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A PROTOTYPE TEST STAND FOR TESTING INSOLATED ROTOR SYSTEMS

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Abstract

The article discusses assumptions for a prototype test stand designed for testing rotors in the conditions of work at their nominal speed, in particular gyrocopter and helicopter rotors. In the work presents an overview of similar solutions of test stand presented in the available literature and solutions proposed by companies, such as Swangate International or Luftfahrttechnik GmbH. Beyond these solutions the article also contains test stand used so far at the Institute of Aviation, these solutions were prepared for testing one type of rotor (for example: only for gyroplane rotors). The article provides the steps of designing a new test stand, which one of the basic assumptions is that it will be a universal test stand, giving the possibility to test different types of rotors. The article discusses two concepts of the stand with electric engine as a drive, gives the advantages and disadvantages of each concept, and indicates the selected solution. In addition to design and applied drive solution of the stand, the measuring part and data acquisition were also discussed. Moreover, the article focus on the advantages of rotor testing using the presented solution, as well as problems encountered during tests, in particular related to construction free vibrations and resonance. Vibration and resonance of the test stand are very important aspect of the entire design process, because it affects the quality and safety of the tests.

Keywords: *test stand, main rotor, design, construction resonance*

1. Introduction

In the last few years, the development of light and ultralight rotorcraft has been observed. This applies to both helicopters and gyroplanes. Market is focused, among others, for private customers, enthusiasts, and businessmen. Recipients are oriented to new solutions, improvements that increase flight comfort, economy, distance and flight speed. In addition to the design of completely new rotorcraft solutions, great emphasis is placed on the development of new main rotors, with new airfoils and new technology of manufacturing using composite materials [6].

The primary structural elements in rotorcraft, which is undoubtedly the main rotor, are subjected to numerous tests before being permitted to fly on an aircraft. These include, among others, strength tests required by aviation regulations. However, the tests required by the aviation regulations will not provide answers on the subject of rotor properties. Therefore, to evaluate structural and aeromechanical performance of the main rotor, tests simulating hover conditions are carried out. Since precious information regarding dynamic balance, noise, aeroelastic stability, vibration and performance as well as structural integrity of rotors at hover condition can be assessed in Whirl Tower tests, these test systems are considered vital in rotor design [1-3]. The article discusses the solutions of research stands used for testing different properties of helicopter or gyroplane main rotors. In the further part of the work, several research stands so-called whirl towers are presented and briefly discussed.

This article also provides an overview of the prototype device, which was developed at the Institute of Aviation in the Centre of Transportation and Energy Conversion. Presents the main assumptions of the project, design steps and calculations.

2. Main rotor test stand overview

In the world, several companies deal with, among others, construction of test stands and measurement systems dedicated to dynamic tests of rotorcrafts rotors and propellers [4].

One of these companies is Swangate International along with WT-BladeMaster (shown in Fig. 1). Swangate International developed hardware systems for 'whirl towers', for example, systems for tracking and balancing rotor blades. Whereas WT-BladeMaster provides rotor towers, helicopter rotor blade whirl stands, with up to date and technically advanced available for do a demanding and highly accurate quality assurance dynamic testing of helicopter in the world today [9]. The photographs below show some whirl towers system, which were designed and manufactured by mention companies.

Fig. 1. The example of Swangate International and WT-BladeMaster 'whirl towers' system [9]

Another company involved in manufacturing research stands systems – 'whirl towers' is Luftfahrttechnik GmbH (shown in Fig. 2).

Fig. 2. The example of Luftfahrttechnik GmbH 'whirl towers' system [10]

The solutions presented above are advanced 'whirl towers' used in General Aviation, to test and dynamic balancing main rotors for advanced rotorcraft constructions.

Another solution of 'whirl tower' test system, shown in Fig. 3, is discussed in the literature [3]. This solution for smaller rotorcrafts were designed and manufactured in Turkish Aerospace Industries. The main properties of this test stand are rotor blades are mounted at 6 m high, the maximum motor power of the system is 560 kW with maximum torque – 7780 N/m, rotor revolution speed is 744 RPM and maximum dimeter of tested rotor is 8 m.

