euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015
www.euspen.eu

New machine tool concept for two-side ultra-precision machining

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Abstract

The requirements regarding workpiece surface quality, geometrical and positional accuracy as well as tolerances for linear and angular dimensions are increasing. Furthermore, the machine technology limits and defines the manufacturing quality directly. Hence, the Fraunhofer Institute for Production Systems and Design Technology IPK and the Institute for Machine Tools and Factory Management IWF of the TU Berlin have developed a new machine tool concept for ultra-precision machining. This enables two-side machining of the front surfaces of optical elements. The concept aims at increasing the economic efficiency of ultra-precision machining.

Keywords: ultra-precision engineering, ultra precision machine, hydraulic expansion chuck

1. Introduction

Industrial requirements of the arithmetical mean deviation Ra < 10 nm as well as tolerances for linear dimensions $T_L \leq 1$ µm and angular dimensions $T_A \leq 1''$ are no longer unusual. To fulfil these demands, new production processes and methods, quality measurements, measuring systems and techniques are in the focus of current research. For example, new mathematic algorithms, improved software with higher resolution and new materials are currently developed. Furthermore, physical, technical and economic limits still exist. In those cases, new concepts with regular components are able to increase the process efficiency.

2. Ultra precision machine tool

Ultra-precision machine tools use natural granite with high stiffness K, high damping D and low thermal expansion coefficient α as machine beds. Moreover, machine beds are impregnated by a coating to overcome the disadvantage of hygroscopicity.
The rotation motion of the main spindles is realized by aerostatic bearing torque motors. Advantages of those spindles are the exactly controlled spindle speed and the high concentricity a_c even at a high spindle speed n.
The linear axes feature as hydrostatic bearings and are driven by linear motors. The hydrostatic bearings guarantee stick-slip is eliminated. Furthermore, ultra-precision machine tool feature passive pneumatic damping elements and are placed on a decoupled ground.
For the axis position measurement systems glass scales with resolution $r \leq 1$ nm are used and programming increments $i_P \leq 1$ nm of ultra-precision machine controls are state of the art.
As workpiece clamping systems vacuum chucks are used [1]. Since the production of free-form surfaces on the flat face of optical components are often required, slow-slide-servo (SSS) and fast-tool-servo turning (FTS) are practiced. As spindle can be use an indexing spindle. The spindle is integrated into the controller as an interpolating component. For fast-tool-servo turning, an additional piezo-actor is integrated into the infeed axis [1, 2].
Currently ultra-precision machine tools that allow simultaneous machining of opposing optical front faces don´t exist on the market. That disadvantage leads to high production times on the one and to geometrical errors between the surface contours on the other hand.
For this reason the Fraunhofer Institute for Production Systems and Design Technology IPK and the Institute for Machine Tools and Factory Management IWF of the TU Berlin have developed a new machine tool concept which enables two-side machining of the front surfaces of optical elements. The development of the new machine tool concept was divided in the principal design of the two-side ultra-precision machine tool and the design of the chuck which can be integrated into the machine design.

3. Development of the machine design

The developed concept should be able to meet the requirements for two-sided processing of the flat faces. As a result, appropriate components must be selected for the main spindle, the feed axes and the machine bed. In addition, the components have to be arranged to each other. Moreover, a large working space is available and the dimension of the machine tool is low. Furthermore, collisions must be avoided. The guideline VDI 2222 was used to find possible variants. Three concepts were favoured in the end of the variant determination. The preferred option was determined by a utility analyse method according to Grundig. The three concepts and the customized preferred option are shown in figure 1.

