10th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2006, Lloret de Mar, Spain, 11-15 September, 2006

MONITORING OF THE MACHINING PROCESS FOR ALUMINIUM AND STEEL

Peter Norman[1]
Matti Rantatalo[2]
Inge Svenningsson[3]
Alexander Kaplan[1]
[1,2]Luleå University of Technology
[1]Division of Manufacturing Systems Engineering
[2]Division of Sound and Vibrations
[3]AB SANDVIK COROMANT

ABSTRACT
Avoiding vibrations and tool failure during machining is of great importance for most machining applications, especially when manufacturing slender parts with thin walls as in aerospace industry. Excessive vibrations during machining of such a part will affect its fatigue life. Vibrations can be avoided by choosing appropriate process parameters, such as feeds and speeds.
In order to predict the behaviour of a component while it is being machined and to adjust the process parameters so that harmful vibrations are avoided, a machining optimisation and control system is envisaged consisting of several modules. The present work studies the correlation between on-line sensor signals and properties of the machined surface.
The experiments are done in a 5-axis, high-performance milling machine. Machining and on-line signal detection of an aluminium alloy and of a hardened steel type is studied for three different settings of the feed rate.
The on-line applicability of the sensor test-bed during the cutting process is demonstrated, providing highly valuable vibration information on the process.

Keywords: milling, spindle, analysis, stability, vibration, machining

1. INTRODUCTION

The milling process and how the parameters affect the stability, forces and surfaces generated is well known and has been researched during many year s, from the beginning of the '60s, where Tobias [1] looks into how to design machine tools considering vibrations during cutting, to the more recent work by Altintas [2] and Liu [3]. The use of accelerometers and force sensors is widely spread throughout the industry and the academic world for monitoring and studying the process and spindle behaviour. Different types of force sensor systems are described by Milfelner [4] and Rehorn [5]. The sensors can be used in different setups and evaluated with different mathematical models as shown by Kuo [6]. Another measuring method of acquiring data on the part behaviour during processing is LDV (Laser Doppler Vibrometry), see Rantatalo et al [7]. To move the experiments into the virtual world the Finite Element Modelling technique (FEM) is used, which can simulate many static or dynamic events. The biggest advantage over experimental work is that cases can be studied with many variables for lots of variations. FEM techniques are used by milling tool manufacturers [8] to design and optimize the tool geometry and performance, e.g. to simulate the workpiece movement during cutting [9] and in turn to calculate the tolerances of the finished part. When milling slender parts the general way of doing this is to stop machining at intervals to measure the eigenfrequencies of the work piece. Instead of stopping the machining process it is possible to predict the workpiece dynamics as a time saving operation demonstrated [10].

The authors have developed a sophisticated test bed [10] composed of measurement sensors cooperating with numerical methods in order to monitor and study the machining process and in turn the product quality. To get an accurate prediction and learn about the process, several experiments have been performed. The present work deals with the stability of the system spindle/tool/workpiece and how the process is affected and monitored during milling of two materials at different feed rates.

2. EXPERIMENTAL SETUP

The experiments were carried out in a Liechti Turbomill ST1200 five axis HSM machine (25 krpm, 60 Nm torque). Two materials were studied, namely the aluminium alloy AA 7010 and the hardened steel SS2541-03. The workpieces were pre-milled to get a curved surface, enabling us to keep the spindle head completely at rest during milling by only moving the table. This way of machining removes disturbances related to the fast movement of the spindle head that may affect the accelerometers. It also enables the use of Laser Doppler Vibrometer on the polished ring mounted on the tool. The tool used is a 16mm R390 mill with two inserts. The axial depth of cut was set to 5mm and the radial to 1mm.

The signals logged during milling are: (i) the feeding force components F_x, F_y and F_z by using a Kistler 9257A force platform, see Figure 1, (ii) the vibrations by two charge accelerometers in x- and y-direction (cutting and transversal direcation, respectively) placed on the lower bearing of the spindle housing, see Figure 1. The LDV is used to verify the accelerometer measurements. The data were logged with a pulse system from Brüel&Kjaer.