Fig. 3. The TAI whirl tower system [3]

The Institute of Aviation several test stands of this type have been made. These positions were not as advanced as the above-discussed constructions. The stands were designed and manufactured for testing specific construction solutions of main helicopter and gyroplane rotors. The first such solution was a whirl tower for testing three - blade main rotor dedicated for two seat and then for unmanned helicopter design in Institute of Aviation called the IS-2 and then respectively ILX-27. The stand consists of a symmetrical tower to which the gear and the original rotor hub of the helicopter were mounted. The drive was carried out by a combustion engine with a power about 200 HP.

Fig. 4. The whirl tower system for helicopter three-blade main rotor

This type test stand construction was performed for the project titled ‘New Autorotation Rotor’, as a result of which new rotors, with new airfoil, dedicated to gyroplanes were designed and tested. Now these rotors can be purchased from a Polish company – Artur Trendak Aviation, which implemented this technology. Test bench (shown in Fig. 5, left) specially designed and constructed for gyroplanes rotors is equipped with three-axis acceleration sensor to control the vibration of stand, four force sensors to measure thrust, reflective optical sensor, which measures the speed of the rotor. A rotor mounted on the position was powered by engine through shaft, one-way clutch, gearbox and rubber clutch protecting the rotor against temporary overload propelling torque [5]. The maximum power of the stand was 180 HP. Test position – whirl tower was equipped with a rigid, two – bladed, teetering rotor, adequately oversized to ensure safety during tests. The distance between the blades and the ground was 3 m.

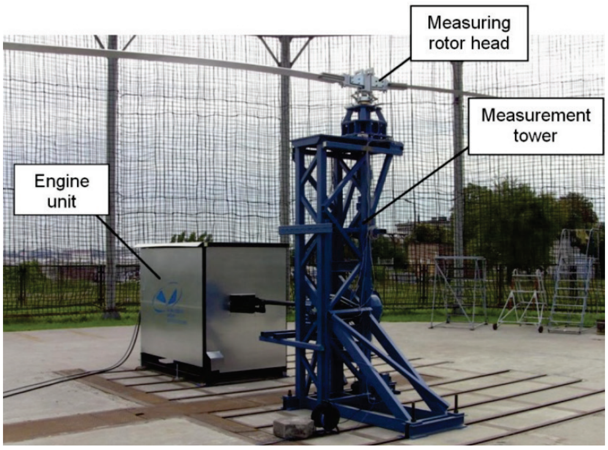

Fig. 5. The whirl tower system for gyroplane main rotor tests (left) and stiffened construction for testing helicopter rotors (right) [5]

Whirl tower for the needs of another project, concerning the implementation of new composite (made in prepregs technologies) rotors for light and ultra-light helicopters was modernized. During the preliminary tests, it turned out that the resonance that occurs during the test achieves dangerously high level. After performing the resonance tests of the stand with additional loading mass and modal analysis, appropriate supports were designed, shown in Fig. 5 (right).

3. Prototype whirl tower stand

The test stands at the disposal of the Institute of Aviation were designed and manufactured for the needs of a specific project. However, growing interest in research on new helicopter and gyrocopter rotors occur. Furthermore, interest about the possibility, determining the various structures vibration, which are within range of helicopter rotors. All this contributed to the development of a new whirl tower type test stand concept that will meet the requirements of the market.

The aim of the project was to extending the scope of measurement possibilities of the stand, reduce the risk of stand resonance, ensure the possibility of easy sensors installation and additional advantage of the position had to be its ability to move. The main aspect of the work is the use of an electric motor as a drive. With a 315 kW (410 HP) engine, the research capabilities are extended to testing rotors dedicated to four-seat helicopters. In addition, adaptation of the measuring system to the atmospheric conditions, which will improve the process of test preparation, thus it leads to significantly reducing the time of tests itself.

