ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0010.3222

GYROPLANE ROTORS VIBRATION TESTS

Małgorzata Wojtas

Institute of Aviation
Department of Transport and Energy Conversion Division
Krakowska Av. 110/114, 02-256 Warsaw, Poland
tel.: +48 22 8460011 ext. 224, fax: +48 22 8464432
e-mail: malgorzata.wojtas@ilot.edu.pl

Michał Trendak

AVIATION Artur Trendak
Nowowiejskiego Street 26A, 96-313 Jaktorów Kolonia, Poland
tel.: +48 46 8565224
e-mail: michal@trendak.eu

Abstract

The article presents vibration test of three different types of gyroplane main rotors. The test was carried out on a specially prepared test bench using a Red Led Tacho Sensor measuring system. Tests were conducted for the project „Research and development works on innovative construction of aircrafts of weight over 560 kilograms at the company Trendak Aviation". The work outlines the basic properties of the gyroplane vibration and gives their sources. The research focused on the gyroplane main rotor vibration related inter alia to the rotor imbalance as well as rotor hub connector construction. Tested rotors consisted of three different types of gyroplane rotor blades and innovative universal hub connector with positive coning angle of 2.8º. The article summarized the basic properties of three types of gyroplane the rotor blade, marks advantages of use hub connector witch constructional dihedral angle. Discusses the principle of operation of measuring device, tests methodology starting from instrument calibration. The results of the measurements are shown in the graphs in polar coordinates. The vibration measurement is carried out in two axes, in x-axis, longitudinal, along the rotor radius and in y-axis, perpendicular to the x-axis, in the direction of the chord of the rotor blades.

Keywords: *rotor vibration, rotor blades, teetering rotor, hub connector, rotor imbalance*

1. Introduction

In rotorcrafts design the vibration phenomenon is crucial. As a result of machine elements vibration harmful interference in the proper functioning of rotorcrafts appears. Vibrations have adverse effect on the strength and durability of rotorcraft; also have bad influence on their operator and excessive noise generation [4]. The control of vibration is important for four main reason:

- to improve crew efficiency and hence safety operation,
- to improve the comfort of passengers,
- to improve the reliability of avionic and mechanical equipment,
- to improve the fatigue lives of airframe structural components [1].

Gyroplanes unlike helicopters because of the simple construction have fewer sources of vibrations affecting the whole machine. No auxiliary rotor means no vibration source at the end of the fuselage. Gyroplane pusher propeller or rarely, tractor propeller is a source of high-frequency vibrations. A significant source of gyroplane vibration is its control surfaces. In the case control surfaces are operated in the propeller stream, it means a strong turbulence effect, and thus a low frequency surface vibration [5].

As described in literature [1, 2, 11], the largest source of vibration in the case of helicopters is their main rotor. However, in gyroplanes rotor mast is lighter and less rigid than the helicopter gearbox shaft. Further, the need to place the rotor sufficiently high above the gyroplane fuselage, so that the rotor does not brush against the fuselage, reduces the vibration frequency of the main rotor and reduces vibration transmission to the fuselage. In addition, the lack of cyclic control also reduces the vibrations transmitted from rotor. The autogyro rotors are mostly two-blade teetering rotor type not equipped with the alpha hinge, which reduces vibration level in the plane of blades rotation and eliminates ground resonance [5, 10]. However, in gyroplane the rotor blade hub connectors are used. Typically, in such constructions the hub arms are perpendicular to the axis of rotation. The advantages of such solution are inter alia: light weight, simple construction what affects low cost of manufacturing. Unfortunately, this solution also 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. It is known, however, that the use of a construction dihedral angle greater than 0º, positively affects the reduction of the blade bending moment in thrust plane what causes vibrations reduces on the main rotor and consequently, increase the safety and comfort of gyroplane flight [3].

Another characteristic of rotors that affect the formation of significant vibrations is from imbalance of the rotor. Rotor imbalance can be indicated in rotor vibration tests on the test bench or during a gyroplane flight.

This article deals with autogyro rotors vibration tests on a test bench using Smart Avionics' Red Led Tacho Sensor system. Vibrations of three autogyro rotors with universal hub connector with positive structural dihedral angle were tested.

2. Features of measurement system

The research was carried out on an outside test bench equipped with an innovative hub connector with constructional dihedral angle of 2.8º. The hub connector has been designed and manufactured in the Artur Trendak Company [9]. One of the main features of the connector is its universal character; this means that it has been designed to work with different types of autogyro blades. For tests three types of rotor blades with different aerodynamic profiles, different chords and spans, made of aluminum alloy and also carbon composite were used. The vibration of each of the assembled rotors was tested using a Red Led Tacho Sensor measuring system.

