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A First Prototype of an Active Boring Bar Tested in Industry

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Abstract

Metal cutting is a common process in the manufacturing industry. Vibration problem during metal cutting is a reality for these manufactures. The vibration level depends on many different parameters such as material type, dimensions of the workpiece and boring bar, cutting data and operation mode. Internal cutting is one of the most troublesome operation modes, without any continuous monitoring and control from an operator grave vibration levels quickly arises. From the industry point of view this is an expense in the production line. The reduced tool life and the coarse surface finishing caused by the large vibration will force the operator to stop the cutting process, either to change tool when it is broken or change cutting data like decreasing the cutting depth. Any interference like this increases the working time for each component tremendous. These problems have been located and examined in an industry producing and renovating components using a lathe. One lathe was chosen for further investigation by experimental modal analysis and analysis during operational mode. The examination was done in an environment with machining processes in full operation mode and also during non-working ours. After analyzing the problem different solution where scrutinized and a first prototype where constructed. The solution to the problem is an active boring bar. This paper will present the procedure from analyzing a problem in industry to the test of the first prototype of the solution.

INTRODUCTION

In metal cutting operations, the machining processes frequently introduce productivity degrading vibrations. In internal turning operations, this problem occurs more frequently as long and slender boring bars usually are required to perform the internal machining of workpieces. These vibrations are often directly related to the low-order bending modes of the boring bar [7, 8]. The problems can be addressed using conventional methods as: redesigning the system, implementing tuned passive damping or implementing active control. The first method is usually not feasible and the second method is tuned for a narrow frequency range comprising a certain bending mode frequency i.e. not flexible [3, 4]. The active control is thus more suitable e.g. concerning the frequency range and the system flexibilities. One example of vibration problem during metal cutting was selected from the manufacturing industry. The company Acticut International proposed a solution to suppress the vibrations based on an active control. But first a thorough investigation had to be carried out concerning the tool vibration using different boring bars and clamping conditions for a number of different workpiece materials and dimensions, cutting tools and cutting data. Narrowing the problem and focusing on one particular desired boring bar (C5- MWLNR-27140-08) see Figure 3 and Figure 4, the process continued by examination of the dynamic properties of this boring bar. Implementation of an active solution requires a modification of the boring bar structure, thus a change of the dynamic properties is expected. These changes are not allowed to interfere such that new undesired problems appear, for example making the boring bar too flexible or moving resonance frequencies so they coincide with other structural resonance frequencies of the machine tool system A number of different designs of the active boring bar where tested with respect to the dynamic stiffness. They were also designed to be able to produce a force level at certain frequency determined from estimates from the preliminary measurements. When a design complying with the specification was developed it was time to test the prototype, not only in the laboratory lathe but also in the lathe with vibration problem at the selected manufacturing industry. Thus further measurements with an active system in industry were conducted, finalizing the project of designing a first prototype.

Methods

The first step was to examine the problem experienced in industry. In order to get an appropriate and detailed description of the actual problem recordings was made during metal cutting by means of operating deflection shape (ODS) measurements [2]. The lathe in industry was a Gildemeister Max Mller see Fig. 1 a) and the lathe in laboratory was a MAZAK 250 Quickturn see Fig.1 b). Also measurements on another CNC lathe (FEMCO WNCL-35) in industry were conducted for comparison. The lathe in the laboratory is accessible 24/7 and most of the development was carried out here, but this lathe also differs from the lathe Gildemeister in industry. One drawback is the size of the workpiece possible to be mounted in the Mazak lathe compared to the Gildemeister lathe. Which prevents to reconstruct some of the vibration problems observed in the selected lathe in the manufacturing industry. All signals where collected simultaneously with a front-end data acquisition unit (HP VXI E1432) with a capacity of 16 channels with a sampling capacity of 51.2kSa/s. Before starting the cutting process, all sensors and cables where protected using tape, resistant against heat. This was done to protect the sensitive equipment against the warm and sharp chips that is produced during the cutting

a) b)

Figure 1: a) Gildemeister MAX MÜLLER lathe, b) MAZAK 250 Quickturn lathe.

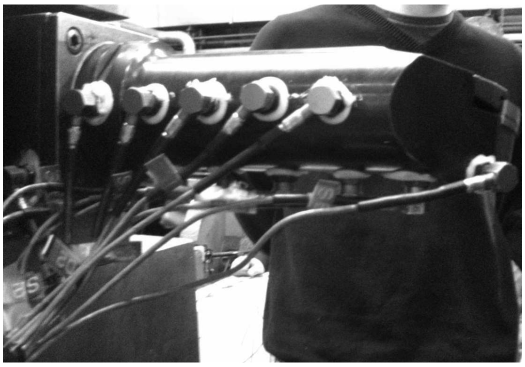
process.

