STAND FOR ELECTRIC MEASUREMENT OF SMALL PROPELLER POWER UNIT PERFORMANCE IN WIND TUNNEL

Peter Gašparovič – Michal Maťaš

The paper describes the design process of the low cost stand for measurement of small power units consisting of an electric motor and propeller. The design is based on the characteristics of the propeller, qualified estimate of the thrust and torque, electric method of the force measurements and commercially available components. The design is verified by the measurements in a wind tunnel on a typical model propeller and demonstrates that the employed design is suitable for the building of the cheap measuring stand for measurement of model propellers.
K e y w o r d s: propeller, measurement, tunnel balances, propeller performances

1 INTRODUCTION

The measurement of propeller requires complex equipment, therefore the performances of model propellers are usually not known. Neglecting the viscosity and compressibility of the air, the propeller performances depend on rotational speed and axial velocity. Therefore, to acquire the propeller performances, it doesn’t suffice only to measure the thrust and torque. It demands to keep the axial velocity and rotational speed under control. The control of the rotational speed can be substituted by its precise measurement. Control of the axial velocity can be achieved by experimenting in a wind tunnel, or in real flight. The first method is simpler, but it requires expensive wind tunnel. Manufacturers of model propellers don't have required equipment for measuring of their performances, therefore we had to devise our own equipment, solving the same task as they solved at University of defence in Brno [1].

1.1 Definition of propeller

To keep the airplane in steady level flight it needs the driving force to compensate aerodynamic drag. The driving force – the thrust – can be provided by a propeller power unit. The propeller is that part of the power unit, which absorbs mechanical energy on the shaft, and develops the thrust. The propeller of the airplane is bladed machine working in the air. The propeller creates the thrust by reaction with its environment, where the air is given change of momentum in opposite direction to the direction of the thrust on blades of the propeller.

The blades are based on the same working principle as the wing of airplane, but the details and dependences are more complicated, therefore the performances of the propeller are not so easily computable as the performances of the wing.

The word propeller is derived from the Latin word for driving. The device has another name – airscrew. In principle, the word airscrew denotes the machine, whose shape resembles screw, which is moving in air. The propeller doesn’t need to have the screw shape, like the airplane’s propeller does have, and similarly, the airscrew doesn’t need to function for driving the movement, like the airplane’s airscrew does. The example of other airscrews, besides airplane propeller, are: wind turbine, ventilation fan, boat propeller, helicopter rotor.

1.2 Aerodynamic performances of propeller

Geometrically similar propellers have similar aerodynamic performances. Similarity of aerodynamic performances is evident, when they are expressed in dimensionless form. This makes it possible to eliminate differences in the working conditions of geometrically similar propellers with different size. Diversity of conditions is caused by different circumferential speed and axial velocity. Dimensionless variables are criteria of similarity themselves.

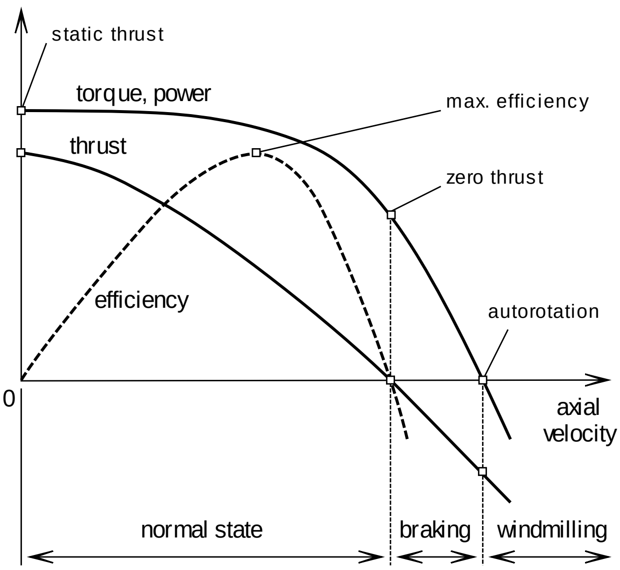

Figure 1. Aerodynamic performance of propeller

The working condition (working state) of the propeller depends on two independent variables – axial velocity and rotational speed. The rotational speed is usually kept constant (as a parameter) to simplify presentation of performances in 2D graph through individual performance curve for each rotational speed. The working state is uniquely described by two dependent variables, usually selected from the variables of thrust, torque, power, performance, or their non-dimensional form. Remaining dependent variables are easily derived from independent variables and two selected dependent variables. For example, the performance P is derived from torque Q and angular speed Ω by simple relation:

