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Angle measurement with a Hall effect sensor

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Abstract

One field of work of the Institute of Flight Systems of the German Aerospace Center (DLR) is the investigation of flight characteristics of helicopters. For this task DLR operates the research helicopter FHS (Flying Helicopter Simulator/Type EC135) and a model helicopter wind tunnel test stand.

The tail rotor of a helicopter has a significant impact on flight characteristics like vibration and noise. Sensors for the measurement of thrust, rotor speed, and pressure are already available. This paper presents a sensor for the acquisition of the flapping motion of the tail rotor. After an introduction and an explanation of the challenges of the measurement task, the mechanical and electrical integration of a smart and intelligent Hall sensor into the model test bed is described. Results from a wind tunnel test are discussed.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Helicopters are complex and highly dynamic flight vehicles. Several aerodynamic characteristics still need to be investigated, such as for example the interaction between the main and the tail rotor. This interaction is one reason for unwanted noise and vibration. In cooperation with national and international partners from industry (e.g. Eurocopter, Agusta) and research centres (e.g. ONERA, NLR) the German Aerospace Center develops technologies to increase the performance of helicopters. For this and related fields of research DLR operates several test facilities. One is the research helicopter FHS (Flying Helicopter Simulator, figure 1) [1], developed by Eurocopter Germany and DLR.

In addition to the full scale helicopter the Institute of Flight Systems [2] has operated a helicopter model test bed for more than 20 years [3]. During this time the requirements concerning the sensor equipment has increased constantly, not only in terms of the number of sensors, but also in terms of the mechanical dimension, power consumption, performance and cost reduction for each individual sensor.

Over the years more and more sensors have been integrated into this test bed. The most important sensors are strain gauges, pressure sensors, accelerometers and temperature sensors. The latest development has been the integration of a Hall sensor for the measurement of the flap angle.

This paper presents the use of a small Hall sensor mounted on the tail rotor of a model helicopter to measure the tail rotor flap angle (figure 2). Additionally the integration of this type of sensor into the main rotor helicopter blades to measure the angle of active integrated flaps is discussed as a future project.

Figure 1. Flying Helicopter Simulator FHS.

In both applications, the dimension of the sensor has to be very small, since the mounting space of the sensor is limited due to the mechanical construction of the tail rotor and the main rotor blades.

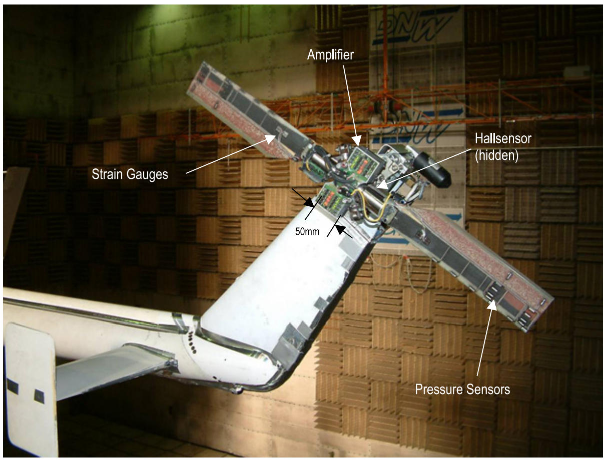

Figure 2. Helicopter tail rotor model in the German–Dutch wind tunnel (DNW).

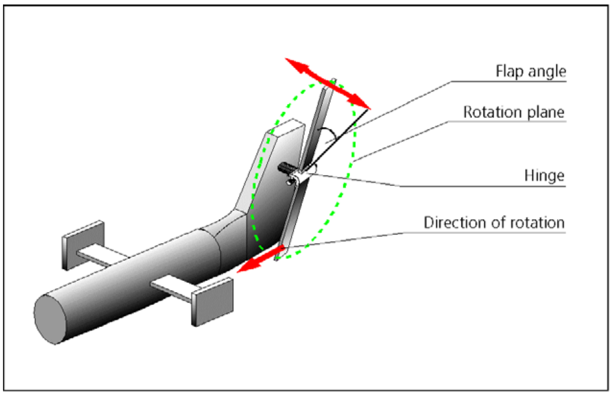

Figure 3. Flap angle on a tail rotor.

