Increased Productivity due to Jerk-decoupled Feed Axes of the 5-Axes Milling Machine "Neximo"

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Abstract

With the development of highly dynamic machine tools, flexibilities of the machine structure represent a major challenge in machine tool design. High machining forces and accelerations induce static and dynamic deflections of the machine frame which affect the accuracy of the machine negatively. To master this conflictive aim of high dynamic feed drives and simultaneously increased machining accuracy, the IFW developed the 5-axis machine tool prototype "Neximo" with jerk-decoupled x- and y-axes. This paper presents the results of the performed vibration measurements and the achievable increased productivity in machining processes by higher jerk limits due to the applied jerk decoupling technology.

1 Introduction and Motivation

Dynamic feed drives provide high acceleration gradients which also lead to an intense vibration excitation of the machine frame. This conflict is traditionally met by a severe limitation of the reference value regarding the jerk and therefore of the effective dynamics of the drive [1]. Thus, the reduction or avoidance of the machine frame excitation without jerk limitation is a relevant research topic. For this purpose different approaches have been developed in terms of the impulse- or jerk-decoupling technology, the impulse compensation and the trajectory shaping [1]. Cross references to older developed systems are given in the presented recent references.

Table 1: Resulting time saving at different jerk limits for a position step of 200 mm

Jerk limit	positioning time	time saving
50	0.504 s	-26.0 %
100	0.4 s	0 %
250	0.2947 s	26.32 %
500	0.244 s	39.03 %
1,000	0.221 s	44.78 %
2,000	0.2102 s	47.47 %

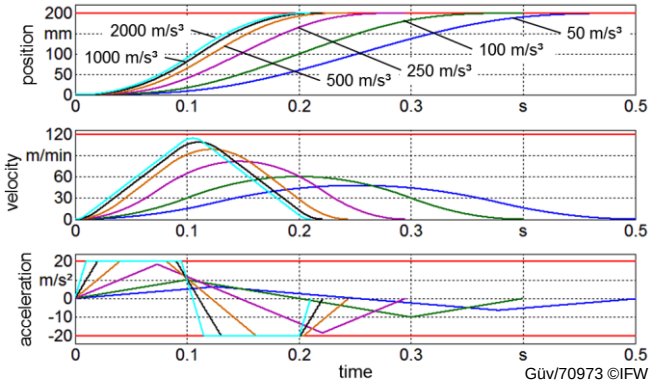

Figure 1: Position trajectory at different jerk limits

Exemplarily considering the resulting positioning time for a position step of 200 mm of a machine axis with a maximum speed of 120 m/min and a maximum acceleration of 20 m/s² (see Figure 1 and Table 1) clearly shows the potential of increasing the jerk limitation. Compared with a conventional standard maximum jerk of 100 m/s³, a tenfold to 1,000 m/s³ leads to reduction of about 45% in positioning time.

2 Machine tool "Neximo"

For increasing the jerk limit without increasing the vibration excitation of the machine frame, a new 5-axis machine tool prototype with integrated innovative jerk-decoupling technology in the x- and y-axis (see Figure 2) was developed at the IFW [2]. This prototype enables the analysis of this technology in 5-axes milling processes. Additionally, the z-axis is equipped with an active magnetic guidance for the compensation for static and dynamic errors and enhancement of the machining accuracy. The jerk-decoupling technology is based on a movable secondary part of the linear direct drive, which is connected to the machine frame by independently adjustable spring-damper-elements [3]. This arrangement enables a mechanical low-pass filtering of the dynamic drive forces, so that the vibration excitation of the structural machine frame modes can be significantly reduced compared to non-decoupled feed axes. As spring-elements pneumatic muscles are used to vary the stiffness by the pneumatic pressure and the damping can be adjusted by using a magnetic damping unit. The movable secondary part is guided through the new and

patented relative guidance [3]. Hereby, the investment costs and the friction losses of the needed additional guidance for the secondary part are clearly reduced.

