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[1.] Petr KONEČNÝ

MICROMILLING USING PNEUMATIC SPINDLE – EXPERIMENTS AND APPLICATION

[1.] CTU in Prague, Faculty of Mechanical Engineering,
Department of Production Machines and Equipment,
Horská 3, 128 00 Prague, CZECH REPUBLIC

Abstract: Pneumatic high speed spindle is a response to ever increasing demands on machine tools. Designers of contemporary products require machining of smaller details of higher shape complexity. This means that smaller tools have to be used for machining. To be able to keep the defined cutting speed of a smaller tool we have to increase spindle speed. There is a limit, however, of standard machining spindles. To overcome this problem a pneumatic spindle has been introduced as an accessory device applicable to any machine tool. With speed of up to ten times higher than the speed of regular spindle we are now able to effectively machine complicated shapes using tools of diameter as small as 0.1 mm. This paper presents practical results of high speed pneumatic spindle application for real industrial products. Furthermore there are results of experimental testing and machining introduced to give a better perspective of behaviour of pneumatic spindle during cutting process. These experiments show reactions of spindle speed to extreme cutting conditions. The practical applications show production of radial turbines and distributors, making a groove with depth of 10xD and more.
Keywords: high speed pneumatic spindle, application, cutting process, experimental testing

INTRODUCTION

Contemporary machining applications have been increasing their demands of shape complexity of the final product. The reason is clear. The market asks for innovative products to satisfy increasing customers' needs. This fact would apply mainly to electronics market where designers are coming up with new looks of mobile phones, tablets or laptops with an overwhelming speed. To keep up with such a standard, machine tools have to be constantly innovated. To satisfy such requirements, smaller machining tools have to be used so as to fit in smaller gaps. When we consider a technological point of view we find out that with decreasing diameter of the tool we have to increase spindle speed to meet the defined cutting speed for certain tool and material. These facts have initiated a development of a high speed pneumatic spindle.

DESCRIPTION OF PNEUMATIC SPINDLE

The pneumatic spindle has been designed in Research Center of Manufacturing Technology (RCMT) at Czech Technical University (CTU) in Prague. The first working sample was ready in 2008. It has been subjected to various testing and experiments. Based on test results a new generation of the high speed pneumatic spindle has been designed [1]. This new generation emerged in 2011.

The spindle is capable of reaching 142 000 RPM at its maximum. It is driven by a radial pneumatic turbine and fitted with ball bearings with ceramic rolling elements. The turbine runs under standard air pressure of 6 bars. There is also a control unit that is capable of setting and keeping the spindle's speed at a constant value.

The second generation spindle (see Figure 1) has been subjected to even more tests and experiments. Furthermore it has been used in many practical applications. Results of such tests are described in this paper.

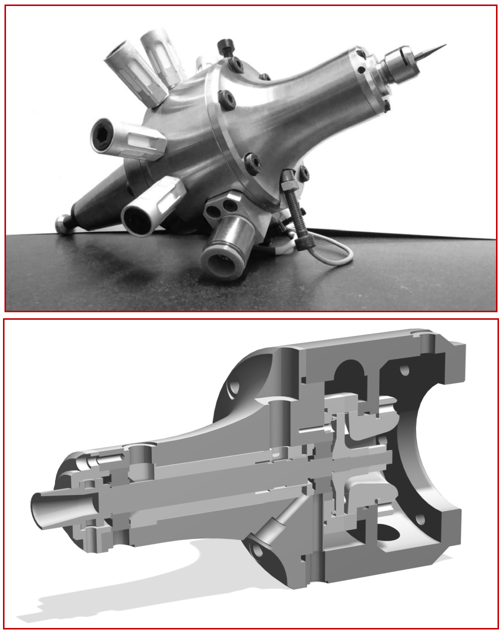

Figure 1: The second generation of high speed pneumatic spindle

DESCRIPTION OF EXPERIMENTS

As mentioned above the pneumatic spindle has been subjected to various experiments which were to find maximum speed [2], control parameters [3], maximum performance and torque [4], resonance vibrations [5], etc. Although all these tests have shown good results of the pneumatic spindle's overall theoretical performance the practical application was yet to be undergone.

