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Measurement of Torque Moment of Aircraft Electric Drive Unit

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Abstract. Aircraft Propeller Testing Laboratory of VZLÚ Praha-Letňany has taken part in a project called „EPOS" – the development of an electric drive unit for small airplanes, with power up to 60 kW. The article describes preliminary phases of power testing of the complete propulsive unit in its first design modification on a ground test stand. The torque moment was measured using a special shaft element equipped with strain-gages.

Introduction

The global objective of the EPOS project – acronym for „Electric POwered Small aircraft" – is development of the electric power unit (EPU) for a small two-seater aircraft and its flight verification. The leader of this project is the company EVEKTOR, very famous producer of ultralight and very light aeroplanes.

Of course, the idea of electric driven flying is not unprecedented – some electric powered aircrafts already exist in Czech republic even, but they are most often characterized by special design similar to gliders, with respect to achieve very small drag, and they are usually one-seat only. Our project is tasked to verify possibilities of nativity of such EPU that would yielded propulsion for typical, nowadays already existing sports aeroplanes. Therefore performance characteristics of the EPU must be comparable with the combustion engine Rotax 912 which is widely used in ultralight category aircrafts now. The flight time with the EPU installed in the aircraft of Evektor´s EuroStar/SportStar series with the standardly defined accumulator unit is supposed to be 1 hour.

The project is aimed at implementation of the whole cycle beginning from definition of power system components, through construction of functional prototypes of the power unit up to its verification, by installing it in a modified, already existing aircraft and verification in flight. The output should be therefore a completely tested power system. The EPU consists of the BLDC type electromotor by the company ROTEX Electric, system of electronic control unit by MGM compro company, the controlling system in cocpit and the system of accumulators with their management system. The propeller is designed by VZLÚ and namely the Aircraft Propeller Testing Laboratory also cooperated during testing and performed some special measurement.

Very small dimensions of used brush-less DC electromotor RE X90-7 with "out-runner" conception can be viewed in Fig. 1, its weight is about 17 kg. The power of the first developing modification of the motor was expected between 40 – 50 kW. The diameter of the three-bladed propeller is 1.625 m.

Experimental evaluation of power

At the beginning phase of the EPOS project was resolved that the electromotor will not be tested separate on some special dynamometer brake for many reasons and the assessment of power characteristics will be performed with complete propulsion unit, i.e. the motor with the propeller. VZLÚ disposes of a special stand, intended for propeller ground testing, usually equipped with a piston engine of Rotax 912 series. So it was adapted for the electric motor and its equipment.

The adjustable propeller was used as a brake. The main task was to establish power-speed characteristic curves of the electromotor, whole drive unit respectively, that is why a set of short „full-power“ runs with different settings of propeller-blade angle was realized. The next phase was execution of long-running tests of the EPU in order to observation of temperature changes on important parts.

Fig. 1. The first run of the EPU mounted on the VZLÚ ground testing stand, at that time still without the measuring shaft element.

Measuring chain and devices

The experimental verification of the electromotor power was realized in a way of the measurement of transmitted torque moment on the shaft, namely by using of a special element (mounted between the engine shaft and the propeller hub). It was equipped with strain gauges which read out its torsional deformation. The strain gauges, RY81-3/350 (rosette) type produced by the company HBM, were mounted on the shaft element, but only those at angles of ±45° to the longitudinal axis of the shaft were used for purpose of torsion measurement in typical configuration of full bridge circuit. It is expected that this wiring is able to compensate relative changes of temperature caused by air-flowing during shaft rotation and keep the fixed „zero". It is also supposed that this wiring of the gauges compensates a tension loading (by propeller thrust) or relevant bending of the shaft.

Fig. 2. Special shaft element equipped with strain gauges.

The key part of the measuring chain is a device for transmission of measured signals from the rotating part to a base. We use a wire-less telemetric Kraus MT-32 system which transmits the data on frequency 433 MHz using PCM modulation (high noise immunity). The KMT modules on the rotating part (i.e. bridge amplifiers and the transmitter) are usually assembled on a disk platform for our typical measurement of propellers (Fig. 3), but a specific mounting to another just measured structure must be very often designed and manufactured.