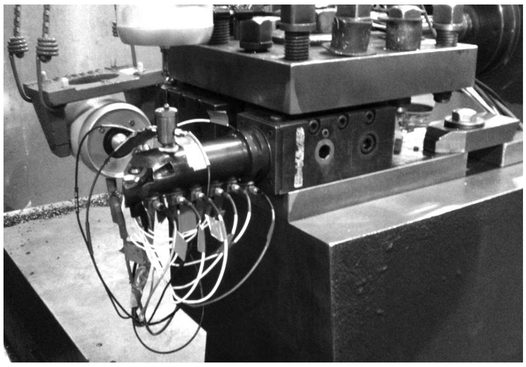
ODS Measurement

To examine the spatial dynamic behavior of the boring bar during metal cutting, the acceleration at a number of different spatial locations on the structure (boring bar and clamping house) was measured simultaneously. By considering the phase and amplitude of the response signals from the accelerometers on the operating structure, it is possible to produce an estimate of operational deflection Shapes, The amplitude is measured by either auto-power spectrum or auto-power spectral density estimates depending whether the signal is tonal or random [5, 6]. And the phase between each spatial position is estimated from the cross-power spectrum. 14 accelerometers where attached to the boring bar mainly in two orthogonal directions, seven in cutting speed direction, six in cutting depth direction and one with 45 degrees between both cutting depth and feed direction, see Fig. 2 a).

Modal Analysis

The next step was to examine the dynamic properties of the boring bar mounted in its default clamping house. This was done using two shakers exciting the boring bar close to the tool tip in two orthogonal directions, cutting speed direction and cutting depth direction. The shakers were exciting the boring bar via a stinger rood connected to an impedance head, thus measuring the driving point in respective direction. At the same time the acceleration at 12 other locations along the boring bar was measured, see Fig. 2 b). Further modal analysis was conducted using other boundary conditions such as different lathe and different clamping house.





a) b)

Figure 2: a) Operational deflection shape setup on the Gildemeister lathe. b) Modal analysis setup on the Gildemeister lathe.

Control Setup

When the development of the prototype was finished it was time to evaluate its performance. A feedback control approach based on the feedback filtered-x algorithm[1, 9] was chosen for this application. This algorithm was implemented on a DSP from Texas Instrument (TMS320C32). As feedback signal an accelerometer mounted nearby the tool tip in cutting speed direction was used. The signal from the accelerometer was then amplified with a charge amplifier. The control signal, i.e. the reconstructed output signal from the DSP was amplified using a custom design charge amplifier connected to the actuator, see Fig. 3. The

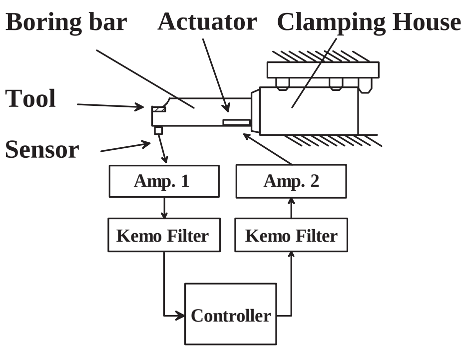


Figure 3: a) Control setup of the active boring bar.

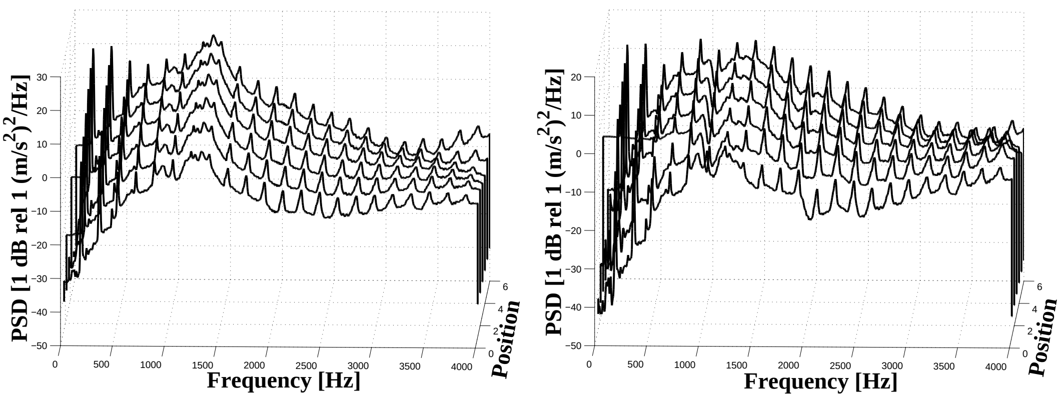
actuator was implemented with respect to attenuate vibration primarily related to the fundamental bending mode of the boring. The maximum force produced by the actuator is 3000 N.

