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Optimized workpiece clamping systems for automated micro production

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Abstract

Micro machining becomes more and more important for a wide range of applications. In medical technology – to name only one example – many biocompatible parts are produced by machining shape memory alloys or titanium alloys. All of these fields require repeatable and stable machining processes as well as high accuracy to ensure safe industrial processes. However, most of the machine tools are relatively large compared to the size of the workpieces or structures they have to produce. An alternative approach is the use of size-adjusted machine tools. This new machine concept particularly benefits from a space-saving design as well as high flexibility and mobility. Also, these machines need size-adjusted components, like workpiece clamping systems or spindles.

One crucial element in machining processes is the workpiece clamping system. Its key function is the fixation of workpieces. The clamping system must absorb occurring process forces. High stiffness is also necessary to resist under load so that a high dimensional accuracy is achieved and deformations are avoided. Another claim is high flexibility regarding not only the workpiece shape but also its material.

Previously performed investigations have shown that magnetic and adhesive clamping systems offer all of the mentioned specifications. This paper presents two size-adjusted workpiece clamping systems, that are set up accordingly to these clamping principles. The clamping systems are designed to be used in automated production tasks. They were also extensively tested in micro machining environment regarding their overall performances like clamping forces for instance.

Micro production, size-adjusted machine tools, workpiece clamping systems

1. Introduction

An alternative approach in micro production is the use of size-adjusted machine tools. This machine concept deals with machines that have cubic installation spaces with edge lengths of 450 mm [1]. These machines are adjusted to the size of workpieces and structures that have to be machined. However, due to small dimensions of these machines, required size-adjusted machine components are rarely available on the market. That leads to fundamental redesign of components like spindles, feed axis or workpiece clamping systems.

Especially in micro machining workpiece clamping systems have to ensure a rigid, stiff and non-destructive fixation of workpieces to achieve high dimensional and surface accuracy.

Conventional machine vices are able to clamp nearly any kind of material as long as the workpiece has appropriate clamping surfaces. The smaller these clamping surfaces get the bigger is the required clamping force. This results in highly stressed workpiece surfaces. Thus, filigree workpieces often get damaged. A further drawback of machine vices is the limitation of the machining area due to clamping jaws on two sides of the workpiece. In this case, multi-sided machining often requires additional time consuming clamping and probing operations.

This leads to the development of workpiece clamping systems, that are able to fixate workpieces at only one clamping surface. In addition, these systems must be flexible regarding the workpiece material and shape.

Previous work deals with the conceptual design of workpiece clamping systems with alternative clamping principles [2].

In this paper, two workpiece clamping systems are presented, that are designed for size-adjusted machine tools. They are extensively tested regarding clamping forces, clamping stiffness and their usage in micro machining environment.

2. Workpiece clamping systems

The presented workpiece clamping systems meet the requirement of clamping a variety of workpiece materials and shapes at only one clamping surface. These clamping systems are also designed for fully automated production tasks. Connection ports for external electrical signals provide the possibility to clamp or unclamp workpieces by wire.

2.1. Adhesion clamping system

The process of clamping workpieces by means of adhesive forces requires a clamping medium. During solidification of the clamping medium the needed clamping forces occur. At first, the clamping medium has to be applied between the workpiece and the clamping surface in its liquid state. Depending on the clamping medium additional energy is required to change the state of the clamping medium from liquid state to solid state.

The presented adhesion clamping system (fig. 1) is designed for the operation with water and wax as clamping media.

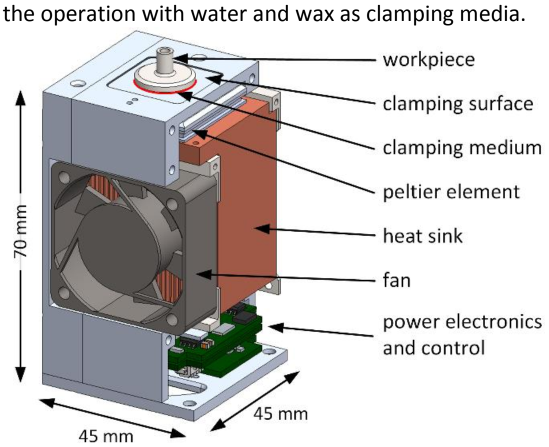

Figure 1. Sectional view of the adhesion clamping system.

A Peltier element is used to solidify or to melt the clamping media. It functions as a controllable electro-thermic heat pump between the clamping surface and a built-in heat sink.

Clamping workpieces with solidified water (ice) permanently requires energy to maintain sub-zero temperatures. Compared to water, wax has the big advantage, that it is solidified in conventional machining conditions at approx. 20 °C. Energy is only required, to liquefy the wax for workpiece positioning and removal.

2.2. Magnetic clamping system

Magnetic clamping systems typically have multiple permanent magnets located in a plastic cage under a laminated top plate. This kind of clamping systems moves the magnets translationally relative to the laminated top plate. The position of the magnets controls the magnetic flux. Thus it is possible to clamp or unclamp the workpiece.

