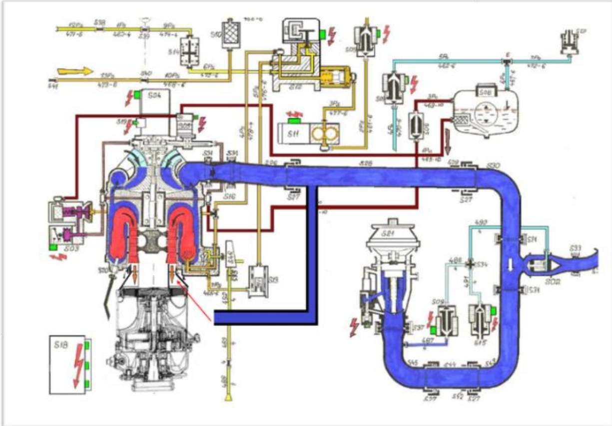

Figure 2. Scheme of Saphir-5 system and its new air system [10]

2.1. Experimental engine design

In the third chapter, Methodology of work in the Design of an experimental engine, I deal with the creation of an experimental engine as it continues in the fourth chapter, which are connected to each other. The experimental engine consists of a Saphir-5 auxiliary energy unit and a free gas turbine with a reducer. The aim of the thesis is to create a turboshaft drive unit from the Saphir-5 structure and a free gas turbine. The Saphir-5 auxiliary power unit comes from the Aviation Museum in Košice and, as mentioned, it represents part of an experimental engine in my diploma thesis. The free gas turbine, which comes from the TS-21 turbine starter, is located at the airport in Žilina and serves as a teaching aid for students. The free gas turbine from the TS-21 turbine launcher that we have available in the airport classroom has a 160 mm diameter rotor and its design is based on a gas turbine disc with grooves for the attachment of blade tree locks, which is an unusual technique for such small turbines. Mostly in such a case, "blisk" rotors are preferred, where the blades are part of the turbine disc and are cast as a single unit [6].

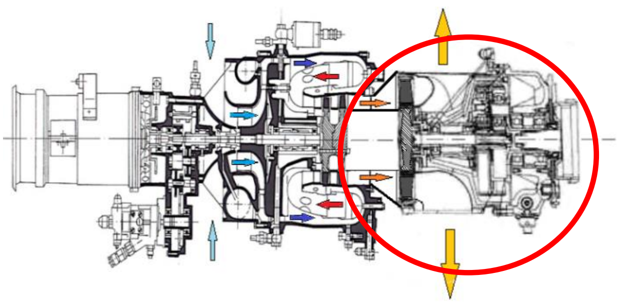

Figure 3. Prototype of experimental turboshaft engine [11]

The subject of picture no. 3 is a turboshaft experimental engine, which is set as a goal to achieve in the diploma thesis. Two main parts can be identified from its construction. The left part consists of a gas generator, where the mixture of fuel and air is burned and the subsequent creation of hot gases. These exhaust gases continue to the right side of the engine. The first part houses a free gas turbine together with a reducer. This section of the engine is focused on using the energy of hot gases and converting them into mechanical energy.

3. Work results and evaluation

The following sections of the fourth chapter deal with calculations of thermodynamic circulation and gas turbines of the first, second and free gas turbine stages. Next follows the design of the stator ring, for the production of which I obtain the results from the calculations. At the end of this chapter, I evaluated the results of the work [10].

3.1. Calculation of thermodynamic circulation Saphir-5

It contains the specified parameters and input values for the calculation of the APU Saphir-5 thermodynamic cycle. The aforementioned thermodynamic cycle calculation includes parameter values such as temperature, pressure before and after the output device, before and after the compressor, after the main combustion chamber, after the gas turbine and free gas turbine. It also analyzes the work of the gas turbine, the work of the compressor, the overall degree of expansion, engine power and fuel consumption. An important aspect is that the calculation of the thermodynamic cycle refers to the Saphir-5 auxiliary power unit, which makes it possible to determine the indicated parameters for further calculations of the gas turbine and further continuation of the design of the experimental engine. I use the Microsoft Excel program for all thermodynamic circulation and gas turbine calculations [10].

Table 1. Results of thermodynamic circulation

VELIČINA	HODNOTA	JEDNOTKA
p_{0c}	101 325,6	Pa
p_{1c}	99 299,1	Pa
p_{2c}	307 827,2	Pa
p_{3c}	286 279,3	Pa
p_{4c}	157 577,3	Pa
p_{5c}	104 998,04	Pa
p_{6c}	104 669,3	Pa
T_{0c}	288,15	K
T_{1c}	288,15	K
T_{2c}	427,4	K
T_{3c}	973,15	°C
T_{4c}	849,9	K
T_5	729,5	K
$T_{5c'}$	7774,9	K
T_6	768,7	K
$\Delta\overline{w}_{PTC}$	0	$N.kg^{-1}.s^{-1}$
W_{Kc}	177 083,5	$J.kg^{-1}$
W_{Pc}	102 131,2	$J.kg^{-1}$
W_{TKc}	142 751,02	$J.kg^{-1}$
$W_{VPT'}$	86 760,7	$J.kg^{-1}$
π_{VPT}	1,50	1
P_{ekv}	102 637,9	W
q_{pal}	0,0004871	$kg.h^{-1}.W^{-1}$