The tacho sensor consists of a light source, a light detector and a signal processor all packaged together as one robust unit. It emits bright red light, which is reflected back from retroreflective tape that is attached to one rotor blade and subsequently detected. Digital signal processing techniques are used to increase the tacho sensor’s immunity to spurious flashes of light and general changes in the ambient light level [6]. For gyroplane rotor balancing, the accelerometer and the tacho sensor must be mounted on the rotor head so that were as close as possible to the source of vibration how is shown shame on Fig. 1.

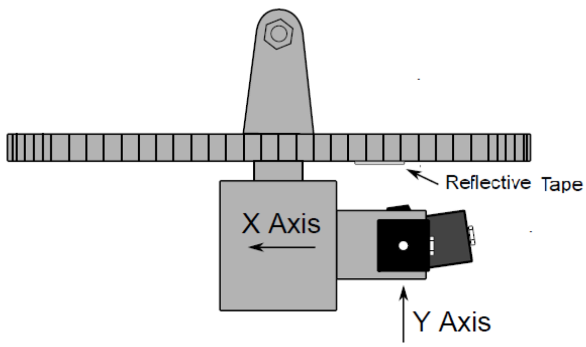


Fig. 1. Scheme of front view of sensors mounted on rotor head [6]

The Red Led Tacho vibrator measures vibrations in two axes. In X axis, longitudinal, forward along the span of the rotor and in Y-axis, pointing right perpendicular to the X-axis, along chord of the rotor blade. Fig. 2 shows the sensors mounted on the test bench.

Fig. 2. Test bench – rotor head with positive coning angle hub connector and mounted sensors

3. Autogyro rotor types

Three different types of gyroplane blades were used for the tests. Two aluminum rotors and one composite rotor were tested. Tab. 1 summarizes the basic properties of the rotors.

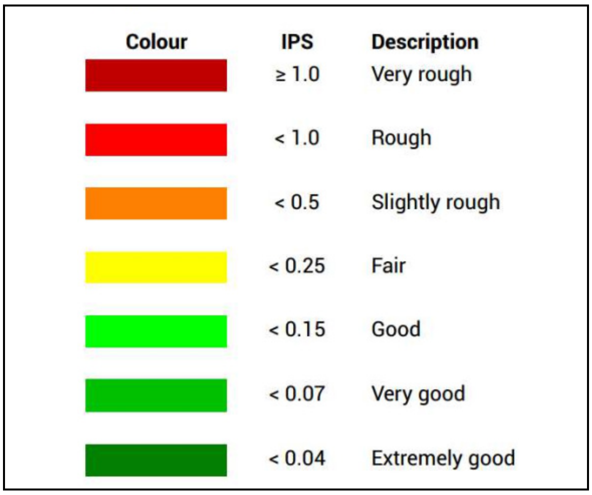
Tab. 1. Different rotors properties

Item	Type of rotor	Blade airfoil	Blade chord, mm	Blade material	Rotor span, mm
1	Wiśniewski AAT-050	NACA 9H12	200	aluminum alloy	8600
2	Wiśniewski 220 ILOT	ILW-LT-11.0	220	aluminum alloy	8600
3	WS-0-50	ILW.11/10/09.D10.0 (variable 11/10/9% along the blade span)	Variable along the blade span	carbon composite	8800

The first and second type of rotor describe in Tab. 1 are a typical rotors used for small gyroplanes class D, C and B, rotors all have the simplified construction made of aluminum alloy. The third one is an advanced composite structure dedicated for gyroplanes class B and A, larger autogyros with more advanced construction and capabilities. This blade has variable airfoil along the span, and the tip reduces the aerodynamic drag and noise [7, 8, 12].

4. Experiment and results

Sensors measure the vibration in the two axes X and Y as described in Chapter 2 of this article. The results are depicted in polar graphs where the vibrations in the X-axis are marked by circles, and the vibration in the Y-axis by means of squares. The polar graph for clarity is highlighted in colours where colours and vibration values are explained in Fig. 2.



Colour	IPS	Description
	≥ 1.0	Very rough
	< 1.0	Rough
	< 0.5	Slightly rough
	< 0.25	Fair
	< 0.15	Good
	< 0.07	Very good
	< 0.04	Extremely good

Fig. 3. Summary of the vibration levels along rotor span with their descriptions and colours

Firstly, the measurement and calibration of the sensors was performed prior to the target measurements. Two verification measurements were made. During the first measurement, verification points 1 to 14 were obtained. In second measurement, after the main rotor was moved by 180 degrees relative to the rotor head, further verification points numbered 15 to 24 were obtained.

The results of vibration tests of the three types of autogyro rotors are shown in Fig. 4 for Wiśniewski AAT-050 rotor, in Fig. 5 for Wiśniewski 220 ILOT rotor and in Fig. 6 for WS-0-50 composite rotor.

