Abrasive Vibration Polishing of Complex Molds

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Abstract

Optical and medical industries are demanding a large variety of optical elements exhibiting complex geometries and multiple opto-functional areas in the range of a few millimetres [1]. Therefore, mold inserts made of steel or carbides must be finished by polishing for the replication of glass and plastic optics [2]. Due to the mold insert's complex geometry, state-of-the art fabrication is still a time consuming and hence an expensive manual polishing process. In this paper the authors present the development of a new abrasive polishing process for finishing complex mold geometries to optical quality. First, the vibration polishing concept and a classification of applicable vibration motions with their feasibility for the machining of certain geometries will be presented. In the following, the modification of a conventional polishing machine is presented.

1 Vibrational motion for polishing complex geometries

Especially for plastic optics a trend can be seen that one component must fulfil many functions, which lead to complex part geometries. Hence, the mold geometry must have the same complexity as the replicated optic. To machine these molds a process with rotational polishing pads is not applicable. Today these complex mold geometries are not machinable in automated processes, so often expensive hand polishing is necessary.

In the proposed abrasive polishing process the required relative velocity between polishing pad and workpiece surface is realized by linear vibrations. The absence of rotation of the pad opens up the possibility to machine new types of surface geometries.

In vibration polishing different kinematics are applicable depending on the workpiece geometry which have a direct influence on the polishing result. In principle the possible motions are single axis or two-axis vibrations with a superimposed feed motion of the polishing tool, as shown in figure 1.

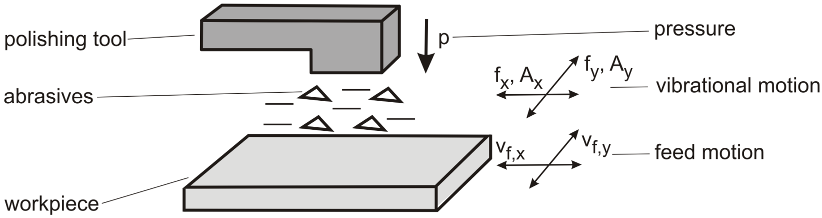

Figure 1: Possible kinematics and feed motions of a two-axis vibration polishing process

Due to the substitution of the rotational motion of the polishing tool by a vibrational motion, a larger variety of workpiece geometries is machinable, e.g. finite grooves, or cavities (cf. figure 2). The polishing pads can be adapted to the shape of the functional surfaces and may have a larger contact area compared to rotary profile polishing.

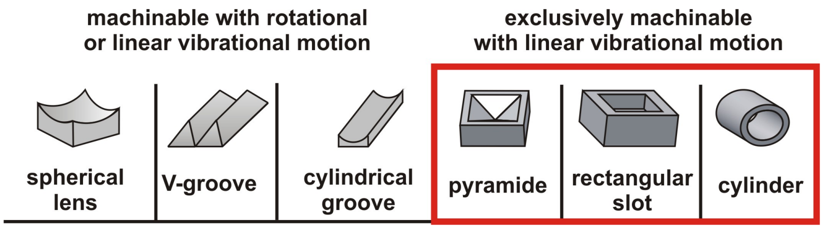

Figure 2: Examples for workpiece geometries for abrasive vibration polishing

2 Machine-tool set-up for vibration polishing

The experiments were performed on a modified Precitech M300 aspheric polishing machine with three linear axes. The vibration polishing device is powered by a voice-coil actuator, shown in figure 3. With this set-up, vibration frequencies of about $f = 50$ to 200 Hz are achievable with an amplitude up to $A = 0.25$ mm. Typically a surface roughness $Sa < 5$ nm is achieved on hardened steel with a vibration frequency of $f = 100$ Hz, an amplitude of $A = 0.25$ mm and with hard wood as a polishing tool.

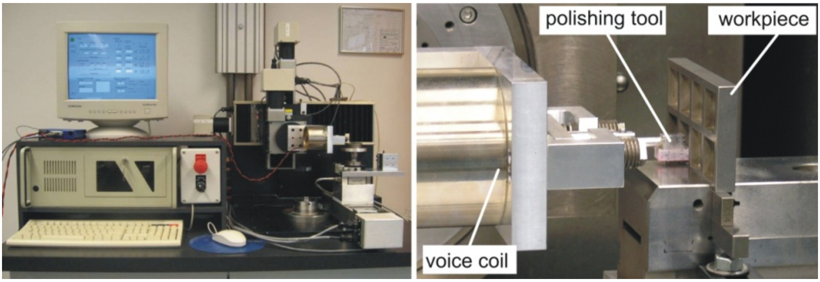

Figure 3: Modified aspheric polishing machine for abrasive vibration polishing

3 Characterisation of the vibration polishing process

In order to investigate the validity of Preston’s hypothesis on the linear dependence of the material removal rate

$$\frac{dz}{dt} = k_p \cdot p \cdot v_r$$

for the novel vibration polishing process, where k_p is Preston’s coefficient [3], the polishing pressure p, polishing time t and relative velocity v_r, were varied in polishing experiments with hardened steel samples. The polishing system consisted of a synthetic felt pad and an oil-based polishing suspension with diamond abrasives with an average grain size of 1 µm. The experiments were repeated four times.

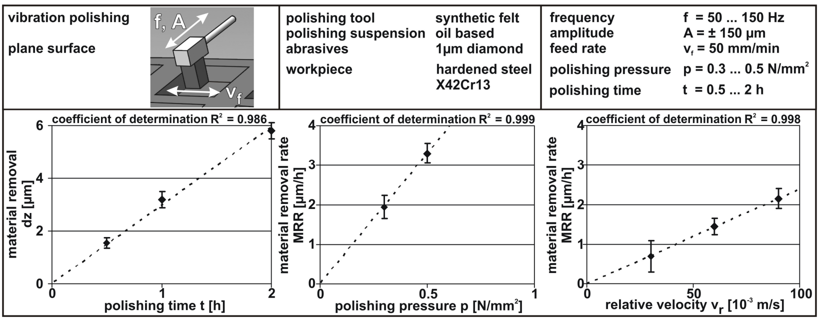

Figure 4: Testing of the Preston hypotheses for abrasive vibration polishing

Figure 4 (left) shows the linear increase of the material removal dz over polishing time t. The coefficient of determination R^2 = 98.6% indicates that the material removal is a linear function of the polishing time t, with a high degree of confidentiality. Figure 4 (center) shows the linear behavior of the polishing pressure, confirming the validity of Preston’s equation for vibration polishing.

The average relative velocity between polishing pad and workpiece is calculated from the total distance s and time t for one vibration period. The polishing pad covers $s = 4 \cdot A$ (amplitude) during one period of oscillation. Hence, the value of relative velocity is calculated by

$$v_r = \frac{ds}{dt} = \frac{4 \cdot A}{f^{-1}} = 4 \cdot A \cdot f \ .$$

The material removal rate was examined in dependence of the frequencies f = 50 Hz, 100 Hz and 150 Hz. It is evident from figure 4 (right), that a linear dependence of frequency - and thus, also the relative velocity - and the material removal rate applies. Therefore, the Preston equation can be applied to vibration polishing within the analysed parameter range without restriction.

4 Summary

The new developed abrasive vibration polishing process is applicable to complex mold geometries due to the substitution of the rotational pad motion by a vibrational motion. It was shown that the Preston hypothesis, which is valid for conventional abrasive polishing processes, also applies to vibration polishing.

Acknowledgement

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