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GYROPLANE ROTOR HUBS STRENGTH TESTS

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Abstract

In this article a review of rotor, hub constructions were presented. Discussed rotor's hub is made of composite or aluminum alloys materials. Two types of rotor hub were presented (four-blades and two-blades teetering rotor hub), each of them are dedicated to gyroplanes. Typical gyroplane main rotors are characterized by simple design, especially in case of rotors for light gyroplanes. In the following part of the article the type of strength tests required by certification process were shown. The test programs based on legal aspects of admission to the flight tests taking into account legislation such as CS 27 (Subpart C – Strength Requirements), CAP 643 British Civil Airworthiness requirements Section T Light gyroplanes, ASTM F2972. Furthermore, this article discusses strength tests of gyroplane rotor hub such as measured parameters, methodology of measurement, types of sensors, course of test, test stands, and limit loads. The loads during "pull-up from level flight" manoeuvre are limit loads during tests. Required additional processes, like a verification the same parameters by two types of method were shown i.e. deformation of structure were tested by strain gauges and reverse engineering. Strength tests had to be made before flight test, based on results of them aircrafts are flight authorized. In conclusion, the results of tests were presented and fulfilment of legal assumptions and requirements were shown.

Keywords: *gyroplane, strength tests, rotor hub, aviation regulations*

1. Introduction

This article discusses the one of the primary gyroplanes components – rotor hubs. At the beginning of work, the development of gyroplane rotor hubs is presented. Straight hubs with arms parallel to the rotor axis of rotation are presented up to more complex hub designs with a positive cone angle or four rotating hub arms. The main attention is focused on strength tests of the gyroplane rotor hubs. Shortly discussed strength tests based on the requirements contained in aviation regulations, like: ASTM F2972 (Standard Specification for Light Sport Aircraft Manufacturer's Quality Assurance System) [7] for simple solutions of gyrocopter rotor hubs. The final goal focused on tests of the strength of the four-plane rotor hub designed for Class A gyroplanes (four- or six-seater gyroplanes). The scope of the tests was established with the Polish Civil Aviation Authority with reference to CAP 643 British Civil Airworthiness requirements Section T Light gyroplanes [2] and CS 27 – Small Rotorcraft (Subpart C – Strength Requirements) [4]. These tests were part of the type-certification tests for the newly designed gyrocopter rotor hub.

2. Gyrocopter rotor hubs review

Main rotor of gyroplanes is rotating because of autorotation phenomenon, air flowing through the rotor disc is essential to generate rotation. The primary function of the gyroplane rotor is lift force generation needed to keep the machine in the air. The thrust is generated by a pusher or uncommonly tractor propeller.

Most of gyroplanes are equipped with two-blade teetering main rotors with one centrally located beta hinge. Typically in such constructions the hub arms are perpendicular to the axis of rotor rotation, such construction is shown in Fig. 1.

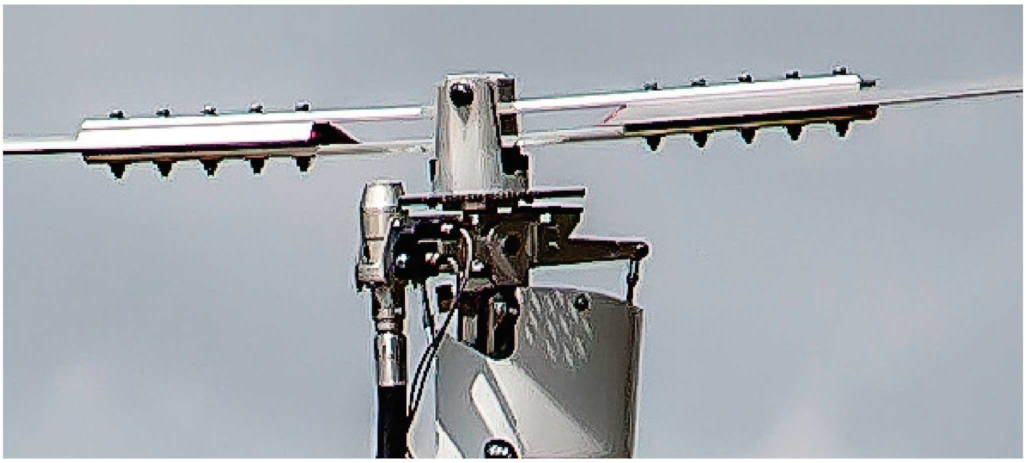

Fig. 1. Rotor hub with arms perpendicular to the axis of rotor rotation [13]

