

# Testing of High Speed Milling Spindle

Ing. Josef Kekula

Supervisor: Doc. Ing. Jaroslav Rybín, CsC

## ***Abstract:***

The paper deals with the experimental measurements of power of milling spindle prototype with air-turbine drive by compressed air. An integral part is the measurement of these devices in terms of performance and torque, which brings major complications especially in this high levels of speed. For measurements was used special measuring stand which was build for this purpose. Spindle was measured in the whole speed range, and results were compared with commercial air spindle.

## ***Key words:***

*(High speed spindle, measuring of torque, micro-milling, eddy current brake, air turbine drive)*

## **1. Introduction:**

Manufacturing of small parts using technology of micromachining places demands on spindles. High revolution number is necessary for high speed cutting using small diameters tools if we want good results. Machining of small parts is required nowadays, especially in medical industry for machining tiny implants and in aerospace industry too. Commonly used spindles on producing machines are unsuitable for this technology. High speed additional spindles are good choice for improving this process. These devices increase level of cutting speed. Especially air-driven spindles are simpler and cheaper than spindles with electric motors. For the operation of these devices is needed just source of compressed air, filtration unit and eventually appropriate regulator for speed control of spindle.

Is very difficult to determine of performance of this equipment, given the high revolutions, which this spindle achieve. Due to the turbine drive is the only one way of verification of the power by artificial braking of the spindle and measuring of the torque. Equipment which would be able to measure of power in this levels of speed, is not available on the market. Hence was build eddy current brake for high speeds and special measuring stand for this purpose. This stand allowed the measuring of power for high speeds. Measured performance will help determine the energy consumption of micro tools for micro machining.

## **Description of spindle:**

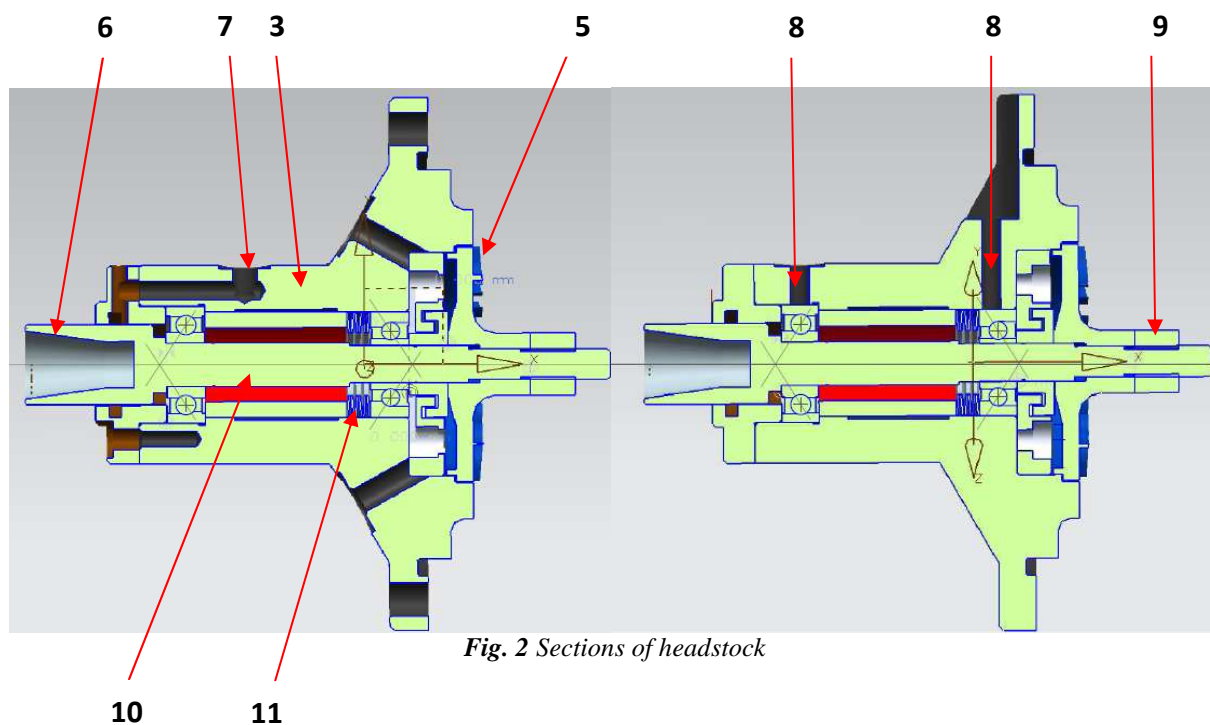
The spindle is composed of spindle stock (3), distributor (2) and a clamping cone (1) which allows the device clamped to the main spindle. For clamping the tool spindle is used interface ISO 40. In the spindle stock is imposed the shaft (10) in the hybrid ceramic ball bearings, with angular contact (12). Bearings are preload by spring washers (11). Lubrication is ensured by long life grease. To seal the bearing space is used pressurized system (7), which continues to fill the bearing space with filtered air and prevents dirt from the surroundings. The spindle is designed for milling tools with cylindrical shank diameters ranging from 1 to 7 mm. In the micro milling tools are now standard shank diameter of 3 mm and 4 mm. The front side of shaft is fitted with a hollow (6) for clamping tools with high precision collet in ER 11 size.

