»iTool« Design of a Diamond Grinding and Lapping Machine

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Abstract

New sophisticated products in the field of precision engineering and optics require diamond tools of highest accuracies in combination with cutting edges that differ from the common spherical form.

Within an industry driven research project, the Fraunhofer IPT has developed a novel diamond grinding and lapping machine to machine high precise diamond tools with spherical and – innovative – aspherical shapes. To achieve the proposed requirements of the diamond tools in terms of accuracy and shape, a machine design based on fundamental considerations of the axis configurations was realised [1,2]. Furthermore, the conduction of the grinding process was considered as well and influenced the design of the machine [3,4].

1 Kinematics of the diamond grinding machine

To meet the requirements, the machine consists of ten axis with two machining spindles. As a result of the demanded high accuracies in the sub-micron range, the design of the machine was realised with the focus of enabling the user to machine the diamond tool in one setting. This will eliminate the errors that are due to the change of references when machining the contour and the chip surface of the diamond tool on different machines, which is the state of the art. Therefore, the diamond grinding machine has the three machining stations contouring of the cutting edge, machining of the chip surface and measuring of the whole diamond tool.

The contouring of the cutting edge is dependent on four feed axis (A, B, Z and Z’) and the first grinding spindle, which is mounted in an excentric spindle to obtain a continuous change of the grinding direction that is advantageous for the machining of monocrystaline diamond tools. Firstly, the desired clearance angle is adjusted by the A-axis that is realised as a goniometer to achieve maximum working space. The radius of the tool is influenced by the position of the Z-axis, whereas the Z'-axis is moved in accordance to the angular position of the B-axis, which defines the opening angle of the tool, to overlay an aspherical shape on the constant radius.

After that, the chip surface is finished at the second machining station with the vertical mounted grinding spindle. Similarly, the chip angle is controlled by the position of the A-axis. The machining is basically conducted by the feed of the high precise vertical Y-axis.

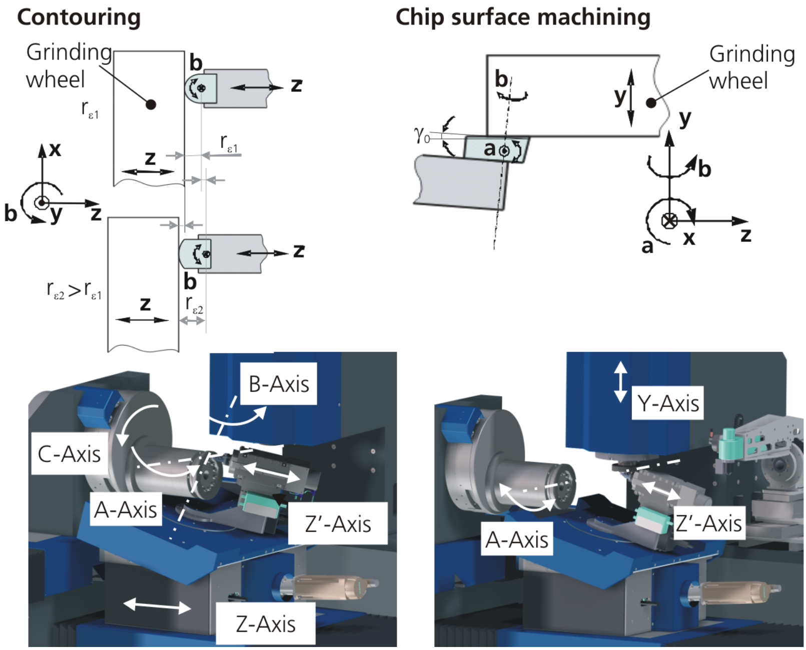

Figure 1: Machining station of the diamond grinding machine

To check the accuracy and form of the diamond tool a measuring system based on a white light interferometer that is mounted on a multi axis stage assembly was implemented into the machine. The stage assembly consists of two linear and one rotary axis to enable the observation of the whole tool. As a result, the machine will enable manufacturers to conduct the final machining and characterisation of new innovative diamond tools in one setting.

