Air bearing grinding spindle for manufacturing of tools with ultra small diameters

M. Walk, J.C. Aurich
University of Kaiserslautern; Institute for Manufacturing Technology and Production Systems, Germany

walk@cpk.uni-kl.de

Abstract

The manufacturing of tools with ultra-small diameters by grinding is a demanding area of tool production. The requirements on the grinding spindle to manufacture for example micro end mills or micro pencil grinding tools are very high. To fulfill these requirements an air bearing grinding spindle for manufacturing micro shank tools with diameters smaller than 50 µm is developed. In this paper the spindle concept and the design is shown as well as the prototype analyzed by measuring the run out errors and axial vibrations. Furthermore, some micro tools with dimension structures smaller than 10 µm, ground by the air bearing grinding spindle are shown and discussed.

1 Introduction

An efficient and precise process for micro tool manufacturing is grinding [1]. At the Institute for Manufacturing Technology and Production Systems (FBK) micro tools with ultra-small diameters (< 50 µm) are manufactured in an integrated desktop sized machine tool by grinding in the last years [2]. The grinding process is implemented by an external plunge-cut grinding process with grinding spindle with 12 mm rotor diameter and 120.000 rpm rotation speed. The spindle has a radial air bearing, an axial ball to plate bearing and is propelled by an air turbine. The run-out error is smaller than 0.8 µm. On top of the spindle two grinding wheels are mounted. The first one is for pre-grinding and has a diameter of 30 mm, a thickness of 200 µm and a grain size of 20-30 µm. The second one is used for fine grinding operations and is attached 1.8 mm above the first grinding wheel [3] **(Figure 1,** left**).** After approximately 300 - 400 manufactured tools, the ball to plate bearing is worn. The wear induced an axial oscillation of the rotor and the tool manufacturing process becomes instable. To solve this problem, a grinding spindle with axial and radial air bearing is developed.

2 Air bearing grinding spindle

The air bearing grinding spindle in the existing desktop sized machine tool has to be exchanged against the new developed air bearing grinding spindle. Therefore, the grinding spindle has to fulfil the following requirements:

- A compact spindle design for the integration into the machine tool.
- A small run-out error (≤ 0.8 µm (sect. 1)) for manufacturing micro tools.
- A electro motor drive for easy and variable changing of the rotation speed.
- Conventional available components for easy components change in case of spindle damage.
- One grinding wheel with a middle grain size (#2500) to implement the whole grinding process.

2.1 Spindle design

The developed air bearing grinding spindle has a compact design for integration into the desktop sized machine tool. The whole spindle has a diameter of 54 mm and is 110 mm high. The air bearing grinding spindle comprised four different components: the spindle body, the air bearings, the spindle rotor and a clamping device for clamping a grinding wheel with a middle grain size (**Figure 1**(right)).

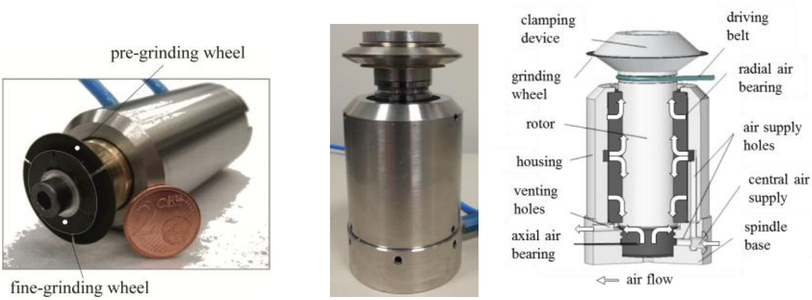

Figure 1: grinding spindle with 12 mm rotor and two grinding wheels (left), protoype of the new developed air bearing spindle (middle) and model (right) (one grinding wheel)

The spindle body consist of two different parts (the spindle base and the housing), which are made of stainless steel to protect the components against rust and oxidation. The rotor is running in an axial and a radial air bearing. The air bearings are integrated into the spindle body (the axial air bearing in the spindle base, the radial air bearing in the housing). On the top of the rotor a clamping device for grinding wheels clamping is adapted (**Figure 1**). Using grinding wheels with a diameter of 48 to 56 mm, the rotation speed of the spindle has only to be 4000 rpm to implement an adequate cutting speed (10 m/s) for micro tool grinding in cemented carbide. The rotor is driven by an external electro motor through a driving belt.

