PROPELLER MEASUREMENT STAND SYSTEM

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The article deals with a practical realization of a measurement propeller stand for data acquisition with the aim on an automated system for the acquisition of electromotor and propeller data that are used as a propulsion unit on small unmanned aerial vehicles (UAV). Described are BLDC motors as the most commonly used propulsion on small UAVs and also BLDC motor driving methods are characterized. Mechanical construction, software and initial test results are presented.

K e y w o r d s: BLDC motor, measurement, propeller stand

1 INTRODUCTION

Small UAVs are the subjects of many researches and tests, mainly in the military area. They are currently also penetrating the civilian applications area and they are used by different operators in the areas of aerial photography, photogrammetry, search operations, delivery, etc. [1]. In the few last years the BLDC motors have widely spread as the propulsion systems for small UAVs, since they have advantages in their high efficiency, long lifetime, low noise and good torque parameters. Since they are the most used propulsion in micro, mini and small UAV category, it is necessary to optimize the driving system composed of the BLDC motor and propeller. For this purpose a measurement propeller stand was constructed.

2 BLDC MOTORS IN AVIATION INDUSTRY

In the aviation industry, many driving systems integrate in their structure utilization of an electromotor. Based on the concrete application, there are requirements the electromotor has to meet: small dimensions, good performance, high reliability and relatively simple construction. This is the reason why BLDC motors are used on board of airplanes or UAVs. The BLDC motor often operates with a changing load that requires a very fast regulation and dynamic response. Examples are gyroscopes and robotic arms. The BLDC motors are controlled via feedback loop with system specified control algorithms.

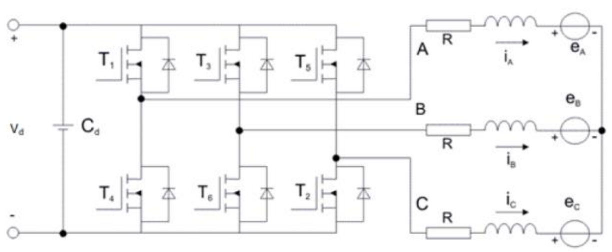

Figure 1. Schematic diagram of BLDC motor control.

Aviation applications of the BLDC motors include high speed centrifugal pumps or high speed cameras. In these applications the motors can achieve over 15000 rpm. When operating with this speed, it is necessary to take into account the requirements on mechanical construction and electrical power parameters. One of the most significant factors is the control algorithm accuracy that controls the voltage and current values during the transitions from stable operation mode and dynamic change of the load. Since the BLDC motors do have very fast control loop, they are suitable for applications that demand fast responses.

3 BLDC MOTOR CONTROL METHODS

This type of motors requires a driving unit, often called electronic speed controller (ESC). ESC controls the switching of power field effect transistors (FET) to generate rotational magnetic field from DC power supply. Considering the properties of BLDC motors from the control point of view, the most significant factor is switching in the right time among the windings to achieve the best efficiency [2]. This cannot be done, if we do not know the position of the motor shaft. There are two control methods used:

- Control with sensors.
- Sensorless control.

3.1 Control with sensors

This method is used in more demanding applications, where it is not only important how fast the motor spins, but also the precise position of the motor shaft is required. For this purpose are used sensors utilizing measurement of non-electric quantity, such as optic, magnetic or ultrasound signal properties. Currently, mainly used are magnetic Hall sensors.

The sensing is accomplished by three Hall sensors with 120° spacing (considering a three phase motor). Based on the magnetic field generated by the rotor magnets, the sensors are sensing positive or negative magnetic field pole and positive or negative voltage is generated. The disadvantage of this method is that there has to be space for the Hall sensors placement and precise spacing among them. This often causes higher price. The inaccurate placement results into the bad shaft position sensing and less efficient electronic commutation [2].

Position sensors are increasing the price and dimensions of the BLDC motor, they are often sensitive to temperature, what makes them suitable only for operation under 75°C. Also, with more components used, the question of reliability comes. This is why sensorless control is more widespread.

