# Process and machining system for optical surfaces

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## Abstract

Conventional manual polishing is the most common finishing process step in an otherwise completely automated process chain for free formed dies and moulds made of steel. As constant process parameters cannot be provided by the worker, manual polishing carefully approaches the goal to obtain fine surfaces down to 5 nm Ra and form accuracies better than 1 µm at the same time and requires up to 30 minutes per square centimetre. Therefore, a manual process cannot be implemented efficiently in terms of economic aspects. For steel, ultra precision diamond machining cannot be applied because of high diamond tool wear.

The material removal of processes based on indefined cutting edges such as grinding, lapping and polishing are mainly driven by the combination of materials and the process parameters cutting speed, contact pressure and specific duration [1]. In order to perform a deterministic fine machining, thus controlling and keeping these parameters constant is essential. Furthermore, the investigation on fine machining of steel surfaces identified micro chipping as most responsible for material removal [2]. For this reason, a modular force controlled machining system, which is guided by a 6-axis robot arm, was developed at Fraunhofer IPT. The machine can perform both rotational and oscillating removal motions and applies an additional rotation for multidirectional surface treatment. With regard to first polishing attempts the system enables the automated fine machining down to 10 nm Ra starting with 400 nm Ra in less than 5 minutes per square centimetre.


## 1 Design of the polishing machine

To achieve the required control of the process parameters polishing force and speed as well as gain flexibility in polish open geometries but edges and corners, too, a configurable machine system structure has been designed. To insure correct tool path tracking on the workpiece surface over the complete process time a 6-axis robot arm guides the polishing spindle. Since the robot positioning is inaccurate and tools wear down, axial distance compensation is mandatory. The entire system is framed in a machine housing that contains auxiliary functions like the tool changers, the electrical cabinet and the control unit.

### 1.1 Structure of the polishing spindle

To adjust the spindle to varying polishing tasks, combinations of different polishing kinematics, tools and forces are needed. Solutions with different system borders and locations of chuck interfaces that allow the automated configuration of the spindle have been considered. The result of this evaluation is illustrated in figure 1. A modular configurable system was chosen, that consists of the robot, one main base module and exchangeable kinematic modules and tools.

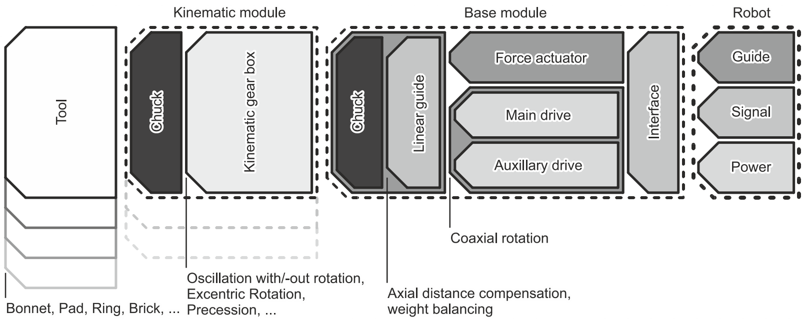


Figure 1: Functional structure of the modular configurable main base system

The main base is permanently attached to the robot and contains all drives, sensors as well as an air pressure driven distance compensation with weight balancing and the chuck interface to the kinematic modules. The kinematic modules are pure mechanical gear boxes with additional chucks to the specific tools that translate the two rotations provided by the base into different motions in the contact between tool and workpiece. There is oscillation, rotation, precession and in addition eccentric movement.

### 1.2 Kinematic of the polishing spindle

The wide range of kinematic motion that can be configured by the relatively simple kinematic modules founds on the kinematic of the main base module that is shown in figure 2. It is divided into the output slide and the drive unit. The slide travels almost frictionless in axial direction as part of the distance compensation and consists of two coaxial output shafts rotating independently. The main drive, the auxiliary drive and the force actuator are located in the drive unit. Both parts are linked by special clutches with axial clearance and the rode of the pneumatic actuator. All layers of independent movement are highlighted on the bottom of figure 2.

As the kinematic modules are mounted to the outer shaft that is part of the auxiliary drive train they rotate with its speed – for example at eccentric frequency.

