euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
www.euspen.eu

Improvements of a novel size-adjusted machine concept

K. Dröder[1], H.-W. Hoffmeister[1], T. Tounsi[1]

[1]*Institute of Machine Tools and Production Technology, Technische Universität Braunschweig, Germany*

t.tounsi@tu-braunschweig.de

Abstract
Micro machining is gaining in importance due to the increasing miniaturization of today's components. This trend applies to a large field of application, where brittle and hard-to-cut materials are often used. These materials are machined with high-precision surface finishes and low dimensional deviations.
For microsystems, the structures to be produced or even the entire component are relatively small compared to the size of common machine tools. A novel approach is the use of machine tools, which are adjusted to the size of the structures that have to be machined. This new machine concept particularly benefits from a space-saving design. This results in further advantages such as high flexibility, that is needed to adapt the machine's configuration to the appropriate machining processes.
In this work, one novel size-adjusted machine concept is analyzed and improved. Properties such as static stiffness and thermal effects on the tool center point are investigated. Based on the behavior of the machine structure at thermal and mechanical loads, design improvements are derived. Inaccuracies due to assembly errors are minimized by increased functional integration and therefore reduction in the number of single components. The static stiffness is being improved by increasing the second moment of area of mechanically loaded parts. Thermal deformations are minimized or almost completely negated by a symmetrical design of motion platforms.

Micro machining, size-adjusted machine tools, machine concept

1. Introduction

In micro machining, common machine tools are unreasonable large compared to the size of structures and workpieces that have to be machined. This leads to the approach to design machine tools, which are size-adjusted to workpiece dimensions. These small and compact machine tools offer working space to installation space ratios, that are higher compared to conventional machine tools. Small outer dimensions and low weight results in high flexibility, that allows to reposition size-adjusted machine tools very easily. Production lines can be set up and revised very fast. Expensive space on shop floor can be used for a large number of machine tools.

In this paper one size-adjusted machine tool concept is presented and improved. These improvements primarily lead to reduction of load induced deformations at the tool center point (TCP).

2. Novel size-adjusted machine concept

The presented concept of size-adjusted machine tools is based on the latest results of the priority program 1476 of the German Research Foundation "small machine tools for small work pieces" [1]. This concept offers a working space to installation space ratio of 0.44 in xy-plane and a ratio of 0.13 in z-direction. This ratio can mainly be achieved by cooperative axis motion [2]. Outer dimensions of the machine tool are 450 mm x 450 mm in x-y-plane and 515 mm in height. This movement principle enables further size reduction by simultaneously moving workpiece and tool. For this reason, two identical 3-axis motion platforms have been set up. These platforms are mounted on a cube-shaped machine frame (Figure 1). This machine frame is made of carbon fiber reinforced plastic and therefore has a good damping behaviour. One platform consists of two orthogonally arranged linear drives. These drives are coupled to a parallel kinematic for movement in x-y-plane. An additional actuator ensures movement in z-direction.

This leads to a combination of two drives (tool and workpiece) per direction. To reach desired feed speed between workpiece and tool only half of this speed is needed per drive. Travel length of each axis can be divided in half as well.

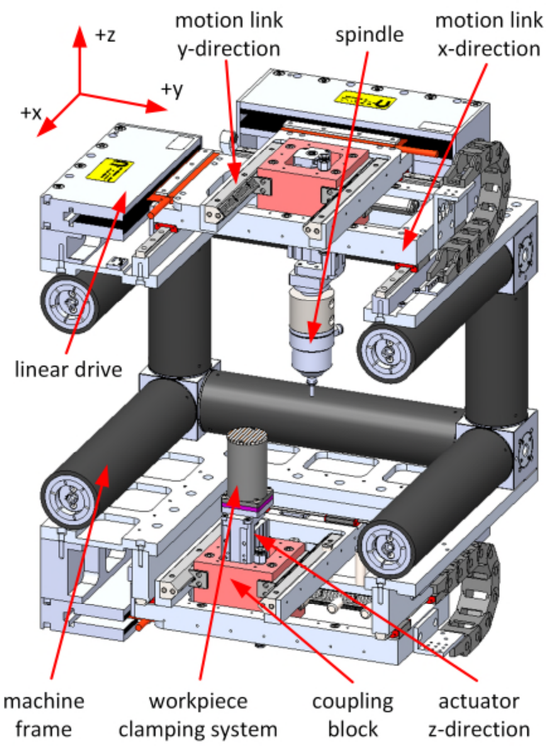

Figure 1. Improved design concept of a size-adjusted machine tool in milling configuration.

All components needed for one machine configuration are mounted on one platform. These platforms can be exchanged to quickly adapt the machine's configuration to appropriate machining processes. Figure 1 shows the machine in milling configuration.

3. Design improvements

Arrangement of components on the platform especially the linear guides and the motion link are redesigned in this improved concept. Before, the motion link consisted of five individual parts and the whole assembly was guided on three rails on the platform. The improved motion link now consists of only one monolithic part. Assembly errors that could lead to a tensed motion link structure and therefore to inaccurate motion do not occure any longer (Figure 2).