This solution is the most well known and most often used in the construction of small lightweight gyroplanes, because of its advantages, inter alia: light: weight, simple construction what affects low cost of manufacturing. However, the growing interest and faster development of such aircraft type goes hand in hand with the search for new solutions that will increase their total weight and performance and at the same time increase the safety of flights. On the one hand, the development and the search for new solutions are associated with structural changes in the gyroplane hubs. On the other hand, solutions are being sought to reduce the mass of structural components e.g. by the use of composite materials. In many cases, the changes are introduced in construction of hub arms so-called rotor hub blade connector.

Solution describe above has its weaknesses, it causes significant stresses on the rotor components, what leads to increased vibration of the rotor and mechanical damage to the blades and hub connector. Reduction of vibrations and load on the rotor hub is especially important when talking about new gyroplanes – B and A class. Which can be used not only for recreational flights, but also as an excellent means of transporting people and goods [9].

In order to overcome the described defects occurring at the hub with straight arms, it is enough to use a blade connector with positive coning angle. It sounds simple, but in fact, the connector design encounters many difficulties. One of such difficulties is the right selection of the coning angle. According to the calculations and analyses contained, among others, in literature [3, 12] the best range of coning angle is between 2 and 3 degrees. Another difficulty is the design of the hub connector itself, because there are many solutions for connector with a positive coning angle. Structures more complicated, consisting of several elements include a main beam provided with a middle part, and side arms. In each of the sidearm are placed at least two mounting holes (shown in Fig. 2) [10, 12].

As well, aluminum alloy [3] or composite structures with built in coning angle. In the pictures below, two variants of composite gyro hubs, are shown. Fig. 3 shows the prototype element of the gyrocopter rotor hub, made in hybrid technology consisting in combining the carbon composite with a special adhesive substance with a high-strength aluminum alloy referred to the literature [11]. Using this technology is possible easily to obtain a structure with a positive coning angle.

The Fig. 4 presents a carbon-composite hub with build in positive coning angle, design for gyroplanes A and B class.

However, the development of gyrocopter rotor heads did not end with modifications and improvements of two-bladed teetering rotors. Some went a step further and proposed solutions of a four-blade teetering rotor head, discussed in Chapter 4.1, dedicated to A class gyroplane.

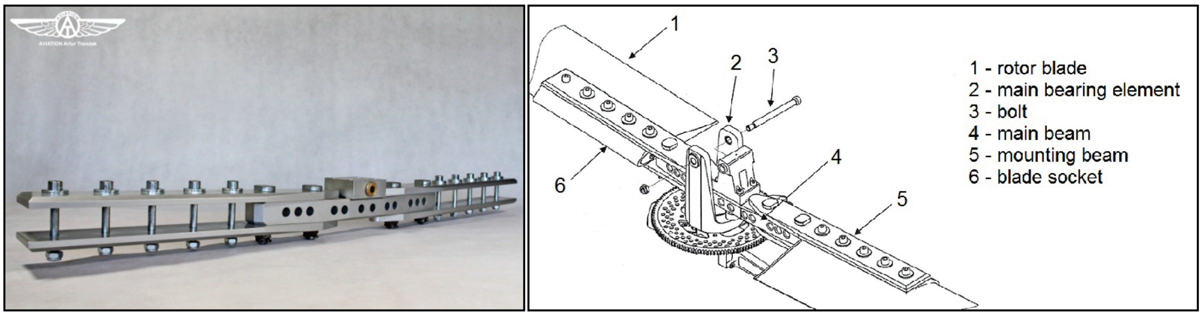

Fig 2. Hub connector with positive coning angle construction: connector visualization and construction shame of connector [10]

