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Deterministic lapping of anodized precision components with slightly curved surfaces

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Abstract
Although lapping of curved surfaces has been replaced by precision grinding in many cases, especially in optics manufacturing, its use can be advantageous over grinding under certain conditions. The task investigated is the precision machining of slightly curved cylindrical surfaces of mechanical components made of aluminum, which were pre-machined by 5-axis CNC milling and anodized with a layer of about 25 µm thickness. The lapping process was performed with a specially designed lapping device mounted on the wheel head of a CNC surface grinding machine. This allowed the tool path to be freely programmed with the CNC control of the surface grinding machine. The shape accuracy and the roughness of the workpieces were measured with a tactile profilometer. The lapping process significantly improved the shape accuracy of the components (cylindricity) and the roughness.

lapping, functional surfaces, …

1. Introduction

For the primary functional surface of the precision components ("wafer assembly platform") considered here (Fig.1) with cylindrical or toroidal geometry, relatively high hardness and high wear resistance are required in addition to high dimensional accuracy.

In the application, it is important to guide and position the wafers for the assembly process with very high accuracy. Due to the complexity of additional secondary functional surfaces or geometry elements, the component is made of an aluminum alloy with low residual stresses. This results in very low deformation of the component after a 5-axis CNC milling process, enabling high-precision pre-machining.

To meet the requirements for hardness and wear resistance, the parts are subsequently anodized. The shape accuracy of the envelope geometry of the surface is of high importance for the function and, to a lesser extent, the roughness.

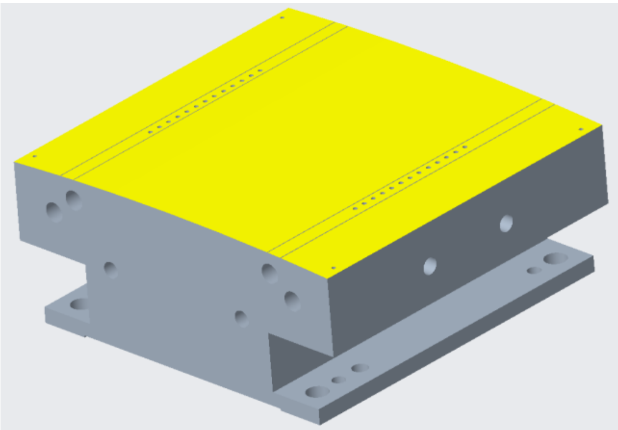

Figure 1. Wafer assembly platform (radius of curvature 670 mm)

Thus, to achieve the precision required of the primary functional surface, the shape deviation must be less than 0.5 µm while the radius tolerance is less than 0.2 % despite the boundary conditions resulting from the low anodized layer thickness.

2. Experimental setup

2.1. Workpieces

In the following it is described the precision machining of slightly curved cylindrical surfaces (radius in the specific case R = 670 mm) of mechanical components with a rectangular base area of 96 mm x 90 mm and a test area of 50 mm x 38 mm made of aluminum. Pre-machining was done by 5-axis CNC precision milling. Subsequently, the parts were anodized with a layer of about 25 µm thickness. The general objectives were to improve the shape accuracy and roughness of the cylindrical enveloping surface.

2.2. Lapping device

The lapping device was specially developed for this machining process. The lapping device has a gimbal mount of the lapping tool and enables an adjustable lapping normal force by means of a balance beam (Fig. 2).

Additionally, the lapping device has an adjustment unit for aligning the cylindrical axis of the lapping tool parallel to the workpiece cylindrical axis. The lapping device was mounted on the wheel head of a CNC surface grinding machine. The relative movement between the lapping tool and the workpiece, the path velocity and the overruns in both circumferential and axial direction can be freely programmed with the CNC-control of the surface grinding machine.

The lapping tools (tool material: brass) with a special designed structure were also machined by 5-axis CNC precision milling. Fig. 3 shows a schematic presentation of the lapping tool.