3.2. Calculation of gas turbine

The next step in this chapter is the gas turbine calculation, which includes a detailed calculation of the gas turbine rotor and stator. In table no. 1 the data are entered for the continuation of the calculation. In the design of the experimental engine, we use a free gas turbine with a reducer, which consists of a rotor ring, but the stator ring is missing. Therefore, it is important to focus on the calculations of the stator blades, for the further continuation of their design and application on the experimental engine. Based on the obtained results, I will design the stator ring of the gas turbine [10].

3.3. Stator ring design

In the fourth chapter, I also focus on the construction of the stator blades and the design of the flange connection of the free gas turbine, which is related to the stator. The main reason is to prevent the hot exhaust gases from passing directly to the turbine rotor, which could lead to energy losses, since this free gas turbine consists only of the rotor. It is necessary to direct the gases correctly and accelerate them as much as possible in the stator vanes. The material used for the design of the stator blades consists of stainless-steel sheet. In order to achieve this goal, it is necessary to implement a distribution ring that will correctly direct the output hot gases from the stator to the rotor. This design is crucial for optimal efficiency and reliability of the free gas turbine.

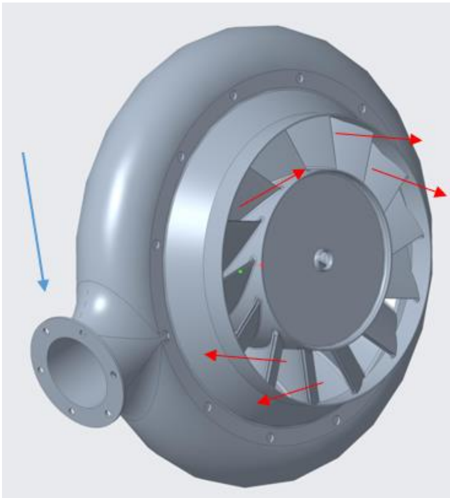

Figure 4. Draft of the stator ring

One of the components is a flange that allows connection from both sides between the individual parts of the Saphir-5 and the free gas turbine with the reducer, thus ensuring a solid and tight integration between these components. Hot exhaust gases from the Saphir-5 enter the stator ring from the right side. The flange on the left shows the exiting hot gases from the stator, which are also mixed with the supply air from the air system.

The design of the 3D model of the stator ring as an intermediate member and connection of the APU Saphir-5 with a free gas turbine with a reducer is a complex technical solution that integrates several important functional elements. The stator ring, which forms this intermediate part and the connection, has several tasks that affect the performance and reliability of the entire system.

The stator ring is composed of stator vanes which are hollow and are the key components ensuring the efficient distribution and control of the airflow and hot gases in the gas turbine. Supplying air to the inside of the stator ring taken from the air system enables cooling of the stator blades. Subsequently, the supplied air rises into the stream of gases and increases the amount of gases that enter the rotor of the free gas turbine. It serves for cooling purposes, which is important for reducing heat loads and increasing blade life [11].

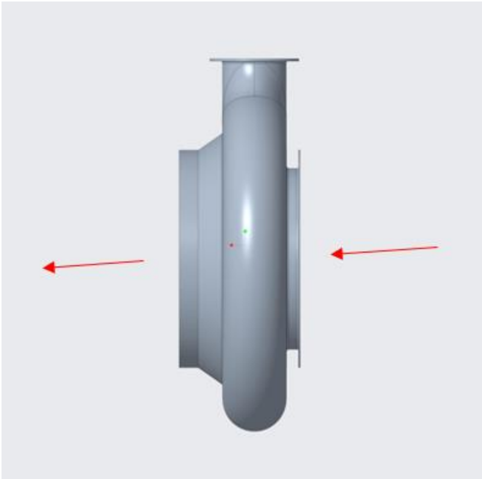

Figure 5. Draft of the stator ring

3.4. Strength analysis

The main purpose of the strength analysis is to assess certain properties of the material, whether it meets the necessary requirements. These requirements apply to the strength, resistance of the material and its safety against dynamic, static and thermal loads. Strength analysis provides certain techniques and procedures for identifying the maximum load, weak points of the structure, material, and subsequently proposing changes to increase strength and durability.

I used the Creo 7.0 software again for the strength analysis. I performed an analysis of the strength of the stator ring, which identified the more critical points of the material and the overall structure. Smaller loads were recorded around the circumference of the stator ring, as it is not directly under the influence of the exiting hot gases. This condition is shown by blue color, which represents a value from 80 MPa to 154 MPa. Greater stress concentration is shown successively in green, yellow and orange from approximately 191 MPa to 451 MPa. A higher stress concentration was found in the areas of the stator mounting flange from both sides, where material weakening can occur [11].
From the point of view of stress concentration, the stator ring withstands the loads, which confirms that the structural design is safe. The results of the strength analysis show that the design is strong enough to withstand these types of loads acting in the area.