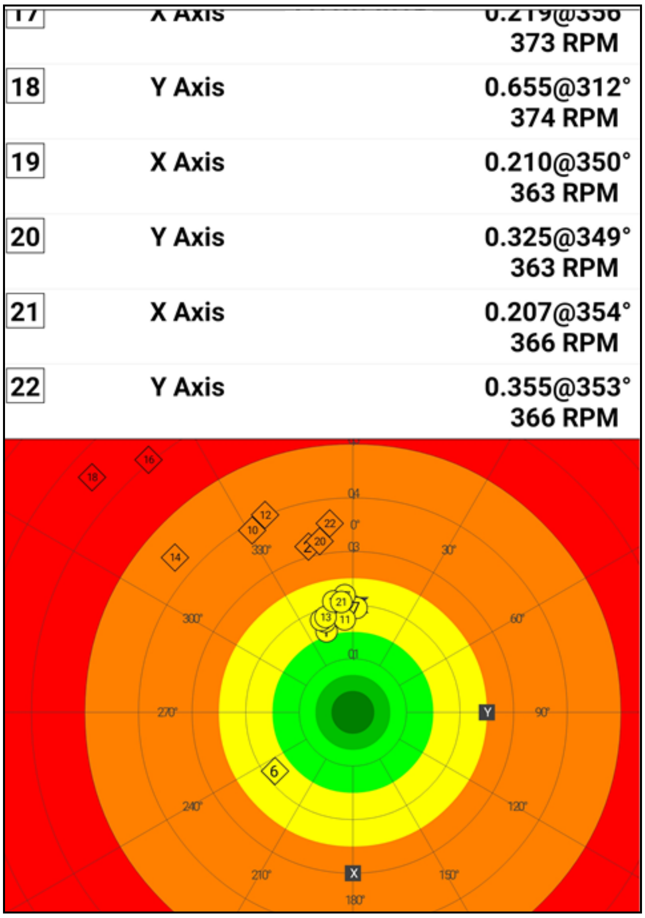


Fig. 4. Vibration levels along rotor span for WISNIEWSKI ATT-050 gyroplane rotor

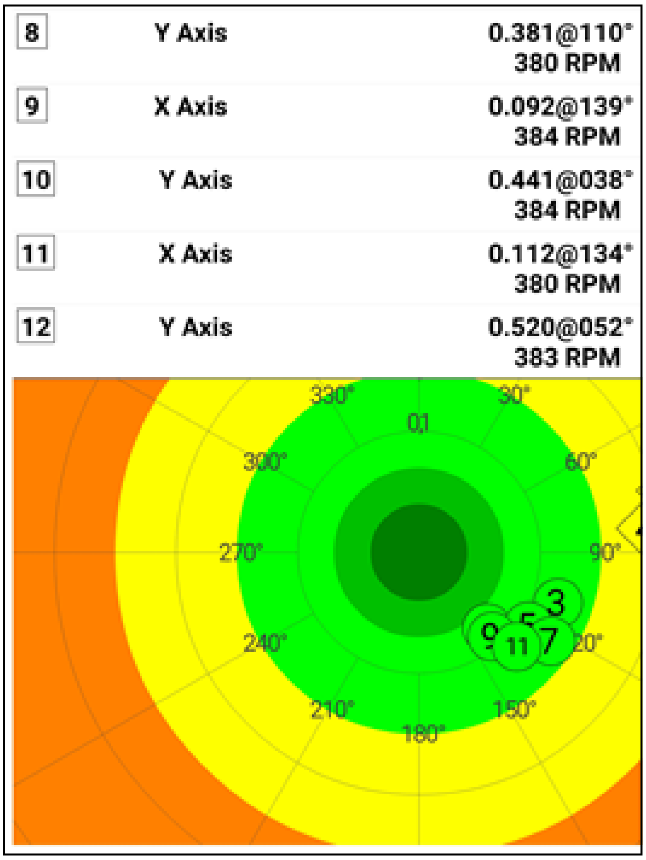


Fig. 5. Vibration levels along rotor span for WISNIEWSKI 220 ILOT gyroplane rotor