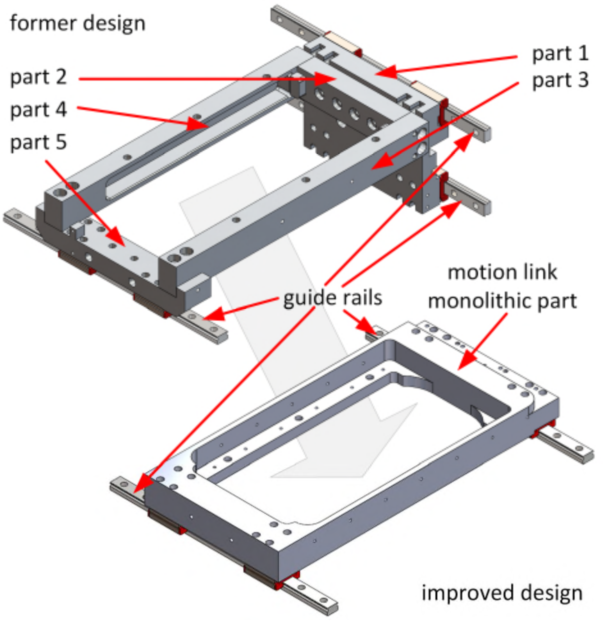

Figure 2. Design improvements of motion link. Bottom-right: improved design.

The new arrangement of only two guide rails per motion link allows higher motion accuracies, due to simpler assembly and alignment processes. After machine assembly, straightness errors of the guide rails of 1.5 µm were achieved. Angular errors of 1 µm / 100 mm were measured between x and y axes. Furthermore, the second moment of area of the motion link was improved by 37 %. This leads to a more stiff design.

Static FEM simulations were performed to simulate and optimize the rigidity of the machine structure during design phase. Static forces of 35 N were applied to the coupling block of the machine in each direction. Figure 3 shows the stiffness map of the machine kinematics loaded in x-direction in dependence of the position of the coupling block in x-y-plane.

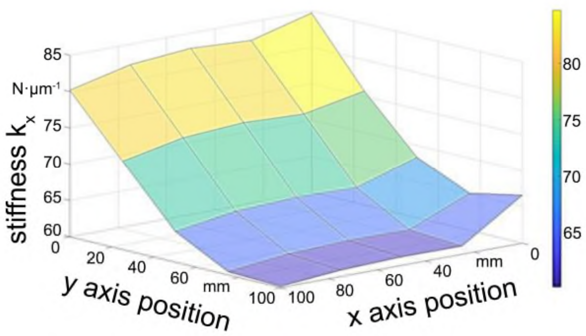

Figure 3. Static stiffness of machine kinematics, loaded with 35 N at the coupling block in x-direction.

Highest stiffness in x-direction is nearly 85 N·µm^{-1}. This map also shows the comfort zone of the machine tool. Highest stiffness is only achieved when the motion link of y-direction is at position 0. This is due to the asymmetric cross section of the platform.

Stiffness results for other load directions are also evaluated and summarized in Table 1. Overall, the stiffness of the machine kinematics was improved by 16 %.

Table 1. Static stiffness of machine kinematics, loaded with 35 N.

Direction of static load	Highest stiffness [N/µm]	Lowest stiffness [N/µm]
x-direction	84.7	60.2
y-direction	61.5	56.6
z-direction	69.2	38.9

These results were achieved by static forces that were applied to the coupling block. When applying these forces to the collet of the spindle, these values are reduced by a factor of 10. This is mainly due to the mechanical structure of the actuator and the large lever arm.

Thermal simulations were performed as well. In the improved design, the motion links are designed so that they can be arranged thermally symmetrical to each other. In worst case, heat dissipation in linear drives can causes temperature gradients of up to 40 °C. Due to symmetrical arrangement this results in deviations at the TCP of only 0.1 µm in x-y-plane and up to 1 µm in z-direction. This is an improvement of nearly 30 %.

4. Conclusions

In this work, an improved size-adjusted machine tool concept has been presented. Design improvements of machine kinematics increase the static stiffness of loaded parts by 16 %. This leads to higher accuracies during machining.

Motion links for movement in x-y-plane are designed and arranged to reduce thermal load induced errors on the TCP. Heat dissipation from linear drives leads to deformations of the machine structure. Due to the symmetrical design of both axes, the deformations act in opposite directions. The overall deformation is nearly completely compensated.

Geometric errors were measured during assembly of the machine tool. Straightness errors of 1.5 µm and angular errors of the guide rails in x-y-plane of 1 µm / 100 mm were achieved.

Further investigations will deal with the validation of the simulated static stiffness. It is also planned to measure geometric errors at the TCP with laser tracking measurement systems. Machining tests will compare achieved workpiece accuracies with conventional machining results.

Acknowledgements

The authors would like to thank the German Research Foundation (DFG) for funding this work as part of the priority programme SPP 1476 "Small machine tools for small workpieces".

References

[1] Wulfsberg J, Sanders A 2017 Small Machine Tools for Small Workpieces *Final Report of the DFG Priority Program 1476* pp 213-229

[2] Verl A, Hoffmeister H-W, Wurst K-H, Heinze T, Gerdes A, Kalthoum M 2012 Kleine Werkzeugmaschinen für kleine Werkstücke *wt-online **11/12*** pp 744-749