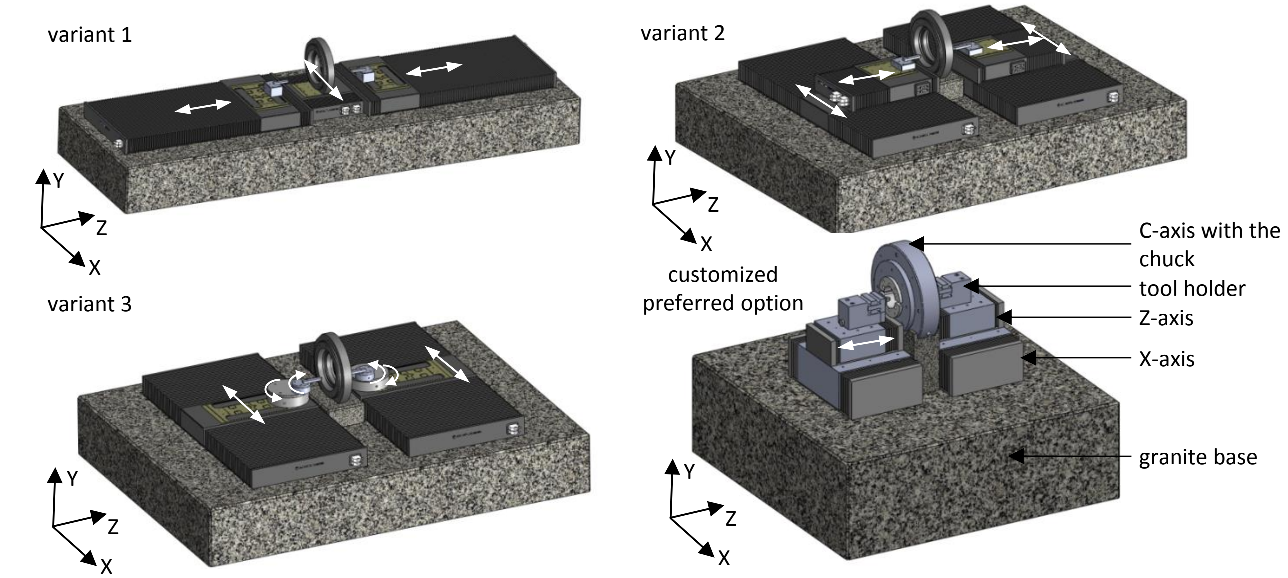

Figure 1. Possible variants after using the guideline VDI 2222 and the customized preferred option

Axes and drives are arranged to make two-sided machining possible and the specifications of the components meet the requirements for ultra-precision machining. The drive axis (C-axis) is designed as an aerostatic-bearing rotary hollow-shaft direct drive. This is mounted on a granite machine bed. One available rotary hollow-shaft direct drive has an inner aperture $a_i = 150$ mm, an axial runout $a_a \leq 60$ nm and a concentricity $a_c \leq 100$ nm. Currently, the drive axis is assigned the machine zero point (the machine´s point of origin) and guarantees two-side accessibility.

High-precision hydrostatic bearing x-z-cross stages are used as feed axes. Both cross stages are mounted on the machine bed and calibrated to the machine zero point with minimal difference.

4. Chuck for the workpiece

A chuck based on hydraulic expansion is applied to fix the workpiece inside of the rotary hollow-shaft drive. The chuck can be used for diameters from 25 mm ≤ D ≤ 80 mm in 5 mm steps with intershells. The intershells are manufactured as slotted sleeves. The chuck is shown as a cut view in figure 2.

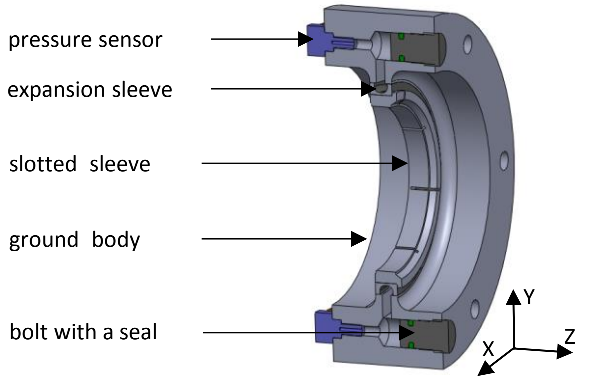

Figure 2. Hydraulic expansion chuck with slotted sleeve

The concept of the chuck guarantees the necessary clamping force F_{Cl} with permissible deforming at the workpiece. This is proved by the simulation program ANSYS, Canosburg, USA. The workpieces are made of germanium (Ge) with a Young´s modulus E = 103 GPa and silicon (Si) with a Young´s modulus E = 131 GPa. The diameter is D = 70 mm and the width varies 4 mm ≤ W ≤ 10 mm for both workpieces. The results of the FEM-simulation show a maximum deformation on the flat surface of $\delta_{fs} = 1$ nm for germanium.

5. Conclusion and outlook

The concept is able to increase the economic efficiency of ultra-precision machining, because both front surfaces with ultra-precision requirements can be manufactured simultaneously. Other advantages are that opposite reclamping error can be eliminated and surfaces and structures may be positioned to each other better. Thus, the position deviations on workpieces can reduce that demands of the machine technology. Further, the machine concept allows not only turning processes. Milling or drilling manufacturing is possible too. Currently, one disadvantage is that only cylindrical components can be manufactured. Hence, in further studies the chuck will be optimized to clamp cubic workpieces too and the results will be validated with experiments. Other tasks are integrating measurement systems, optimizing the machine control and cutting tests with varied parameters. The prototype machine tool concept with simplified components is shown in figure 3.

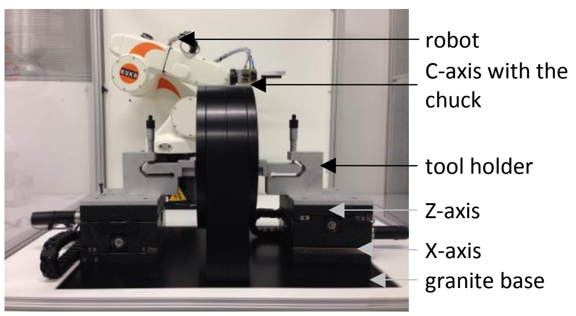

Figure 3. Prototype of the new concept machine tool

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