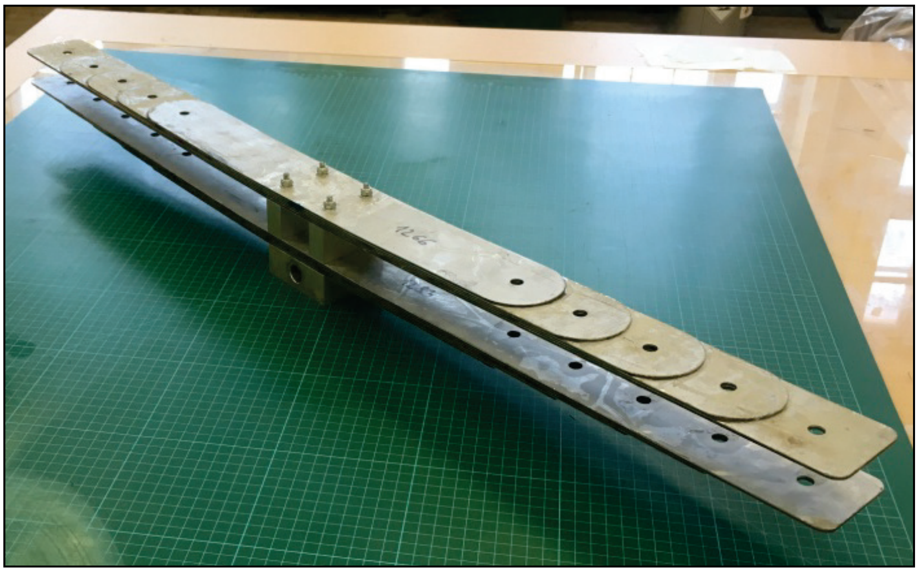

Fig. 3. Rotor hub connector with positive coning angle – hybrid material construction

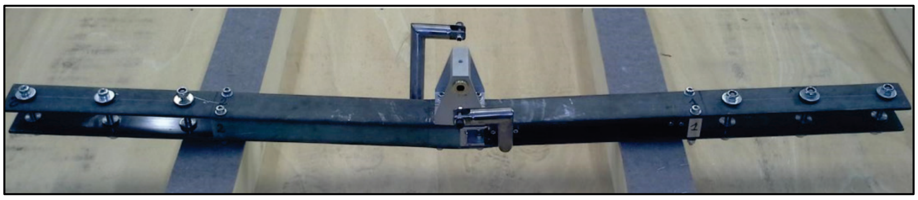

Fig. 4. Rotor hub connector with positive coning angle – carbon composite construction

3. Strength tests

Strength tests of new solutions of rotor hubs are very important for safety reasons. The aviation regulations refer to strength tests in a general way. They contain information on the factors should be met in the test, e.g. taking into account composite materials.

Generally, strength tests of rotor hub itself or only blade connector are carried out for the prototype elements, before assembly for flight tests. Tests are performed to damage loads, the value of which defines the safety factors. According to regulations, construction element should withstand such loads for 3 seconds. If necessary, the test is carried out until the element is destroyed. Often tests are carried out only to 100% permissible loads. In this case if element is not destroyed, as well as no plastic deformation was observed, with reference to the verification methodology adopted, testes element may be admitted to flight testing.

This procedure was implemented during the test of a carbon composite rotor hub briefly presented in, the previous chapter. The test consists in a gradual increase of the force (simulating centrifugal force) by the actuator until the appropriate force value was obtained, determined in the test program, For the purpose of the test, the load was assumed to be a centrifugal force, derived from the total weight of the blade in the flight condition corresponding to the gyrocopter conditions, i.e. $F = 45\ 159$ N. The bending forces, due to the built-in coning angle, were assumed zero, while the torsional forces were negligibly small.