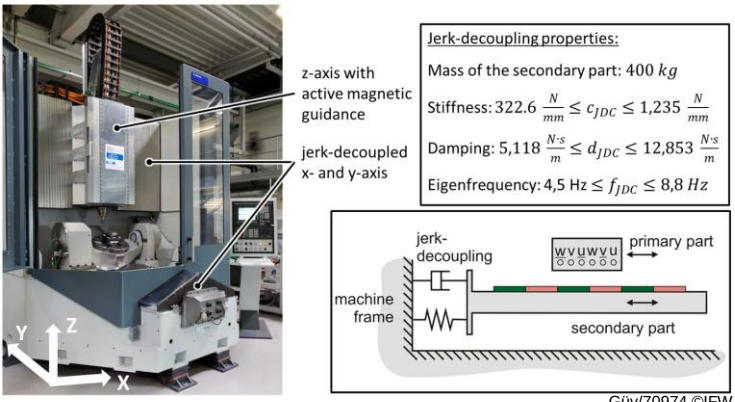

Figure 2: Jerk-decoupled machine tool "Neximo"

3 Increase in Productivity

For the analysis of the effectiveness of this technology vibration measurements of the x- and y-axis of the "Neximo" machine tool are carried out. The vibration is measured on the basis of the position signal of the linear scale of the feed axes, which is comparable to the relative vibration between tooltip and workpiece, as comparative measurements have shown. Additionally, the machine frame vibration is externally measured using a laser vibrometer. The experiments show a reduced vibration response with active jerk-decoupling (with JDC) in comparison to the measurements with clamped jerk-decoupling slide (without JDC).

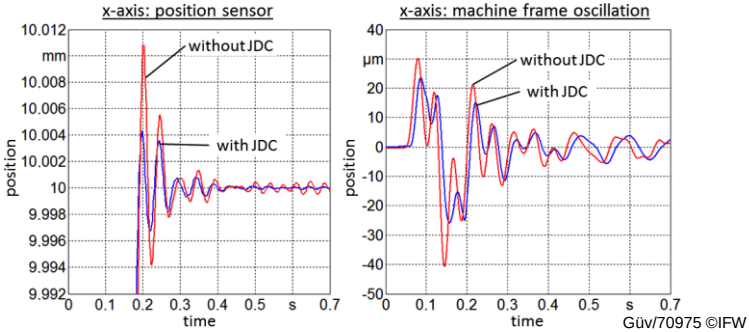

Figure 3: Vibration measurement without and with jerk-decoupling (jerk: 250 m/s³)

Exemplarily, in Figure 3 the comparison of the vibration measurements of the x-axis for a positioning step of 10 mm with rapid traverse and a jerk limit of 250 m/s³ are presented. Hence, the effectivity of the jerk-decoupling technology in a milling machine was verified and the jerk limitation could thereby be increased in the x-axis from 50 to 200 m/s³ and in the y-axis from 100 to 500 m/s³.

In addition, two reference workpieces of the German NC-society were manufactured with and without the jerk-decoupling technology. The results show a reduced processing time for the "Test Workpiece for the 5-Axis Simultaneous Milling Machining" of 3.2 %. The comparison of the machining time for the 3-axes "Test Workpiece for High Speed Cutting (HSC)" is given in Table 2. Due to higher jerk limits an increase in productivity of 1.8 % for the roughing process and 4.3 % for the finishing process are achieved without negatively influencing the machining accuracy, which has been confirmed by measurements on a CMM.

Table 2: Machining time of the 3-axes workpiece without and with jerk-decoupling

	jerk limit			machining time	
	x-axis	y-axis	z-axis	roughing	finishing
without JDC	50 m/s³	100 m/s³	100 m/s³	2:43 min	1:34 min
with JDC	200 m/s³	500 m/s³	100 m/s³	2:40 min	1:30 min

4 Conclusion

The carried out oscillation measurements of the new machine tool prototype "Neximo" confirmed the reduction of the machine frame vibrations by using the jerk-decoupling technology. Thus, the jerk limit and productivity of machine tools can be increased without negatively influencing the machining accuracy, whereupon the achievable percentage enhancement severely depends on the workpiece. In addition, the tool changing time is clearly reduced, which is currently not taken into account.

References:

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