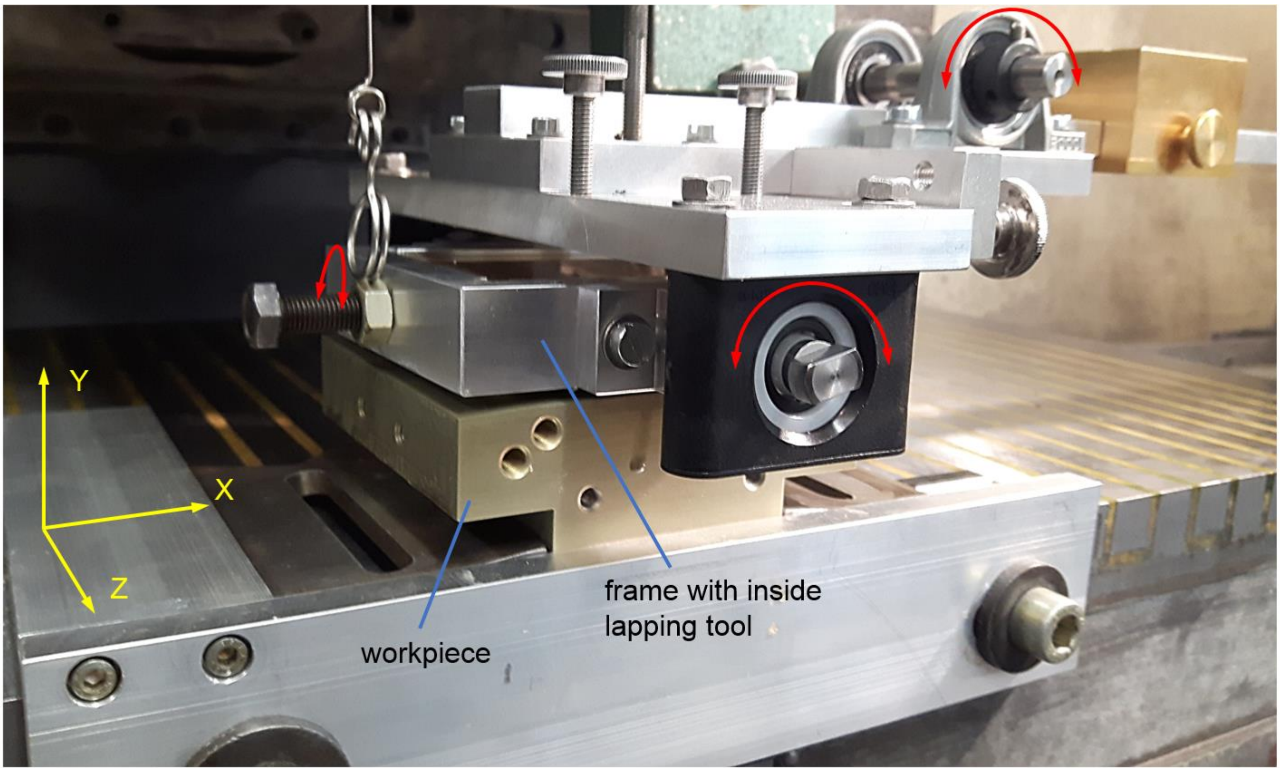

Figure 2. Lapping device with workpiece

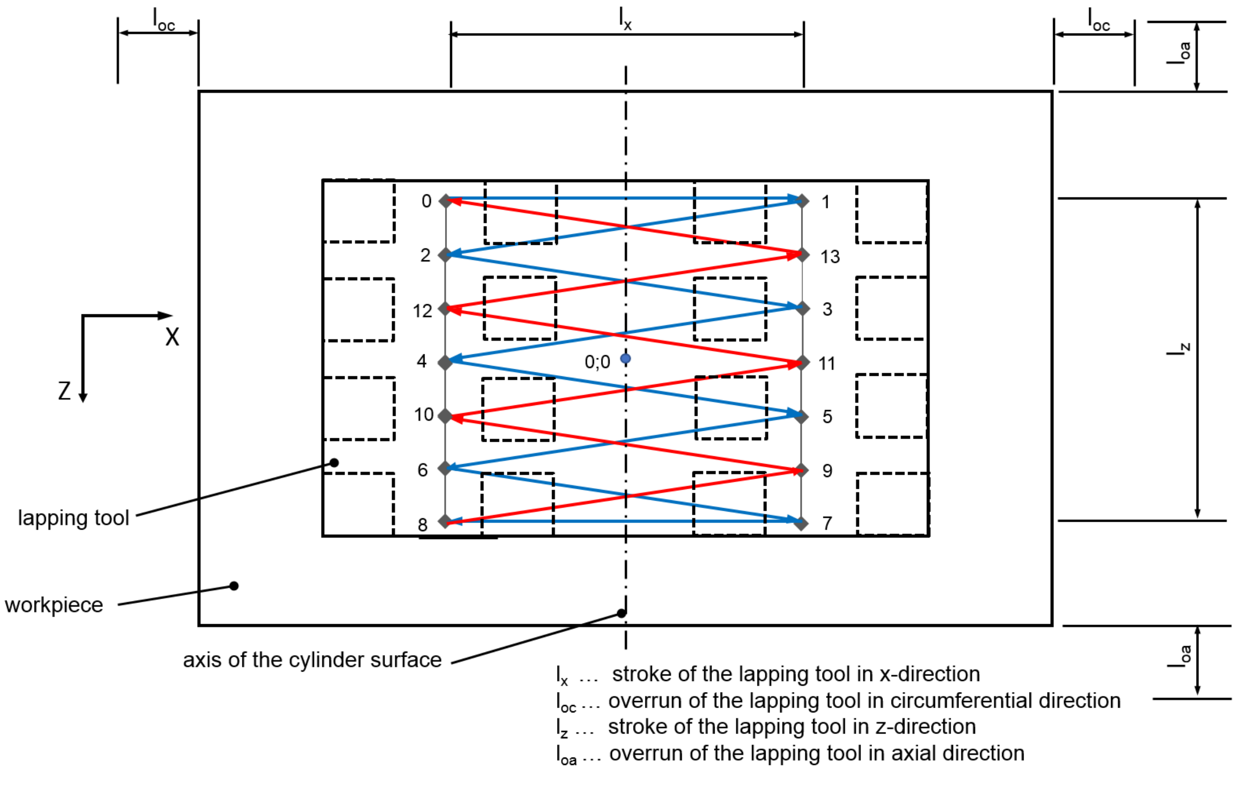

Figure 3. Schematic representation of the path of the lapping tool center (0;0). The blue and red arrows and the numbers 0 -13 indicate the path respectively the end positions of the lapping tool center point during one cycle

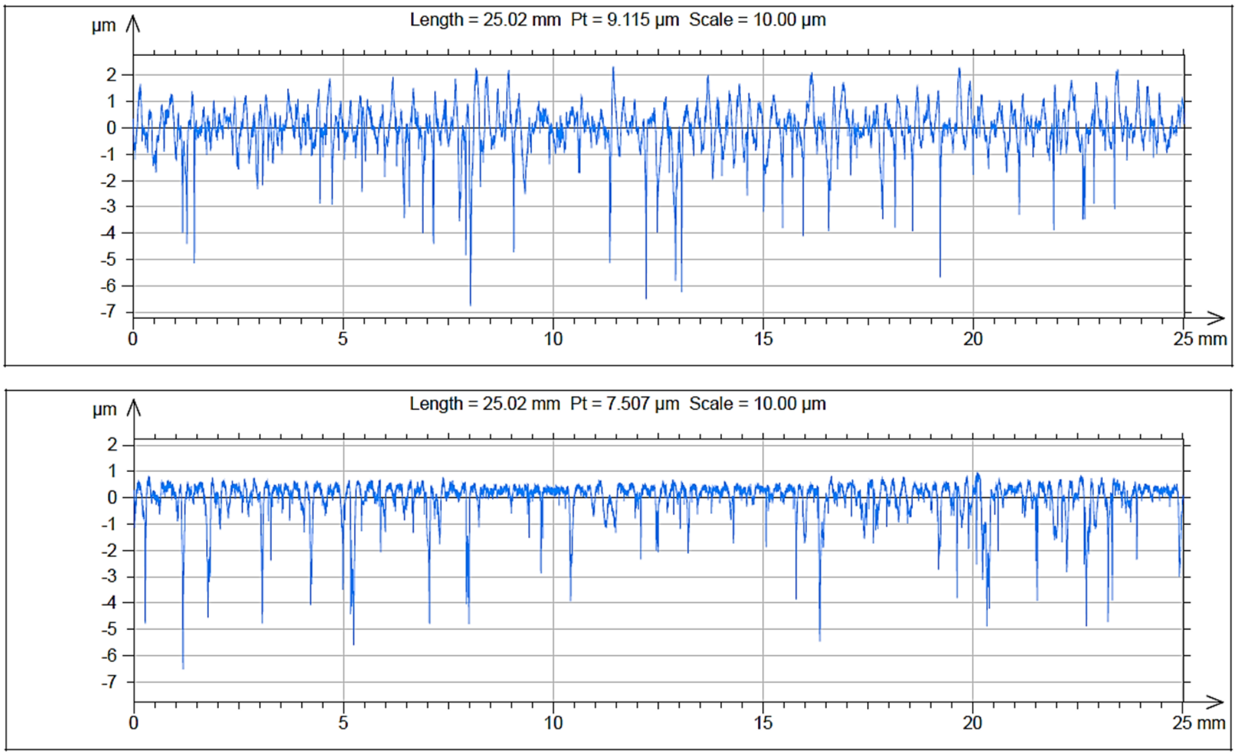

Figure 4. Roughness profiles of the anodized layer in the initial state and after 180 lapping cycles with diamond slurry D6

2.3. Machining experiments

The axes of the CNC system of the surface grinding machine are used both for positioning the lapping tool and for the relative movement between lapping tool and workpiece during the lapping process.