2. Flap angle of the tail rotor

The tail rotor of the BO105 helicopter consists of two blades. The blades being mounted on a hinge are variable in pitch (figure 3). The flap angle is the result of different airstream velocities of the forward (flight direction) and backward (against flight direction) running blade of the rotor. This aerodynamic condition results in different lift moments, which again lead to a sine oscillation of the blades. The effect increases with higher flight velocities.

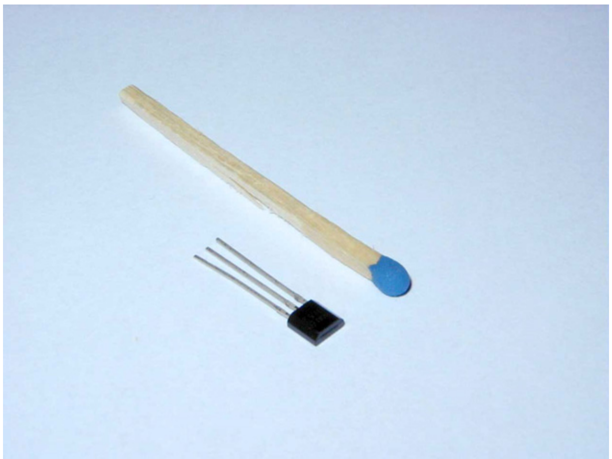

Figure 4. Hall sensor from Micronas.

3. Hall sensor

For the measurement of the flap angle the HAL800 sensor from Micronas was selected (figure 4). Its mechanism is based on the principles of the Hall effect. The sensor measures the flux density of the magnetic field and delivers a proportional electrical output voltage [4].

The sensor consists of an integrated A/D converter, a D/A converter, a low pass filter and an EEPROM. A great advantage of this sensor is its programmability. This allows setting and storing specific parameters, such as for example the specification of the magnetic material, the output voltage and the filter ranges (i.e. selecting a cutoff frequency of 0.5 kHz or 2 kHz).

In order to be able to program the sensor an adapter board is connected between the sensor and the serial interface of a PC. The adapter board requires a power supply of 15 V DC, which is passed onto the sensor. The adapter board communicates with the sensor via a modulation of this supply voltage. The normal operational voltage of the sensor is 5 V DC. The operation with the nominal voltage disables the modification of the parameters.

4. Integration of the sensor in the model

Due to the mechanical construction of the tail rotor and the small size of the measurement equipment, both the sensor

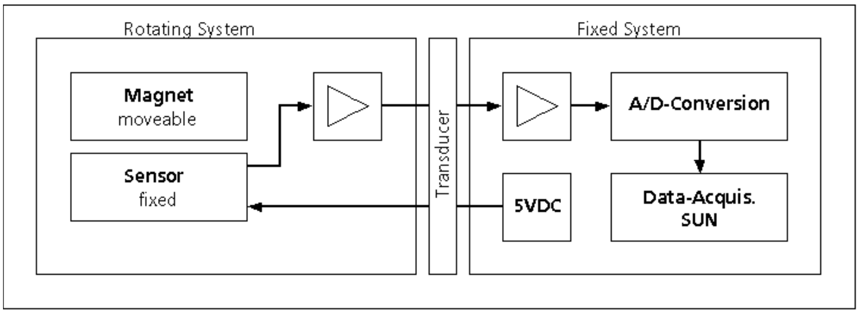

Figure 5. Schematic view of the tail rotor model system.

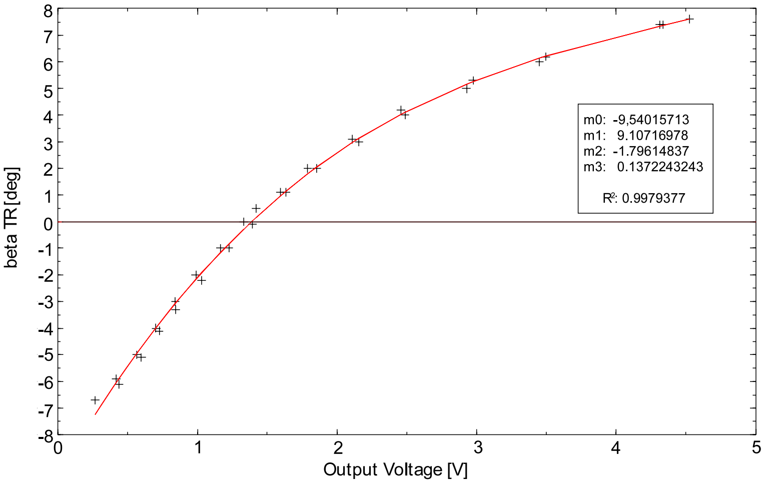

Figure 6. Calibration of the flap angle.

