Studies on the Dynamic Behavior of Milling Tools for the HSC Machining

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Abstract

The paper describes the results of experimental studies concerning the dynamics of milling processes using long, thin end mills, made of cemented carbide, as they are often used in HSC machining. Due to the versatile applications of HSC milling in machining technologies, especially in the machining of free-formed surfaces, the studies are carried out with the main objectives to improve the precision of stability predictions and to gain a deeper process understanding.

1 Introduction

There are a lot of previous studies dealing with the dynamic behavior of milling machines, like analyses of chatter or stability in metal cutting and grinding processes [2]. Another research topic is the modal analysis of manufacturing machines [3]. In the following part, the differences in the determination of the modal parameters for stationary and rotating spindles will be explained.

2 Measurement of the structural flexibility of the tool system

The modal values of real structures are usually determined by analyzing their frequency response. The transfer function represents the frequency-dependent ratio of the system response to the excitation of the system. The analyzed structure is the tool system, which is clamped in the spindle of the machine tool.

The measurement setup consists of three sub systems. The first consists of the unit for excitation and for recording the excitation spectrum. The second subsystem consists of the distance measurement for detecting the vibration response of the tool system, and the third functional unit is used for the evaluation and further processing of the obtained sensor signals. The calculation of the transfer function requires knowledge of the excitation spectrum and the vibrational response of the analyzed system.

2.1 Dependence of the modal properties

In addition to the spindle speed, the tool diameter, the cantilever length, and other system variables and components, such as the type of the tool holder, have an influence on the dynamics of the tool system. Therefore, the goal of this chapter is to investigate the influence of these on the modal properties. The tool length is only considered indirectly, because the length is related to the diameter, the so-called L/d-ratio. This characterizes the slenderness of the tool and is more significant. Only the influence of the spindle speed on the dynamic range is analyzed for the trend of the stability limit.

2.1.1 Analysis of the natural frequencies on a stationary spindle

With increasing L/d-ratios, a trend to decreasing values of natural frequencies is shown in Figure 1. With an increasing cantilever length, the system becomes more resilient and the stiffness of the tool with the same diameter decreases. Furthermore, it should be noted that, at decreasing diameters, the natural frequencies are increasing. The investigation results on the modal masses clearly show a dependence on the tool diameter. With larger tool diameters and a constant L/d-ratio, the actual mass and, thereby, the modal mass increases. This trend was also expected for larger cantilever lengths. But this is not confirmed by the results. The modal mass should increase with the same tool diameter and larger cantilever length, but this is prevented by the stable clamping in the tool holder. This clamping dominates the nature of the oscillation.

2.1.2 Analysis of the results with rotating spindle

Taking the rotating spindle into account adds to the dynamic properties of the dynamic system. The results of the measurements on the behavior of the modal values on the considered speed range confirm that the properties are variable depending on the spindle speed. Figure 2 exemplarily shows the progression of the natural frequencies, damping and modal mass for a tool with a diameter of $d = 10$ mm and a L/d ratio of 12. The maximum spindle speed was limited on $n = 17000\ \text{min}^{-1}$ for security reasons.

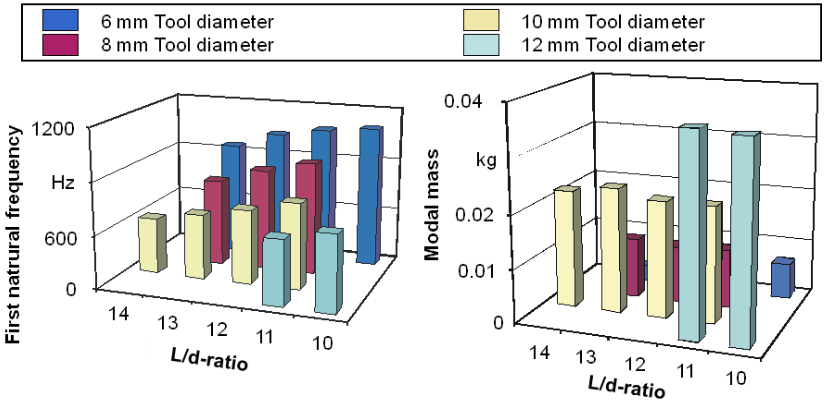

Figure 1: Dynamic properties of the tool system with stationary spindle; left: first natural frequency; right: modal mass

As figure 2 shows, the natural frequency and the values for the damping decreases with increasing rotational speed. In contrast to this, the value of the modal mass increases with increasing rotation speed. The influence of the observed rotation speed on the modal values can have different reasons. For example, in many spindle systems with increasing rotation speed, the bearing stiffness decreases. Rotor dynamic effects such as splitting the natural frequencies could not be observed in the conducted studies.

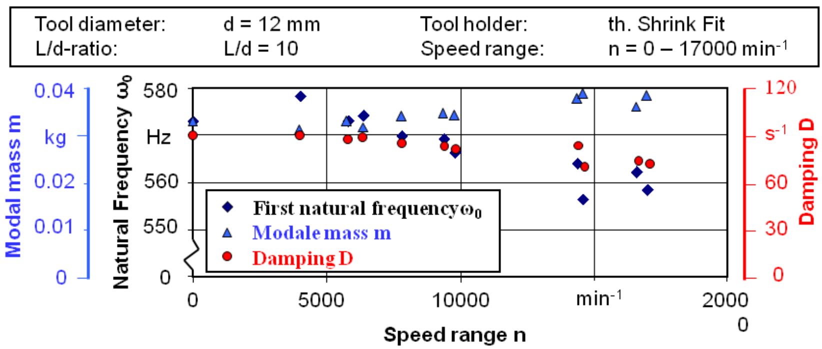

Figure 2: Experimentally determined dynamic properties of a tool system over the rotation speed range: natural frequency, modal mass and damping

First, the dynamics of the tool system were considered in this study. It is assumed that the vibrations occur only on the tool side. Thereby, a simplification of the system is made. This is only possible if there are stiff workpiece structures. However, when thin-walled workpieces are machined, vibrations with distinct amplitudes also occur on the workpiece. These should not be disregarded. Therefore, new approach to couple workpiece and tool vibrations is necessary and should be investigated in further research.

3 Conclusion

Up to now the dynamic properties of the system for computations were assumed as quasi-static, and constant over the observed speed range. The fact, that these values depent on spindle speed and are variable over these range, causes so far a systematic error in the mathematical definition of the stability behavior. The predicted stability maxima were displaced to the real stability maxima at the speed axis. This is due to variable natural frequencies. To increase the accuracy of simulation programs, it is compulsory to take into account the varying natural frequencies over the speed range.

Acknowledgements:

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References:

[1] Enk, D.: Untersuchungen zum dynamischen Stabilitätsverhalten von Fräswerkzeugen zu HSC-Bearbeitung, PhD thesis, TU Dortmund, 2009

[2] Altintas, Y.; Weck, M.: Chatter Stability of Metal Cutting and Grinding, CIRP Annals - Manufacturing Technology, Volume 53- 2, (619-642) 2004

[3] Altintas, Y.; Brecher, C.; Weck, M.; Witt, S.: Virtual Machine Tool, CIRP Annals - Manufacturing Technology, Volume 54- 2, (651-674) 2005