Micro Grinding Technologies

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Abstract

In many applications, like optics, medicine or mechatronics, miniaturization has been a key issue for achieving novel functionalities and optimizing the economic performance of the required machining processes. High precision parts made from brittle and hard materials are typically ground to a specific shape and functional surface features. An important aspect is the machine tool design of micro grinding machines, since the ratio between machine volume and workpiece volume is unfavorable for conventional machine tools. Therefore, the development of small-sized grinding machines and tools is necessary. In this paper, a short survey is being made on grinding systems to machine small parts. In particular, a new approach to the micro grinding process technology will be introduced.

1 Grinding systems for small parts and microstructures

Commercially available ultra-precision machine tools to manufacture small-sized workpieces have mostly evolved from conventional machine tools [1, 2]. Therefore, ultra-precision machine tools have similar dimensions and components to conventional ones and their volume exceeds the dimensions of usual workpieces by many orders of magnitude (i.e. 25,000,000:1). Additionally, the machining efforts and the energy demands rise due to the unfavorable mass ratio between the machines moving masses and the workpiece's mass [2]. Another issue is the larger factory area needed for today's machines and it's higher building costs. For this reasons, the main goal in the future for machining small workpieces is to develop novel machine tools with appropriate size. Fig. 1 - a) shows a small-sized machine tool concept called square foot manufacturing, in which several micro machining units can be mounted onto one square foot sized base plate and work simultaneously on one workpiece. Aditionally, Fig. 1 - b) presents a miniaturized air bearing spindle for this machine tools dimension.|

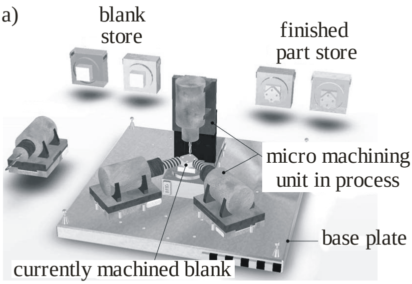

Figure 1: a) Example of a small machine tool - “Square-Foot-Manufacturing” [3], b) Miniaturized air bearing spindle [4]

A more economical and efficient machining of small sized workpieces and structures requires novel machine concepts comprising miniaturized as well as modular tools and tool holders, as shown in Fig. 1-b). These components should be able to integrate various functions into a single device and have smaller dimensions than conventional ones. Regarding a higher integration of the whole tool module, which comprises drive unit, guiding system, tool holder and the tool itself, a novel grinding tool concept with an unprecedented association of hydraulic and magnetic principles is under development.

2 Novel tool concept for micro grinding

The new concept shown in Fig. 2 (right side) features the following original aspects:

- an innovative grinding tool with spherical shape,
- a fluidic drive system to move the spherical grinding tool and
- an electromagnetic, contact-free guide setup to maintain the tool in it’s position.

Because of the novel combination of a magnetic bearing and a fluidic drive in a grinding tool module, this design has compatible dimensions to be used in small-sized machine tools. In order to allow the spherical tool to float between the workpiece and the tool module, the repulsive force induced by the fluid stream F_{fluid} is compensated by the controlled magnetic counterforce F_{mag}, which attracts the ferromagnetic grinding tool. This compensation inhibits the tool’s translational movement in all 3 directions. The rotational axis of the grinding tool is defined only by the direction of the fluid stream and is not limited by any physical axis of the tool (cf. Fig. 2). The major rotational axis is perpendicular to the tools axis, so that the maximum cutting speed is located at the bottom of the grinding sphere.

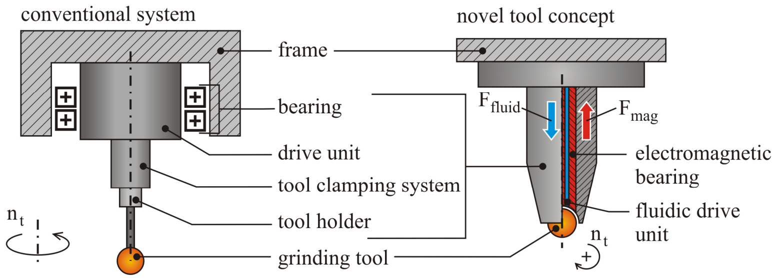

Figure 2: Conventional tool system and novel grinding tool module

3 Investigation of the expected grinding forces

The development of the drive and bearing systems for this novel grinding tool concept requires fluidic and magnetic field simulations depending on measured process forces of the spherical grinding tool during a micro grinding process. The experimental setup is depicted in Fig. 3 (upper right corner). The process forces F_n and F_f, normal and feed force respectively, were measured in an experiment using a 5-axes ultra-precision machine tool by grinding two hard and brittle materials: optical glass (N-BAK2) and aluminum oxide (Al_2O_3). It was not possible to measure the cutting force F_c, due to the insufficient signal-to-noise ratio.

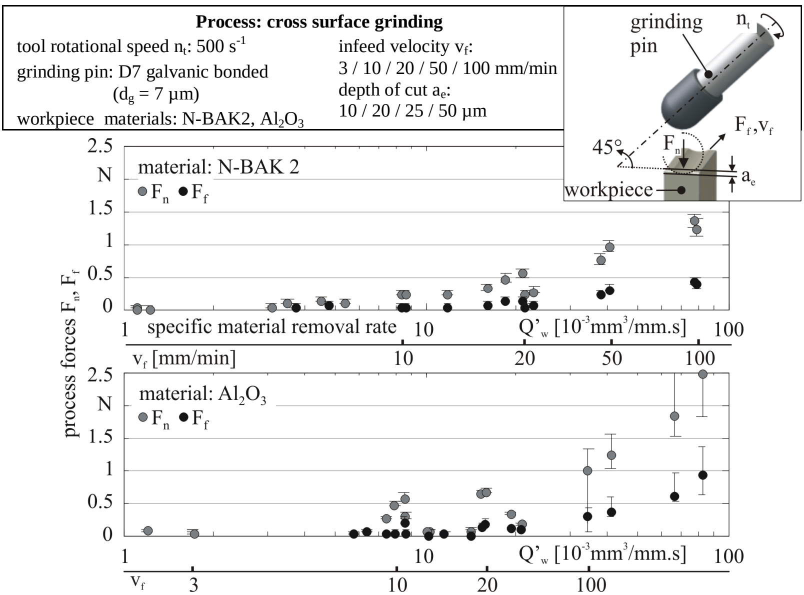

Figure 3: Process forces F_n and F_f over specific material removal rate Q'_w and infeed velocity v_f

The tool applied was a galvanic bonded D7 grinding pin with a grain size of d_g = 7 µm. This tool was inclined at a 45° angle, so the pin rotation resembles the expected ball movement of the new concept. Fig. 3 shows the diagram with the experimental kinematics, grinding conditions and results of the force measurements. The process forces lie under 0.5 N by typical depths of cut (a_e = 10–20 µm) and infeed velocities (v_f = 3–10 mm/min) in micro grinding. These forces, corresponding to a 6 W grinding power, have to be provided by the fluid stream.

4 Conclusion and outlook

The development of small-sized machine tools and components is a key issue to provide a more favorable ratio of ultra-precision machines and small workpieces. An innovative concept of a small-sized tool module is presented, which shows the unprecedented combination of a magneto-fluidic bearing with a fluidic drive and has adequate dimensions for a small machine tool. First analogue experiments showed that the fluidic drive unit should be able to generate a grinding power of about 6 W. The next development steps comprise a tool module prototype and a corresponding 3-axial experimental platform.

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