Before machining, the nominal normal lapping force is set using a laboratory balance by shifting the weight on the balance beam of the lapping device in the horizontal position of the lapping tool. The workpieces were fixed on the magnetic clamping plate with a manual device.The cylindrical axes of the workpiece and the lapping tool are set parallel to the x-axis of the grinding machine.

The lapping tool is brought into contact and aligned symmetrically to the workpiece in the x-z-plane. In this position the coordinates for the workpiece coordinate system are taken over and the CNC program is started.

The relative movement between lapping tool and workpiece during the lapping process is carried out by the x- and z- axis according to the tool path in Fig. 3. The lapping process was carried out in several process steps with manual feed of the diamond slurry.

2.4. Surface measurement

The shape accuracy and the roughness of the workpieces were measured with a tactile profilometer (3D-measurement for shape accuracy /cylindricity, 2D-measurement for straightness of the surface line, circular shape of the peripheral line and roughness).

From the raw data of the 3D measurement, the cylinder shape was removed to compute the radius of curvature and the shape deviation. Based on the roughness profiles the parameters R_z, Ra, Rp and Rv as well as the amplitude distribution and the Abbott curve were computed (robust Gaussian filter $\lambda c = 0.8$ mm).

3. Experimental results

The machining tests were performed with oil based lapping slurries / diamond grain sizes 12 µm/ 9 µm/ 6 µm, the results in this paper were achieved with the grain size 6 µm. The surface measurements were carried out in the initial state and after 20/ 60 /100 /140 and 180 cycles (overruns).

A specific property of the anodized aluminium layer is its porosity with a relatively large number of pores, which are affecting the results of the surface measurements (Fig. 4). This influence was considered by the selected filter type.

During the lapping process the abrasive action of the diamond grains is concentrated on the peaks of the surface topography, whereas the pores are hardly affected. This means that the topography is smoothed from the top. The abrasion of the peaks in combination with the existence of pronounced pores lead to typical curve characteristics of the roughness parameters (Fig. 5).

The parameters Rz and Rp decrease due to the removal of peaks. The reduction of the parameter Ra is less marked. Since

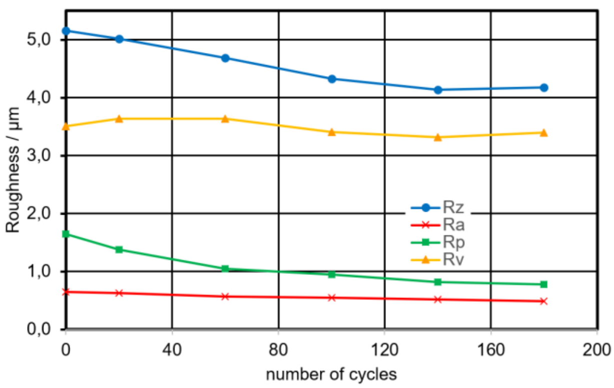

Figure 5. Roughness parameters of the anodized layer as a function of the number of cycles in the lapping process

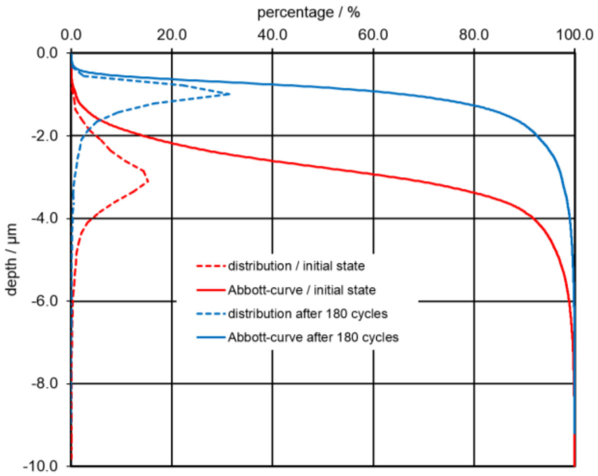

Figure 6. Amplitude distribution and Abbott-curve of the roughness profiles of the anodized layer in the initial state and after 180 lapping cycles

the parameter Rv is primarily defined by the deep pores, its value remains practical unchanged.

