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K. Hecht / J. Bliedtner / H. Müller / T. Schmidt

Optimisation of the laser polishing process concerning process parameters and available glass surface quality

Functionalization of Material Surfaces

Summary: Compared to traditional polishing methods the laser beam is small, flexible and fast. With laser radiation it is possible to finish many outlines or geometries on quartz glass surfaces in the shortest possible time. Start with 600nm for example just one machining step is necessary to achieve a surface quality below 10nm. It's a fact that the temperature developing while polishing determines the reachable surface smoothing and, as a negative result, causes material tensions.
To find out which parameters are important for the laser polishing process and the surface roughness respectively and to estimate material tensions, extensive experiments took place. During these experiments starting and machining parameters were changed and temperatures were measured contact-free.
The results should enable the optimisation and automation of the polishing process and reduce time and tensions.

1. INTRODUCTION

The Optimisation of the process parameters should be carried out by measure temperature and surface quality. This quality is detected by the help of a stylus instrument and exemplarily with AFM-pictures.
From state of the art methods of polishing surfaces with laser radiation are already known. So it is possible for instance to reduce processing time of metallic injection moulding moulds from 30min/cm² to a few seconds per cm² [1]. Also in the field of polishing cast materials good surface qualities were reached [2].
The laser material processing of glass has made good progress whereas the high-precision finish (especially on optical parts) causes still problems. It is barely possible to reach constant good surface quality without creating thermal tensions [3].
To finish the quartz glass parts in this present report a 1.5kW CO2-laser is used. This one is well appropriate because the absorption of CO_2-radiation in quartz glass is near

100%. The glass polishing is carried out by a regional short melting of a thin surface layer with a defocused laser beam. Using laser power adjusted accordingly stock removal is prevented and the smoothing of the surface happens just because the surface tension of the melting layer. This tension is responsible that the profile peaks were levelled and the profile valleys were filled. The depth of melting is about 0.1mm. The analysis should also show, how and how much the starting roughness (Ra_1) and the changeable laser parameters influence the surface quality (Ra_2) in the end. It is also interesting how the parameters have to be changed to reach requested roughness values.

2. EXPERIMENTS

Figure 1 show the experimental setup which is used during the analysis. It is a portal system where the laser beam is coupled in and leaded over different mirrors to a scanner system. A mirror in this scanner is used to move the beam in lines with a maximum speed of v_s=3m/s. Because of this high deflection velocity a polishing line is generated on the glass part. The parts (you can see at the right hand side of Fig. 1 during finishing) have a size of (20x20x~3)mm.

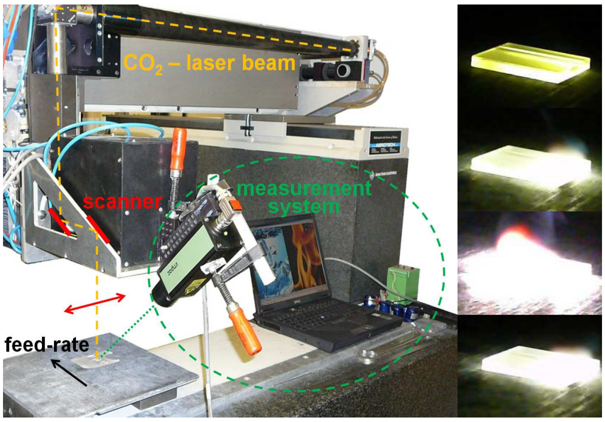

Figure 1: Experimental setup – laser and measurement system; polishing process

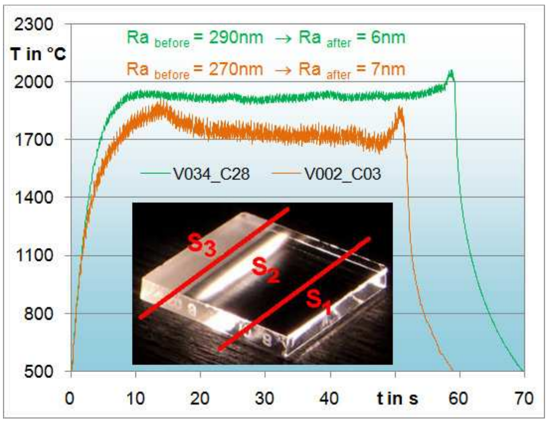

Figure 2: Optimisation of temperature curve; roughness

The feed rate v_f is realized entirely with the axis of the portal system and is diversified in different sections (s_1, s_2, s_3). The measuring spot of the pyrometer for the temperature recording is carried constantly along behind the laser line. The measuring system detects the surface temperature with a sampling rate of 250ms. The developing temperature curve is used for the optimization of the process parameters.