$$P = Q \cdot \Omega$$

The efficiency of propeller is defined by the ratio of the useful power (propulsion of the thrust T at axial speed v) and absorbed power P. This is called *propulsive efficiency*:

$$\eta = \frac{T \cdot v}{P}$$

The situation becomes more complicated when the propeller has variable pitch angle of blades. Such propeller actually represents infinite number of propellers with fixed geometry which differ only in one parameter – the blade angle. Such group of fixed propellers is called a family of propellers. Therefore the performance curves of variable pitch propeller consist of individual performance curves of propeller family. Blade angle (pitch) is measured on control radius.

1.3 Strain gauge measurment of forces

Elastic properties of deformation element are affected by its geometry and material. Deformation elements are classified into three groups [5]:

1. tensile or compressive elements,
2. shear elements,
3. bending elements.

The geometry of deformation element and location of strain gauges is chosen by a way which eliminates sensing of unwanted deformations. For example, the cantilever element for sensing of the normal force contains four strain gauges, which are wired in Wheatstone bridge in such way, that the axial tensile deformation and the bending deformation of cantilever beam at sensor locations are mutually eliminated.

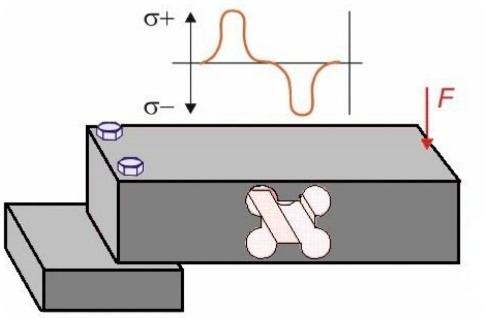

Figure 2. Cantilever deformation element for sensing of the normal force [5]

2 DESIGN OF STAND STRUCTURE

Various schemes of a mechanical structure were considered. The main objectives were simplicity, a low hysteresis of the transfer of loads from the propeller to the deformation element, the mutual independence of the thrust and the torque and insensitivity of measurements to normal force of the propeller.

Consideration resulted in simple sheet-metal structure with levers and low friction axes formed by thin wire. Even during the building of the stand, several detail were modified in order to lessen the dependence on crossflow and precise alignment of levers.

2.1 Choice of measuring element

In order to lower cost and shorten the development, it was decided that commercial off the shelf components will be used. Two commercial scales BEURER KS36 were used. This scale has two measuring ranges up to 2000g, and it has resolution of 5000 levels in both ranges. Included was precise 200g deadweight. Each scale contains one cantilever measuring element with four strain gauges. One element was used for measuring the thrust and second identical element was used for measuring the torque

Figure 3. Scale Beurer KS 36

2.2 Description and explanation of proposal

The main supporting structure is formed by U-frame. The overall dimensions of U-frame and the disposition of details were affected by assumed low cross-section shape which easily fits into the plastic 1.5-litre bottle. The most difficult was to estimate the proper dimension of the torque arm, because no trustworthy torque data of powerplants were available, unlike the torque data. The disposition of details is in the figure 4.

