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High precision milling with a novel compliant machine tool

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Abstract

For precision milling manufacturing machine tools with high stiffness K and high masses m are state of the art. Usually this will be achieved due to heavy and large machine beds and frames. Hence, a new approach based on the compensation of the dynamic dislocation was investigated. The aim of this new approach was to develop a high dynamic machine tool with a compliant machine frame. Therefore, a novel compliant three-axes machine tool for high precision milling based on an Ethercat Technology® and the open source ethercat master etherlab machine is developed by the Technische Universität Berlin and the Fraunhofer Institute for Production Systems and Design Technology. For the dynamic dislocation a Kalman-filter is integrated in the machine control which calculates the tool body with respect to the tool-center-point TCP and its velocity v. For the verification milling structures are manufactured with the compliant machine tool. Various setups were investigated, braced, compliant without compensation and compliant with compensation. Further the feed speed v_f and the gain factor of the control system K_v were modified. To measure the average diameter D_{av} and the concentricity C_δ of the milling structures, the coordinate measurement machine O-INSPECT of the company CARL ZEISS IMT was used. As a result the compliant machine tool can be used for high precision milling processes. Finally, the compliant machine tool is compared with the WISSNER GAMMA 303 HIGH PERFORMANCE, WISSNER GMBH, GÖPPINGEN, GERMANY.

Keywords: compliant machine tool, high precision milling, machine control

1. Introduction

The development of improved cutting tools and machine tools are major aspects of current research in production technology. Machine tools with high stiffness K and high masses m are state of the art to meet the requirements of precision and ultra-precision technology. These systems are typically limited regarding axes dynamics [1]. Therefore, novel machine tool concepts aim at lightweight system design. The presented machine tool design allows high feed drive dynamics and is based on real-time displacement compensation.

The developed control- and design concepts are described in the following and subsequently, the results of an experimental validation are presented. These results are validated by comparison with workpieces manufactured by a micro milling machine tool WISSNER GAMMA 303 HIGH PERFORMANCE.

2. Control- and design-concept

The used control system is based on a Linux real time kernel. Controller input data are CNC setpoints and real time calculated system shift data, whereas corrected setpoints are transferred to the machine control. The used control-loop is based on a Kalman-Bucy filter. In contrast to established control methods, using system acceleration a_D as input parameter, a velocity v_D based control system using an order-reduced FE-Model was implemented. Figure 1 shows the control scheme by example of the position-loop for the X-axis [2]. The control-concept was integrated in a three-axes test stand at the PRODUCTION TECHNOLOGY CENTRE PTC Berlin (Figure 2).

The system design is based on integrated leaf springs to apply determined dynamic weak points.

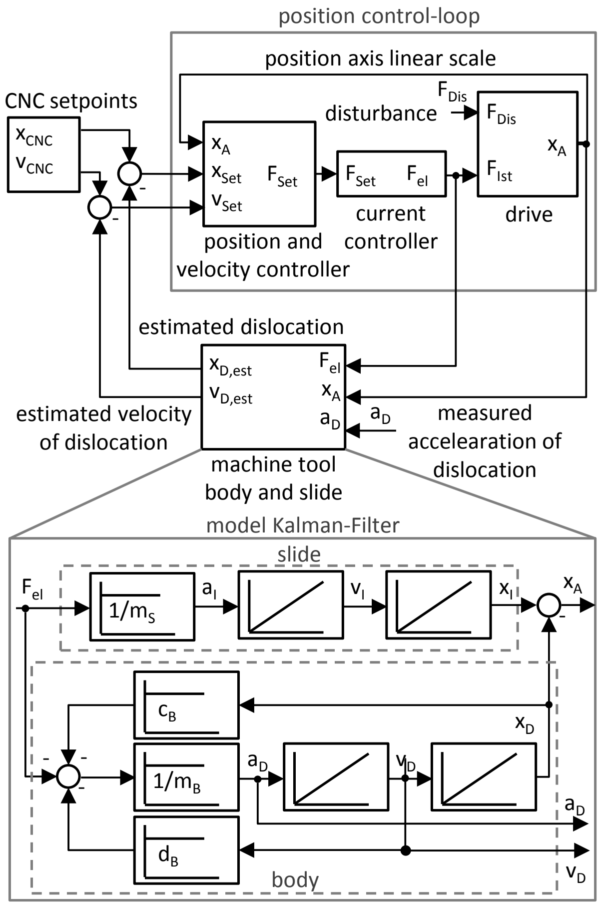
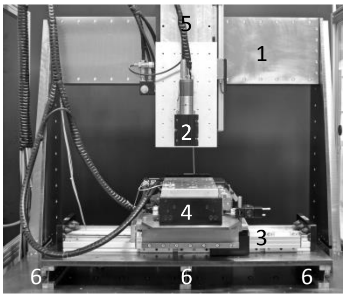


Figure 1. Position-loop for the X-axis with kalman filter model [3]



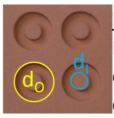
1 Portal
2 Spindle
3 X-Axis
4 Y-Axis
5 Z-Axis
6 Leaf springs

Figure 2. Three-axes test stand derived of the design concept

That reduce the coupling between system eigenforms. The necessary compensation of a particular compliance to a particular feed axis could be assigned [2].

3. Validation and Verification

With the realized three-axes test stand milling experiments in rigid foam material were carried out. Experimental parameters as well as results are presented in figure 3. The experiments were carried out with a cemented carbide milling tool with a diameter d = 1 mm.



