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Laboratory model of a two-blade composite rotor system

Abstract. *The main goal of this work is to show a laboratory system which allows to study the vibrations in a helicopter's rotor model and to determine the dynamic characteristics according to different sets of blades and a wide range of rotor speeds. The research aims at testing different control algorithms to reduce vibrations of the blades in the rotor system using active Macro Fiber Composite (MFC) actuators.*

Streszczenie. *Celem pracy jest przedstawienie stanowiska laboratoryjnego, które pozwala na badania drgań modelu wirnika helikoptera i określenie jego charakterystyk dynamicznych dla różnych ustawień łopat w szerokim zakresie prędkości obrotowych. Zadaniem układu jest testowanie różnych algorytmów sterowania do redukcji drgań łopat układu wirnika przy użyciu elementów aktywnych Macro Fiber Composite (MFC).* ***(Model laboratoryjny dwułopatowego wirnika kompozytowego).***

Keywords: helicopter rotor model**,** MFC actuator, active composite beam, measurement system.
Słowa kluczowe: model wirnika helikoptera, aktywator MFC, aktywna belka kompozytowa, system pomiarowy.

Introduction

Suppression of vibrations in rotating systems with composite blades has wide applications. Such systems are often used in the aerospace industry, but suitably modified can be applied to wind turbines [1, 2]. The most important requirements of their control methods are:

- increasing system stability under adverse operating conditions (preventing excitation of systems, in particular, avoiding their resonances),
- increasing the efficiency of the system (fewer vibrations – smaller losses),
- noise reduction,
- longer durability of mechanical components.

A great majority of the control algorithms with active MFC elements are used for vibration suppression as closed-loop systems (PID, Resonant Controller, PPF – Position Positive Feedback Controller, LQR – Linear Quadratic Regulator) where strain gauges are used as sensors. Thus, it is important to implement measurement and control of blades when they rotate.

The main objectives pertinent to the system are: transmission of measurement signals to the external control system in real time, resistance to external interference with the drive and the executive system, power for actuators and measurement.

Laboratory set-up

The system is based on the experience of the smaller model driven by 1kW DC motor (Fig.1) which is described in the paper [3].

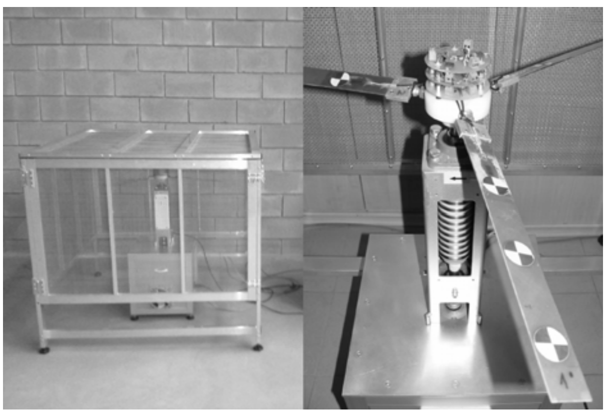

Fig.1. Laboratory model driven by the DC motor

The experimental set-up consists of a rotor which permits to adjust a blade's pitch angle in the range of -15 to +15 degrees. The rotor is driven by an electric drive system and is connected via Bowex M28 curved-tooth shaft coupling. The three-phase asynchronous motor MS112L-4 (5.5kW, 1440rpm, 36.4Nm) is powered by the inverter LG iG5A type SV 055 iG5A-4 (Fig.2).

Fig.2. Motor power system with inverter LG iG5A

The slip ring arrangement (12 rotating connectors) allows the transfer of electrical signals to the periphery of the rotor and the measuring section (Fig.3).

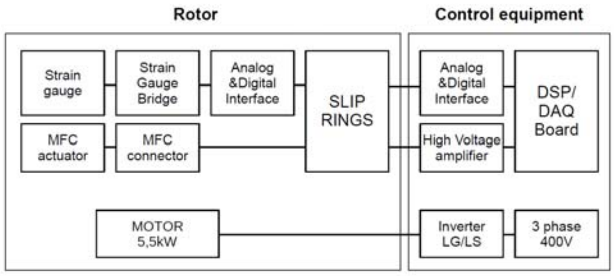

Fig.3. Block diagram of the experimental model

The system enables measurement with analog or digital interface. It is possible to choose four analog or four digital channels and combinations of two analog and two digital connections. Also less electromagnetic noise in the measured signal is observed than for the model with DC motor [4].

In order to provide digital data transmission the rotor head is equipped with two 16-bit A/D converters (LTC1865A), which are connected to the two Atmel microcontrollers (ATtiny4313). CAN drivers (PCA82C250) have been used to implement the two-wire digital interface (Fig.4).