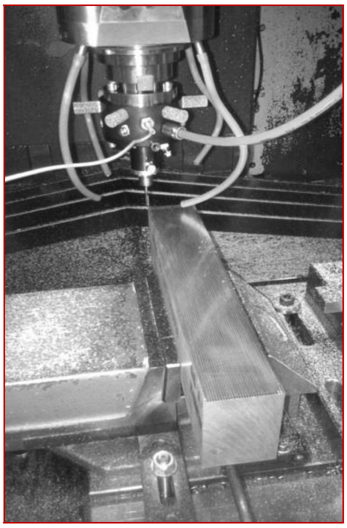

Figure 2: Machine-tool setup for real machining testing

The machine-tool setup for real machining testing is shown in Figure 2. The high-speed pneumatic spindle was clamped in the machine-tool's main spindle. The main spindle was held stopped by its electromagnetic brake. To be able to find out the possibilities of the pneumatic spindle an extreme cutting conditions have been chosen. The tool was a 4 mm flat-end mill with 4 flutes. Material for machining tests was a high durable aluminium alloy (7075) and the cutting conditions can be found in Table 1.

Table 1: Cutting conditions for experimental machining

Tool	Material	Speed	Feedrate	a_z	a_r
4mm flat-end carbide mill	Aluminium Alloy 7075	60 000 rpm	4500 mm/min 0.02 mm/tooth	0.3 mm	1.75 mm

The experiment procedure consisted of machining the whole surface of a large aluminium block (300 x 60 mm) for various cutting conditions. The conditions mentioned here are the most extreme. When we notice the value of feedrate in Table 1, 4500 mm/min is quite high. Thanks to the speed of the spindle we can use such value. If we calculate the feed per tooth (see eq. 1) we get a generally recommended value:

$$ft = \frac{f_{min}}{4n_n} = \frac{4500}{4 * 60000} \approx 0.02 \text{ mm/tooth} \quad (1)$$

where:

f_t	feed per 1 tooth of the tool	[mm/tooth]
f_{min}	feed per minute	[mm.min^{-1}]
n_n	nominal speed	[RPM]

The exceptionally high value of feedrate has to be taken into account because in some cases we might reach a limit of an ordinary machine-tool. In our case we used a 3-axis milling center with linear mangetic motors which have the capability of high speed and acceleration.

EVALUATION

The results of machining test can be seen in Figure 3, the upper diagram shows the overall test which took 3 minutes and the lower diagram is a magnification of a certain part of the record to be able to distinguish speed behaviour clearly. We can notice a drop of speed when the cutting tool enters the material. This drop is about 2.5% which can be considered negligible.

The experiments have proven the spindle to be capable of handling machining processes with relatively large tools applying high performance cutting conditions.

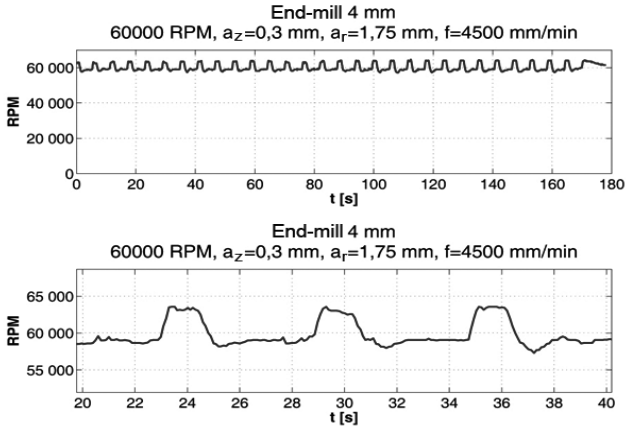

Figure 3: Machining test results

PRACTICAL APPLICATIONS

There have been many practical applications for the university's purposes and for industrial companies already performed using the high-speed pneumatic spindle. A selection of these applications is mentioned further in this paper.

Radial Turbines, Radial Air Distributors

The turbines and distributors have been produced in RCMT on a vertical milling center using the pneumatic high-speed spindle instead of the ordinary machine-tool's spindle.

