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Tool deflection control by a sensory spindle slide for milling machine tools

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Abstract

A conventional spindle slide of a milling center is enhanced to a force „feeling" component for process monitoring and control tasks. The feeling ability is realized by integrating strain gauges in notches machined into the structure. This force sensing allows the identification of the static tool stiffness and enables the online detection of the tool deflection during milling processes. Based on a communication via PROFIBUS between the monitoring system and the machine control, the tool deflection is controlled online in the milling center by adjusting the axis feed. The approach shows considerable improvement regarding surface accuracies.

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Keywords: Feeling machine; process monitoring; process control; tool deflection

1. Introduction

Nowadays, the trend in the production sector is edging towards more individual products. As a consequence, the producers have to adapt to a further increase in the variance of the product spectrum with decreasing its lot size. This development results in generally higher demands on intelligent and autonomous systems for process monitoring and control, that may help to reduce incurred additional costs in comparison to mostly cost optimized series productions.

Systems for process monitoring in milling are widely used. They allow the early detection of process failures such as chattering [1], tool wear and breakage [2], tool deflection [3], clamping failures [4], etc. However, previously developed control systems are generally restricted to optimizations regarding process load [5] or process stability [6]. Approaches for process quality control have been subject to only little research.

The tool deflection represents one of the most important quality degrading effects in milling. It occurs generally in any cutting process due to the compliance of the used tool and process forces. It causes a deviation between the real and the reference path of the tool and illustrates therefore shape and dimension failures on the workpiece side. Required manufacturing tolerances can no longer be maintained. Furthermore, especially in the processing of complex free form geometries and in finishing processes, the tool deflection has a decisive influence on the productivity.

In order to reduce the tool deflection and to achieve the desired manufacturing tolerances, appropriate cutting parameters have to be determined. Therefore, several tests must be carried out in advance of series production. However, this is very time consuming and often associated with high costs. With respect to single-item-production and especially in the mold and die production, where often very tight tolerances are required, this approach has limited application in terms of its economy.

This paper focuses on the development of a monitoring and control system for the tool deflection for milling. The monitoring system is based on a "feeling" spindle slide of a milling center DMG HSC30 linear. The online control is realized by adjusting the axis feed using a data communication between the monitoring system and the machine control.

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2. Sensory spindle slide

The integration of strain gauges in mechanical structures represents generally a promising and a cost-effective way to measure occurring forces. With respect to machine tools, the detection of force-dependent strain becomes more difficult since machine tool components are designed to achieve maximal stiffness and positioning accuracy. However, previous works on a spindle slide of a milling center DMG HSC55 linear show that the application of micro strain gauges into small notches on such a stiff structure is a promising approach for the improvement of the sensitivity to load. Because of the small dimensions of the notches, the changes of the slide main stiffness are negligible [3]. A further challenge by the sensor integration is to find optimal positions in the component, where notches and strain gauges can be applied. These positions depend generally on the component structure and the resulting force flux, which is mainly affected by the support, carriage and the load situations. Changes in the force flux in the structure cause a variation in the strain state and influences the distribution of the sensor positions.

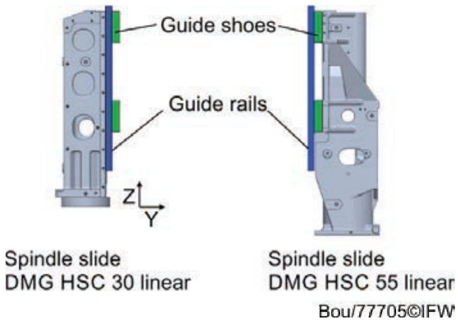

Fig. 1: Carriage situation of the spindle slides in DMG HSC30 linear and DMG HSC55 linear

The spindle slide of the milling center DMG HSC30 linear is subject of the investigation in this work. This slide shows a totally different design and carriage situation to previously investigated spindle slide of the milling center DMG HSC55 linear. The guide rails of the carriage are assembled on the slide side (Fig. 1). While driving the slide along its z-axis, the distance between the lower guide shoes and the free end of the slide is varying and causing changes on the slide stiffness and the force flux. Therefore, these facts has to be considered by determining the sensor positions.

2.1. Approach for sensor positioning

In order to estimate the occurring strain and to determine optimal sensor positions in spindle slide, static structural finite element analyses on ANSYS® Workbench™ are conducted. During simulation, the contact surfaces between the guide rails and the guide shoes are shifted step-by-step equidistantly along the guide rails and are modeled as fixed support by fixing correspondent mesh nodes. Each shifting step corresponds to a new location of the slide along its z-axis with different main stiffness.

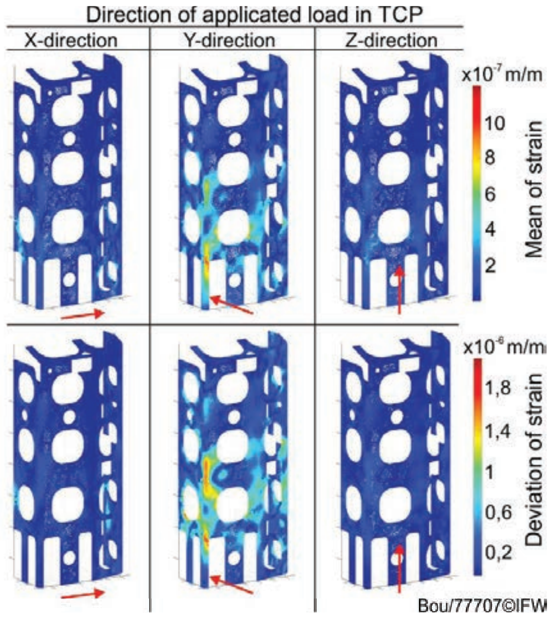

Fig. 2: Mean and deviation values of strain for different load directions

Based on the exported strain values of the slide, each mesh node is statistically evaluated by building the mean value and the deviation of its strain for the simulated load steps (Fig. 2). The strain mean value provides information about the sensitivity of the mesh node to load. Its deviation is a measure of the sensitivity variation while the slide is moving along the z-axis. Accumulations of adjoining mesh nodes showing similar sensitivity behavior represent optimal positions for sensor integration. It can be distinguished between two kinds of sensor positions: the first kind comprises sensor positions that depend on the z-axis position of the slide. Such positions show high mean values of strain and strain deviations. In these positions, strain sensors would generate intense signals showing strong deviation between the z-axis ends. In this case a sensor calibration with respect to the z-axis-position of the slide is indispensable for accurate measuring of the process forces. The second kind of sensor positions is nearly independent of the z-axis position of the slide. These sensor positions show generally lower mean values and lower deviations of strain. However, in such positions, sensor signals with sufficient amplitudes but nearly independent from the actual z-axis position would be provided.

2.2. Realization of the sensing system

After determination of optimal sensor positions, notches are manufactured on the original spindle slide. For strain detection, miniature strain gauges HBM 1-LY11-0.3/120 are integrated into the small notch grounds (Fig. 3). The strain gauges are connected up as a Wheatstone bridge to a new developed miniature electronic device for signal processing. Within the electronic device, the strain signal is filtered, amplified, sampled and finally communicated via CAN-BUS to an industrial PC. The actual version of the device allows