In Fig. 2 two temperature curves are visible exemplarily. The task is it first to adjust the parameters feed rate and length of the polishing sections (s_1, s_2, s_3) in a way, that the temperature rises steep (s_1), stays constant during the finishing process (s_2) and has just a small temperature peak at the end of the part (s_3). The steep rise guarantees that enough energy is inserted to have a good finishing result from the beginning. To reach uniform polishing results, the constant temperature along the whole surface is deciding. To prevent unnecessary additive tensions in the material and rounding the rear edge of the part a heat accumulation has to be avoided. As you can see regarding curve V034_C28 it's possible to improve the unfavourable temperature distribution from trial V002_C03 by optimize the feed rate in the three sections.

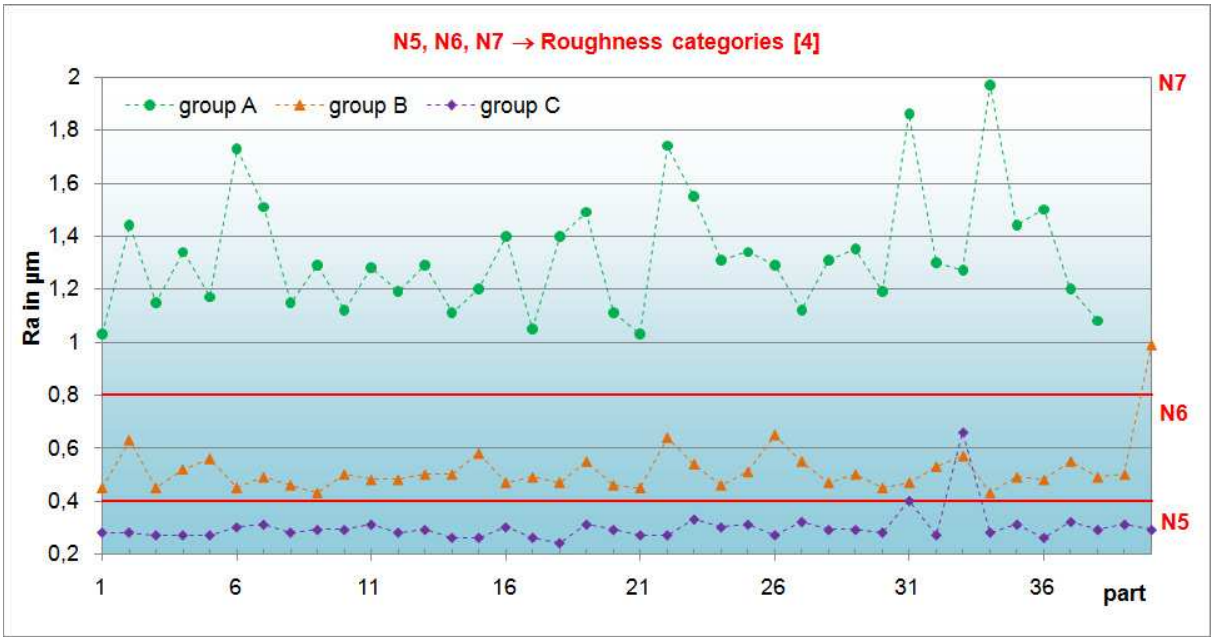

Figure 3: Classification of the parts on the basis of the roughness categories [4]

Beside the temperature the surface quality is a criterion for process optimisation. To check the influence of the starting roughness Ra_1 (before finishing) the parts were divided in 3 roughness groups (Fig. 3). The optimisation of the process parameters is carried out in every group.

During the experiments the following parameters were changed:

- feed rate v_f in 3 sections (already discussed)
- laser output power P, 400...700W
- beam velocity v_s, 400...1000 mm/s

3. RESULTS

After more than 120 tests the influences of the machining parameters and the starting roughness could be studied in detail. Altogether it turned out, that the reachable surface quality depends on the starting roughness. This connexion gets very obvious regarding group A (roughness category N7). It is actually observed that it is not possible to polish the parts of this group well without stock removal. Therefore the parts of group A were no longer considered in this paper.