Generally, the ESC has the three phase output and uses a six-step commutation (Figure 1). An interval for each phase (A,B,C) is 120 electrical degrees. The commutation sequence is often AB-AC-BC-BA-CA-CB. Each implementation of the phase is stated as one step. To achieve maximal torque, commutation should take place each 60 electrical degrees, so the current is in the phase with the back electromagnetic force (BEMF). The commutation interval is designated by the rotor shaft position sensed by the Hall sensors. Concluding, controlling with sensors has these main disadvantages [2][3]:

- Position sensors increase system complexity.
- Extra connections to the ESC are needed, possible sensitivity to interference.
- Harsh environments with higher temperatures, large pressure deviations or increased humidity are causing the sensors to work with decreased sensitivity, accuracy and reliability.
- High precision in sensors placement is demanded.

3.2 Sensorless control

In many cases the sensorless control method is preferred – less space, higher reliability. With this method is the motor shaft position detected by evaluation of BEMF. Induced voltage is sensed on the wire that is not used in the commutation (when AB are switched on, C is the source of the sensed signal). This induced voltage is known as the BEMF and its magnitude contains information about motor shaft position.

During one revolution (360°) there are six zero crossings of trapezoidal BEMF signal (Figure 2). In the right angle ESC provides commutation. The most suitable time for commutation is 30° after the zero crossing. This is known as motor advance and it is the correct moment of commutation in sensorless BLDC motor control [2][3][4].

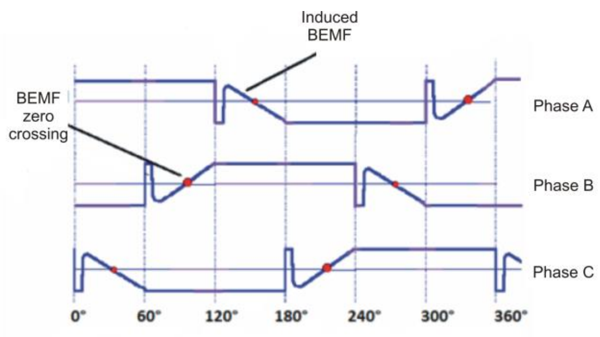

Figure 2. Signals on motor phases with marked BEMF.

4 HARDWARE REALIZATION OF SYSTEM

For measurement and data acquisition from the motor and propeller measurement stand it is necessary to acquire various parameters such as revolutions per minute, electrical current and voltage, propeller thrust and also torque on the propeller shaft. Construction has to meet qualitative attributes like stability, robustness, relatively small dimensions and weight. For this purpose it is necessary to correctly choose the sensors to achieve correct results and provide good optimization of the propulsion system. In Figure 3 is shown photography of the stand with removed aerodynamic casing. Figure 4 shows block diagram of the measurement system.

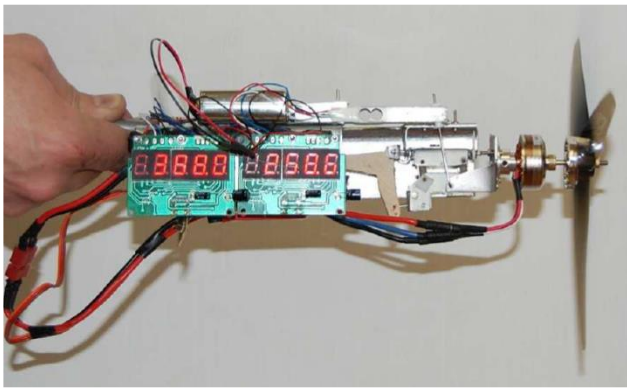

Figure 3. Photography of constructed device.

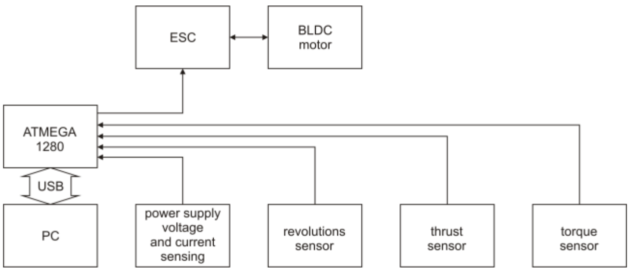

Figure 4. Block diagram of the measurement system.