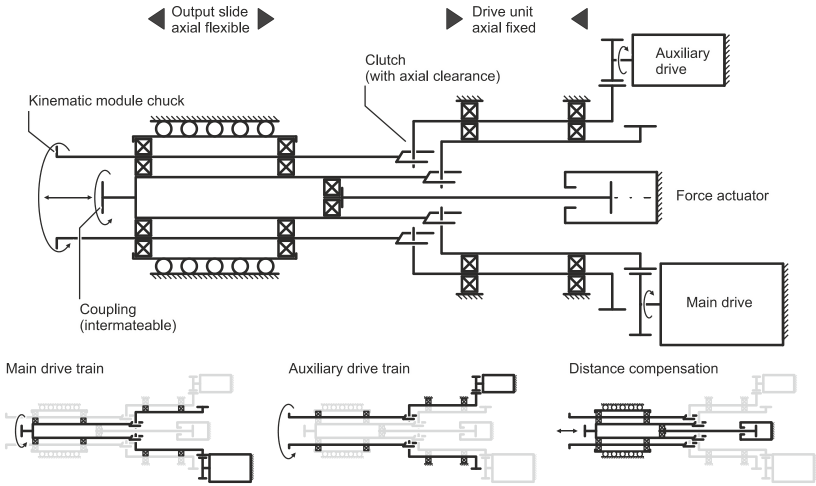


Figure 2: Kinematic design of the main base module

## 2 Performance of the polishing system

The main drive of the machine, as it is illustrated in Figure 3, speeds up to 10.000 RPM for rotational tools and 6.000 RPM (equal to 100 Hz) for oscillating tools. The outer shaft turns the mounted kinematic modules at a maximum frequency of 2 Hz. The process force can be varied between 0 and 40 N with an accuracy of ± 0.2 N and repeatability of 0.2 N. The friction in axial sliding part of the main base module is less than 0.05 N and can be explained with the contact of the clutch and the linear guide of the rod.

As mentioned before, the process duration is 5 min/cm$^2$ to obtain 10 nm Ra starting with 400 nm Ra but form accuracy is low. Even though the process parameter can be controlled within narrow ranges, the geometrical accuracy is limited due to local material inconsistencies like varying composition and texture. Analysing the process investigations regarding roughness and material removal in correlation to the process time, starting at 100 nm Ra is recommended. By that process duration is halved and material removal drops to a fifth [3]. A fine pre-machining decreases the thickness of material to be removed by the final polishing step. In succession to that the form accuracy remains better than 2 µm PV.

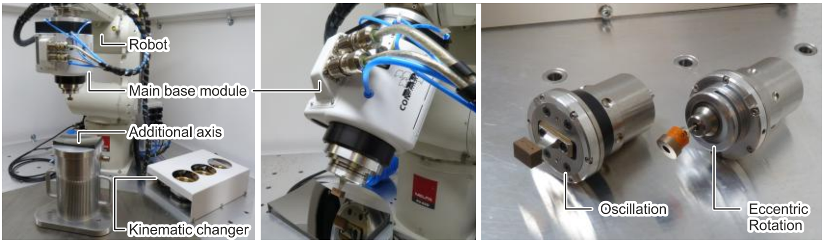


Figure 3: Machine system, main base module and kinematic modules

## 3 Conclusion and outlook

Within this publication the structure of the developed modular polishing system was presented. Furthermore, the independent kinematic layers of motion building the base module form the centre of this innovation. By means of this, the automated manufacturing process of optical surfaces made of steel can be realized. The machine was installed and put into operation end of 2012. Several auxiliary functions are in development and will be added in 2013. The future focus is on simulation of tool removal profiles for more efficient process planning and more convenient programing.

**References:**

[1] Preston, F.W.: The Therory and Design of Plate Glass Polishing Machines, Journal of the Society of Glass Technology, 1927, Vol. 11

[2] Dambon, O.: Das Polieren von Stahl für den Werkzeug- und Formenbau, Berichte aus der Produktionstechnik, PhD Thesis WZL-RWTH Aachen, 2005

[3] Tücks, R.: Automatisierte Feinbearbeitung von komplexen Werkzeugen und Formen aus Stahl, Berichte aus der Produktionstechnik, PhD Thesis WZL-RWTH Aachen, 2012