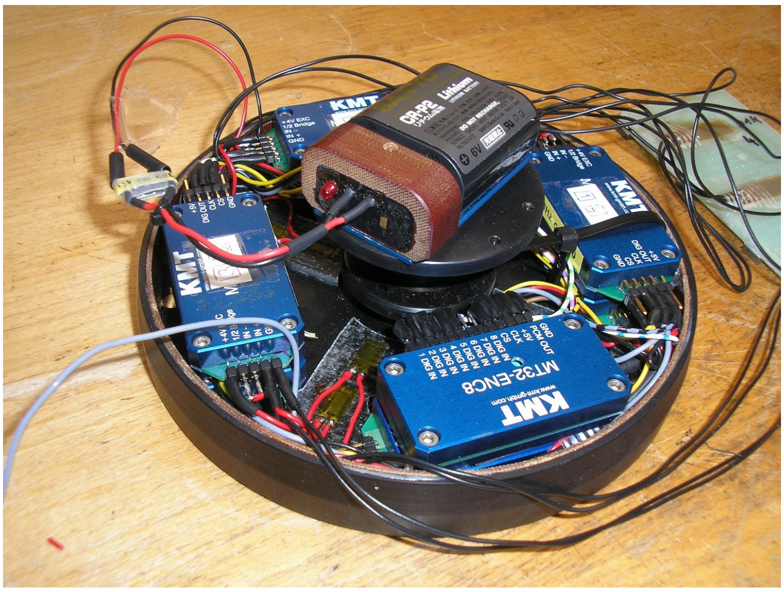

Fig. 3. Modular conception of the Kraus MT-32 system.

The measured signal was led from the Kraus system receiver into a DAQ device based on a digital tape-recorder TEAC GX-1, where all signals (in addition from accelerometers and an inductive sensor) were sampled at frequency of 10 kHz. Data was consequently stored on hard-disk of a Dewetron 2010 computer which was also used for control the GX-1.

Calibration of whole measuring chain was performed in our laboratory using static loading of the shaft element, directly in sensitivity of „voltage – torque moment“, for current setting of the bridge amplifier and wiring configuration. The rotational speed for calculation of the engine power (1) was measured using the inductive sensor A-B/Rockwell DH4NP12 .

$$P = 2 \,.\, \pi \,.\, n \,.\, M_k \tag{1}$$

For data evaluations we use software applications built on LabVIEW platform.

