Investigations of a small Machine Tool with CFRP-frame

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Introduction

Today microcomponents are one of the most important parts in industry as they are used in optical products or in precision and medical applications. However, the installation space of the machine tools used for manufacturing of small parts still is too oversized compared to the necessary working space regarding the small dimensions of the workpieces [1, 2]. Within the Priority Programme 1476 "Small Machine Tools for Small Parts", funded by the German Research Foundation (DFG), a novel kinematic module based on cooperative and inverse motion was developed to minimize the working space of the whole machine frame, as well as the moving masses and the kinetic energy [3].

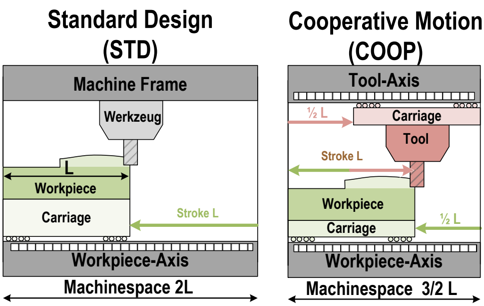


Figure 1: Machine tool design with cooperative motion [3]

1 Energy consumption using Cooperative Motion

The cooperative kinematic reduces quantities like stroke, velocity and motor current. Thus, the consumed energy of a cooperatively driven system differs from that of a standard machine design. Energy is needed to drive both, the workpiece- and tool carriage. The amount of energy depends on the inertia and friction of the carriage.

To provide the electric energy, servo amplifiers are needed for each drive. Another aspect of the energy consumption is the loss due to friction forces occurring within the drive system. A comparison of the friction losses of non-cooperative (STD) motion and cooperative motion (COOP) is shown in Figure 2. It can be seen that if the drive has linear friction characteristics and cooperative motion is used, the frictional loss would be reduced by 50% due to the reduction of velocity and stroke. In case of coulomb friction characteristics, cooperative motion causes the same friction losses as in a non-cooperative setup. In case of a stribeck friction characteristic the frictional losses can only be reduced if the resulting drive velocity after splitting the motion profile still is above the stribeck velocity v_0.

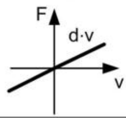
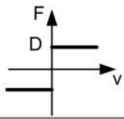
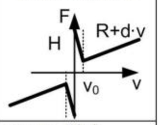
Friction power $P_R = F \cdot v_f$	Linear friction 	Coulomb Friction 	Stribeck Friction 
STD $(v = v_f)$	$d \cdot v_f^2$	$D \cdot v_f$	$v_f < v_0$: $H(v_f)$ $v_f \geq v_0$: $(R + dv_f)v_f$
COOP $(v = \frac{v_f}{2})$	$\frac{1}{2} d \cdot v_f^2$	$D \cdot v_f$	$v_f/2 < v_0$: $H(v_f)$ $v_f/2 \geq v_0$: $(R + dv_f)v_f$

Figure 2: Influence of friction characteristics on the total friction power

Measurements on the prototype [3] showed that the total power consumption related to the kinetic energy could be reduced to about 50% (Figure 3a). However, measurements of the total power consumption of the electrical cabinet showed an increase of about 55% in the cooperative mode (Figure 3b). The reason is the necessary additional drive. It doubles the electrical losses within the amplifiers. Energy savings with cooperative motion can only be achieved if the kinetic and frictional power is higher than the electrical losses within the power supply.