In the next paragraph, strength tests agreed with the Polish Aviation Authority are described in detail. The discussed tests concern the four-armed gyroplane head. The research was carried out at the Institute of Aviation.

4. Four-blade teetering rotor hub

4.1. Test object

The test object is the four-blade rotor hub dedicated to the four-seat class A gyroplanes. In the hub, we can distinguish four main components (Fig. 5) i.e.:

- rotor hub connectors, for mounting the rotor blades,
- cardan frame and joint,
- mounting part of rotor hub,
- elastomeric springs, are responsible for fastening the rotor hub assembly to the gyrocopter mast.

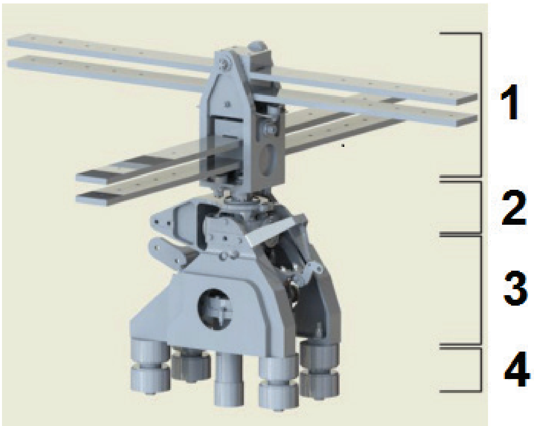

Fig. 5. Construction of four-blade rotor hub (1 – rotor hub connectors, 2 – cardan frame and joint 3 – mounting part of hub, 4 – elastomering springs)

The analysed main rotor hub is a combination of two-blades teetering rotor hubs. Two teetering rotor hubs are arranged offset 90º to one another and vertically spaced apart for structural reasons. The entire head assembly is made of high-strength aluminum alloy used in aviation.

Teetering main rotors is most common and basic construction ensuring relatively simple design and simple use. Unusual solution of four-blade rotor was developed, among others to reduce dimensions of the main rotor, i.e. the rotor diameter and chord span of the blade. In A class gyroplanes (four- or more seats), the main rotor diameters can be much larger than the standard 8 m, and in such a case problem with storage of the aircraft appears.

4.2. Strength tests plan

The four-plane rotor hub [6, 8] described above was subjected to strength tests required for type certification, which took into account the safety factor as well as mechanical resistance and plastic deformation of the structure. Calculations [1] shows that the maximum load on the main gyroplane rotor occur during the ‘pull-up from level flight’ manoeuvre. To simulate the load in laboratory conditions, without introducing three forces acting on the gyroplane rotor during this manoeuvre, the average force was determined. The angle at which load must be applied was also calculated. The angle of the introduced loads was 3.6 degrees relative to the axis of the main rotor (Fig. 6).

During the tests, the following plan was implemented:

A. Verification test stand, data acquisition and registration system during the test at 50% permissible loads.
B. The strength at 100% permissible loads was verified (loads in the "pull-up from level flight" manoeuvre was 29 kN) – for proper results the structure of the rotor hub assembly should not be permanently deformed.
C. The strength at 150% permissible loads was verified (43 kN) – for proper results the structure of the rotor hub assembly should not be damaged after the load is applied for 3 seconds.

4.3. Measurement

During each of stage described in *Strength test plan* deformation in specified area was controlled (signal form strain gauges – 7 control points), distance between elastomeric springs housing and the rotor hub mount area (deflection of the springs) was verified by specially prepared "contact sensor" system, in which photodiodes informed about contact. Distance between the upper surface of the bearing housing and bottom part of the rotor hub assembly, measurement was carried out using optical sensors. Additionally after strength test, the flatness of the cardan frame was verified and geometry of the entire structure was checked and compared to geometry before testing.