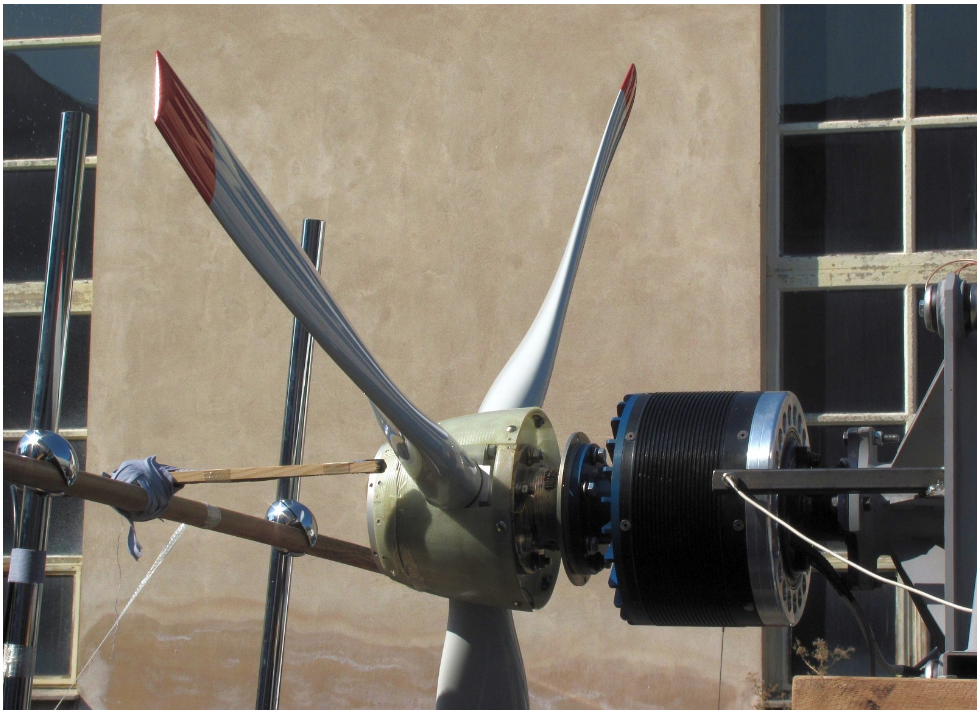

Fig. 4. Measuring shaft element installed between motor shaft and propeller hub, antennas of wire-less transmission of signal and on the right sensor for reading the value of rotational speed.

Measurement

Measuring of EPU characteristics was realized with 6 different settings of propeller-blade angle, each usually consisted of two runs. The EPU was relatively quickly accelerated to "full throttle" regime, it means the width of the voltage pulses generated by the control based on PWM regulation was maximal. The principle of testing and power measuring is demonstrated in Fig. 5: The propeller absorbs due to its aerodynamic drag certain amount of supplied torque moment for given rotational speed (see propeller curves). For a BLDC type electromotor the moment-speed characteristic is most often supposed linear, with an area of intermittent zone above the value of rated torque [1]. But other influences are also important – the design of the electromotor characterized by speed constant K_V [RPM/V], the way of electronic controlling of the motor, etc. The propeller has its limits too – in the case of heavy-duty regimes with high angle of blades a stall-flutter can occur.