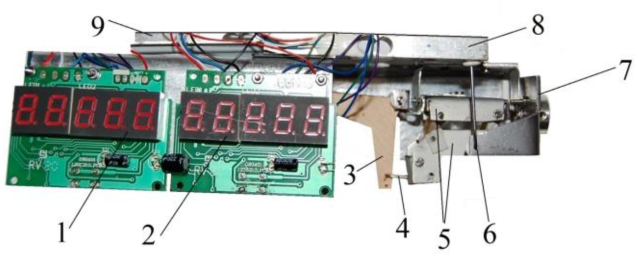

Figure 4. Details of stand

Description of items:
1 The thrust display
2 The torque display
3 L-lever
4 Horizontal link of the thrust
5 Cradle assembly
6 Vertical link of the torque
7 Powerplant support wall
8 The torque measuring cantilever
9 The thrust measuring cantilever

The key element of the stand is cradle assembly with a pantograph. The cradle permits to separate rotational motion due to the torque from the axial motion due to the thrust. Pantograph provides the independence of the measured thrust on precise location of the powerplant, i.e. it ensures that the thrust measurement element senses a force and not a moment. The arms of the pantograph revolve around thin 1.5mm axes with low friction. The low friction is important, because the stand should be able to measure forces as low as 10mN.

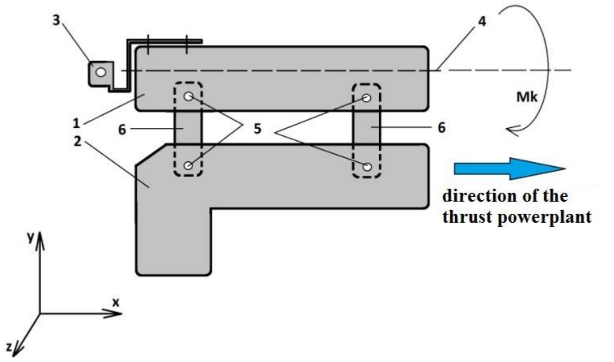

Figure 5. Cradle assembly with pantograph

The cradle assembly with pantograph are the mechanical components of the structure which ensure the transfer of the forces from powerplant. The transfer can be realized even without mechanical axes. Elastic arms could equally well substitute the rigid rotational parts – especially in the case of pantograph arms. However, rigid rotational parts are better suited for our coarse technology, because they permit more inaccuracy in relative alignment of individual parts, without causing excessive pretension loads in links and excessive offset of zero force reading. (We wanted to fully utilize the opportunity of the precise measurement in the low measuring range of the scales in the neighborhood of zero values.)

3 PRELIMINARY MEASURMENTS

Following the successful construction of the stand, we performed rudimentary check of the calibration of the stand. There were unusual and unexplainable readings in vertical position of the stand. However, in the horizontal position of the stand, where the position of the cantilever measuring elements was identical with the position in original device, the readings were in usual range, and the effects of dry friction were very acceptable.

We wanted to perform also preliminary measurement, before we set to calibrate and improve the details. Therefore, the complete stand including aerodynamic fairing, radio receiver, battery and engine speed control module was installed in the low speed wind tunnel of the Faculty of aeronautics of the Technical university in Kosice.

The axial speed was measured by inclined water manometer. We had no control over the rotational speed, because utilized engine speed control (ESC) didn't have regulator. We constrained our measurement to performance curves at two different inputs of ESC. The constant level of rotational speed was checked by run-up of the electric motor at prolonged period and zero axial velocity. The constant level of rotational speed was monitored indirectly through the thrust a torque readings. The curves of the measured thrust and torque are in figure 6 and figure 7.

