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Thermal characterization of a micro polishing machine and effect on path strategy compensation

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Abstract

Micro polishing is an important process when fine surface quality and low form error are required in the micro scale domain. This process has several differences from conventional polishing and some of the factors can not be neglected any longer. In this work, a study on the thermal behaviour of a micro hexapod-based machine is conducted. The main causes of thermal deformations are addressed and analysed. The contributions are then evaluated and compensation path strategies are discussed. The main criticalities when dealing with micro polishing are due to the small tools used. Micro tools require higher speeds than conventional polishing. High spindle speeds generate heat and therefore thermal deformations. This adds up to the movement of the Hexapod while performing polishing. The observed total deformation in the polishing tool axial direction reached 8.2 µm. Such a large deformation can introduce a potential error in the final material removal up to 50% if not adequately compensated.

Keywords: Micro polishing, Thermal stability, Compensation

1. Introduction

Micro polishing is a manufacturing process that is required for several micro scale components [1]. It is able to remove from tens of nanometers to a few micrometers, achieving fine surface quality [2]. Typical micro polishing offsets are ranging between 20 and 100 µm and should remain constant in order to manufacture high-quality surfaces. To allow removal of material on such fine scales. the micro polishing system requires high performances relative to the positioning accuracy, system stiffness, dynamics and thermal behaviour.

This work focuses on the thermal behaviour of a micro hexapod-based finishing machine. The main causes of thermal deformation are analysed and discussed. A first analysis with the means of a thermal camera was conducted to determine the main sources of heat generation thermal expansion. The main contributors were found to be the lower part of the hexapod brushless motors and the bottom of the spindle. In this paper, we separate every single contribution and gives an estimation of the total deformation due to thermal expansion. The thermal characterisation introduced in this work enables path strategies compensation for accurate removal in micro polishing applications.

2. Hexapod-based finishing machine

The machine under study is a hexapod-based finishing machine developed at DTU (see Figure 1). The hexapod has six degrees of freedom being driven by six brushless dc motors with a stiffness of 8 N/µm along Z-axis and 0.7 N/µm along X and Y-axis. The positioning resolution of the machine is of 0.1 µm along Z and 0.25 µm and repeatability of ±0.06 µm and ±0.15 µm along Z-axis and X and Y-axis respectively.

The Hexapod is mounted on a C structure where by means of a ball screw the coarse position along Z-axis can be adjusted to allow polishing of variable sample sizes. On the bottom of the hexapod is attached a spindle from Nakanishi with a maximum rotational speed of 80000 rpm.

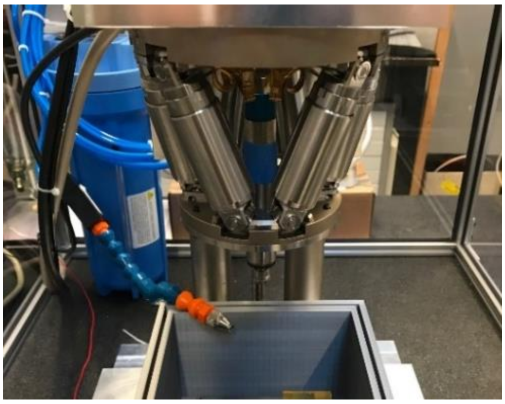

Figure 1. Micro finishing machine.

3. Experimental investigation

Based on a prior analysis the main contributors to the thermal deflection are expected to be the heat generated by the six brushless DC motors and by the spindle. To isolate the contribution of every source of heat, sequential activation of each contributor is performed until thermal stability is reached. Before activating each contributor a position measurement is taken. This is repeated five times when thermal equilibrium is reached to assess measurements repeatability. Moreover, a thermal camera is used to monitor the temperature introduced by each contributor.

Table 1. Sequence event for thermal deformation experiments.

Events Sequence		Time
Hexapod feed [deg/s]	4	2 hours
Spindle speed [rpm]	2000, 5000, 10000, 20000, 40000, 80000	30 min for each speed

The six brushless motors are turned on followed by the spindle. The hexapod performs a spiral motion with an angular feed of 4 deg/s around the Z-axis. After this main contributor had reached thermal stability, the spindle was turned on. Speeds ranging from 2000 to 80000 rpm were investigated. Thermal stabilisation was reached before starting a new test.

3.1 Thermal camera and displacement sensors

Temperature measurements were conducted with a microbolometer array thermal camera, Optris PI 640. The instrument sensitivity is 74 mK. Thermal measurements were carried out through the entire experiments duration, acquiring both the heating and the cooling phases. The sampling rate used for the temperatures acquisition was 0.5 Hz.

Displacements due to thermal deformations were measured using a fixture with three inductive probes arranged to form a Cartesian reference system, see Figure 2 (a). The displacement sensors are the TESA GT 22, characterized by a nominal resolution of 0.01 µm and an MPE of (0.2 µm + 3*ΔL^3), with ΔL travel of measurement. Vacuum pumps were employed to retract the probe tips and displacements due to thermal deformations were measured.