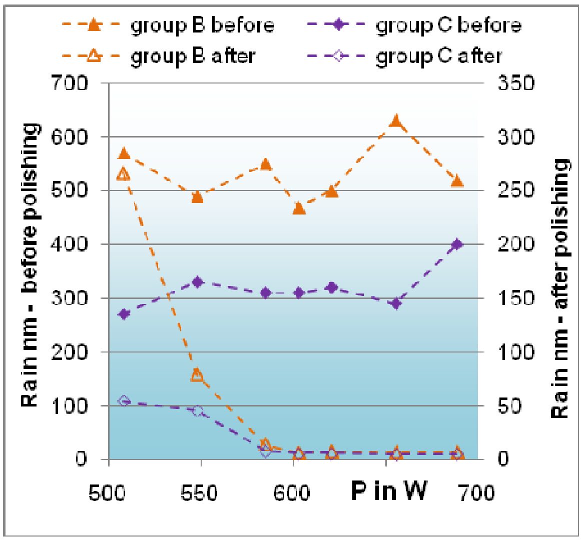

Figure 4: Surface quality depending on laser output power

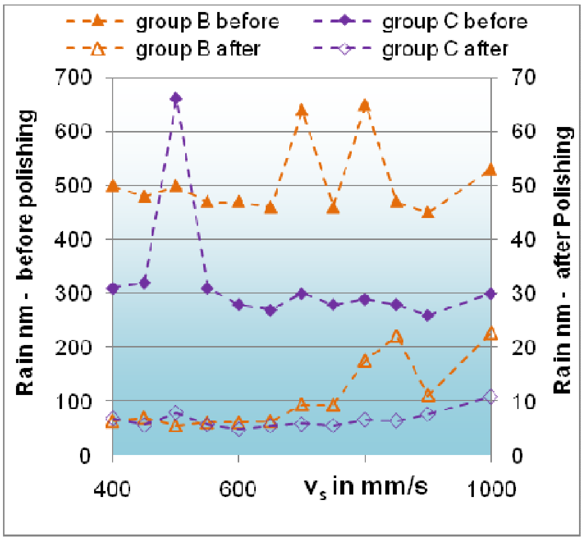

Figure 5: Surface quality depending on laser beam velocity

The influence of the starting roughness changes also with variation of the other parameters. Regarding the dependency of laser output power on Ra (Fig. 4) there is no connexion between starting and final roughness visible at all. Clearly observable is that with increasing laser output power the surface is smoothed more. In the areas of high laser power there is already stock removal because of sublimation. The thickness of the removed layer is between 50 and 10µm.

The laser beam velocity v_s, the speed with which the beam is guided over the surface has also an effect on the reachable surface roughness. The influence of the starting roughness stays partly important while diversifying the laser beam velocity. Considering Fig. 5 it gets obvious that the distribution regarding Ra changes only frictional.

With higher v_s less energy is inserted into the glass parts at all and so the smoothing of the surface abates. However it seems that (between the chosen limits) the beam velocity has no such significant influences on the polishing results as the laser output power for example. It is necessary to check the limits of the influence of v_s in further experiments.

Over the entire time of experiments the temperature curves of every polished part were recorded too. They have to be optimised for each group of parts by changing the feed rate in the three sections. Afterwards their appearance doesn't change much. Just the relation of the parameters (P, v_s) and the maximum temperature (T_{max}) seems still interesting. Due to the pyrometric temperature measurement the measured values do not reflect the real temperatures in the interaction zone on the glass surface. It is not possible to measure these temperatures contact-free so far. But it is assumed that the temperature in the interaction zone is about 2230°C – the vaporisation point of quartz. That's most likely because there is always a light steam of sublimate while polishing.

The temperature measure point is selected in a way that it is located always short behind the polishing line. Because the thickness of the parts is not constant for each group the pyrometer has to be adjusted time and time again. From this it fallows that the distance between measuring spot and interaction zone changes slightly. But even the smallest change of this distance leads to variations of the measured temperature values. That's why the position of the curves is not significant but their appearance however is. Figure 6 shows the curves of T_{max} in relation to laser output power (left) and in relation to beam velocity (right).