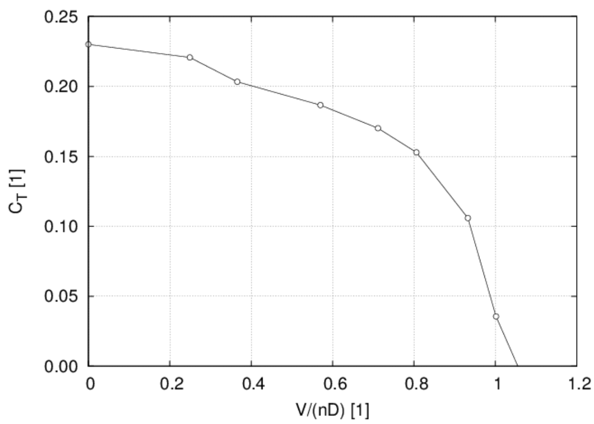

Figure 6. Measured thrust

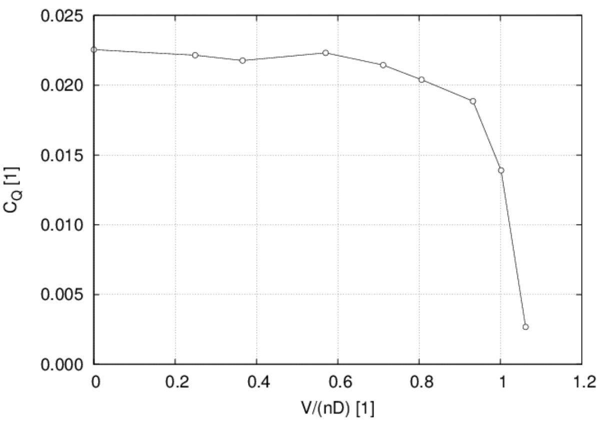

Figure 7. Measured torque

The shape of the curves is usual. Rotational speed was estimated to be 4000rpm, based on estimated efficiency 100%.

The second set of performance curves were measured at elevated rotational speed – approximately

5700rpm – at roughly two thirds of ESC input level. The measured curves were not so smooth, but the doubts about the precision of the measurement disappeared, when the values of the thrust and torque were transformed into the propulsive efficiency.

The propulsive efficiency curves at 4000rpm and 5700rpm are in figure 8 and figure 9. Both performance curves are smooth, only the latter curve exhibits sharply located area of lowered efficiency. Investigation of the possible cause of the lowered propulsive efficiency would require thorough testing, which can be performed later after finishing the stand.

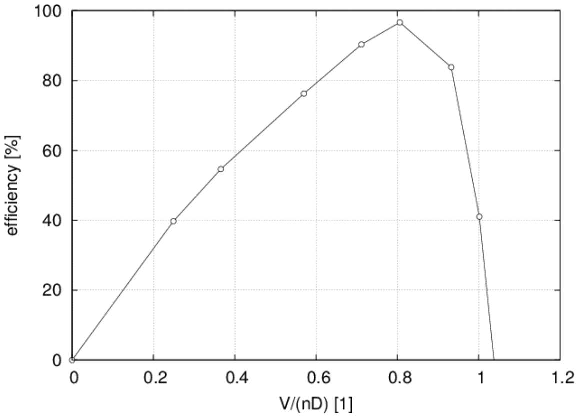

Figure 8. Measured propulsive efficiency

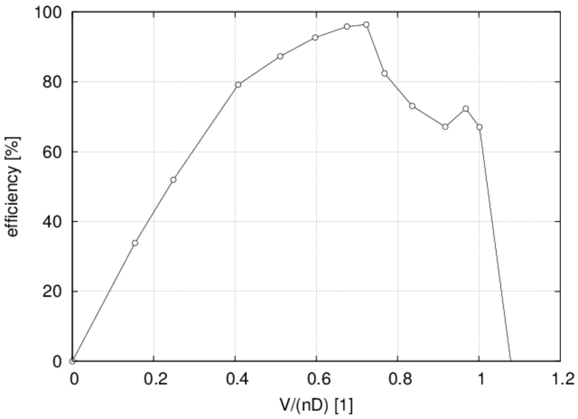

Figure 9. Measured propulsive efficiency at higher rotational speed

The static thrust at the higher rotational speed extrapolated to full power gives 4N, which roughly corresponds to the estimate of the manufacturer (~4.5N).

4 CONCLUSION

Preliminary measurements confirmed that the employed mechanical scheme of the stand and used commercial components are suitable for building a measuring device capable of precise measurements of model powerplants.

In order to make it usable for precise measurements of propellers and electric motors it needs to be equipped additional measurement – the measurement of the rotational speed, and optionally by a regulator of the electric motor speed.

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AUTHORS’ ADDRESSES

Gašparovič Peter, Ing., PhD.
Technical University of Košice
Faculty of Aeronautics
Rampová 7, 041 21 Košice
e-mail: peter.gasparovic@tuke.sk

Maťaš Michal, Bc.
Technical University of Košice
Faculty of Aeronautics
Rampová 7, 041 21 Košice