Results

The results from the preliminary examination are presented as PSD plots of the acceleration signals from the ODS measurements. The accelerance (acceleration over force) of the boring bar mounted in the clamping structure from the modal analysis carried out in industry will be presented together with the quality measure coherence. Last, some PSD plots of the acceleration close to the tool-tip will show the performance of the proposed solution using an active boring bar, having the controller on and off.

ODS Measurement

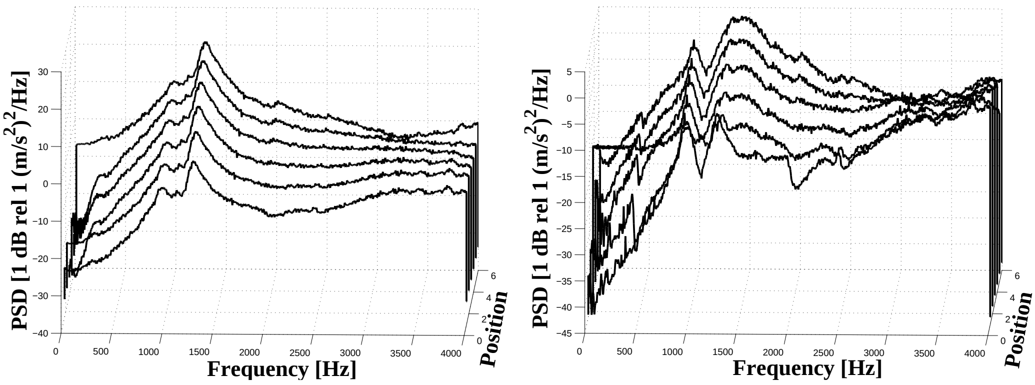
From the auto power spectral density plots of the acceleration signals in Fig. 4, it is clear that one fundamental resonance frequency and its harmonics are dominating the spectra together with an underlying system. It can also be noticed that the acceleration level is higher in cutting speed direction. The fundamental resonance frequency (at 178 Hz) and its harmonics has a deflection shape as a first bending mode (clamped-free boundary condition).



a) b)

Figure 4: PSD estimate from six different positions on the boring bar when machining a workpiece with a diameter of 800 mm, a) in cutting speed direction and b) in cutting depth direction.

When cutting in another workpiece with smaller diameter than 800 mm, i.e. with diameter of 500 mm, the spectra are different; see Fig. 5. The fundamental resonance frequency at 178 Hz does not longer appear, which indicates that the 178 Hz resonance frequency probably originate from the workpiece. In the measurement carried out when machining in the workpiece with the smaller diameter, 500 mm, the underlying system is more significant in the power spectral density estimates. The results from modal analysis will show if the observed underlying system is the boring bars fundamental bending modes. It is also a significant difference in the spatial boring bar vibration behavior between the case of machining in the 500 mm workpiece and in the case of machining in the 800 mm workpiece. The spectra in cutting speed direction are almost 20 dB higher than cutting depth direction at the 1484 Hz resonance frequency when machining in the 500 mm workpiece. But also when machining in the 800 mm workpiece the vibrations in the cutting speed direction for the 1484 Hz resonance frequency were dominating.



a) b)

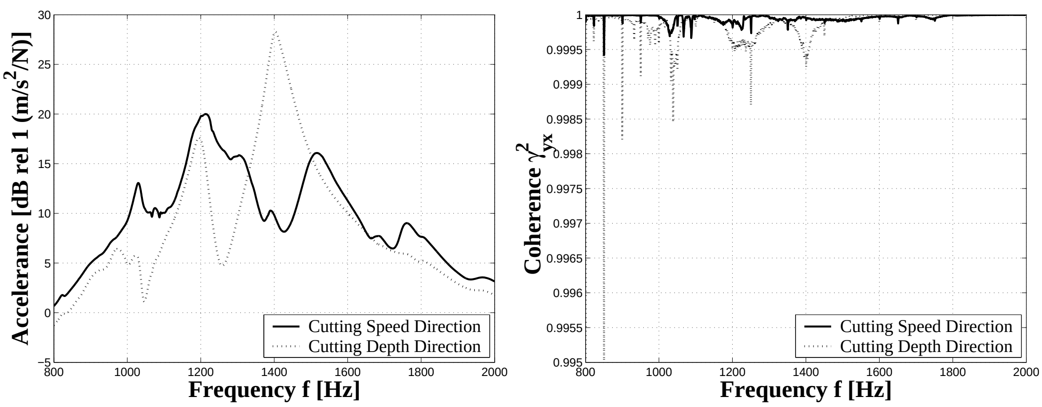
Figure 5: PSD estimate for six different positions on the boring bar when machining a workpiece with a diameter of 500 mm, a) in cutting speed direction. b) cutting depth direction.