Spindle drive is performed using air turbine (5). This is a simple radial centripetal turbine.



**Fig. 1** Prototype of high speed milling spindle-left, assembly of spindle bearings- right

The turbine is driven by compressed air. The turbine is designed for standard industrial pressure distribution, which is on the value of 6 bars. The prototype of spindle is shown in Fig 1 and Fig 2 shown the cut of the headstock, showing its internal structure. Monitoring of speed is provide by the speed sensor which is located in distributor (4), which responds with nut (9) of the turbine. It is also sensing temperature of outer rings of bearings using temperature sensors located in the spindle stock shafts (8) for safe start-up and operation of the prototype. Monitoring the temperature in the start-up is very important, especially when the bearings are lubricated by grease. It is very important in order to allow distribution of grease deposits around the bearing. Temperature is an indicator of proper distribution of grease. Start-up was running well and the temperature of the outer ring of bearings didn't exceed 40°C.

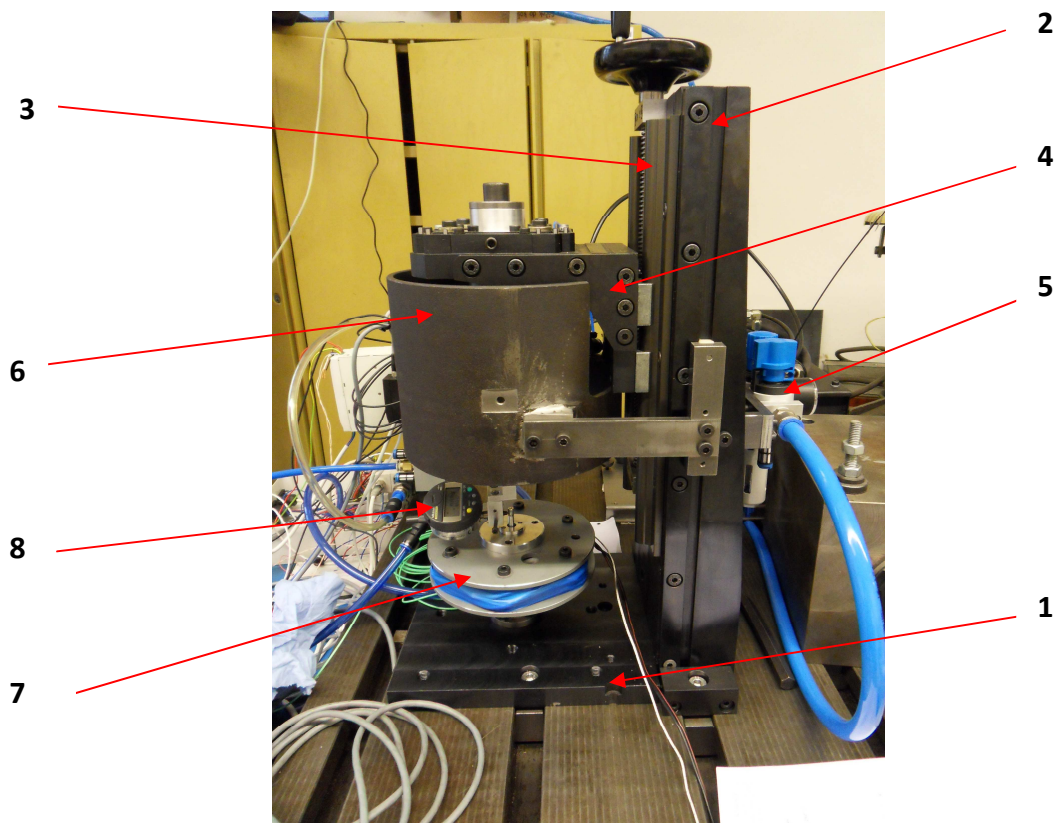


**Fig. 2** Sections of headstock

## 2. Measuring of power

### 2.1. Testing stand

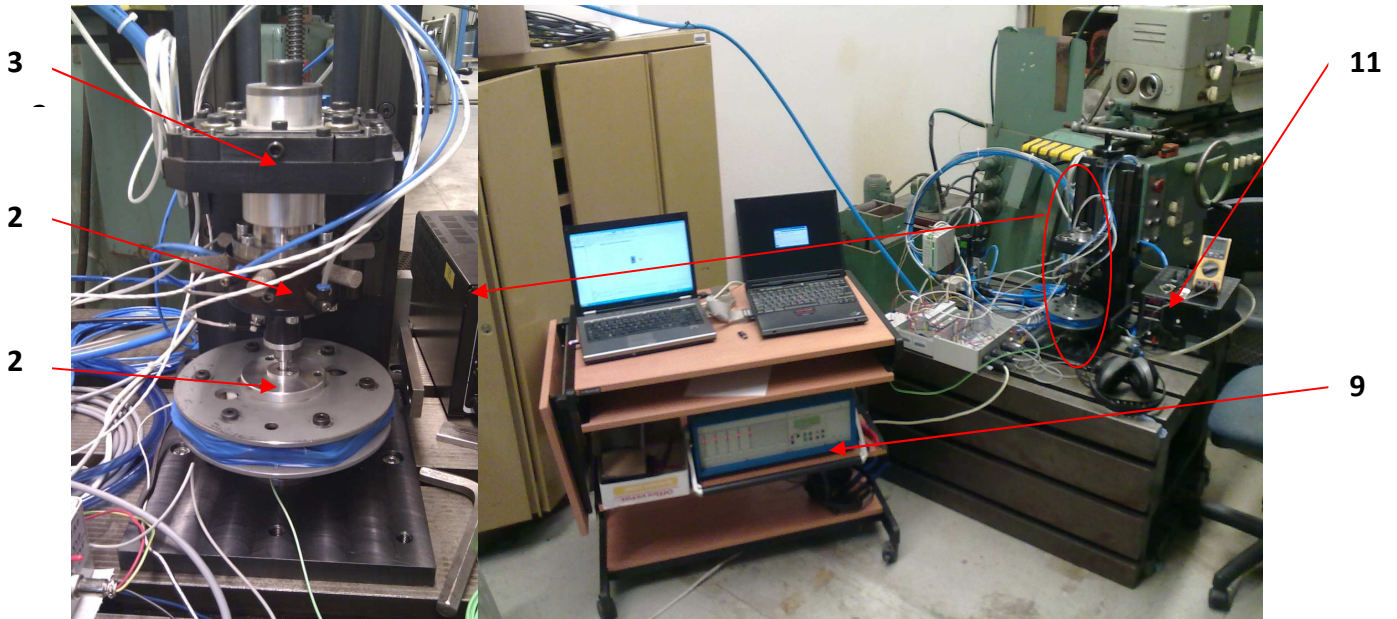
To measure the torque and power was build a special stand shown in (Fig. 3), for the measurement of these devices. It consists of a solid base (1) on which it is attached to the rigid flange (2). These components together form a rigid frame with guide rails (3), after which moves height adjustable console (4), which provides clamping of measured spindles. As a source of air is used the central system of the workshop, the air of this distribution is applied to the filter unit and the pressure regulator (5), the air is then fed into the servo-valve, which ensures speed regulation and then is fed into the spindle to enter the turbine. Operator safety is ensured by the rigid slide cover (6).



*Fig. 3 View of the test stand*

Examined spindle is clamped to the console (4). To measure the torque produced by the spindle, the spindle must be artificially burdened at high speeds. For this purpose, was designed electromagnetic eddy current brake (7). Shank of the brake disc is clamped in the spindle. Both rotating systems must be accurately centered. This is allowed by a centering mechanism on the console, then coaxiality this can be observed below the value of 0.01 mm. The value of coaxiality is measured by using a special equipment which is clamped in the spindle (8). After centering of the brake system with the spindle, is the stem clamped to the spindle collet. The brake is clamped to the base stand through torque sensor, which captures the torque reaction. This is a sensitive piezoelectric sensor viz. Fig 5 (7), which can measure the range of  $+ / - 1\text{nm}$  with the resolution  $0.01\text{ N.cm}$ . For measuring with this sensor is needed electric charge amplifier (9), which converts the electric charge to electrical voltage. This can be then processed by the A / D card in a PC.