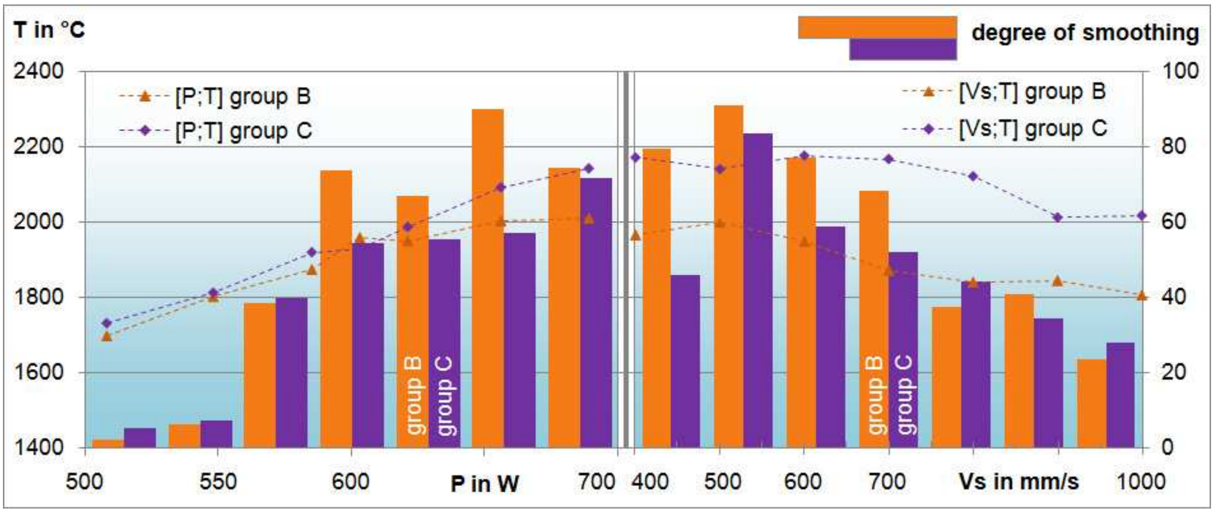

Figure 6: temperature and degree of smoothing depending on P (left) and v_s (right)

It becomes obvious that with increasing power the temperature rises. Against that a higher beam velocity causes a lower maximum temperature. The degree of surface smoothing (Ra_1/Ra_2) follows the temperature profile so far. The outcome of this is that the measured temperature value can be used for process monitoring.

Tests for process automation have just begun. The aim is it to observe the temperature continuously (online) and adjust the process parameters according to the temperature profile. Regarding the results from earlier experiments the laser output power seems to be an interesting parameter for automation. It has the most significant influence on surface temperature and quality. So a laser control system was installed with the task to control laser power. In Figure 7 you can see a schematic of the interconnection of the devices which were needed for process control. It is not necessary to describe all technical details of this control unit because it isn't part of the investigation. This unit was constructed for different control tasks and this is just one example of using it.

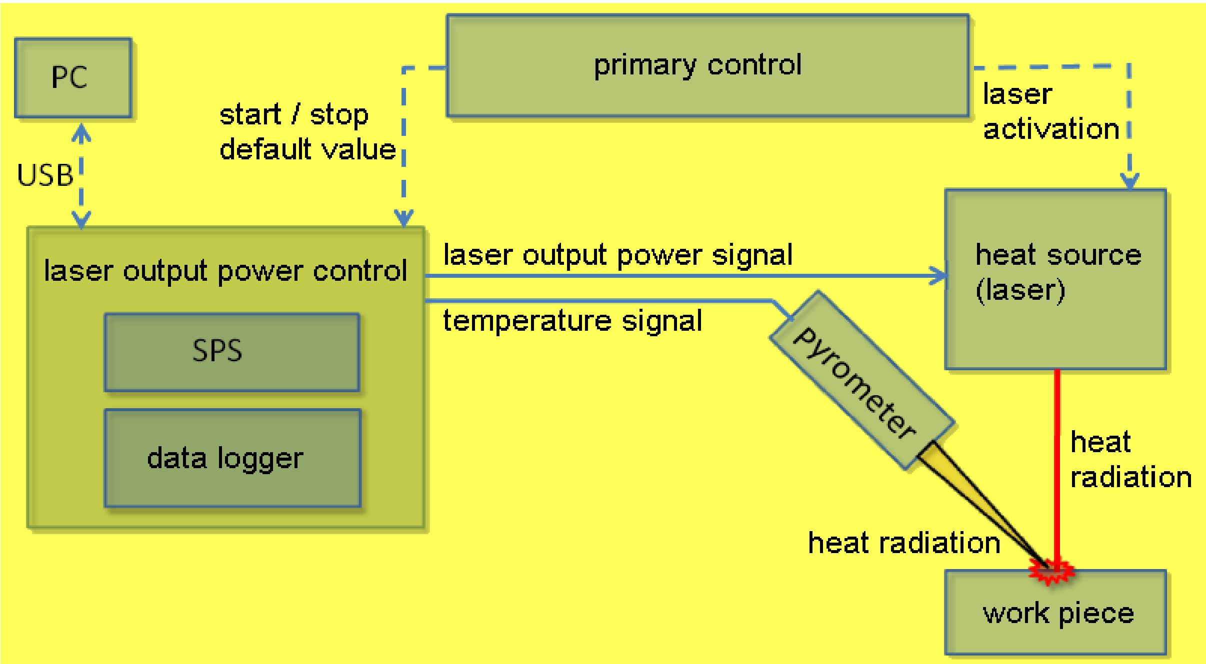

Figure 7: interconnection of devices, schematic [5]