4.1 Thrust and torque measurement

For the thrust and torque measurement were used two tensometers implemented in the construction in such manner that by their stretching and twisting it is possible to measure state parameters during increase or decrease of revolutions.

The tensometer output is in order of μV and it has to be amplified to achieve correct processing with the ATMEGA 1280 microcontroller. For this purpose were used precise bridge amplifiers from Linear Technology LTC1250. These amplifiers are recommended for use in tensometry also for their low noise. Since we have to make the measurement more precise for different small motors categories, there were chosen three measurement ranges as it is shown in Table 1 that are set by the jumper switch on the printed circuit board.

Table 1. Range selection parameters

Selection	Resistance (Ω)	Sensitivity (mV/g)	Maximal thrust (g)
1.	180	6.5	520
2.	300	3.65	950
3.	500	1.4	2500

4.2 Revolutions measurement

Important factor that has to be measured for correct regulation of propulsion unit of small UAV and following evaluation of performance and efficiency are motor revolutions. Since the BLDC motors used on these small UAVs are in the outrunner configuration, the rotor casing area can be used for generation of impulses originating from the reflection signal that is sensed by a photodiode. A small paper strip with changing light and dark areas pattern placed on the casing was used. In this way it is simple to use different motors diameters, only the ratio between dark and light area has to remain constant. Since black and white colors have a different reflection signal magnitude, by evaluation of these transitions it is possible to precisely measure the revolutions. For this purpose was used TCRT5000 sensor from Vishay Semiconductors. It is a one channel reflective sensor with the 950 nm infrared radiation source and a daylight blocking filter on the sensing photodiode. This sensor has a two-gate configuration with the 60 mA maximal forward current.

The sensor output is filtered by a RC low pass filter, which suppresses noise and its values can be changed depending on the motor type. Signal is then fed into the comparator and transformed into a digital signal with TTL standard. This signal is processed with the ATMEGA 1280 microcontroller.

4.3 Voltage and current measurement

For measurement of electrical current flowing into the ESC (often from a Li-Pol accumulator) the ACS758 Hall sensor made by Allegro was implemented. This sensor is capable of measurement both, DC and AC and has very good linearity. This sensor provides high stability during the voltage changes originating from random fluctuations of the ambient electrical field, so the output voltage has small ripple and low additive error. The internal resistance is 100 $\mu\Omega$ what makes it suitable also for high current measurements that are often needed on small UAVs. Generated voltage from the sensor is fed into the 10-bit A/D converter implemented in ATMEGA 1280. This A/D convertor also measures the power supply voltage through a voltage divider to keep the power supply voltage in the measurement range of the converter. The signals are smoothed with 100 μF capacitor.

4.4. Data processing with ATMEGA 1280

For development of software for the 8-bit ATMEGA 1280 microcontroller was used Arduino IDE and Wiring programming language that is very similar to the C programming language. This microcontroller has 10-bit A/D converters, 16-bit timers and pulse width modulation outputs to control the servomotors or ESCs. For communication with PC can be used FTDI chip and USB port.

Measured analogue and digital values are processed into the data of revolutions, current, voltage, power consumption, torque and thrust in the microcontroller and then sent into the PC via the USB bus. The program in the beginning initializes connected peripheries and sets input and output pins, zeroes initial values where necessary and reads in EEPROM stored computation constants. For more precise measurements, the analog values (voltage, current, torque, thrust) are averaged through 100 samples. Revolutions digital signal measurement takes time also during this interval with programmed interrupts on timers.

The acquisition program in PC was developed in C programming language and Code::Blocks IDE. Its purpose is an automation of the whole measurement process. This program not only collects data, but it also presents actual values, stores it in a file on the HDD and controls the measurement process.

5 INITIAL TESTS

For testing purpose a small BLDC motor c2830-21 with 1 % PWM increment from zero to maximal value was used. Acquired data were presented on the monitor during the measurement. In following Figures 5, 6 and 7 are presented some of the measured parameters that were evaluated in two cases:

- No load (black color).
- Two blade slow fly 7x4.5” propeller (red color).