3.1. Two concept of whirl tower

The first concept of the stand was assumed horizontal positioning of the engine, as shown on visualization in Fig. 6. This concept assumes the use of an electric motor at 1500 RPM or 3000 RPM, and an angular gearbox with an appropriate transmission ratio to obtain revolutions behind the gearbox of approximately 600 to 700 RPM, and a torque of approximately 4000 Nm.

The stand in this version would consist of two parts: drive, with the engine properly built and secured, and the whirl tower part with the gearbox. The assumption was that these parts will be disassembled when there will be a need to move the stand. The advantage of this concept is a relatively light construction, each of the parts, which would make it quite easy move when its needed. The main disadvantage of this concept is the need to use an angular gearbox. The design and manufactured such a gearbox that meets the requirements of the test condition of the test bench is a complicated and expensive process. Another disadvantage of this solution is the impact of the drive part on the air flow under the rotor during test. This problem has already been encountered with previous versions whirl towers with combustion engines (as shown in Fig. 4 and 5).

Fig. 6. Concept of the whirl tower system with horizontally mounted engine

After analysing the available solutions for electric motors and expert opinions in this field, it turned out that the best choice would be to use an electric engine with a nominal speed of 700 RPM installed in a vertical position. The solution eliminated two main problems from the project. Unfortunately, it increases the mass of the entire device. Which caused a problem to solve related to moving the stand. The visualization of test stand second concept is shown on the Fig. 7.

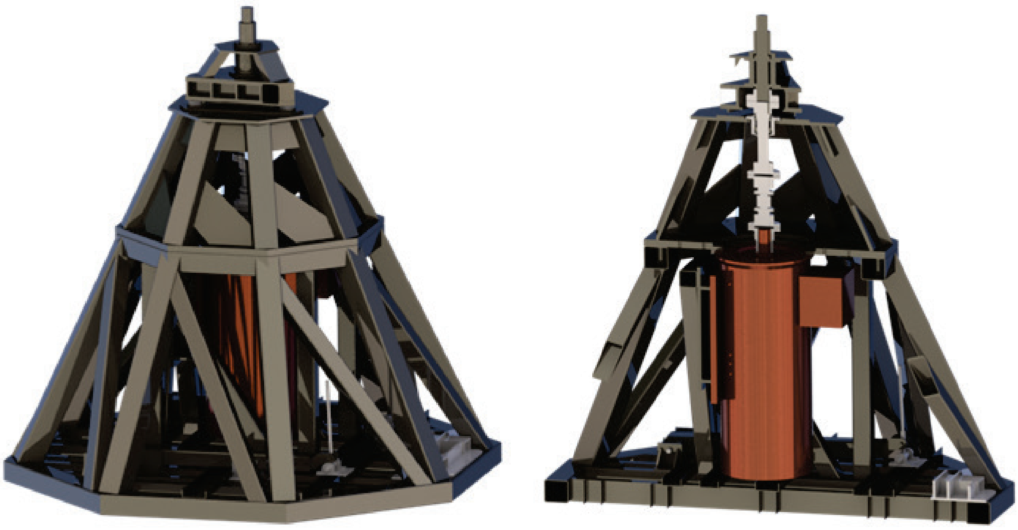

Fig. 7. Concept of the whirl tower system with vertically mounted engine

3.2. Whirl tower design

The research stand, whirl tower, has been designed considering:

- lack of mechanical gearbox,
- vertical installation of the electric engine,
- size of the Helicopter Stand (HS), so called 'Rotunda', describe in literature [5, 7],
- required stand mobility,
- occurrence of construction resonance.

In the test stand (shown in Fig. 8), the following structural elements can be distinguished: the frame, the drive unit, and the measuring rotor hub. The frame is divided into two integral parts, connected by threaded elements, which allows disassembly of the entire structure. Inside the bottom part of the frame an electric motor is mounted in vertical position. In the upper part of the frame there is an engine shaft, a torque measurement sensor on the shaft and a KTR clutch system. Clutch system ensures the transfer of torque to the rotor hub.