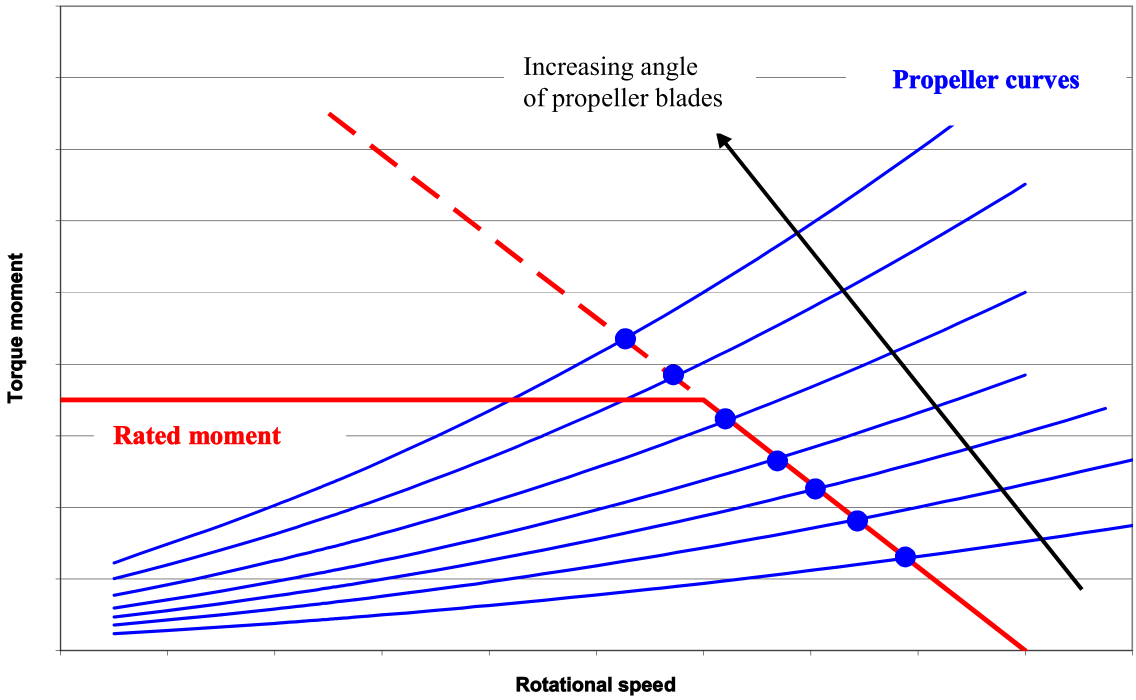

Fig. 5. Principle of testing and evaluation of EPU moment-speed characteristics.

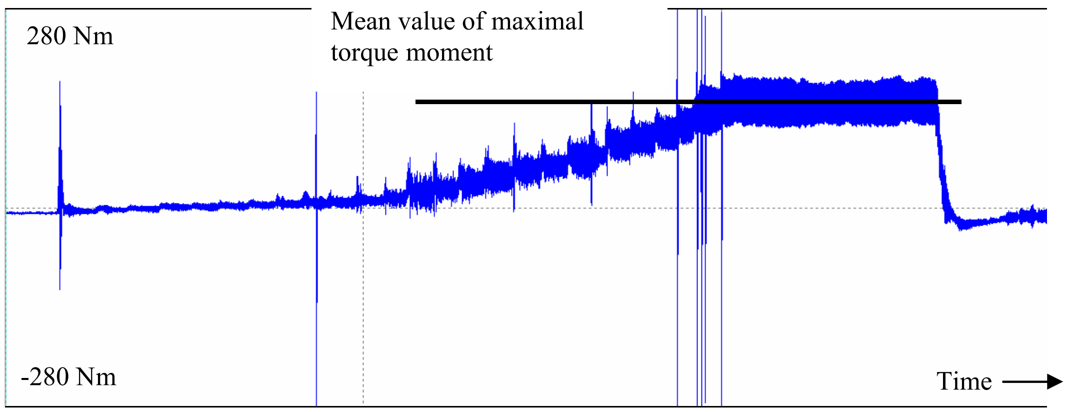

Fig. 6. Example of measuring of maximal torque moment during one test run – propeller blades are set at angle of 15 deg.

In some cases of testing the acceleration was long-running, for purpose of evaluation of dynamic behavior in whole rotational speed range. Likewise long runs in maximal regimes were performed and a stability of the control system was observed.

Vibrations of the stand were also continually measured. There was no resonance in assumed operating speed regimes. It was the positive information for designers although dynamic behavior of the EPU mounted on the aircraft can be somewhat different.

The temperature loading of the electromotor and its power control system was also observed during testing of the EPU. We used a thermovision technique especially for monitoring of the rotating outer shell of the motor (Fig. 7).