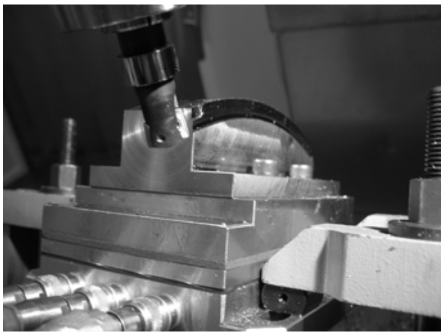


Figure 1(a): Experimental set-up

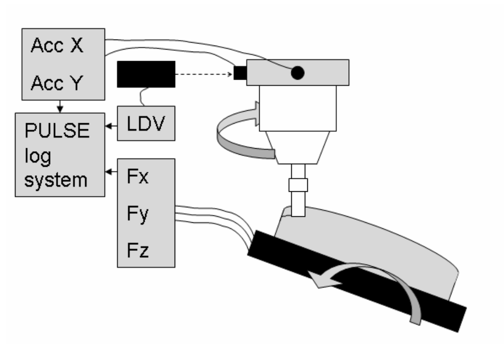
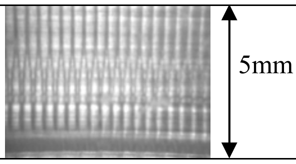
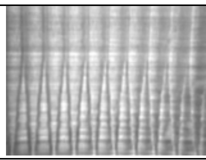
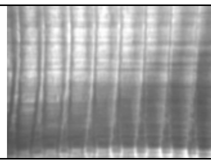
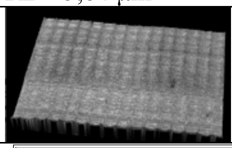
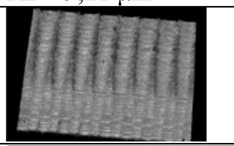
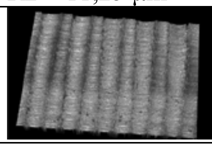
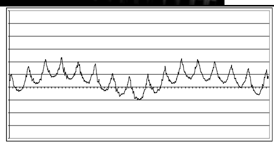
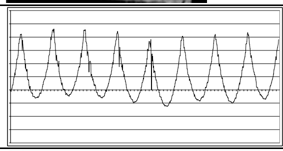
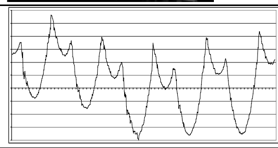
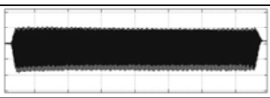
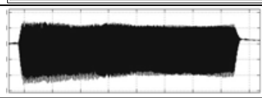
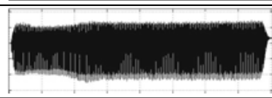
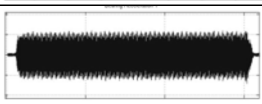
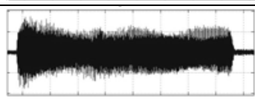
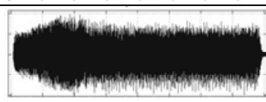


Figure 1(b): Measurement platform

Subsequent to the milling process the optical appearance and roughness of the surfaces was studied through optical microscopy and by a Wyko NT1100 optical profiler. For comparison with the Wyko roughness values of R_a and R_z values a mechanical surface inspection device was applied, too. The rotational speed was chosen as recommended from the tool manufacturer, the feed rates were varied between 6200-13300 m/min for aluminium and between 2600-6000 m/min for steel.