The comparison of the amplitude distribution and the Abbott curve for the initial state and the surface after 180 lapping cycles shows that the amplitude distribution becomes noticeably smaller and the Abbott curve is steeper and shifted upwards as a result of the smoothing, which is in accordance to the roughness parameters (Fig. 4-6). The lapping process significantly improved the shape accuracy of the components (cylindricity, Fig. 7).

4. Conclusions

Slightly curved cylindrical surfaces of mechanical components made of aluminum, anodized with a layer of about 25 µm thickness were machined by a CNC system using a special lapping device and deterministic relative motion between workpiece and lapping tool. According to the specific structure of the anodized layer characteristic curves of the roughness parameters Ra, Rz, Rp and Rv were determined during the machining process. The lapping process substantially improved the shape accuracy of the components (cylindricity).

The deterministic relative motion between lapping tool and workpiece can in principle lead to deterministic shape deviations of the workpiece surface, which can be compensated for by adapting the CNC program of the tool path.

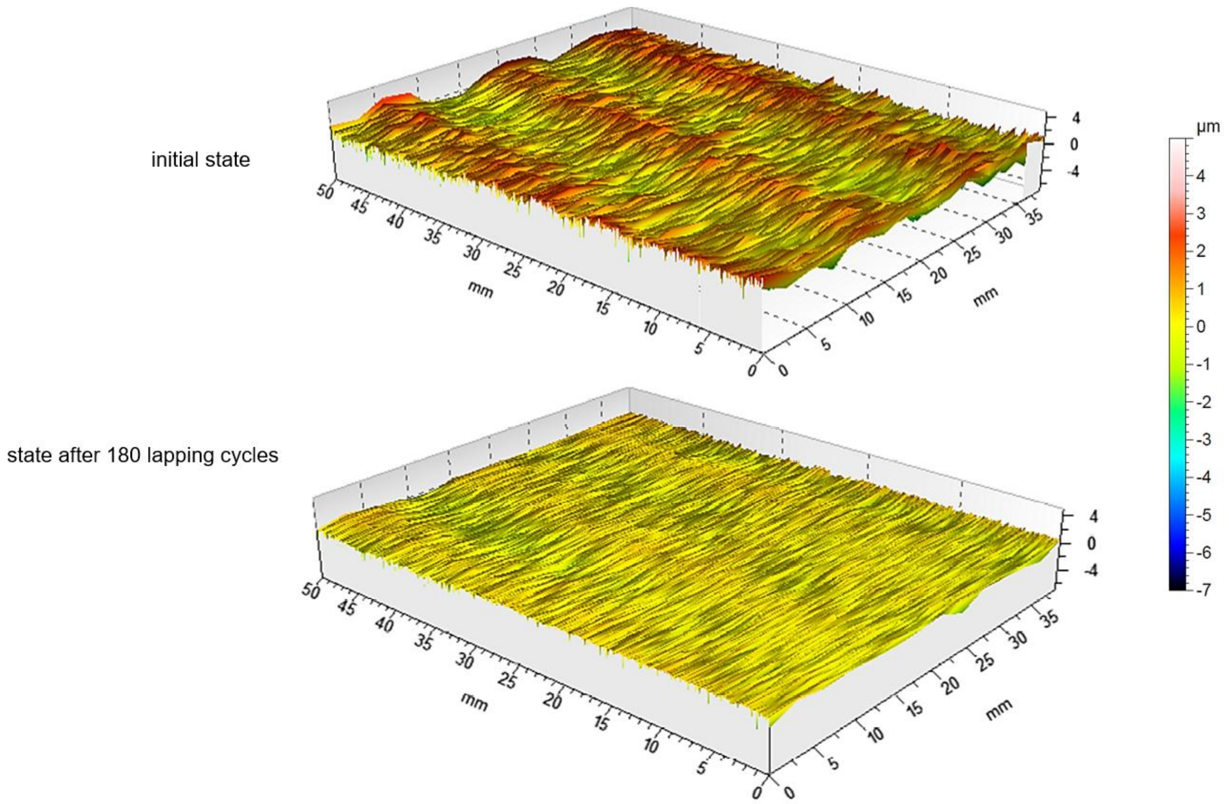

Figure 7. Comparison of the shape accuracy of the surfaces in the initial state and after 180 lapping cycles (cylinder with R = 669.7 mm removed)