2 Design considerations of the goniometric axis

The goniometric axis is a central part of the machine that has been specially designed due to insufficient available axis systems. A crucial step of the design is the estimation of the errors at the tool centre point (TCP) induced by the A-axis. Therefore, the model of the A-axis was transformed into a kinematic sketch, which is shown in figure 2. Due to the limited available space within the machine, the slide that contains the bearings was mounted off centre, which lead to the displayed model. The centre of mass was laid within the distance r_s from the TCP and in the middle of the bearings to obtain equal loads of the bearings.

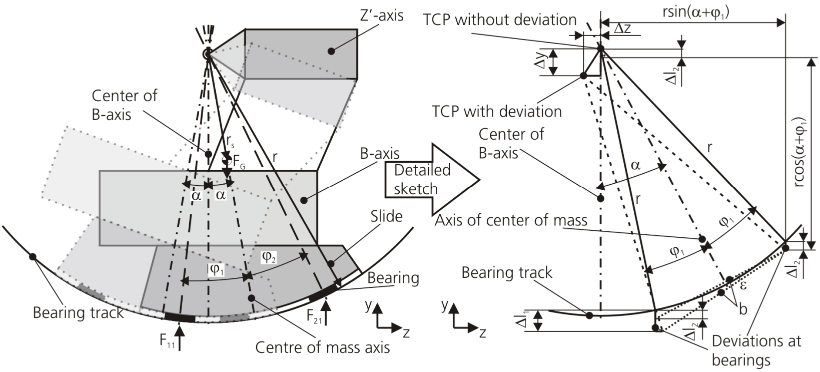

Figure 2: Model and sketch for deviation evaluation due to the A-axis

Based on this model the loads of the bearings F_{11} and F_{22} could be determined dependent on the angle of rotation α and the angular distance between the centre of mass axis and the bearings $\varphi_{1,2}$.

$$F_{22} = F_G \frac{r_s \sin\alpha - r\sin(\alpha - \varphi_1)}{r[\sin(\alpha + \varphi_2) - \sin(\alpha - \varphi_1)]} \quad \text{Eq. 1}$$

$$F_{11} = F_G - F_2 \quad \text{Eq. 2}$$

With consideration of the bearing stiffness $k_{1,2}$ a relating deviation $\Delta l_{1,2}$ at each bearing position could be determined. By assuming an ideal stiffness of the other components the deviation of the TCP was calculated with the following equations that represents a simplified model for a first estimation without incorporating the low process forces.

$$\Delta y = \Delta l_2 + r \sin(\alpha + \varphi_2)\varepsilon \qquad \text{Eq. 3}$$

$$\Delta z = r \cos(\alpha + \varphi_1)\varepsilon \qquad \text{Eq. 4}$$

$$\varepsilon = \arctan\left(\frac{\Delta l_1 - \Delta l_2}{4r \sin \varphi_1}\right) \qquad \text{Eq. 5}$$

Taking the given configuration into account ($F_G = 1530$ N, $r_s = 247$ mm, $r = 275$ mm, $\varphi_{1,2} = 22.5°$, $k_{1,2} = 88$ N/µm) a maximum deviation of the TCP of $\Delta y = 4.4$ µm and $\Delta z = 0.1$ µm could be determined at a maximum rotational angle of $\alpha = 15°$. Since this is outside the necessary tolerances and a higher stiffness can not be achieved with the desired configuration of air bearings, the A-axis will be clamped during machining of diamond tools.

3 Conclusion and Outlook

Within this publication the design of a newly developed diamond grinding and lapping machine was presented. Furthermore, the dimensioning of each axis was exemplarily described on the goniometric A-axis, since it is a specialised development for the discussed machine. On the basis of the estimated errors at the TCP induced by the A-axis, adapted machining strategies were derived. Within the next year the machine will be assembled, broad into operation and tested. Finally, the machining of the proposed high precision diamond tools will be conducted.

References:

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