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Research advances and steps towards the control of geometric deviations in the surface grinding of big components

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ABSTRACT

Achieving and maintaining geometrical accuracy is nowadays the main limiting factor to accomplish an efficient manufacturing process in the surface grinding of big components. The present paper shows a deep research work carried out by means of experimental measurements of shape deviations, infrared pictures of the temperature field distributions and corresponding FEM simulations that confirm the thermal origin as one of the main limiting factors. A deeper investigation about the influence of the environment and cooling conditions, constraints imposed by part clamping and the grinding conditions reveals that the compensation and even control of thermal effects is possible by combining IR monitoring, modeling and simulation, although still being a challenging methodology.

1. Introduction

In metal cutting operations a workpiece geometry is influenced by mechanical and thermal loads. For the understanding and compensation of geometrical shape errors, scientists investigate their influences on the workpiece shape and machine geometry. As a result, it can be said that 75% of the overall geometrical errors of machined workpieces can be induced by the effects of temperatures on the machine and workpiece [1,2]. Other influences are the static and dynamic forces applied on the machine and workpiece and process induced/relieved residual stresses [3].

In surface grinding, where high surface quality and precise dimensional and geometrical accuracy are required, geometrical inaccuracy of the workpiece has been thoroughly investigated, being of particular concern the thermal deformation of the workpiece due to the big amount of heat-generation during the process [4–7]. It was observed that the temperature-gradient induced within the workpiece during grinding generates a large thermal bending moment. Due to this thermal moment, a transient convex profile of workpiece is over-ground during the grinding process. Therefore, the resultant workpiece profile is concave after having cooled down (see Fig. 1).

Nakano [4] was the first one noticing and experimentally studying this effect. He used the finite element method (FEM) to analyze the two-dimensional steady-state temperature distribution of the workpiece in surface grinding, and pointed out the aggravation of the phenomenon due to the progressive heating of the workpiece and the generation of a higher temperature-gradient in successive grinding passes. He showed that the temperature rises following an exponential curve with the number of grinding passes, ultimately reaching more or less constant values. His simulations and experimental results also showed that the longitudinal temperature distribution and the obtained workpiece shape are asymmetrical during the first grinding passes and tend to be symmetrical as the close-to-steady-state final values are reached. He also compared dry and wet grinding results revealing the relevance of cooling conditions in order to diminish this adverse effect.

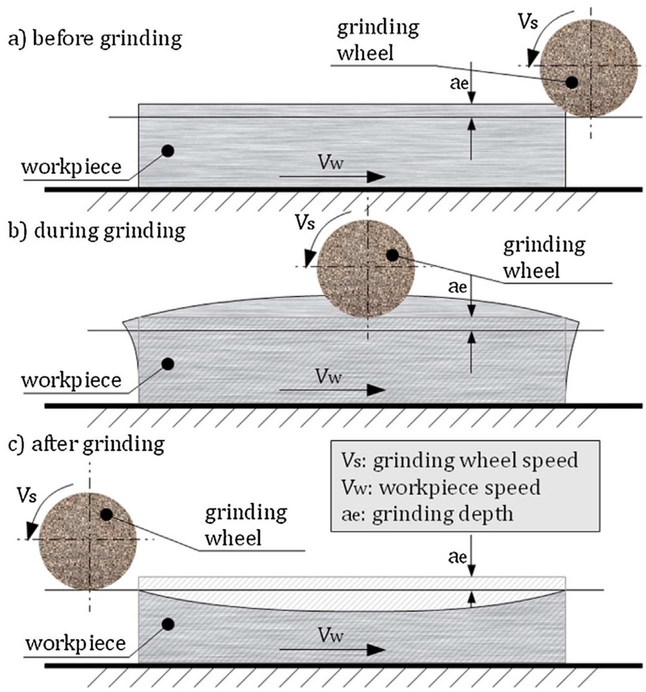

Fig. 1. The mechanism of the concave formation of the workpiece ground surface [8].

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Further works in the literature [5–7] agree with Nakano's conclusions and illustrate how the thermal deformation of the workpiece can be predicted by different modeling approaches. As mitigating tips for this effect, it is pointed out that enhanced heat convection to the coolant [5] and the attraction force of the magnetic chuck [6] can reduce the deformation.

However, it is in general common in the reviewed literature to circumscribe the analysis of this problem to rectangular or beam-shaped relatively small parts, targeting just longitudinal or transverse deviations. Further extension of this problem to arbitrary deformations in three dimensions (3D) is lacking, which is of major interest in the case of complex geometries or the surface grinding of big components. In such cases, thermally induced geometric deformation phenomena may require successive grinding operations on some surfaces to achieve the final tolerances.

The aim of this work is twofold and oriented to the aforementioned large complex geometry components, being these: (1) to show that the origin of geometrical deformations in such parts is mainly thermal, providing a deeper understanding about the influence of the environment and cooling conditions, the workpiece geometry, the constraints imposed by part clamping, the relevance of the definition of optimal grinding conditions and grinding sequence strategies; (2) to show ultimately that the approach of combining IR monitoring and FEM simulation can be a promising technology for the prediction and reduction of thermal errors in grinding operations of large and complex geometry components.