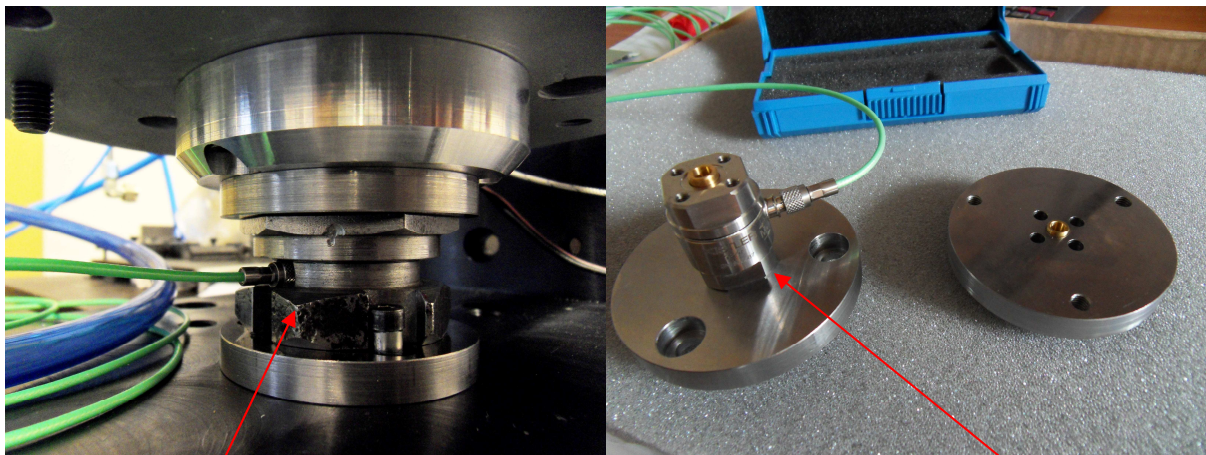




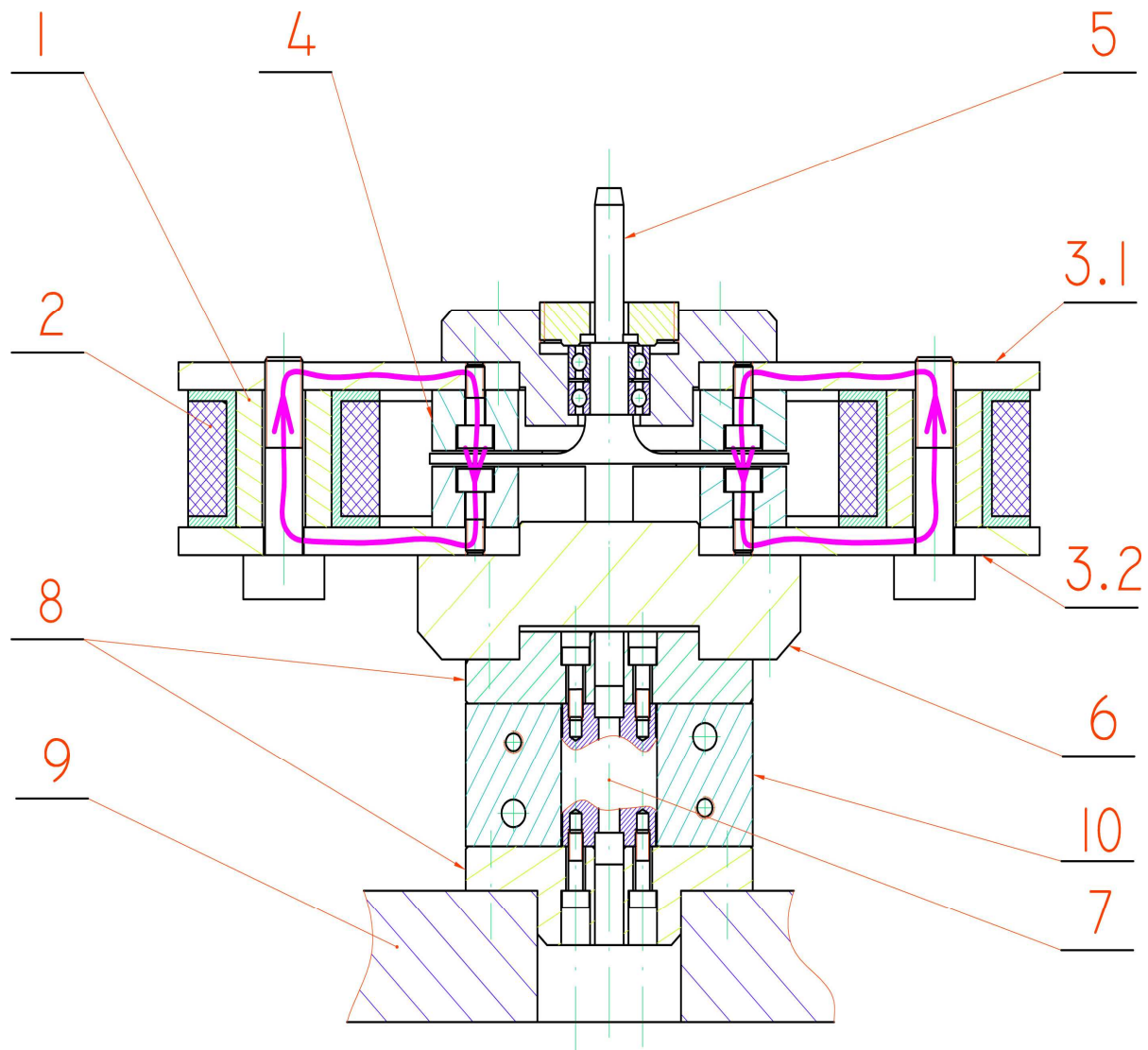
*Fig. 4 View of the complete test stand*

## 2.2 Eddy current brake

Cut of the brake is shown in Fig 6. Spindle is clamped to the shaft of the rotor (5). The disc rotor is made from non-magnetic material and rotate in a gap between the poles (4), through the gap closes a magnetic circuit which is held by the frame of brake (3). Magnetic flux is invoked to the passage of DC current by six winding coils (2), with steel core (1). Supply voltage is regulated in the range from 0 to 30V DC power source (11). The body of the brake is connected through an insulator (6) to sensors flanges (8). Through this flanges is the brake attached to the base stand (9). Adjustable spacer (10) is used to protect the sensor when the measurement is carried out. Torque sensor generates an electrical charge in the load, which is then amplified by the central amplifier and converted to a voltage signal that is suitable for further processing. Measuring range is  $\pm 1$  Nm, maximal resolution is 0.01 Ncm, sensitivity is 2190 pC / Nm. It is also checked temperature of coil of the brake, by measuring the coil temperature, during the measuring is heated up to about 50 ° C.