Return to the present analysis it is important to know, that the control unit works on basis of temperature measurement data. The temperatures symbolise corresponding laser power values. The pyrometer is connected with the control unit and the unit has a connection to the laser system. You can determine a temperature (power) control routine. In this case you teach times and temperatures to the control unit and the laser output power would be adapted accordingly. So there is a permanent comparison between the measured temperature value and the selected. [5]

To apply the control system there are some problems to solve. Remember the measuring point of the pyrometer. It is adjusted short behind the laser polishing line. This “line” is created because the laser spot needs only 50ms to pass over the surface. The pyrometer detects the surface temperature with a sampling rate of 250ms. So the laser spot is sometimes nearer and sometimes farther the measuring point which leads to different measured values. The control system would adapt the laser output power permanently. You’ll get no constant surface temperature. It is necessary to average the measured values. This is done according to the FIFO-method with the control system too. So the system works with an average value out of 10 measured values.

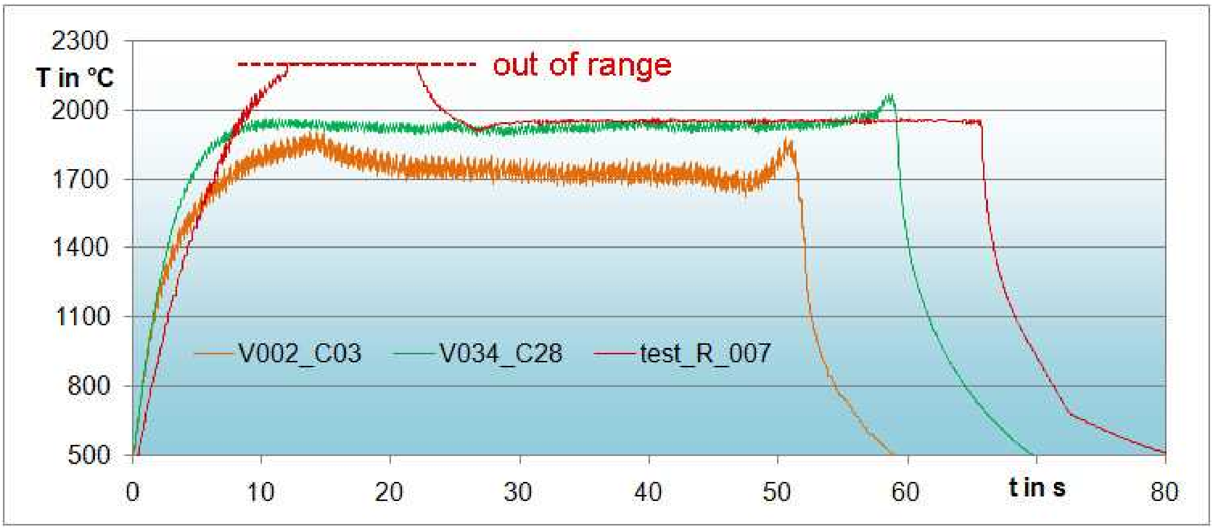

Figure 8: temperature distribution with and without control unit

Regarding Figure 8, the red curve, you can see that it is possible to realise the whished temperature distribution (steep rise, constant while polishing, no peak in the end) without different parameters in different polishing sections using the laser control system. This picture shows regrettably another problem still to solve. In the beginning it takes too much time until the control unit and/or the pyrometer recognise the developing surface temperature. It even rises out of range and there is a lot stock removal. On the other hand the laser control is able to keep the temperature within a limit of 25K.

To solve the problem of overheat maybe different measuring spot positions could be tested. Lay the spot into the polishing line to reduce the influence of heat conduction is one possibility. But altogether further investigations have to fallow to solve these problems. In addition it would be also necessary to develop and apply a construction to hold and adjust the pyrometer high precisely.

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