According to the requirement of the unit approving the new aviation construction (Civil Aviation Authority), it was necessary to check deformation of tested object. Geometry measurement of main rotor hub assembly was carried out before and after the test, using MCAx 25× Manual Coordinate measuring Arm. 3D scanning and inspection software provide CAD models (measuring accuracy 0.03 mm), after comparing the models from before and after load tests authors got information about place and level of deformation. On photographs in Fig. 6, the four-blade rotor hub mounted on test stand is shown.

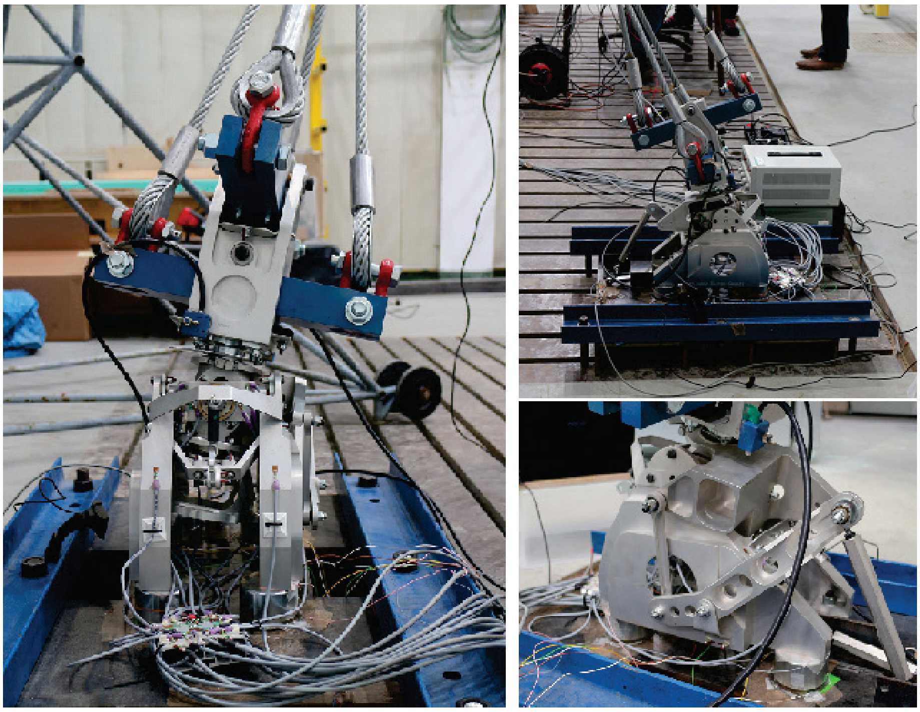

Fig. 1. Four-blade rotor hub mounted on test stand

4.4. Results

According to the requirements of CS 27.305 (a) during the test up to 100% of loads permanent deformation should not appeared. Basing on strain gauges and geometry measurement results of rotor hub assembly met the requirements of aviation regulations. With reference to the regulation CS 27.305 (b) and CS 27.305 (b) (1), the rotor hub assembly during the test up to 150% of the permissible loads cannot be destroyed or deformed during loading for 3 second. During the test, the main verification indicator was strain gauges result. This test shows that even 150% of the permissible loads did not affect the deformation of rotor hub assembly. Other measured parameters confirm compliance with the aviation structures requirements.

5. Conclusion

To sum it up gyroplane rotor hub are characterized by relatively simple construction, description of presented rotors hub and uncomplicated course of certification tests confirmed this statement.

Analysing the results of the conducted research both of mentioned rotor hub meet the requirements of aviation regulations and basis on strength tests may be admitted to flight tests. The loads used during tests corresponded to loads in manoeuvre gives maximum loads on rotor hub (in mentioned case it's "pull-up from level flight"). Decision on admission to the flight test, based on test reports, is issued by Polish Civil Aviation Authority. That is why confirmation of results is so important and sometimes two methods are used to verify the correctness of the critical parameters.

Rotor hub verification by the strength tests before admission to flight test is necessity because of safety reasons.

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