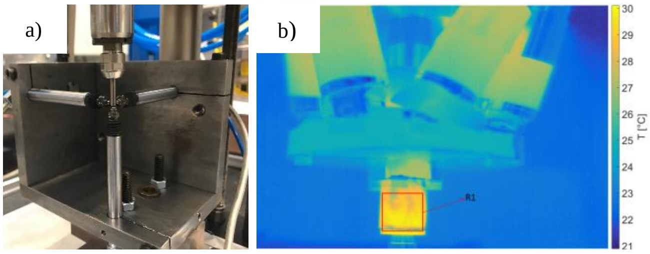

Figure 2. a) Displacement sensors, b) Image from the Thermal camera of the finishing machine with the spindle rotating at 80000 rpm.

4. Results and discussion

The observed deformations in the three axes at thermal steady state when the hexapod motors are activated are shown in figure 3. Also in figure 3, the displacement contribution at steady state for every spindle velocity tested can be observed. The spindle speed has the largest effect on thermal deformations. The displacement along the Z-axis results to be the major one, with a monotonous increasing trend up to 8.2 µm. Along the Y-axis, the displacement increases until 5000 rpm and it decreases for higher spindle velocity. This trend is explained by the C-shape structure geometry and by the relative temperature gradients in the structure, originated from the spindle-generated heat and the differential air convection. In the X-axis the total displacement and therefore the resulting thermal deformation results to be negligible due to the symmetry features of the setup.

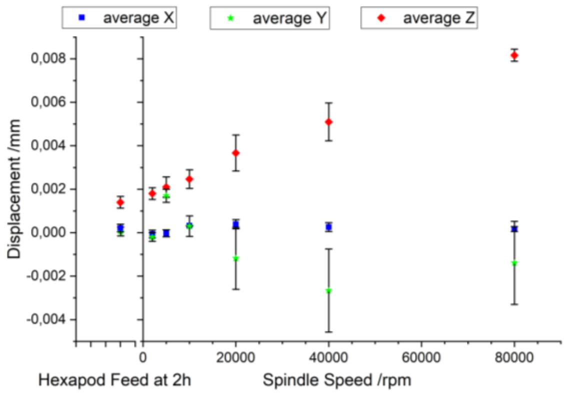

Figure 3. Thermal-induced deformation moving the hexapod along the three orthogonal axes and with different spindle speeds

Analysing the heating temperatures' trends, a correlation between the relative deformations along each axis and the related temperature was found. The average hottest temperature was found to be the region R1 of the spindle, see Figure 2 (b). This is used to find a correlation with the relative deformations, see figure 4.

In figure 4 the relation between the variation of temperature during the 30 minutes of heating versus the total deformation generated is shown. At low spindle speed values, the thermal variation is relatively small resulting in low displacements. Increasing the spindle speed, the spindle body and the part of the hexapod sustain a significant increase of temperature, resulting in a total maximum displacement of 7 µm along Z-axis.

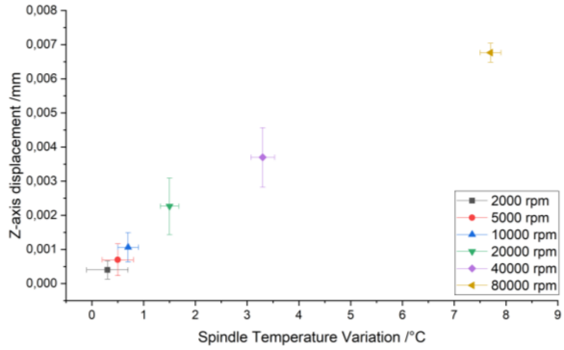

Figure 4. Displacement at different spindle speeds along the Z-axis as function of temperature.

Such deformations cannot be neglected in micro finishing and compensation strategies must be taken into account. A typical offset in micro polishing ranges between 20 and 100 µm, depending on the tool and the sample material. Thus, if the nominal working offset is not properly compensated an error of up to 50% on the material removal is generated. With a full characterisation of the thermal dynamics of the machine, the offset or the total dwelling time can be changed to keep a stable condition during polishing.

5. Conclusion

A thermal characterisation of a micro finishing machine was conducted. The main source of thermal deformations was found to be the spindle. At rotation speeds lower than 5000 rpm, the cooling system of the spindle results to be effective while at higher speeds, up to 8.2 µm of deflection along Z-axis is generated. This deformation cannot be neglected any longer and it has to be taken into account prior to polishing operations. The thermal characterisation enables a thermo-mechanical compensation of the deflections during polishing. Path strategy compensation requires the tuning of the real offset or the dwelling time to keep the optimal polishing conditions. This can be achieved by controlling the robot position with a feedback signal being the thermo-mechanical characterisation.

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References

[1] F. Klocke *et al.*, "Deterministic Polishing of Smooth and Structured Molds," pp. 99–117.

[2] A. Beaucamp et al. "Finishing of optical moulds to λ/20 by automated corrective polishing," *CIRP Ann. - Manuf. Technol.*, vol. 60, no. 1, pp. 375–378, 2011.