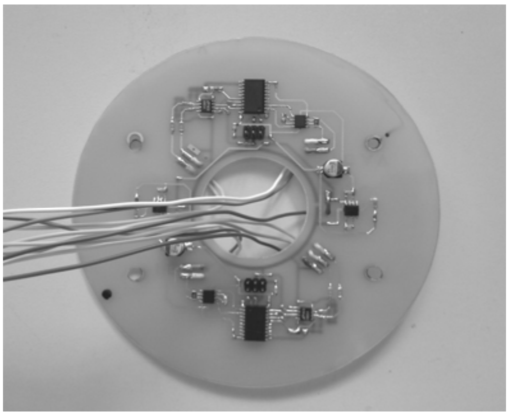

Fig.4. Rotor board with digital interface

The maximum frequency of data transmission tested over slip rings is 0.5Mbit/s. With this limitation the possible maximum sampling rate is 10kSPS for each channel. The frame rate is secured by a CRC8 checksum. The data are transmitted to the peripheral device with integrated 16-bit DACs (LTC2602) which allows the connection to the external data acquisition system. It is also possible to direct transmission of samples by serial interface.

Analog transmission was realised through the slip rings. It was necessary to apply a low-pass filter to reduce the effects of interference generated by the drive. Due to voltage drops and any interference on the slip rings a separate voltage stabilisation system was placed at the rotor for analog and digital parts. In systems for strain gauge measuring bridges precision amplifiers from Analog Devices, AD620, were used.

The modular design allows to connect various types of sensors mounted on the blades, e.g. strain gauges or accelerometers (Fig.5).

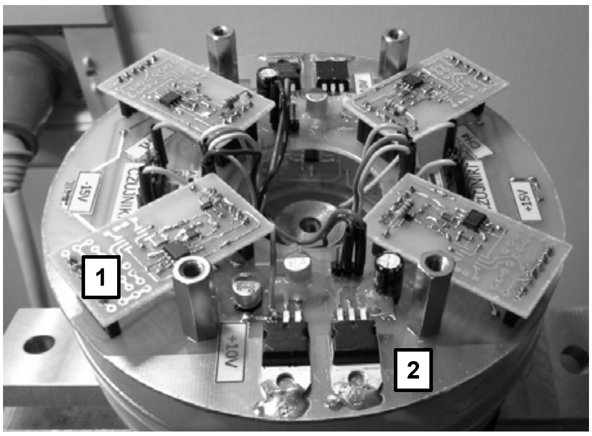

Fig.5. Head equipment of a 2-blade helicopter rotor model and rotating electronic system (1 - strain gauge bridge, 2 - power supply board)

Electrical connections on the rotor allow to supply MFC actuators. Signals on the slip rings have been arranged to ensure a safe gap between the circuits of low and high voltage. Provisions are made for the work of the MFC symmetrical voltage from -500 to +500V. The laboratory model can be controlled by the DSP or DAQ board that works with the MatLab/Simulink software.

Load tests

Estimation of the motor power demands of a two-blade rotor model fitted with an aerodynamic blade profile was made experimentally. Measurements for the power consumed by the motor at various speeds and pitch angles of the rotor blades were performed. At the beginning, seven speeds in the range of 50-350 rpm and six pitch angles relative to the axis of the rotor blade including a neutral pitch angle of 0 degrees were selected. Based on these results, the characteristics of demand for power depending on the rotating speed of the rotor blades with fixed angle settings were determined, depending on the pitch angle of the blades at a constant rotation speed of the rotor. The influence of the rotation speed of the rotor on the demand for power for different angles of the blades is shown in Figure 6, and the effect of the pitch angle of the rotor blades on the demand for power for different rotation speeds in Figure 7.

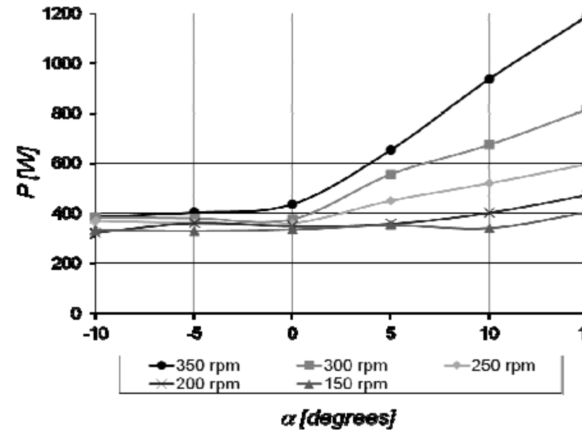

Fig.6. Influence of the rotation speed on the rotor's demand for power for different angles of the blades

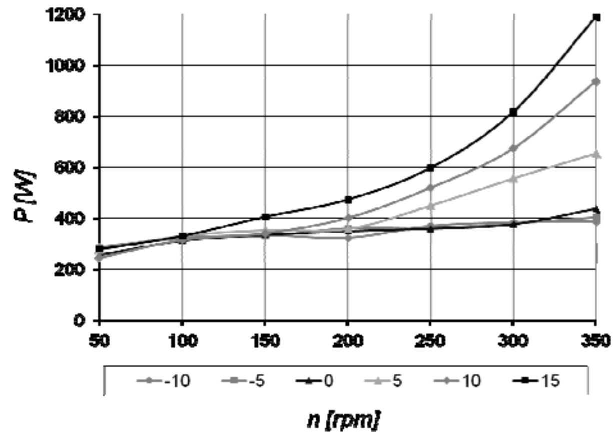

Fig.7. Effect of the angle of the rotor blades on the demand for power for different rotation speeds

The approximate power of the rotor can be estimated using the formula known from the turbine dependencies:

$$P = P_o \frac{\rho}{\rho_o} \left(\frac{n}{n_o} \right)^3 \tag{1}$$

where: ρ – air density, P_o – power for the known speed n_o.