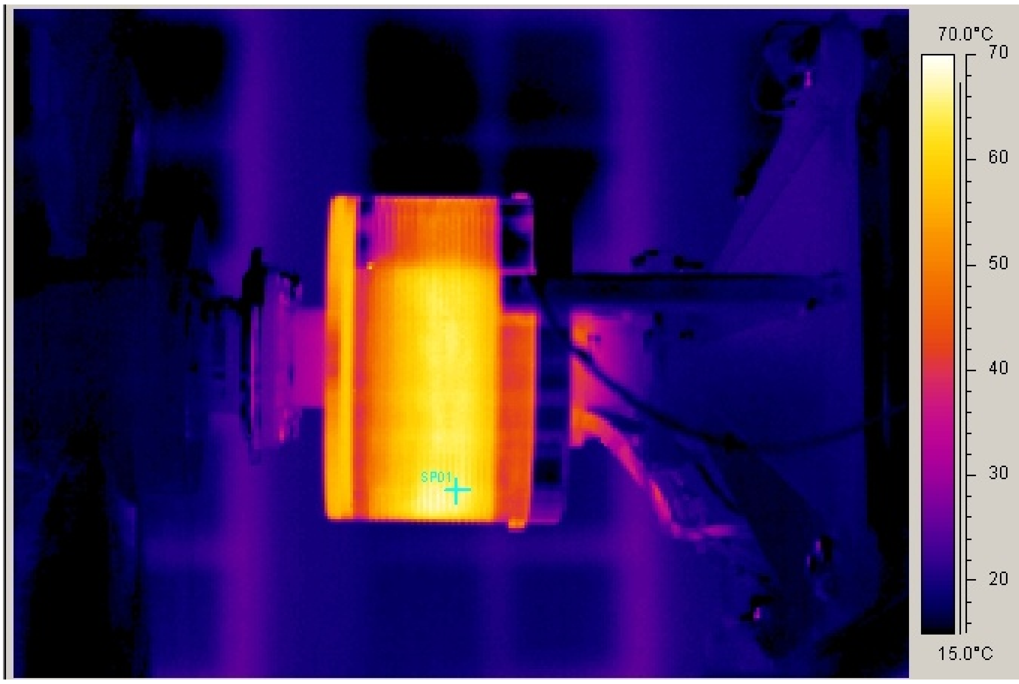

Fig. 7. Survey of the EPU with a thermocamera.

Results

Speed characteristics of the EPU in its first design modification are illustrated in Fig. 8 and 9. It is evident that measured data of the torque moment are formed in assumed linear relation, only in very high-duty condition the control system tried to keep a rated rotational speed. This data was very much important for progressive development of the electromotor and for the first estimation of flying performances.

Torque vibrations are relatively small, in comparison with a piston engine [2]. The amplitudes of torque oscillation are usually not higher than 20 % of the mean value of transmitted torque moment (Fig. 6). But these results are not generic, we have to remember that with using of the relative flexible shaft element we changed the torsional dynamic system „motor – propeller“.

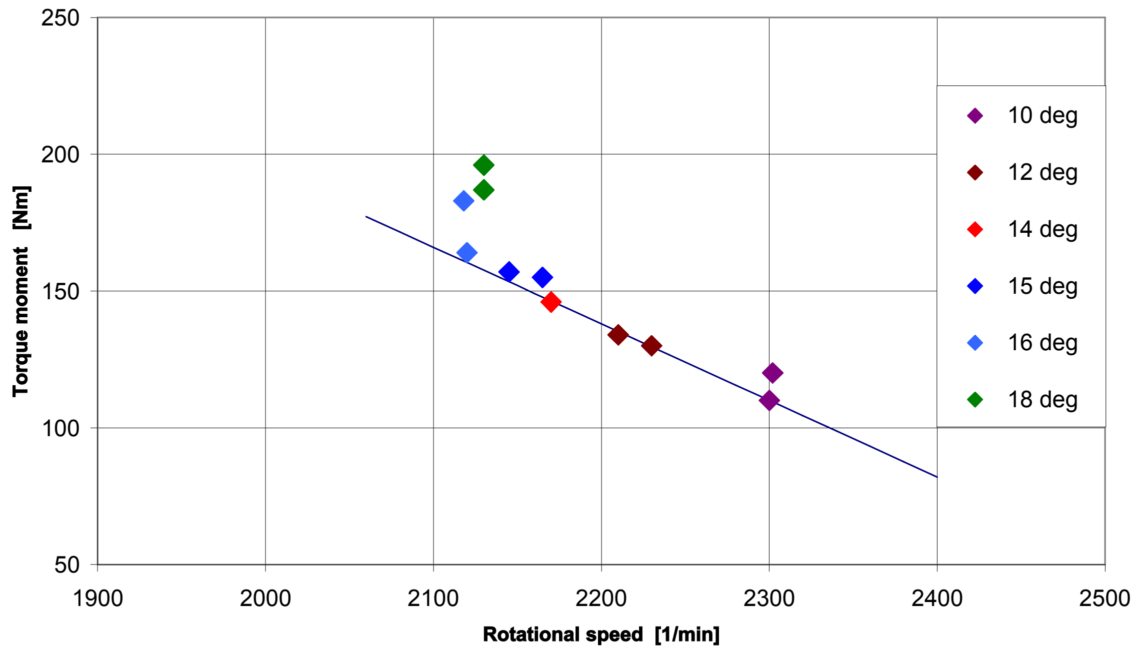

Fig. 8. Torque-speed characteristic of the EPU.