Because of the very high degree of required miniaturisation in this work, space consuming translational movements are impossible. By means of a special arrangement of the permanent magnets, the presented magnetic clamping system controls the magnetic flux by rotation of the caged magnets in full steps of 90 ° (fig. 2). With each step the magnetic flux is either conducted through the workpiece (clamped) or shorted in clamping surface (unclamped). The required torque for the rotation is provided by a gear motor. This enables fully automated workpiece clamping processes.

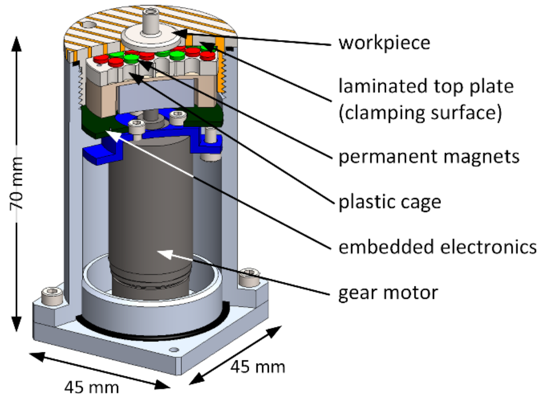

Figure 2. Sectional view of the magnetic clamping system.

3. Evaluation of developed workpiece clamping systems

Experimental tests were performed to evaluate the clamping systems regarding their clamping force and clamping stiffness. For each clamping principle the results show linear correlations between the clamped area between workpiece and clamping surface and the clamping force in feed direction. This relation allows the calculation of specific clamping forces, that can be used to calculate the expected clamping force relative to the workpiece area, that is clamped on the clamping surface (tab. 1).

Table 1. Specific clamping forces and clamping stiffness.

		specific static clamping force/N·mm^{-2}	static clamping stiffness/N·µm^{-1}
adhesive clamping	ice	0.86	1.61
	wax	1.12	1.48
magnetic clamping		0.11	1.96

These results show, that the maximum forces for workpiece fixation are achieved by wax-clamping. In comparison to other values in literature the achieved clamping forces are in the same range, even slightly higher [3].

Another important factor in machining processes is the clamping stiffness. In this work the clamping stiffness refers to the whole system. It is measured between the mounting plate at the bottom of the clamping system and the top of the workpiece where it gets in contact with the tool. Compared to other examinations, the evaluated values for the clamping stiffness (tab. 1) are slightly higher as well [4].

Although magnetic clamping has the lowest specific clamping force, it has the highest clamping stiffness. Therefore, the magnetic clamping system is suitable for machining precise surfaces e.g. moulding tools.

Besides these static properties of clamping systems, machining processes were performed as well. A cuboid steel workpiece (100Cr6) with a base area of 16 mm x 16 mm was used to machine different structures. The maximum diameter of the used tools was 1 mm. With these settings maximum material removal rates of Q_{max} = 229 mm³/min were achieved at maximum process forces of F_{max} ≈ 24 N. All of the three clamping principles ensured a safe fixation of the machined workpieces.

Further investigations deal with the production of mould tools on each of the presented workpiece clamping principles (fig. 3). For comparison, the same mould tool was also produced in a machine vice. Microscopic analysis and analysis of surface roughness shows no visible deviations between of all four produced mould tools.

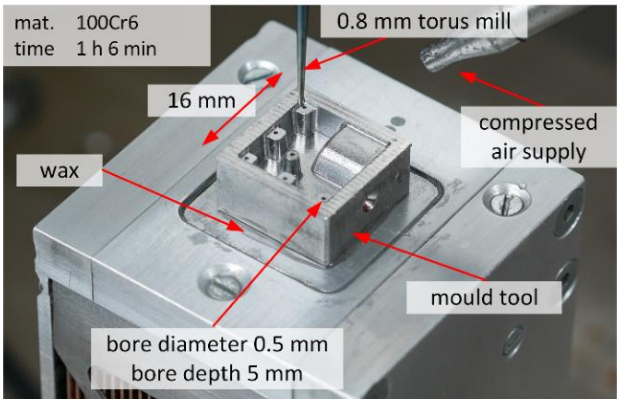

Figure 3. Milling of a mould tool with freeform surfaces on the adhesion clamping system by using wax.

4. Conclusions

In this work two workpiece clamping systems for size-adjusted machine tools in micro machining were presented. These systems have maximum outer dimensions of 45 mm x 45 mm in cross section and 70 mm in height. They are designed to clamp and unclamp workpieces by electrical signals in automated production tasks. The adhesion clamping system works with water and wax and it achieves the highest clamping forces of up to 1.12 N per one square millimeter of the workpiece clamping surface. On the other hand, the magnetic clamping system offers the highest clamping stiffness of 1.96 N/µm.

Extensive trials in micro machining environments show, that both clamping systems are suitable for typical micro production tasks, e.g. producing mould tools.

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