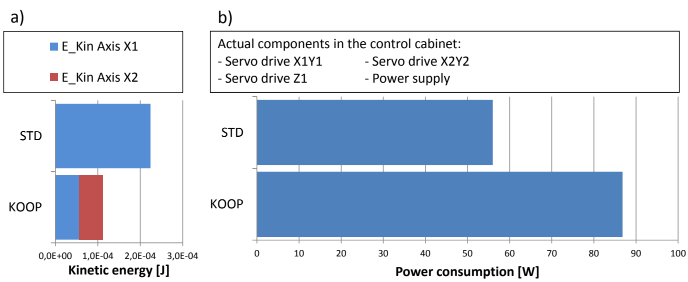


Figure 3: a) Required kinetic energy; b) Power consumption of control cabinet

2 Workpiece clamping via freezing

In order to develop the already mentioned small machine tool, the machine components, for example workpiece clampings have to be made suitable. Within the priority program a miniaturized clamping device was developed for fixing a workpiece via freezing of water [3]. A test workpiece made of 100Cr6 with dimensions 16 x 16 x 8.5 mm was analysed regarding thermal distortion during the freezing process. The results show a distortion in z-direction of 5 µm after a freezing time of 90 s (Figure 4b). Performing higher freezing times showed no modification regarding the thermal distortion. Using this clamping device the test workpiece could be fixed on a peltier element within a freezing time of 20 s.

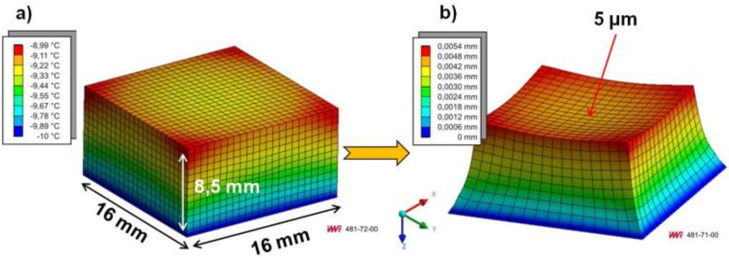


Figure 4: Temperature distribution after freezing time 90 s (a); thermal distortion of the workpiece (b)

3 Numerical Analysis of the CFRP-frame

In order to evaluate the static stiffness and dynamic behaviour of the machine frame the FEM-Software ABAQUS was used. The CFRP (Carbon Fibre Reinforced Plastic) layers were modeled using the “Composite layup”-option. The results showed a suitable configuration of 15 layers with angles of 0° and 90° [3]. With this configuration the calculated static stiffness in z-direction was in a range between 95 N/µm up to 120 N/µm depending on the axis position (Figure 5a) by loading the TCP with experimentally measured feed forces of 1 N in a linear static analysis. Additionally the magnitude of the simulated dynamic response was analyzed to 0,033 µm/N for Eigenmode 5 at 553,68 Hz and 0,03 µm/N for Eigenmode 7 at 639,34 Hz (Figure 5b). However, when using high speed spindles for machining there are high rotation speeds, so the operating frequency will be above 2500 Hz with very low amplitudes (Figure 5b).

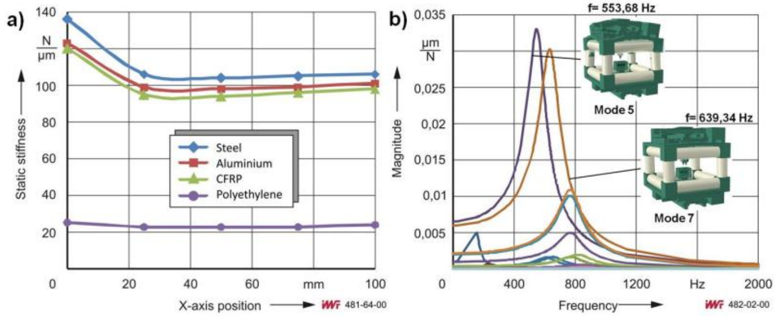


Figure 5: Static stiffness (a) and magnitude of harmonic response of CFRP-frame (b)

Conclusions

Experimental investigations regarding energy consumption in cooperative mode show a reduction of kinetic energy of about 50 %. However the power consumption increases in cooperative mode due to necessary additional drive and electric losses. Numerical Results show a maximum thermal deformation of 5 µm of the test workpiece due to the clamping process. The CFRP-frame shows a high stiffness and low dynamic magnitudes and is suitable for use as machine tool frame also due to its thermal stability and subsequently higher precision of the machine tool.

Acknowledgement

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References:

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