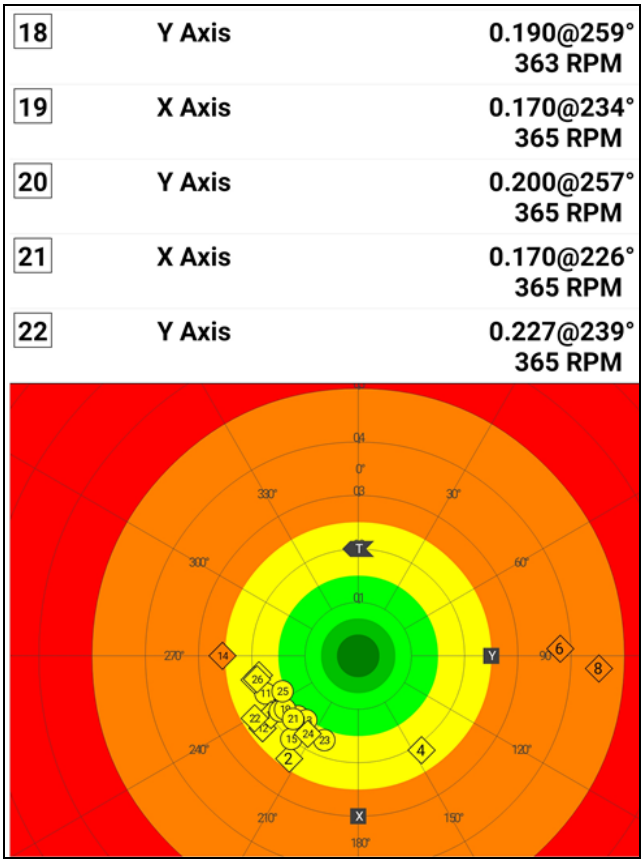


Fig. 6. Vibration levels along rotor span for WS-0-50 composite gyroplane rotor

As is shown in the polar graphs (Fig. 5 and 6), the verification points for the rotor WISNIEWSKI 220 ILOT gyroplane rotor and WS-0-50 composite gyroplane rotor are within the acceptable range of vibration levels. Higher vibration levels has rotor WISNIEWSKI ATT-050, exceeding in some points 0.5 IPS.

5. Conclusion

The article discuses basic sources of gyroplane vibrations. However, main attention is focused on the main rotor vibration. This article presents the research of three different types of gyroplane rotors on the test bench using a vibrometer.

Test results show the distribution of the vibration level for each of the rotors in the two axis: X-axis, along the radius of the rotor and Y-axis, perpendicular to X-axis, along the rotor chord. The minimum vibration level is characterized by the rotor WISNIEWSKI 220 ILOT, the level of vibration is below 0.25 IPS. A similar level of vibration has a rotor with composite blades named WS-0-50; however, several characteristic points are out of the range of 0.25 IPS. Higher vibration levels has rotor WISNIEWSKI ATT-050, nearly half of the measuring points are in the range of 0.5 to 1.0 IPS. One of the most obvious reasons for which the rotor has the highest level of vibration is its bad static balance. The second issue which worth to consider is fitting to a hub connector with a positive conning angle of 2.8º.

Acknowledgements

The work has been accomplished under the research project, entitled „Research and development works on innovative construction of aircrafts of weight over 560 kilograms at the company Aviation", co-financed by the European Union from the Funds of the European Regional Development Fund.

References

[1] Bramwell, A. R. S., Done, G., Balmford, D., *Bramwell's Helicopter Dynamics*, Butterworth-Heinemann, 2001.
[2] Cheol-Yong, Y., et al., *Dynamic Characteristics of Helicopter Bearingless Main Rotor*, Journal of the Korean Society Aeronautical and Space Sciences, Vol. 44, No. 5, pp. 439-446, 2016.
[3] Cieślak, S., I*nstability of the gyroplane teetering rotor in axial flow*, Transactions of the Institute of Aviation, No. 2 (235), pp. 28-37, Warsaw 2014.
[4] Kania, M., *Modeling of helicopter blades flapping in CATIA V5*, Postępy nauki i techniki, No.7, p. 94-101, 2011.
[5] Krzymień, W., *Vibration properties of the gyrocopter*, Transactions of the Institute of Aviation, No. 219, pp. 234-239, Warsaw 2011.
[6] *Red LED Tacho Sensor User Manual*, Smart Avionics Ltd., 2013.
[7] Sobieszek, A., Wojtas, M., *Composite rotor blades tests essential before mounting on gyroplane*, Journal of KONES Powertrain and Transport, Vol. 23, No. 4, pp. 487-494, 2016.
[8] Stalewski, W., *Aerodynamic design of modern gyroplane main rotors*, Transactions of the Institute of Aviation, No. 1 (242), pp. 80-93, Warsaw 2016.
[9] Trendak, A., *Łącznik wirnika wiatrakowca*, RP Patent PL409109, 2014.
[10] Vainilavičius, D., Vygantas, A., Marius, M., *Analysis of autogyro rotor balancing and vibration*, IEEE Metrology for Aerospace Conference, Conference paper, pp. 416-420, 2015.
[11] Wiśniowski, W., *Identification of main helicopters resonances by ground vibration test*, Journal of KONES Powertrain and Transport, Vol. 22, No. 2, pp. 287-291, 2015.
[12] www.wirnikautorotacyjny.pl.