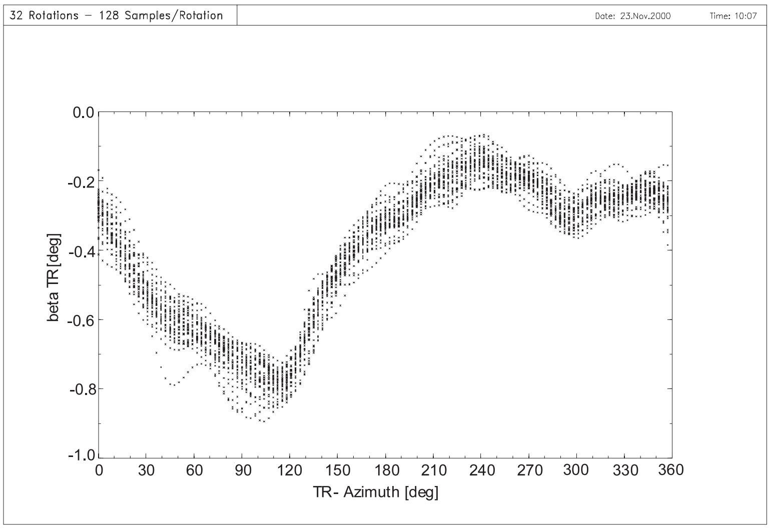

Figure 7. Flap angle at hover.

and the magnet were installed with two-component glue. The sensor was installed on the fixed side of the hinge and the magnet was installed on its moveable side (figure 5).

After the integration of the flap angle sensor the system was calibrated. As a calibration curve the following third-order polynomial was chosen (figure 6):

$$\beta(U) = m_3 \cdot U^3 + m_2 \cdot U^2 + m_1 \cdot U + m_0$$

(flap angle β, sensor output voltage U and numerical constants m_0 to m_3).

The reason for the non-symmetrical curve is the non-symmetrical movement of the magnet out of its centre position.

5. Results

As an example two measurements are shown. The selected flight conditions are hover (figure 7) and level flight at a flight velocity of $v = 18 \text{ m s}^{-1}$ and a heading of 18° (figure 8). The latter means that the x axis of the helicopter is turned by 18°: a heading of 90° would mean the flight direction is sidewards. Each figure shows the flap angle as a function of the rotor position. An angle of 0° means that the reference blade shows downwards. 32 tail rotor rotations were acquired with 128 samples/rotation.

In the hover condition (figure 7), only the airflow of the main rotor and the construction of the fin have an influence on the flap angle. Thus, on both blades the aerodynamic conditions are almost the same, resulting in small flap angles (note the scaling of the y axis).

In the level flight condition (figure 8) the flap angle is clearly a function of the cosine of the rotor angle. Due to interference with vortices caused by the main rotor during forward flight no constant aerodynamic conditions exist at the tail rotor blades and thus the flap angle varies a little bit with every revolution.

For this condition a Fourier transformation of the flap angle measurement results in a peak at 92 Hz (figure 9).

