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Large-scale surface texturing by vibration assisted face milling

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Abstract

Surface texturing is a process of applying specific structures onto a surface in order to change its properties or visual appearance. In this paper an advanced machining technology is presented, enabling to machine user defined textures onto the component's surface on conventional CNC milling centres. The technology is based on a piezo-actuator driven face-milling tool, capable of tool tip displacements with a variable frequency up to 4000 Hz and a maximum amplitude up to 30 µm. The control system of the actuator is linked to the angular spindle position and the translational machine axes, allowing to determine the tool tip position in real-time and to freely manipulate the control signal according to that information. It is able to perform machining of large-scale and almost seamless texture areas and in the depth range from 2 to 30 µm. The dynamics of the tool enable a fast and controlled depth of cut variation during the cutting process while using process parameters applied in real-life industrial processes. This machining process allows to outperform the widely used laser texturing process by means of material removal rate in the specified process boundaries. The technology is demonstrated by machining of a texture with different geometrical features and will be evaluated on process time and resulting quality.

Surface texturing, face milling, fts, machining

1. Introduction

Either for changing the visual appearance or the properties, the demand for customized surfaces with a texturation is increasing. Currently a lot of manufacturing processes exists to influence the surface texture, but only a few of them are capable to perform user customized textures with non-stochastic geometrical elements. Machining based processes offer a high material removal rate and degree of customization. There exist various vibration assisted machining methods [1, 2]. They have all in common, that the workpiece has to be turned. This makes these methods limited in texture area, size, as well as workpiece size and mass.

The presented technology is capable of machining customized and geometrically defined structures on flat surfaces [3]. The operation itself is integrated in a conventional face milling process. This is made possible due to a special piezoelectric driven tool and a control system. So far only a limited area (along a feed lane) could be texturized by this technology. We demonstrate a method to combine these structures almost seamlessly to generate a surface texture on a large scale. A big advantage of this method is, that it can be used on conventional cnc milling centres, on any flat metal workpiece surface substituting the finishing process step.

2. Setup

2.1. Tool design

Texturing requires highly dynamic tool movements as well as a high stiffness. Thus, the used tool is actuated by a piezoelectric element. The controlled cutting of textures requires vibration frequencies below the eigenfrequency due to occurring phase shifts above this frequency range. The moving mass has to be as small as possible. For an active positioning in axial direction, the piezo ring-actuator is placed between a tool holder and a frame. The tool holder is mounted with two flexure hinges designed as steel spring membranes. The hinges themselves are attached to the frame. By means of this type of bearing, only one degree of freedom – namely the translation in axial direction – is possible. For the integration into conventional milling machines, a standard spindle connection (DIN 69893 HSK-A 63) for milling spindles is considered. The realization of the piezo-actuated tool is shown in Fig. 1. In order to reduce the moving mass, the tool holder is made of titanium. Since piezo actuators can only generate a force in one direction, the actuator is preloaded by a central disc spring assembly.

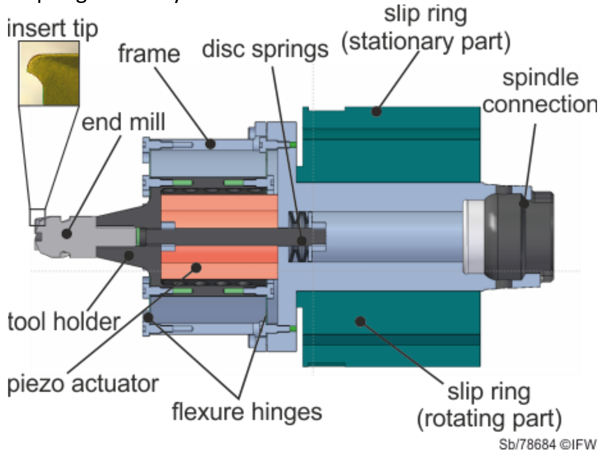

Figure 1. Sectional view of the piezo-actuated tool.

2.2. Process and control system

The texturing is performed by a single tooth face milling operation (20 mm face mill head) with an additional controlled vibration in axial direction. This movement results in a modulation of the depth of cut in the range of the possible piezo deflection (Fig. 2). The modulation is performed according to a pre-calculated piezo excitation signal, generated

by a control system and is dependent on the angular spindle and x-axis position. It is based on a grey scale image, representing the shape and depth of the texture.
In the beginning the image data has to be transformed into a structuring matrix. This matrix contains the deflection signals for each feed step depending on the angular tool tip position. The matrix size is predefined by the maximal deflections per revolution, cutting speed and feed rate. Following this, a Matlab/Simulink model processes the matrix along with the information of the angular tool position during the process. The start and end of texturing operation is triggered by a predefined x-axis position, this makes it possible to match textures elements between separate feed lanes. It is necessary to handle these signals in real time. Therefore, a dSpace real-time computer system is used to run the model. The system's sampling frequency of $f_s = 40$ kHz is set to decuple the maximum tool vibration frequency of $f_{struc} = 4$ kHz and to gain satisfying results regarding the processing load and smooth tool tip movements. There is no closed loop position control implemented yet. The output signal of the system is amplified by a high-voltage amplifier and send to the actuator.