Milling structure:
Material: rigid foam
d_I = Inner diameter = 4 mm
d_O = Outer diameter = 10 mm

Used milling Tool:
Cemented carbide
d = 1 mm
z = 2

Legend: ○□ stiffened ●■ soft ●■ soft, compensated

Not.	meaning	Not.	meaning
1.1	stiff; v_f = 2 m/min; K_v = 40	2.3	soft; v_f = 2 m/min; K_v = 200
1.2	stiff; v_f = 2 m/min; K_v = 100	2.4	soft; v_f = 4 m/min; K_v = 200
1.3	stiff; vf = 2 m/min; K_v = 200	3.1	soft & compensated; v_f = 2 m/min; K_v = 40
1.4	stiff; v_f = 4 m/min; K_v = 200	3.2	soft & compensated; v_f = 2 m/min; K_v = 100
2.1	soft; v_f = 2 m/min; K_v = 40	3.3	soft & compensated; v_f = 2 m/min; K_v = 200
2.2	soft; v_f = 2 m/min; K_v = 100	3.4	soft & compensated; v_f = 4 m/min; K_v = 200

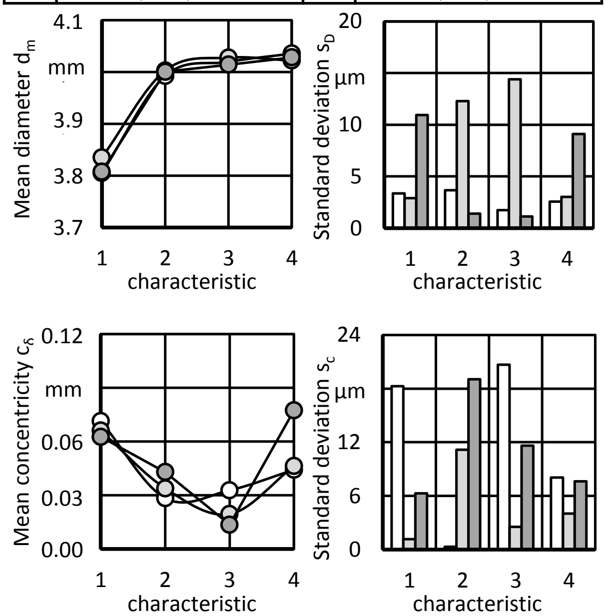


Figure 3. Results of the milling process with the test stand

The test stand was used in three configurations:

1. frame stiffened by mechanical components K=550 N/µm
2. frame without stiffening, no compensation
3. frame without stiffening, with compensation

A compliant and compensated machine tool frame with a feed rate v_f = 2 m/min and a gain factor for the velocity K_v = 200 was used for the experimental evaluation. The geometrie features roundness and inner diameter are illustrated in Figure 3 (top). Machining forces and workpiece-tool interactions could be excluded by using rigid foam as workpiece material.

A concentricity of c_δ = 13 µm and a mean diameter of d_M = 4.01 mm ± 1 µm could be achieved with this setup. The results were measured with a tactile coordinate measurement machine tool O-INSPECT, CARL ZEISS IMT, OBERKOCHEN, GERMANY.

In addition, the results of the compliant machine concept were compared with the machining by two different setups (table 1) of a micro milling machine tool WISSNER GAMMA 303 HIGH PERFORMANCE, that is representative for commercial state of the art high-precision-machine tools.

Table 1 The different Setups of the Wissner Gamma 303 HP

Setup	Depth of cut a_p	width of cut a_e	spindle speed n	feed speed v_f
A	0.1 mm	0.1 mm	25000 1/min	2 m/min
B	0.1 mm	0.1 mm	25000 1/min	4 m/min

The results of the comparison are presented in table 2.

Table 2 Results of the milling process with the Wissner Gamma 303 HP

v_f	Mean diameter d_M	s_D	Mean concentricity c_δ	S_c
A	3.94 mm	1 µm	14 µm	1.6 µm
B	3.90 mm	2 µm	33 µm	2.5 µm

The geometry features were also measured with the tactile coordinate measurement machine O-INSPECT described above. With increased feed speed v_f, the concentricity of the cylinder c_δ increases. The compliant and compensated machine tool achieves a comperable concentricity c_δ = 14 µm to the WISSNER GAMMA 303 HP. The important difference is that the dynamics of the feed-axes in conventional high precision machine tools are limited [1, 2], whereas this is not with the compliant machine tool frame.

4. Conclusions

The paper shows the ability of compliant machine tools to produce micro structures within specification. Here a suitable control-loop for the feed axis system is used to fulfil the needed requirements. The verification of the compliant machine tool was performed by experimental validation. The measurement results of machined structures in rigid foam workpiece material illustrate the high potential for this machine tool design.

However, in comparison to a conventional machine tool design, axis dynamics have a significant influence on machining result. Thus, lightweight machine tools with high dynamic feed axes can lead to increased efficiency in micro production.

References

[1] Zatarain, M., Ruiz de Argandoña, I.: New Control Techniques Based on State Space Observers for Improving the Precision and Dynamic Behaviour of Machine Tools, Annals of the CIRP, 2005 54/1:393 – 396

[2] Uhlmann, E.; Eßmann, J.; Wintering, J.-H.: Design- and control-concept for compliant machine tools based on controller integrated models In: CIRP Annals Manufacturing Technology 61, 2012, No 1, pp. 347 – 350.