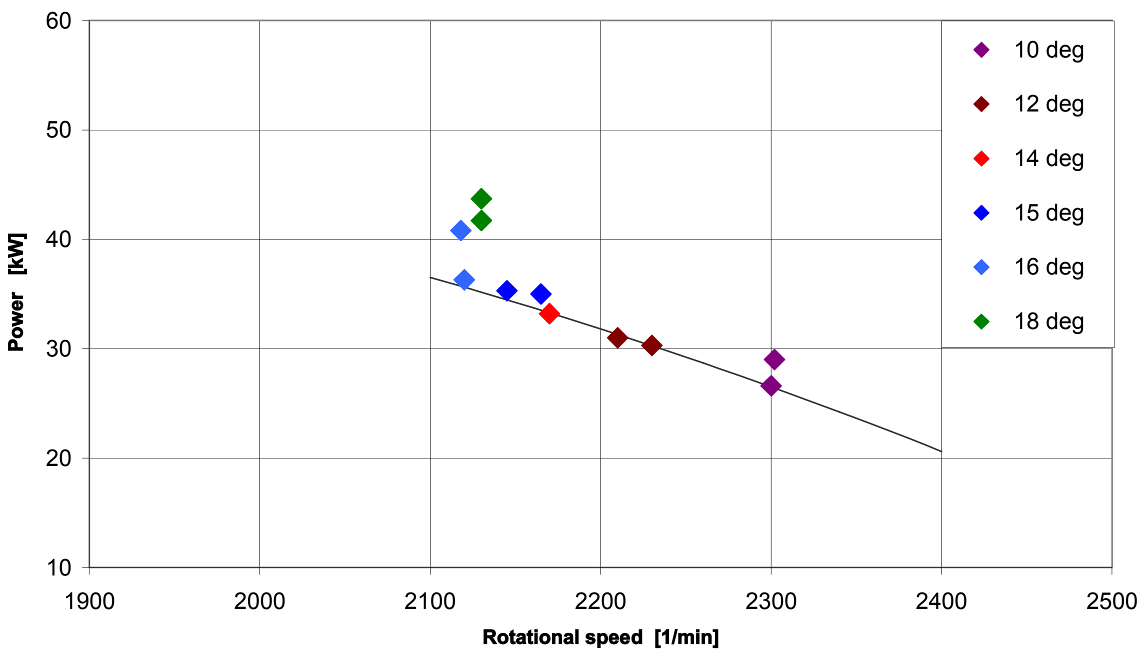

Fig. 9. Power-speed characteristic of the EPU.

Conclusion

The paper presents a relatively standard measurement of the torque moment on a motor shaft. But the application of new (on principle) power unit designed for aircrafts has made this measurement unique. The tests were performed in autumn 2012, with the first version of the electromotor. Naturally, some changes had to be implemented to the EPU on the basis of achieved ground-test results and the power has been increased. The maiden flight of the SportStar EPOS aeroplane was realized from the Kunovice airport on March 28, 2013.

The SportStar can be equipped with two pairs of containers each housing 45 lithium polymer cells. Since the plane is fully electric, no fossil fuels or motor oil are needed. Without combustion, the aircraft is also much quieter for both crew members and populations lying below its path. Evektor's site [3] claims that the operation costs of the SportStar are much lower, especially with the fuel being 75 % less expensive. The fewer number of the components in the compact power also help to drive down the maintenance bill.

Fig. 10. SportStar EPOS aircraft – one of the first testing flight. Photo by Evektor.

Acknowledgements

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