Based on the experimental results, for 5,5kW motor drive the estimated realisable maximum rotor speed for +15 degrees pitch angle of the blades is equal to about 570 rpm (Fig. 8).

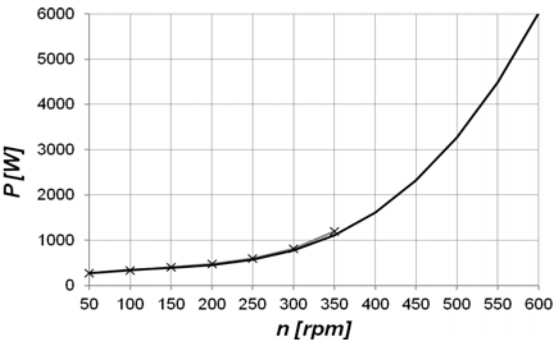

Fig.8. Estimation of the maximum rotor speed for the blades angle equal to 15 degrees

Studies have shown a progressive growth of power as a function of the rotor speed for positive angles of the attack angle. For negative angles a small decrease of power consumption by the rotor is observed.

Preliminary vibrations tests

By using an advanced optical system, vibration measurements were made for the rotor. The measurements were performed by means of the industrial 3D measurement system PONTOS HS (GOM). The reference point was placed on the enclosure of the motor, however the measurement points was placed on the rotor blades.

Preliminary results of the oscillation frequency, approximately equal to the rotor speed of 60 rpm/min, are presented in Figure 9, where laboratory stand, measured points arrangement and vertical displacement of the two selected points versus time are presented.

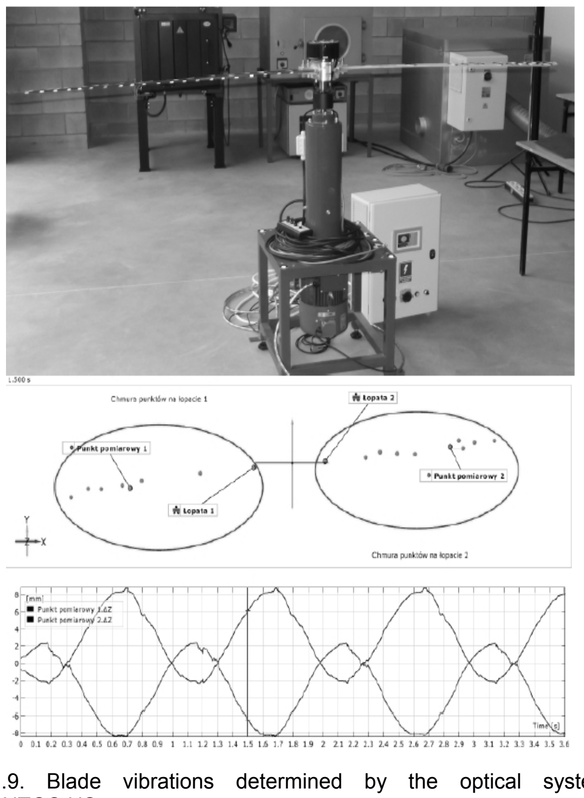

Fig.9. Blade vibrations determined by the optical system PONTOS HS

Conclusions

In order to examine dynamic properties of a helicopter rotor, two models were created, both powered by electric motors. The first model was equipped with a rotor with blades in the shape of composite beams and was driven by brushed DC motor. That construction did not accurately simulate the aerodynamics of a real rotor and additionally a commutator of the motor generated electromagnetic interferences with measuring signals (which affected the measuring model of the beam deformation). Thus, the second model was designed and created, this time with the rotor exactly resembling the aerodynamics of a real helicopter rotor. Due to the increased power demand, a more powerful, asynchronous motor was used, additionally enabling analogue, wide range speed control. The motor was fed by a frequency inverter, which reduced the electromagnetic interferences. In order to galvanically connect the static and moving components, the slip rings were utilized. In that way, a continuous flow of measurement and controlling signals was secured as well as power supply for the electric systems and MFC actuators. In order to increase accuracy, electronic systems conditioning signals were employed in the rotating part, which enabled the increased precision of data transmission through the conversion into digital form. The initial tests proved the model to be successful. Moreover, they showed that the employed motor was adequately selected and that it is possible to study the rotor dynamics in the ranges close to the real conditions. As a result, the model is capable of detecting blade vibrations and enables active vibration reduction by the control system.

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