3.5. Summary of results

Using the Saphir-5 thermodynamic circulation calculation, I acquired temperature and pressure parameters, which I applied to the next process to achieve gas turbine calculations and especially to achieve strength analysis. Saphir-5 gas turbines were calculated based on certain parameter values. It provides an idea of the individual speeds, geometric dimensions and state variables of the gas turbine. I calculated that the determination of the spacing of the rotor blades of the first stage of the gas turbine is based on 0.008 m, and at the same time, in terms of the number, approximately 35 blades are needed. For the second stage, the spacing result is 0.0052 m and the number of rotor blades is 40. The determined free gas turbine stage spacing is based on 0.014 m and 30 rotor blades to determine the number.

After processing the calculations, I assembled a 3D model of the stator ring. To make it, the obtained data were needed, as already mentioned, that is, the outer diameter and the inner diameter of the rotor impeller, as well as the angle of inclination and the magnitude of the relative velocity, which shows the entry of gases into the blade grid. Another necessary data is the number of rotor blades. Based on the rotor parameters found in the calculations, the stator parameters are subsequently determined. This is because the stator properties are based on the rotor properties. As part of the simulations of the strength analysis of the stator ring, the voltages show slightly higher values than expected. However, despite this increase in tension, sufficient strength and resistance of the material remains, which is included among the advantages of the design.

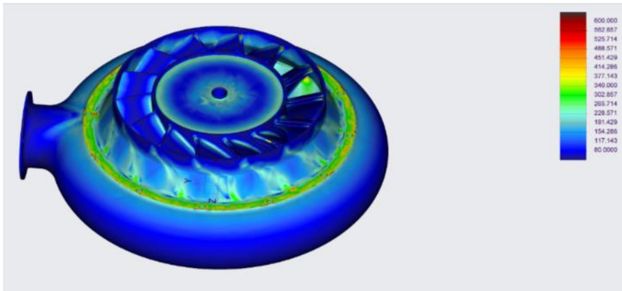

Figure 6. Strength analysis

4. Conclusion

In the final thesis, I focused on the calculation and optimization of the crown of the free gas turbine blades in order to create a new experimental turboshaft engine. The theoretical part of my work is divided into two chapters, which deal, for example, with turbine propulsion units. Aircraft jet engines have undergone some development, with their performance, high speeds, efficiency and reliability being their specific characteristics. In these chapters, I brought the theory about the components that make up the jet engine and their functions. I focused in more detail on the gas turbine, which is of key importance in the operation of the engine. By passing a hot stream of gases through a turbine, thermal energy is converted into mechanical work. The gas turbine thus drives the compressor and other aggregates, which leads to the production of the necessary thrust for the movement of the aircraft. In addition, I dealt with the theory of auxiliary energy units, their distribution, functions and specifically analyzed APU Saphir-5 and its technical parameters.

When preparing the theoretical part of my work, I mainly used book publications, which represented an important source of information. In addition, I also used Internet resources that provided me with other relevant data and information. In order to ensure the correct work methodology, I developed a system that helped me organize material and resources. This system enabled me to effectively apply the acquired knowledge not only in the creation of the theoretical part, but also in practical applications.

The third and fourth parts of my diploma thesis make up the practical part, which deals with the design of an experimental engine. At the same time, he deals with the design of the stator ring as a flange to connect the Saphir-5 and the free gas turbine with the reducer, including the corresponding calculations for the design. In the creation of this practical part, I was helped by resources that provided me with the necessary information for calculations and the subsequent design of the stator ring. The design of the experimental engine in this section describes in detail the concept of a turboshaft power unit and illustrates what such a power unit should look like. This image includes that Saphir-5 connection with a free gas turbine and reducer. To create the design of the stator ring, I used the 3D software Creo 7.0, which enables the creation of digital three-dimensional objects through three-dimensional modeling. In this process, basic geometric shapes such as points, lines, surfaces and objects are defined to achieve the desired stator ring design.

For calculations, I used documents containing calculation exercises that provided me with the necessary formulas. I used the Microsoft Excel program directly to apply these calculations, which allowed me to effectively process and analyze the results and optimize the design of the stator ring according to the necessary criteria.

At the end of the fourth chapter of my thesis, there is an evaluation of the results that confirm the successful outcome of the final work, namely the test turboshaft engine. After analyzing the achieved results, it is possible to confirm that at the maximum revolutions of the free gas turbine and after applying the measured ratio of revolutions of the gas turbine to the shaft, it was possible to achieve the desired revolutions of the output shaft. This result indicates that the engine is also capable of driving a propeller and operating as a turboprop engine.

The test prototype from APU Saphir-5 has the potential to serve as an experimental engine for testing different fuels. These fuels include LPG, ethanol, methanol, or hydrogen or vegetable oil. This engine can also be used for further research purposes or as a basis for future work in this area. In addition, it can serve as a teaching aid at Žilina Airport.

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