*Fig. 5 Piezoelectric sensor of torque –right, built-in the brake - left*

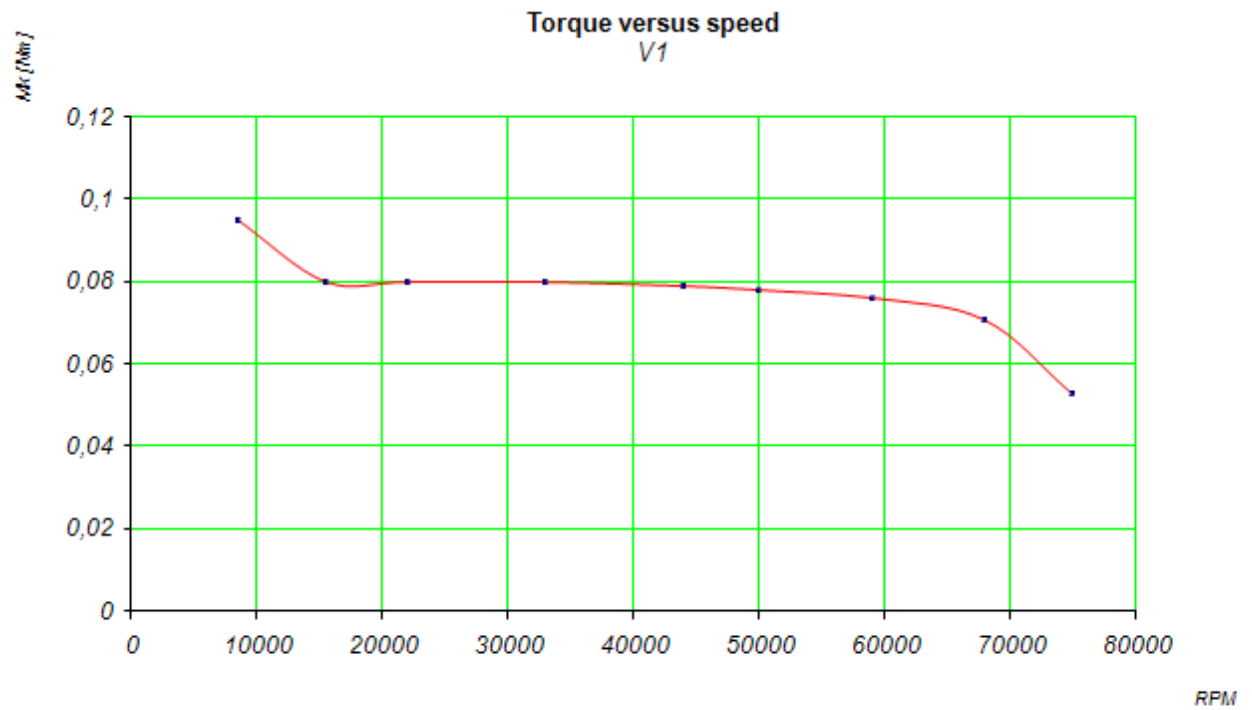


*Fig. 6 Section of eddy current brake*

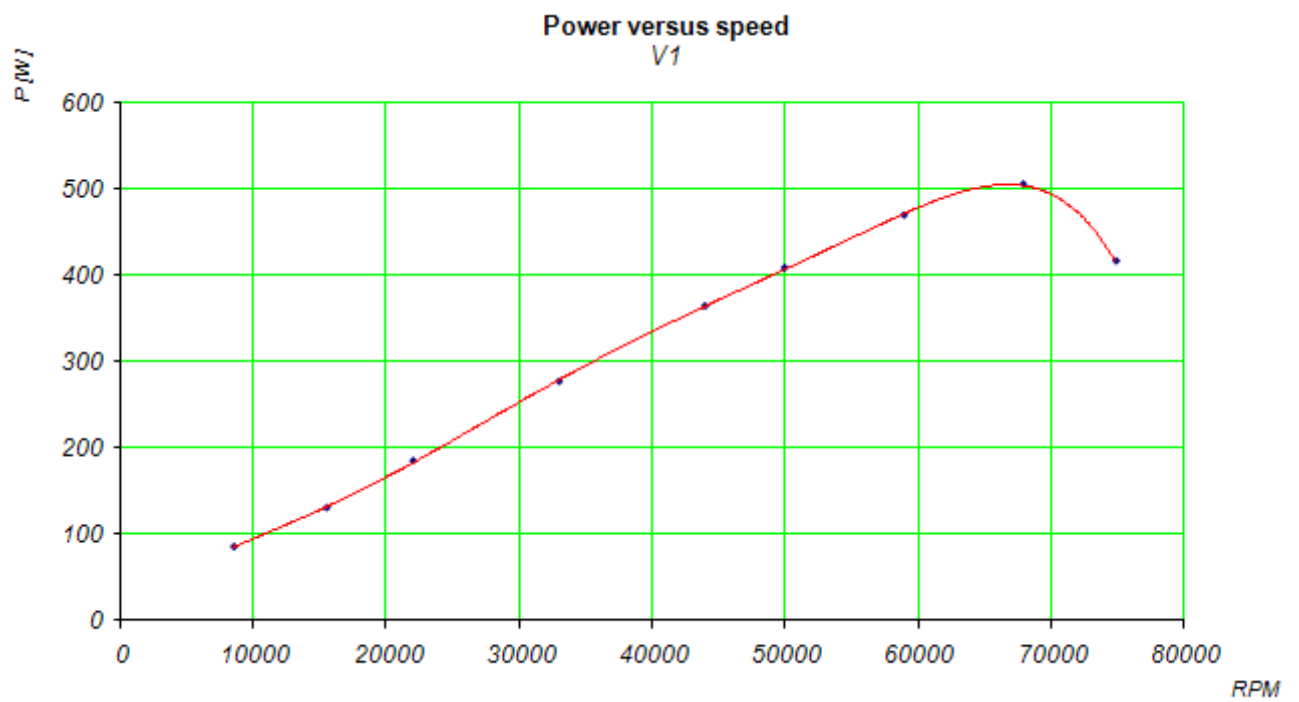
### 3. Measurement and results

For comparison of the results was measured also Deuschle air-spindle from the German manufacturer. Prototype of V1 spindle was designed for  $80 \cdot 10^3$  RPM rated speed at which would act torque 0.061 Nm, thus designed drive power is about 500 W. For the spindle from German manufacturer is given only a maximum level of speed:  $70 \cdot 10^3$  RPM, torque or power the manufacturer doesn't specify. Progressions of the torque versus speed are shown in the following charts for each examined spindle. In the next is shown the progressions of performance versus speed and the final comparison of the two spindles. In the measurement are captured of discrete value of torque. The procedure starts with the maximum braking power (max current flowing in coils) and the air supply is still open to the maximum for a maximum power in measured point. Gradually in a few steps, it is reduced supply current to the brake coil to achieve completely brake release state, when the spindle reaches a maximal speed. The torque is always captured in steady state. From the measured torque is still subtracted the torque of passive resistance (frictional moment), which is measured in release state at same level of speed.