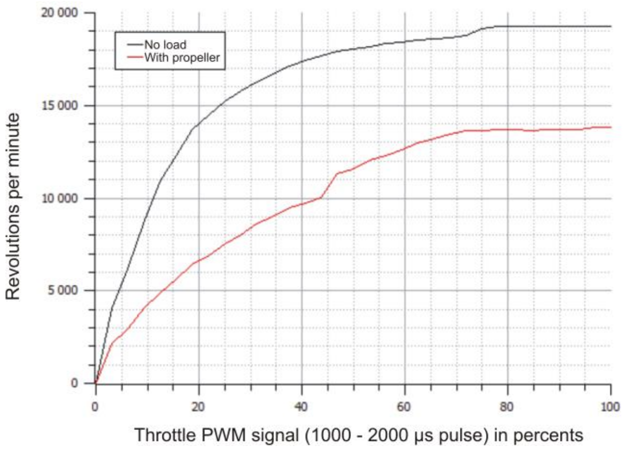

Figure 5. Revolutions measurement test.

Following graphs shows the electrical current and voltage values that met the theoretical predictions. With no load, the current quickly settles at 1 A, with a propeller load it reached maximum of 9.7 A.

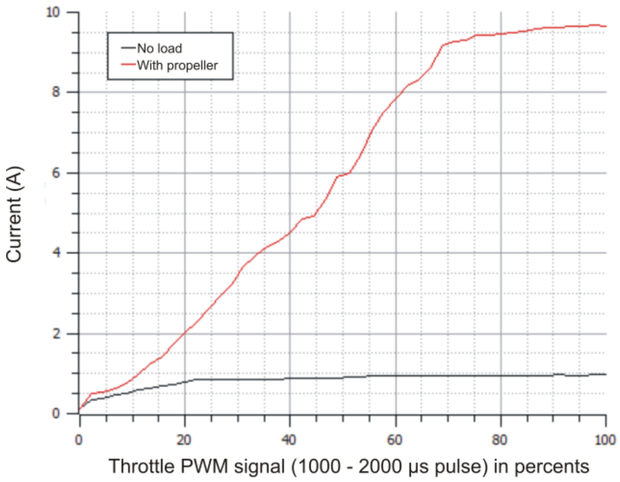

Figure 6. Current measurement test.

For powering of the motor was used Li-Pol battery as a generally used power supply on board the small UAVs. As it can be seen from Figure 6, it was not a top class battery since noticeable output voltage drop occurred.

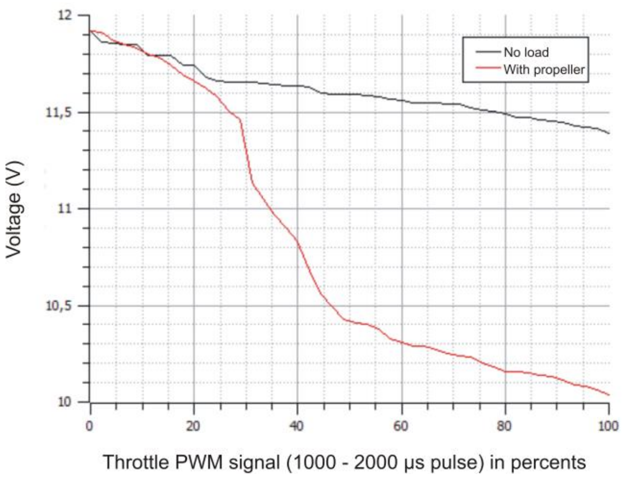

Figure 7. Voltage measurement test.

5 CONCLUSION

The developed measurement propeller stand is a relatively simple device and can be used with the aerodynamic tunnel at the Faculty of Aeronautics. The system provides automated measurements of revolutions, power consumption, thrust and torque and therefore helps to optimize the electrical propulsion system of small UAVs. Initial tests confirmed the proper operation of the measurement system.

In the nearest future component optimization and tests in the mentioned aerodynamic tunnel is planned. This system will be used for creation of the measurement results database and through the internet it will be accessible to everybody working in the area of small UAVs.

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