Piezo Ceramic Actuators versus High Magnetostrictive Actuators in the Active Control of Tool Vibration

Linus Pettersson, Lars Håkansson, Ingvar Claesson and Thomas Lagö

Department of Signal Processing, University of Karlskrona/Ronneby
Sweden

March 11, 1999

Abstract

In the turning operation chatter or vibration is a frequent problem, which affects the result of the machining, and, in particular, the surface finish. Tool life is also influenced by vibration. Severe acoustic noise in the working environment frequently occurs as a result of dynamic motion between the cutting tool and the workpiece. These problems can be reduced by active control of machine-tool vibration. In the active control system for the control of tool vibration a tool holder construction with integrated high magnetostrictive actuators was used. However, high magnetostrictive actuators generally have a non-linear behavior and it is a well known fact that non-linear properties in the forward path in an active control system is likely to degrade the robustness of the control system. A new generation embedded active tool holder shanks based on piezo ceramic actuators has been developed. Based on spectrum estimates, both coherence spectrum and frequency response function estimates has been calculated for both the old tool holder construction and the new generation active tool holder shank. From the results it follows that the phase delay is smaller and the linearity of the new generation active tool holder shank are superior compared to the old technology. The physical features and properties of the new generation active tool holders are superior to the old tool holder.

1 Introduction

In the turning operation the tool and tool holder shank are subjected to a dynamic excitation due to the deformation of work material during the cutting operation. The stochastic chip formation process usually induces vibrations in the machine-tool system. Energy from the chip formation process excites the mechanical modes of the machine-tool system. Modes of the workpiece may also influence the tool vibration [1]. The relative dynamic motion between cutting tool and workpiece will affect the result of the machining, in particular the surface finish. Furthermore, the tool life is correlated with the amount of vibrations and the acoustic noise introduced. The noise level is sometimes almost unbearable. These problems can be reduced by active control of machine-tool vibration. This has been successfully implemented by using the well known leaky filtered-x LMS-algorithm to control the response of a FIR filter controller in the active feedback control of tool vibration [2]. However, in the active control system for the control of tool vibration a tool holder construction with integrated high magnetostrictive actuators was used and these actuators generally have a non-linear behaviour. Non-linearities in the response of the forward path is likely to degrade the performance of the control system. To solve this problem a new generation embedded active tool holder shanks based on piezo ceramic actuators have been developed.

2 Experimental setup

The experiments have been carried out on two different forward paths. The first forward path is based on a tool holder construction with integrated high magnetostrictive actuators. The tool holder construction is based on two bipolar actuators. The bipolar design is motivated by a desire to achieve linear behaviour, and is composed of two actuators that work with 180° phase difference. In order to operate the bipolar actuator, a large current amplifier (5kW) was used. The second forward path is a new generation active tool holders, based on embedded and sealed piezo ceramic actuators in both the top and the bottom surface of the tool holder shank that work with 180° phase difference, a small amplifier (30W) was used.

To measure the vibrations in the cutting speed direction accelerometers were mounted on the cutting tools. The frequency band of the broadband Gaussian distributed excitation signal to the forward path signal was 10-15000 Hz.

3 System identification

A common measure on to which extent the output signal from a dynamic system can be linearly explained from the input signal of the system is the coherence function $\gamma^2_{xy}(f)$ which is given by the relation [4]:

$$\gamma^2_{xy}(f) = \frac{|S_{xy}(f)|^2}{S_{xx}(f)S_{yy}(f)} \quad (1)$$

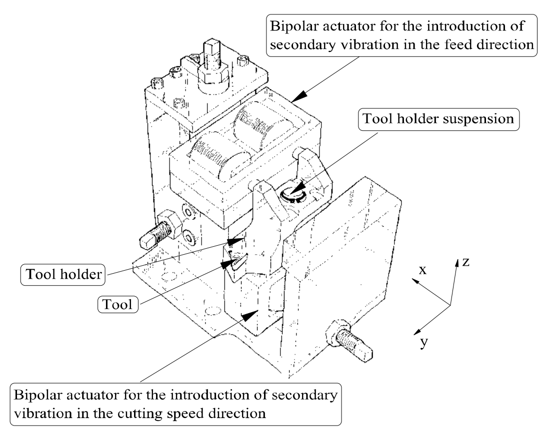

Figure 1: The old tool holder construction with magnetostrictive actuators

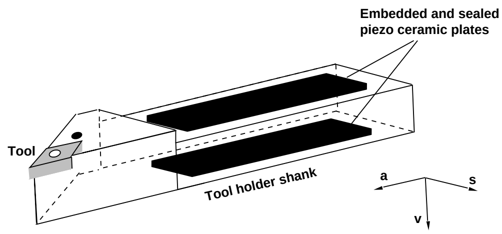

Figure 2: The new generation embedded active tool holder shank with piezo ceramic actuators

where $S_{xy}(f)$ is the cross spectral density between the input signal $x(t)$ and the output signal $y(t)$, and $S_{xx}(f)$ and $S_{yy}(f)$ is the auto spectral density for the signals $x(t)$ and $y(t)$ respectively. Furthermore, a least-squares estimate of the frequency response function for a dynamic system can be obtained through [4]:

$$H_{xy}(f) = \frac{S_{xy}(f)}{S_{xx}(f)} \quad (2)$$

The spectral densities for the input signal $x(t)$ and the output signal $y(t)$ as well as the cross spectral density between these signals where estimated using Welch's method [3].