Fig. 8. New whirl tower: visualization with rotor hub and blades (left), frame of the whirl tower with the mounted engine (right)

The mobility of the stand is provided by 'retractable chassis'. The chassis consists of two wheels made of steel with a diameter of 300 mm and a track width of 80 mm. The stand can be moved using a forklift truck with a minimum lifting capacity of 3.5 tons. The pitchfork of truck is placed in a designated place on the stand frame. The stand chassis is lowered and the forklift truck lifts the stand to a height of about 200 mm and push or pulls them (shown in Fig. 9).

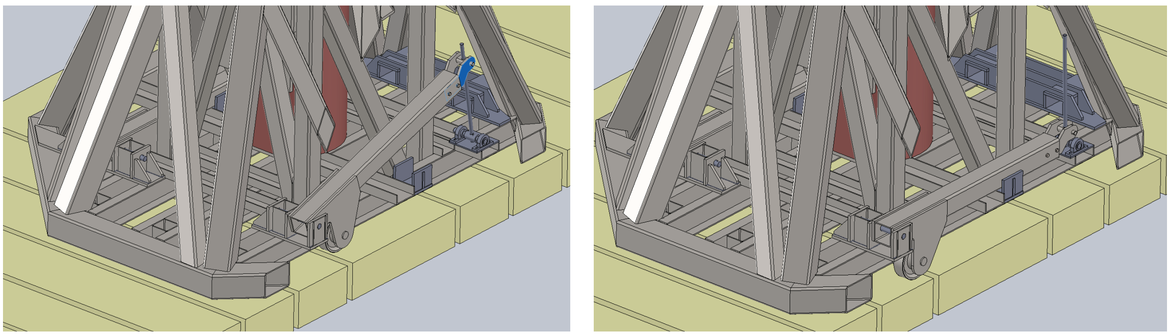

Fig. 9. Whirl tower retractable chassis

3.3. Whirl tower modal analyses

The critical step was to perform a modal analysis of the designed test stand. Modal analysis was performed using the finite element method FEM in the Nastran/Patran environment. The purpose of the analysis was to determine the eigen frequencies/free vibration of the structure. As the frequency limit of the vibration mode, the maximum vibration frequency of the tested rotors was assumed, i.e. maximum rotor speed, about 500 RPM (8.33 Hz) multiplied by number of rotor blades (≤ 3) what gives us 25 Hz. Taking into account a certain reserve for other operating conditions, the frequency range was adopted up to 60 Hz.

Table 1 summarizes the results of the frequency calculation and the form of the free vibrations of the whirl tower. As seen in table in the range of the accepted frequency (i.e. 60 Hz) only two frequency modes are included.

Tab. 1. The free frequencies for the basic model of the whirl tower

n	Frequency *f* [Hz]	harmonics	Frequency mode description
1	43.9	1.75	1. flexural in XZ and YZ plane
2	45.3	1.81	2. flexural the XZ and YZ plane with local displacement of the vertical engine plate in the X direction
3	72.4	2.86	3. flexural the XZ and YZ plane with local displacement of the horizontal engine plate in the Z direction
4	90.3	3.61	1. flexural –torsional In the YZ plane

4. Conclusion

Whirl towers type research stands are used by many companies dealing in the design, manufacturing and testing of rotorcrafts. Such test stands have in their possession companies from 'General Aviation' sector as well as small private companies.

During the design of whirl towers, many challenges appeared, one of which are vibration and resonance of the stand. These are dangerous phenomena that can lead to the stand and research object destruction. Therefore, it is important to perform modal analyses when designing such stand. For the research stand discussed in this article based on the results of the MES calculation, it can be assumed that resonance phenomena should not occur with the rotor shaft speed considered. So it can be assumed that for two and three – blade rotors, rotating about 500 RPM (rotors with a diameter of between 8 and 9 m), there is no risk of stand resonance. One of the difficulties in stand design, which affects the potential resonance, is required stand mobility. Therefore, it was important to design a position that would be as symmetrical as possible, with as much weight as possible.

The design of the whir tower is continued, apart from the mechanical aspect, the measurement aspect is also very important. It is principal that the data acquisition system being developed enables an accurate and reliable measurement, in real time, the largest number of parameters of the tested object.

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