## Results of measurement for V1 spindle

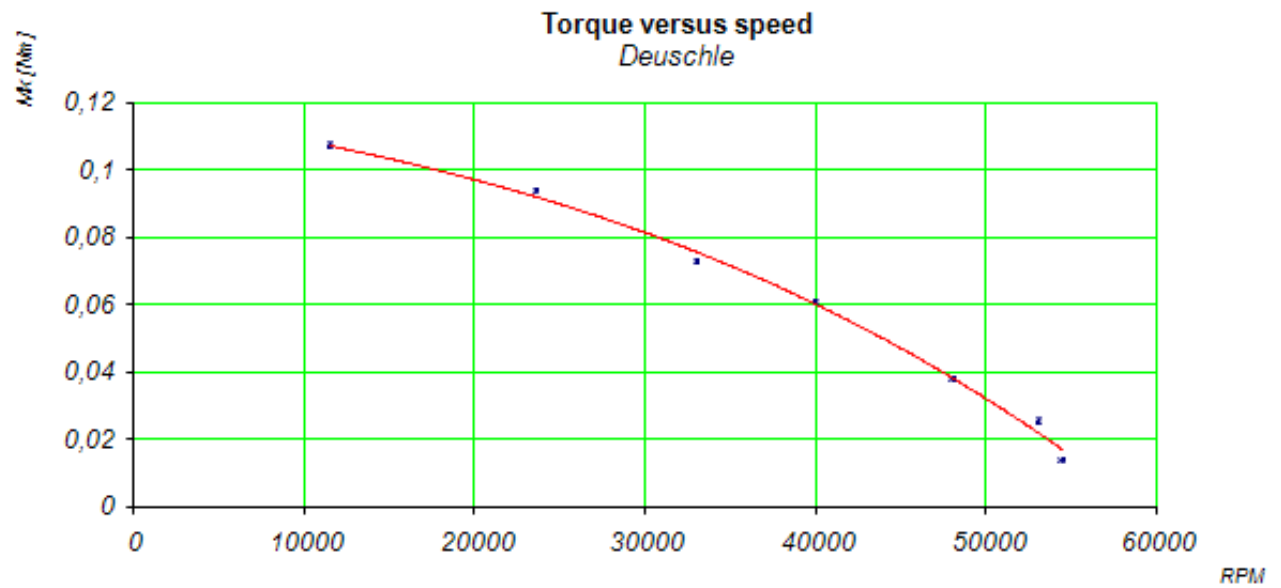


*Fig. 7 Torque versus speed – V1*

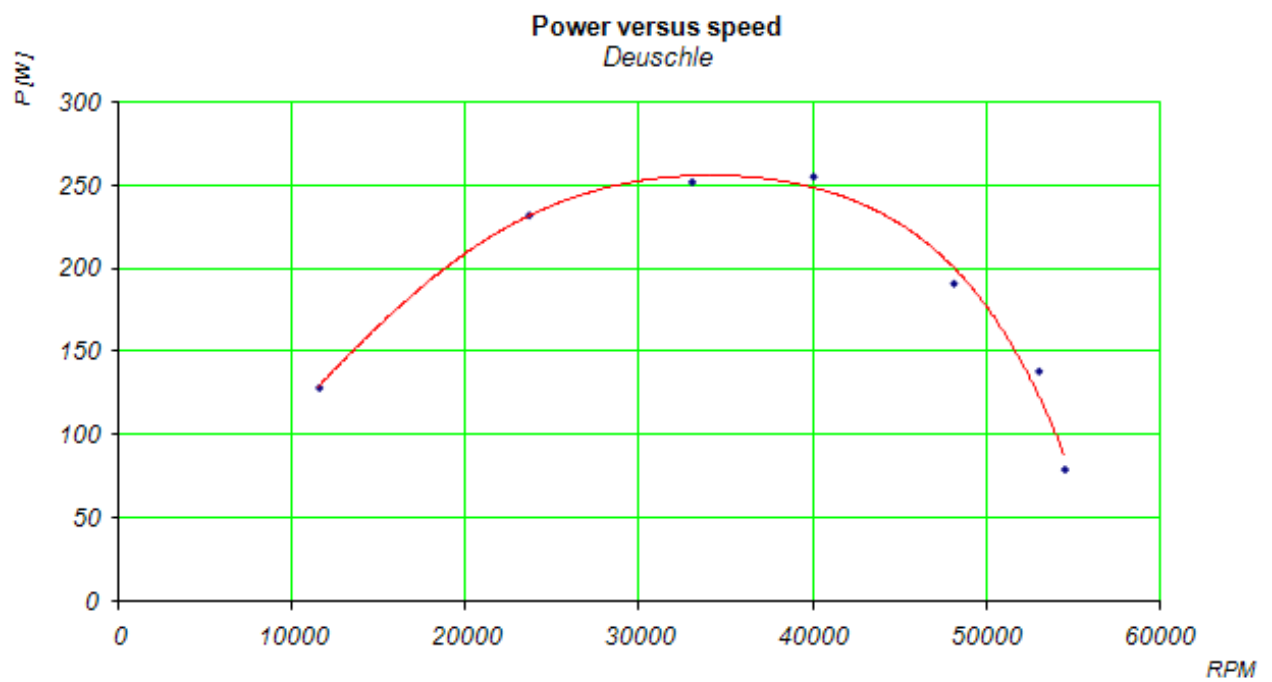


*Fig. 8 Power versus speed – V1*

## Results of measurement for Deuschle DPZ45 spindle

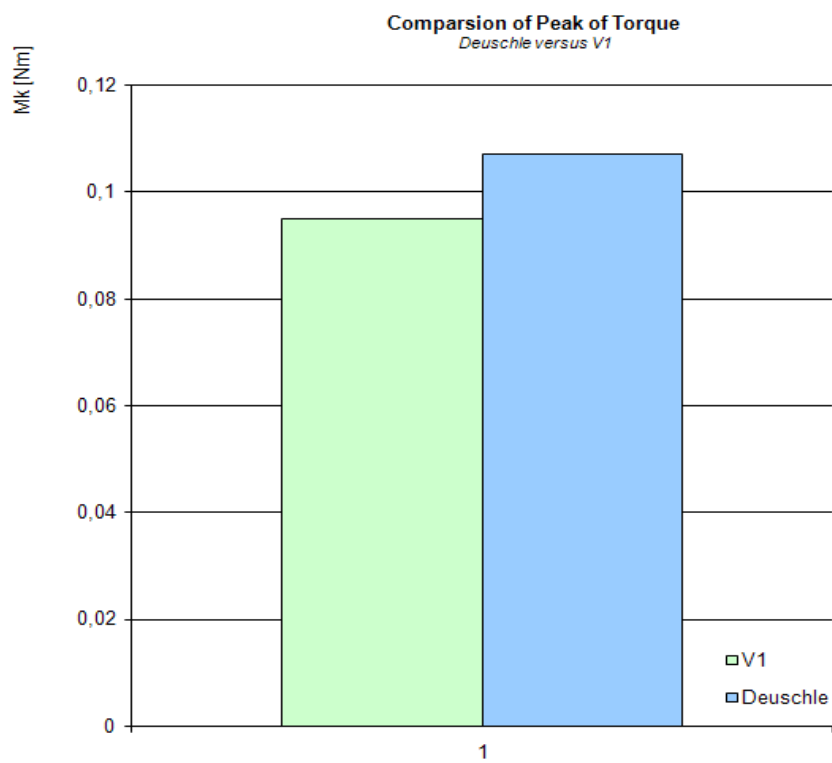


**Fig. 9** Torque versus speed - Deuschle

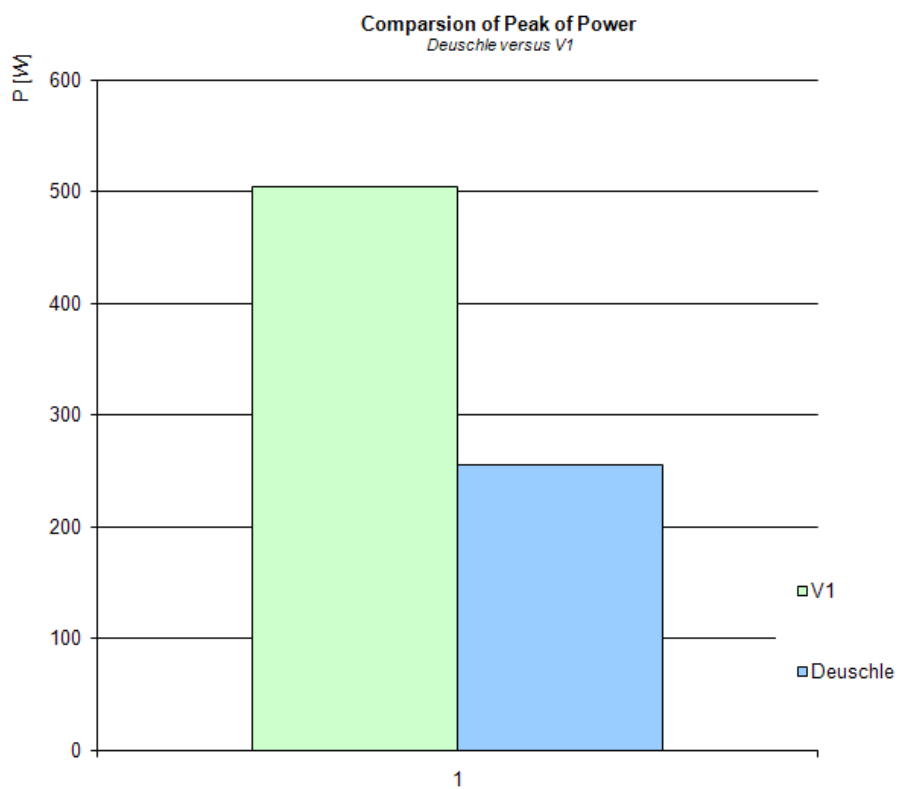


**Fig. 10** Power versus speed - Deuschle

### 3.1. Comparsion of the results



**Fig.11** *Comparsion of peak of torque*



**Fig. 12** *Comparsion of peak of power*



#### 4. Conclusion

Using a special stand for measurement of spindles was measured prototype of high speed spindle V1. It was found its torque and power and it was also measured spindle of commercial producer, who served as a comparative sample. By measuring was identified the performance of both spindles. For the V1 spindle was observed the maximum power to about 490W versus 250W for commercially