3. RESULTS

Figure 2 summarises the results from the six test runs performed, i.e. three different feed rates in two different materials, namely aluminium AA7010 in Fig. 2(a) and steel 2541-03 in Fig. 2(b). When examining the results correlations can be found between the surface roughness and the logged signals, particularly with respect to the envelope level of the signal amplitudes. Low feed rate gave a rather smooth surface, while a higher feed rate resulted in a rougher surface where the process seems to become less stable both for aluminium and steel. The highest feed rate in aluminium is still stable but both signals appear increasingly noisy, indicating an increase in surface roughness. The difference between the surface roughness measurements depends on the methods that are used. (A journal publication describing the research work in more detail is under preparation.)

(a) Aluminium 7010 n = 19 000 rpm	Feedrate: fz=0,16 fn=0,32 v1 = 6200 mm/min	fz=0,3 fn=0,6 v2 = 11500 mm/min	fz=0,35 fn=0,7 v3 = 13300 mm/min
Roughness through Mechanical Surface Inspection (MSI)	Ra = 1,23 µm Rz = 4,80 µm	Ra = 1,58 µm Rz = 6,12 µm	Ra = 1,73 µm Rz = 8,52 µm
Optical microscopy			
Roughness through optical profilometry	Ra = 0,73 µm Rz = 5,84 µm	Ra = 1,25 µm Rz = 9,21 µm	Ra = 2,08 µm Rz = 11,25 µm
Optical profilometer 3D profile z(x,y) Area about 4 x 4 mm			
Optical profilometer: Surface profile z(x) z-axis [0...10 µm] x-axis [0...5 mm]			
Force signal F_y [0...100 N] along y- (= cutting-) direction [0..150 mm]			
Accelerometer signal a_y [-200...200 m/s^2] along y-direction [0...150mm]			

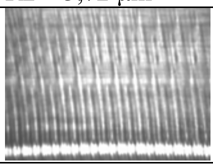
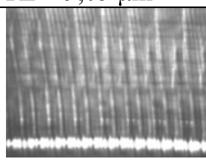
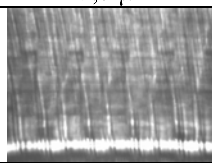
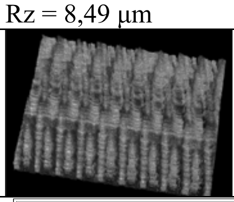
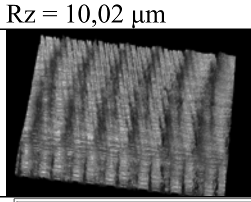
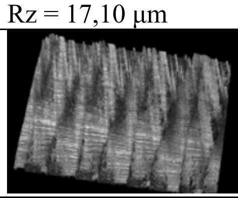
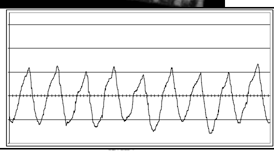
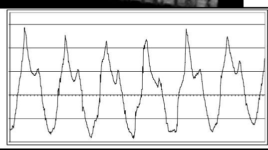
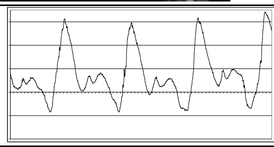
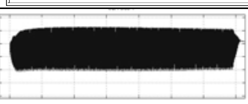
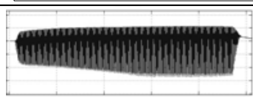
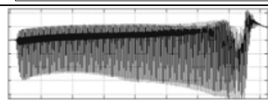
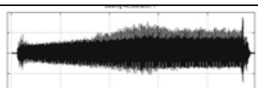
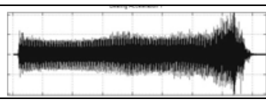
(b) Steel 2541-03 n = 4800 rpm	Feedrate: fz=0,27 fn=0,54 v1 = 2600 mm/min	fz=0,4 fn=0,79 v2 = 3800 mm/min	fz=0,63 fn=1,25 v3 = 6000 mm/min
Roughness through MSI	Ra = 0,74 µm Rz = 3,72 µm	Ra = 2,20 µm Rz = 9,05 µm	Ra = 3,29 µm Rz = 13,7 µm
Optical microscopy			
Roughness through optical profilometry	Ra = 1,76 µm Rz = 8,49 µm	Ra = 2,02 µm Rz = 10,02 µm	Ra = 3,46 µm Rz = 17,10 µm
Optical profilometer 3D profile z(x,y) Area about 4 x 4 mm			
Optical profilometer Surface profile z(x) z-axis [0...11 µm] x-axis [0...5 mm]			
Force signal F_y [0...300 N] along y-direction [0...150 mm]			
Accelerometer signal a_y [-200...200 m/s^2] along y-direction [0...150mm]			