Modal Analysis

The frequency response function estimate for the driving points, produced in the modal analysis, shows more than the two expected resonance frequencies; see Fig. 6 a). The two resonance frequencies are expected to be the fundamental bending modes. It is possible to have influences from both modes in each frequency function estimate depending on whether the excitation was in exact same direction as the mode shape or not. Frequency response function estimates for the clamped boring bar were produced with different excitation signals and different force levels. No nonlinearities were observed using the selected excitation levels. As a quality measure the coherence function was used. The coherence function estimates corresponding to the frequency function estimates in Fig. 6 a) is shown in Fig. 6 b). The estimated mode shapes were found at 1395 Hz and 1484 Hz in cutting depth direction and cutting speed direction respectively.

Controlling

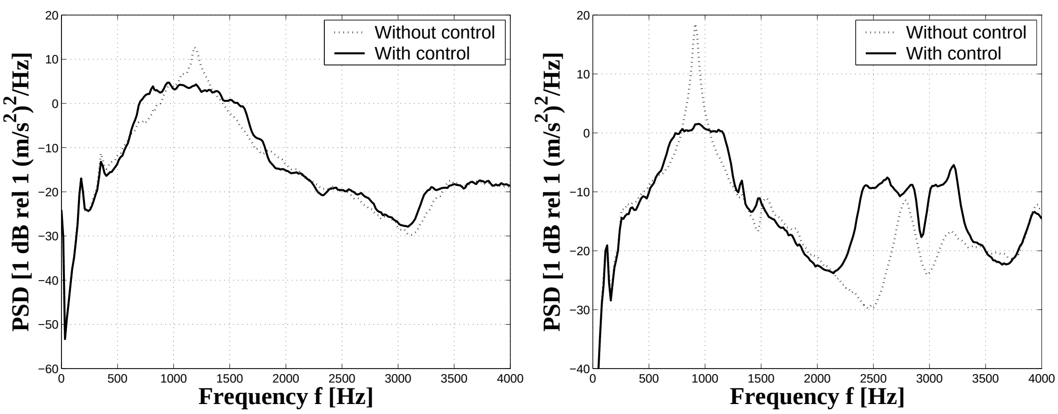
The active boring bar was designed to attenuate vibrations related to the fundamental bending mode of the boring bar in cutting speed direction. A workpiece with a diameter of 248 mm was machined; resulting in broad band excitation of the boring bar. The performance with and without active control is shown in Fig. 7 a), the level of attenuation was approximately 9 dB. The active boring bar was also tested in another lathe (FEMCO WNCL-35) in industry. As can be seen from Fig. 7 b) the resonance frequency is lower in frequency indicating that the system has been changed. It is also observable that the level of attenuation in this lathe was



a) b)

Figure 6: a) Frequency response function estimate of the driving point on boring bar close to the tool tip in both cutting speed direction (solid line) and cutting depth direction (doted line), b) the corresponding coherence function estimate

approximately 18 dB.



a) b)

Figure 7: a) Power spectrum density of the boring bar vibration in cutting speed direction with control (solid line) and without control (doted line). Vibrations when cutting on a workpiece with a diameter of 800 mm. b) Power spectrum density of the boring bar vibration in cutting speed direction with control (solid line) and without control (doted line). Vibrations when cutting on a workpiece with a diameter of 248 mm.

SUMMARY and CONCLUSIONS

A first prototype of an active boring bar of the model C5-MWLNR-27140-08 has been developed and tested to reduce a severe vibration problem in the manufacturing industry. Different results presented in this paper show a working implementation of the active control approach. The results have also indicated different possible improvements of the active boring bar design as well as of the clamping structure. The force produces from the actuator will be affected by the stiffness of clamping structure, compare Fig. 7 a) and b). Further development concerning clamping house and other types of boring bars are in progress. These solutions address the same vibration problems as the first prototype did, as well as vibrations from the lower frequency regions.

Acknowledgments

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