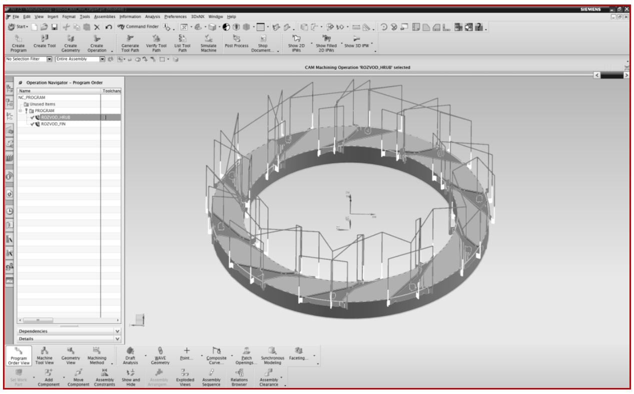

Figure 4. The turbines and distributors

Figure 5: Production of radial air turbine and distributor

Table 3: Cutting conditions for turbines and distributors machining

Tool	Material	Speed	Feedrate	a_z	a_r
1mm flat-end carbide mill	Aluminium Alloy 7075	60 000 rpm	2400 mm/min 0.02 mm/tooth	0.2 mm	0.35 mm

Both turbines and distributors are to be used in the pneumatic spindle itself. The difference from the current ones is changed design and different pressure and flow characteristics.

If we compare machining time for 1 mm 2 tooth end-mill when using a regular machining spindle and the high-speed pneumatic spindle we can easily conclude the following relation for a 10 000 RPM regular spindle:

$$f_{min} = f_t * n * 2 = 0.02 * 10000 * 2 = 400 \text{ mm/min} \quad (2)$$

Now let's compare the feedrate applied for pneumatic spindle in Table 3 which is 2400 mm/min and the feedrate for regular spindle from (2) which equals 400 mm/min. Clearly the difference is a multiple of 6.

The machining time for a turbine was 7 minutes with the pneumatic spindle. It means that a regular spindle would take 42 minutes to manufacture the same part.

Deep Groove

A challenging practical application has arisen on demand of a Czech machine-tools builder. They were seeking for a method to replace electro-erosion technology with a faster process. The task was to produce a slot which is 0.8 mm in width and 8 mm deep. We had the opportunity to put our high-speed pneumatic spindle to test in this application.

A machine tool setup can be seen in Figure 6 on the left. Due to the length of the tool which was 10xD we had to use cutting conditions according to increased fragility of the tool.

Table 4: Cutting conditions for machining the deep groove

Tool	Material	Speed	Feedrate	a_z	a_r
0.8 mm flat-end carbide mill, 10xD	Aluminium Alloy 7075	80 000 rpm	1000 mm/min 0.006 mm/tooth	0.05 mm	0.8 mm

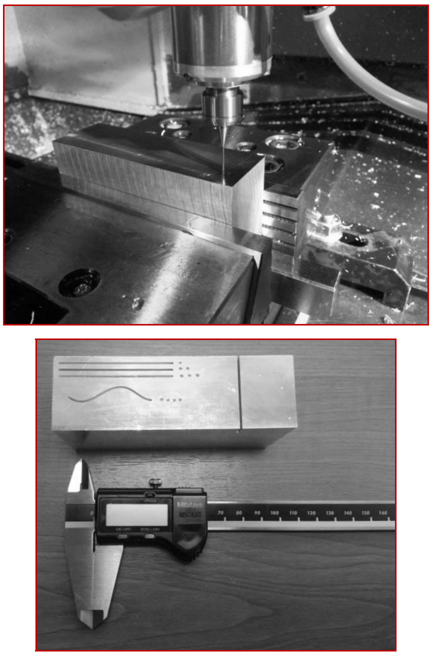

Figure 6: Deep groove. A machine tool setup and the result

The cutting conditions are in Table 4. The final result was very satisfactory. It is pictured in Figure 6. An 80 mm long groove took 8 minutes to produce. Time was a challenge as well. In competition with the electro-erosion the micromachining was about twice as fast.

The production of the grooves has also been tested in the industrial partner's workshop. The tests were very successful. This fact proved the high speed spindle to be very flexible and applicable on wide spectra of machine tools.

CONCLUSION

The high-speed pneumatic spindle has proven its use in a series of experiments and practical applications conducted at university laboratories as well as in real life workshops. There were much more practical applications performed using the spindle. For example there was a raster of micro holes produced for Czech Science Academy. The holes were 0.15 mm in diameter and 0.02 in depth.

There are more experiments and tests to undergo in the future development. At this time there is also a new version of the spindle being prepared.

The increased demand for high speed spindles can be clearly noted in research field. There are both electrical [6, 7] and pneumatic [8] spindles designs. If we take a look at pneumatic spindles there's still a room for improvement especially when we are concerned with speed control. The high speed pneumatic spindle developed at RCMT can fill in this gap and offer a competitive design along with the speed control.

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