Figure 2: Machined surface and corresponding monitoring signals for (a) aluminium and (b) steel

4. CONCLUSIONS

- For both materials (Al-alloy, steel) the roughness (appearing as a regular peak-valley profile along the machining direction) increased for increasing feed rate
- At higher feed rate a sub-pattern with second surface peaks appears at the machined surface, this can be derived to the radial run-out and angular misalignment of the tool inserts.
- Optical and mechanical roughness measurements agreed qualitatively, but not quantitatively
- For the first time on-line signals from the whole sensor platform developed, namely from force sensors, accelerometer sensors and an LDV measurement, were successfully acquired, demonstrating the on-line applicability and potential of the platform and its instruments
- Correlations were found between the detected signals and the surface roughness profile
- Disregarding a transient regime at the beginning or end of the process, a stable signal can be detected, the envelope of the amplitude showing correlations with the roughness – nevertheless the transient signal behaviour needs further investigations
- At low feed rate a smooth, stable signal envelope was observed in contrast to disturbances at higher feed rate
- For process monitoring further signal analysis and generalizing studies are required.
- Studying the machining process behaviour and its physical context to the signals is desirable

5. ACKNOWLEDGEMENTS

The authors acknowledge the support from Mr. Kourosh Tatar, Mr. Jens Carlevi with measurements and from Mr. Tore Silver for the CNC programming. The authors are grateful to funding of the research work by the Research Council of Norrbotten, project no. NoFo 05-024, and VINNOVA, project no. 2002-00163.

6. REFERENCES

[1] Tobias, S.A., Machine tool vibration research. International Journal of Machine Tool Design and Research, 1961.
[2] Altintas, Y., Manufacturing automation: metal cutting mechanics, machine tool vibrations, and CNC design, Cambridge: Cambridge University Press, 2000
[3] Liu, X. and K. Cheng, Modelling the machining dynamics of peripheral milling. International Journal of Machine Tools and Manufacture, 2005.
[4] Milfelner, M., F. Cus, and J. Balic, An overview of data acquisition system for cutting force measuring and optimization in milling. Journal of Materials Processing Technology, 2005.
[5] Rehorn, A.G., J. Jin, and P.E. Orban, State-of-the-art methods and results in tool condition monitoring: a review. 2005.
[6] Kuo, R.J., Multi-sensor integration for on-line tool wear estimation through artificial neural networks and fuzzy neural network. Engineering Applications of Artificial Intelligence, 2000.
[7] Rantatalo, M., K. Tatar, and P. Norman. Laser Doppler Vibrometry measurements of a rotating milling machine spindle. in Eighth International Conference on Vibrations in Rotating Machinery, University of Wales, Swansea UK. 2004.
[8] Wertheim, R. and A. Satran. Design and performance of cutting tools using FEM. in CIM 2002 Computer Integrated Manufacturing and High Speed Machining - 8th International Scientific Conference on Production Engineering, Jun 13-14, Brijuni, Croatia, 2002.
[9] Ning, H., et al., Finite element method analysis and control stratagem for machining deformation of thin-walled components. Journal of Materials Processing Technology, 2003.
[10] Norman, P., M. Bäckström, M. Rantatalo, A. Svoboda, and A. Kaplan: A sophisticated platform for characterization, monitoring and control of machining, Measurement Science and Technology, 2006