2.2 Spindle components

The used air bearings are conventional available porous carbon air bearings. This porous carbon ensures a uniform air pressure and equal air distribution across the bearing´s face. That makes the difference to conventional orifice type air bearings in regard to the damping and crash resistance. Furthermore, the carbon surface provides greater bearing protection in the case of air supply failure. In addition, this porous carbon allows removing the bearings during air failure without damaging the support surface [4]. The axial and radial air bearing have a diameter of 25 mm. The orientation of the air bearings to each other which can vary by the manufacturing tolerances can be changed by six screws in the lower spindle body part which make it possible to align the vector of the air bearing´s surface to an angle of 90 degree to each other. Only in this alignment the spindle rotor can rotate and the air bearing system runs. Both air bearings are supplied by compressed air (shown in **Figure 1**) through one central connection and integrated in the spindle body. The used air of the air bearings is vented through six venting holes in the lower part of the spindle body. The spindle rotor is made of hardened steel (Aisi 440c). The spindle rotor surface is polished for better performance of the system air bearing-rotor. On the top of the rotor a clamping device for clamping grinding wheels is provided.

3 Measurement and grinding tests

The prototype of the developed grinding spindle is characterised by measuring the axial and radial run-out error of the spindle rotor. Therefore, three capacitive displacement sensors with a resolution of 10 nm are used to measure the radial and axial error motion of the spindle. These sensors are oriented in cartesian XYZ-coordinates. The pressure level of the air bearings is set to the operation pressure

(0.65 MPa). The axial and radial run-out are measured at the spindle rotor (without clamping device). Up to 4000 rpm axial run-out error below 0.1 µm and a radial run-out error below 0.8 µm has been measured (**Figure 2 (left)**). The measured radial run-out error corresponds with the values of the air bearing spindle described in section 1. The non-wear characteristic of the axial bearing and a maximum axial error value of 0.1 µm make the manufacturing of ultra-small tools possible.

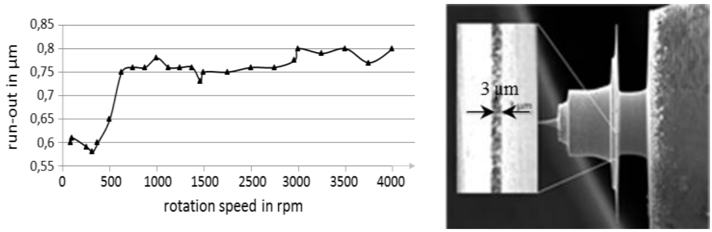

Figure 2: left: measurement plot of radial run-out error, right: ground test structure

After measuring some grinding tests are done. Therefore, micro tool blanks are ground in cemented carbide by an external plunge-cut grinding process. Furthermore, the influences of the axial oscillation of the grinding process fine discs with high aspect ratio are ground. The ground test work piece is shown in **Figure 2**. The right picture shows a fine cemented carbide-disc with a thickness of 3 µm and aspect ratio of approximately 50. The tool tip has a diameter of 6 µm (length 40 µm).

4 Conclusion and outlook

In this article a grinding air bearing spindle development is described. The grinding spindle design allows the clamping of conventional available grinding wheels. With the adapted clamping device an easy and precise change of worn and damaged grinding wheels is possible. The spindle prototype is characterised by measurement and test structures like a micro tool blank with 6 µm diameter or a fine WC-disc with a thickness of 3 µm and a aspect ratio of 50 are ground. In future the influence of the different grinding wheel clamping devices on the spindle properties will be analysed and if necessary spindle components will be optimized.

5 Acknowledgement

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