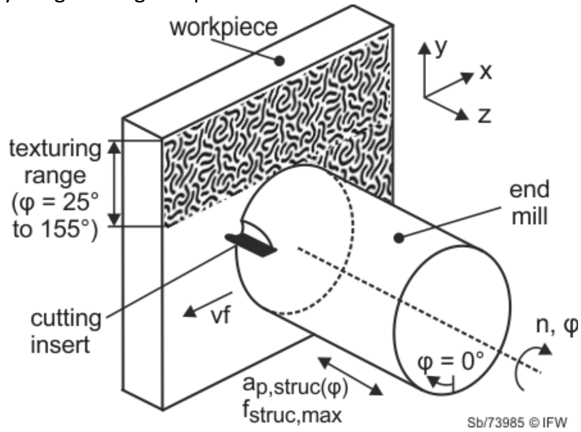

Figure 2. Tool kinematics.

3. Experiments

To demonstrate the capabilities of this method in regard of process time and quality, the texture shown in Fig. 2 was machined under different process parameters (Table 1) on a 5-axis milling centre DMU 125P duoBlock. The workpiece material was Al7075. As cutting insert SECO XOMX060202 was used with a special preparation as shown in Fig. 1. The varied quality relevant process parameters are feed rate f_z and the ratio of v_c/v_z. The texturing range is chosen to be between 25 to 155 degrees to minimize the influence of the changing feed width along the tool engagement angle.

Table 1. Process parameters.

parameter set	v_c [m/min]	$f_{struc,max}$ [Hz]	f_z [mm]	text. range [°]
A	37.7	2000	0.066	25-155
B	15.1	4000	0.02	25-155

The machined surface (Fig. 3) was measured optically with a NanoFocus µSurf System with a 10x lens. The measured data was post processed with a 3x3 median filter to remove measurement noise.

The measurement shows that the edges in the seam area do not show any offset between the feed lanes. However, due to the currently not optimized control strategy a small bar is visible. No shape distortion of the elements is visible. The edge accuracy depends primarily on the feed rate f_z and matrix resolution. The edge skewness is primarily influenced by the ratio between v_z and v_c and the enclosed angle between φ and edge tangent.

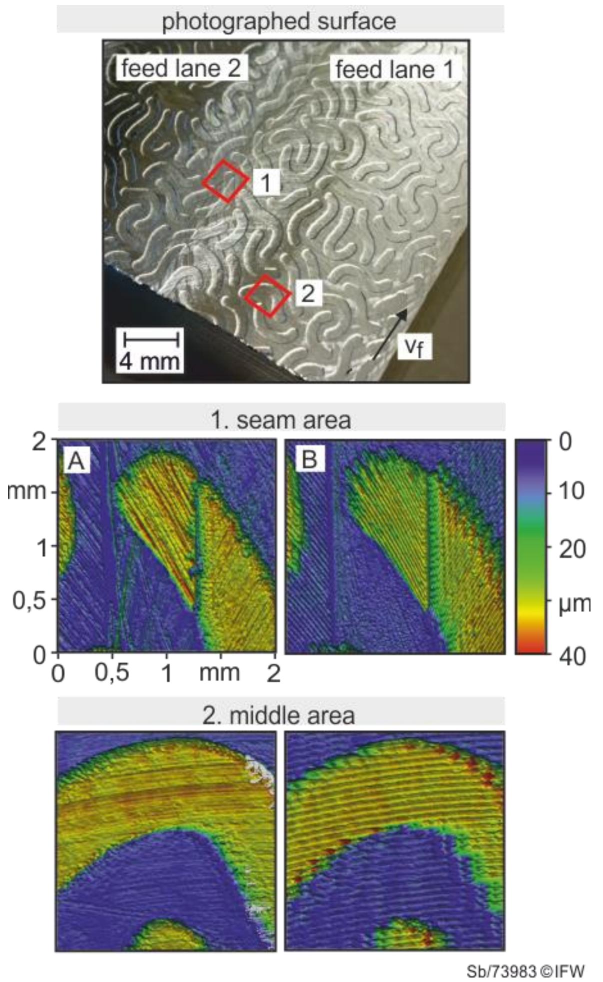

Figure 3. Close-ups of the machined surface.

5. Conclusion

By using a piezoelectric face milling tool, it is possible to texturize flat metal surfaces. A big advantage over other machining based technologies is the flexibility in texture area, size and process time, as well as the fact that this presented tool and method can be used on conventional cnc milling centres. However, limitations exist. Regarding process time inaccuracies have to be accepted in terms of edge skewness and shape. Based on the performed experiments, approaches can be deduced to improve the accuracy. Sharper structure edges and a seamless transition can be achieved by an intelligent control strategy. Smaller texture element dimensions and better surface finishes can be realized by an improved cutting edge design and even smaller feed rate f_z.

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