2. Experimental examination of heat-induced shape deflections

Transient shape deflections have been experimentally analyzed on several tests carried out on a Gantry type surface-grinding machine where three different machine tool structural components have been ground (all cast iron):

Component 1: 3000 mm length milling machine RAM
Component 2: 3400 mm height milling machine column
Component 3: 8000 mm length grinding machine bed

In the following lines test description and results obtained on the experiments carried out over Component 3 are detailed. Processing of Component 3 involves surface grinding of 8000 mm length V and Flat shaped guides (see Fig. 2).

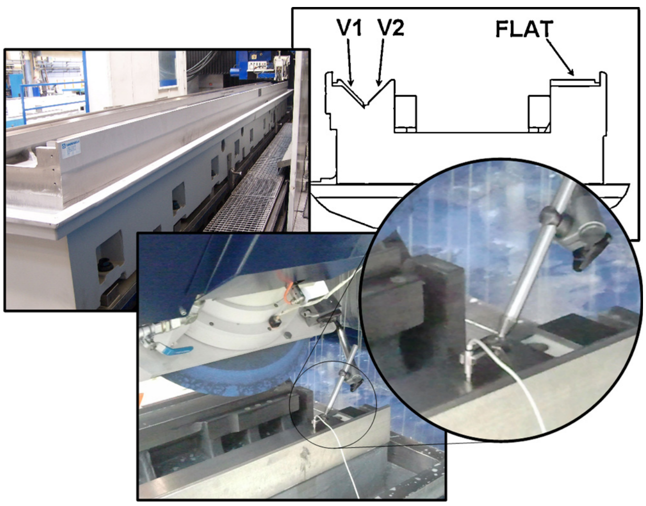

Fig. 2. Surface grinding of 8000 mm length V and Flat shaped guides on grinding machine bed. Flatness measurement using capacitive probe.

Grinding conditions employed during the tests are:

- Table feed speed: 25 m/min.
- Stock removal in each roughing pass: 0.01 mm.
- Total stock removal: number of passes over each surface depends on the stock left by previous milling operations and the amount of material to be removed to achieve the required dimensional tolerances.
- Grinding wheel speed: 27 m/s.
- Grinding wheels: flat guide: 55N46H15VPH902W V guides: 93A46H15VPH601W.
- Cooling conditions: 150 l/min (coolant at room temperature oriented towards contact point).

Room temperature and coolant temperature were kept under control at all times (within ±1 °C). Initially workpiece and machine were stabilized at room temperature and machine warm up was carried out. Prior, during and after each grinding operation, part surface temperature was measured by means of thermocouples and/or infrared (IR) camera. Due to the characteristics of the material, low temperatures and no changes in surface properties of the measured and compared bodies, temperature, emission angle, and wavelength dependence of emissivity has been neglected. Straightness and flatness of guides were measured using dial indicators, capacitive probes and laser interferometer.

2.1. Operation description and experimental results

- First operation: V1 (external side of V guide) is ground. Straightness of V1 just after this operation is 7 μm with a convex shape (outwards) (Fig. 3).
- Second operation: flat guide is ground. Heat generation and temperature gradient are noticeably higher in this guide than compared to grinding of V1. Flatness just after this operation is 5 μm. Straightness is measured again on V1 and rises up to 50 μm with a concave shape (inwards).
- Stabilization: 45 min. of stabilization with continuous coolant shower at room temperature is applied. Straightness of V1 is measured again and reduces to 4 μm with a convex shape (outwards). Flat guide's flatness provides a value of 15 μm (concave).
- Fourth operation: V2 (internal side of V guide) is ground. After this operation straightness of V1 is measured again and rises again up to 30 μm with a convex shape (outwards). Straightness

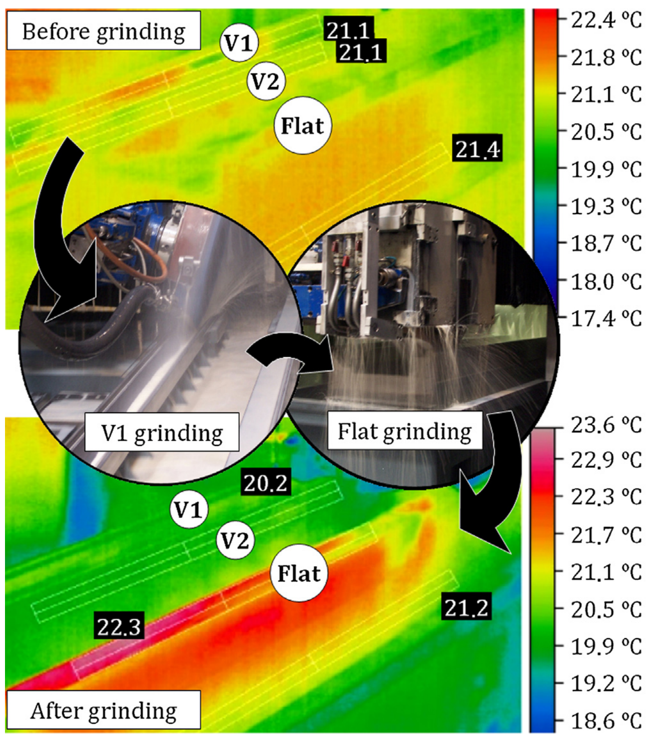

Fig. 3. Surface grinding of 8000 mm length V and Flat shaped guides on grinding machine bed. Temperature field distribution was monitored using an IR camera.