produced spindle, which is almost 50% less of power. From comparison of torque characteristics can be seen that the spindle V1 is able to provide approximately constant torque in the range 15-60.10<sup>3</sup> rpm, while the DPZ spindle torque curve is constantly downward. The peak of torque is measured by 7% lower at V1 spindle than spindle DPZ. In addition, spindle DPZ didn't able to achieve the declared maximum speed 70.10<sup>3</sup> RPM by manufacturer, but its maximum is at release load state only 55.10<sup>3</sup> RPM. The drive of V1 spindle was designed to power 500W at 80.10<sup>3</sup> RPM during the test of performance was measured the power 490 W at 70.10<sup>3</sup> RPM, which can be considered as a good agreement measured and calculated values. At higher speeds the spindle V1 hasn't already been operated, due to the occurrence of the first natural frequency of the rotor, accompanied by the occurrence of unwanted vibrations. The V1 is the first prototype of additional milling spindle, which provides a good ground for developing a new prototype of high speed spindle, to achieve higher levels of monitored parameters and improvement the dynamic behavior using a more rigorous design of the rotor and spindle drive.

#### 5. Reference

- [1] Kekula, J., Konečný, P. a Burian, D. : Možnosti ověřování vlastností vysokootáčkových vřeten. Praha: RCMT, ČVUT v Praze, 2009. V-09-074.
- [2] Kekula, J., Konečný, P.: Regulace a testování přídatného vřeten se vzduchovým pohonem. Praha: RCMT, ČVUT v Praze, 2009. V-10-057.
- [3] An Ultra High Speed, 500 000 RPM, 1 kW electrical drive system. Zwysig, C., et al. Zurich : Power Electronic Systems Laboratory ETH, Zurich, 2007.
- [4] An Ultra High-Speed Spindle for Micro-Milling. Ziegert, John C. a Pathak, J., P. Gainesville, FL, USA: Department of Mechanical and Aerospace Engineering, University of Florida, 2003.