4 Results

In Fig. 3 an estimate of the coherence function for the forward path based on the tool holder construction with integrated high magnetostrictive actuators is shown. Fig. 4 shows the coherence function estimate for the forward path based on the new generation embedded active tool holder shanks based on piezo ceramic actuators. From Figs. 3 and 4 it is obvious that the new generation active tool holder shanks based on piezo ceramic actuators can to a much greater extent be explained by a linear system in comparison to the old tool holder construction.

In Fig. 5 the estimated Bode diagram for the forward path based on the tool holder construction with integrated high magnetostrictive actuators is presented. Fig. 6 shows an estimate of the Bode diagram for the forward path based on the new generation embedded active tool holder shanks based on piezo ceramic actuators. From Figs. 5 and 6 it is obvious that the new generation embedded active tool holder shanks based on piezo ceramic actuators introduce a significantly smaller phase delay.

5 Conclusions

From coherence function estimates in the Figs. 3 and 4 it follows that the linearity of the new generation active tool holder shank are superior compared to the old technology. It is also obvious from Figs. 5 and 6 that the new generation active tool holder shank introduce a significantly smaller phase delay than the old tool holder construction with integrated high magnetostrictive actuators. Both the fact that the phase delay is smaller and that the linearity of the new generation active tool holder shank are superior compared to the old technology is advantageous for the feedback control of tool vibration.

6 Acknowledgement

The project is sponsored by the Foundation for Knowledge and Competence Development.

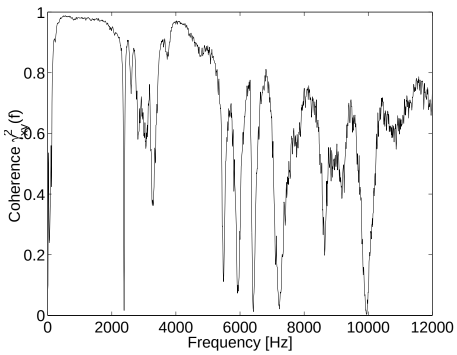

Figure 3: Coherence function estimate for the forward path based on the tool holder construction with integrated high magnetostrictive actuators.

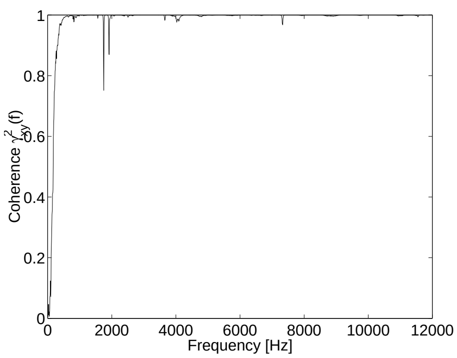

Figure 4: Coherence function estimate for the forward path based on the new generation embedded active tool holder shanks based on piezo ceramic actuators.

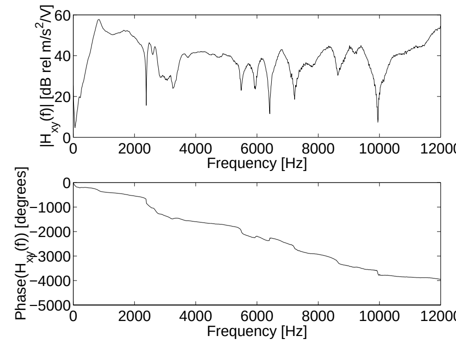

Figure 5: Bode diagram for the old tool holder shank based on high magnetostrictive actuators.

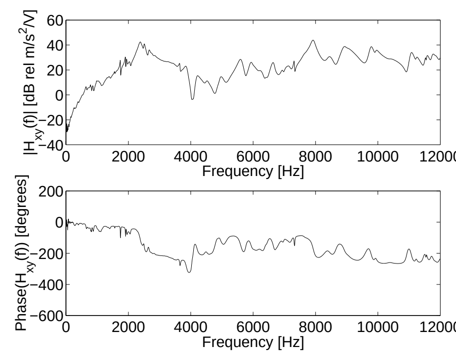

Figure 6: Bode diagram for the new tool holder shank based on piezo ceramic actuators.

References

[1] P-O. H. Sturesson and L. Håkansson and I. Claesson, Identification of the Statistical Properties of the Cutting Tool Vibration in a Continuous Turning Operation - Correlation to Structural Properties, Journal of Mechanical Systems and Signal Processing, Academic Press, 1997, vol 11, nr 3, July

[2] I. Claesson and L. Håkansson, Adaptive Active Control of Machine-Tool Vibration In a Lathe, IJAV-International Journal of Acoustics and Vibration, 1998, vol 3, nr 4, Invited

[3] Manolakis, Digital Signal processing, 3rd edn, Prentice Hall

[4] Julius S. Bendat and Allan G. Piersol, Random Data, 2nd edn, Wiley-Interscience