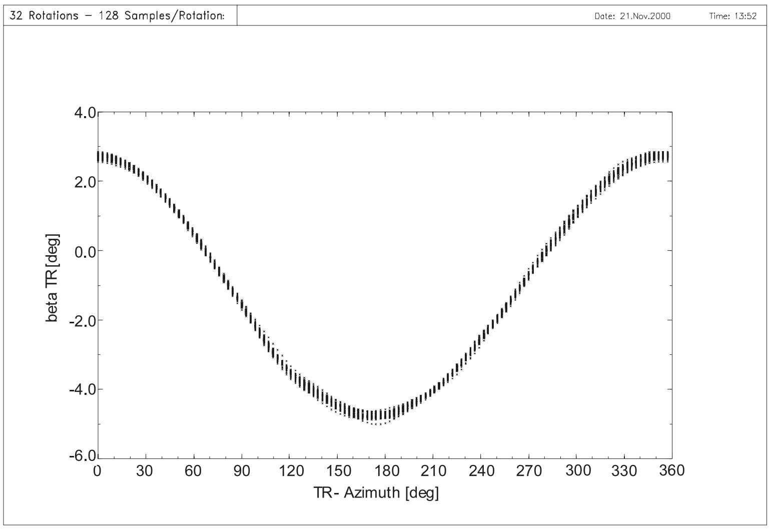

Figure 8. Flap angle at level flight ($v = 18$ m s^{-1}).

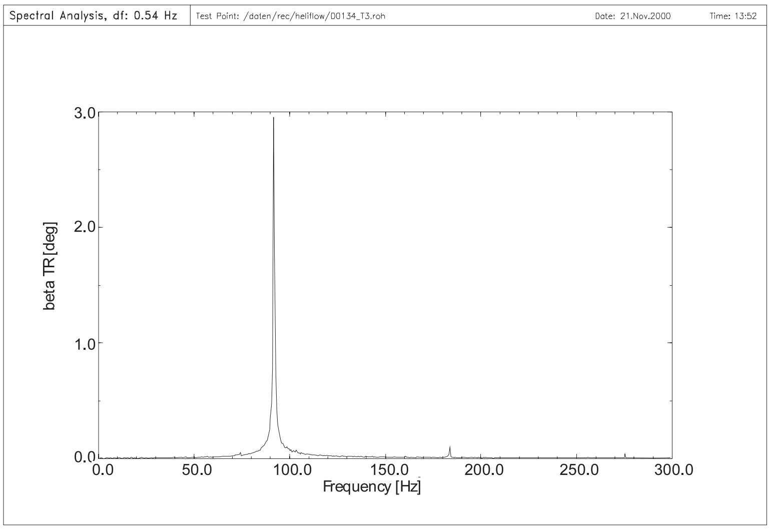

Figure 9. Fourier transformation of the flap angle measurement from figure 8.

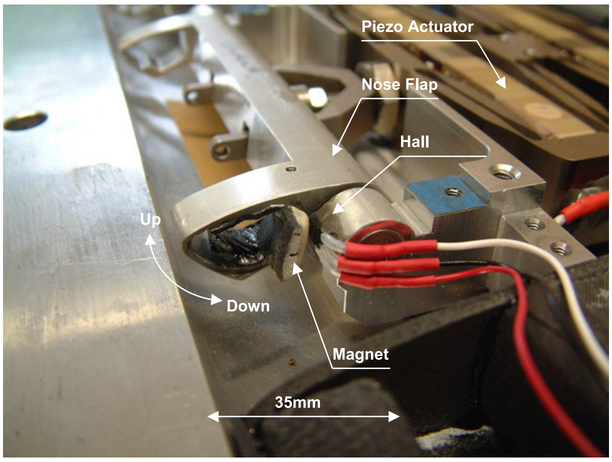

Figure 10. Active nose flap (developed by EADS) with Hall sensor.

This value is identical to the rotation speed of the tail rotor (5520 rpm) which was measured separately.

6. Integration of the sensor on the active main rotor blades

In order to avoid stall effects in the outer area of the retreating main rotor blade a new blade is currently under development by EADS, ECD and DLR [5, 6]. This blade is equipped with a small movable flap. The hall sensor is used to measure the deflection of this flap. The sensor is installed at the hinge of the blade and the magnet is glued on the movable nose flap. The tests with the new blade will be conducted in one of the wind tunnels of the DNW at Göttingen, Germany. Figure 10 shows the arrangement of the flap inside the blade, including sensor and actuator (the top part of the airfoil is not installed).

7. Conclusions

The usage of a Hall sensor for the measurement of the flap angle of a rotor blade has turned out to be a very effective, space-and cost-saving solution. In spite of extremely high vibrations and the high rotation speed of the rotor, the system shows a very robust mechanical and electrical performance.

With the experience from the wind tunnel tests with the model, good results can be expected for the active main rotor blades.

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