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FFT and Wavelet-Based Analysis of the Influence of Machine Vibrations on Hard Turned Surface Topographies*

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Abstract: With hard turning, which is an attractive alternative to existing grinding processes, surface quality is of great importance. Signal processing techniques were used to relate workpiece surface topography to the dynamic behavior of the machine tool. Spatial domain frequency analyses based on fast Fourier transform were used to analyze the tool behavior. Wavelet reconstruction was used for profile filtering. The results show that machine vibration remarkably affects the surface topography at small feed rates, but has negligible effect at high feed rates. The analyses also show how to control the surface quality during hard turning.

Key words: surface topography; fast Fourier transform (FFT); wavelet; hard turning; machine vibration

Introduction

Hard turning is an established industry process in industry for finish machining of a wide range of hardened steel workpieces. Hard turning allows manufacturers to simplify their processes and still achieve the desired surface finish quality. In recent years its benefits compared to competing processes such as grinding have drawn much attention all over the world. Hard turning has advantages in terms of the increased flexibility of the machining technology, higher rate of material removal, better environmental characteristicses, and less cost[1-3]. But hard turning on ultra-precision machine tools is not wide spread due to its limited turning accuracy. Therefore, the various factors and conditions affecting the surface quality need to be further analyzed. Since hard turning does not include a secondary step to improve surface quality, further analysis is needed to enable manufacturers to accurately predict the surface quality of hard turning finishes.

This work seeks to develop a better understanding of how the surface profile is generated during hard turning. There are many parameters which impact surface quality, such as cutting speed, feed rate, tool geometry and defects, and machine rigidity. Much research has been done in this field, with most based on simulations or mathematical modeling[4-8]. This paper developed an experimental approach to analyze the surface topography generated by hard turning with measurement data processed by fast Fourier transform (FFT) and Wavelet techniques. The FFT is mainly used to transform time domain signals into the frequency domain. However, in this paper, the FFT is applied to the space domain signal. The wavelet analysis is used to analyze frequency features of the profile to determine the effect of machine vibrations on the hard turned surface topography for various feed rates.

1 Experimental Setup

The profiles of shafts manufactured by hard turning were measured in the test. As Fig. 1 shows, the

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measurements were parallel to the feed direction (the shaft axis) with three traces arranged around the shaft.

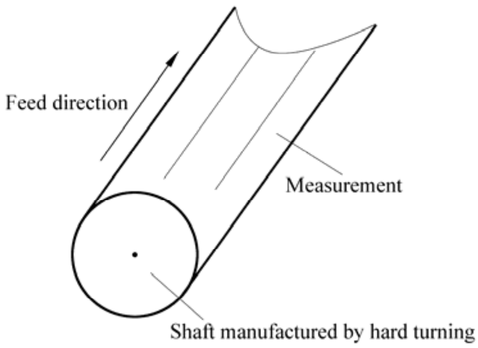

Fig. 1 Measuring the profile of the shaft manufactured by hard turning

The measurements were made using a Mahr Concept 4p perthometer.

The profiles of the work piece were measured on work pieces manufactured by hard turning using various feed rates. The cutting tool insert CNMA120408_14000802 was used with shafts turned on "Index" and "Monforts" machines, with the "Monforts" machine being much more rigid than the "Index" machine. Hence, the machine had different vibration characteristics during turning. The hard turning was conducted with feed rates: 0.05 mm/r, 0.08 mm/r, 0.12 mm/r, and 0.15 mm/r (r is the abbreviation for revolution).

2 Data Processing

Matlab was used to analyze the profiles. The measured data (.xls file) was directly loaded by the program as input, with the results outputted mostly in the form of figures. All the loaded data was treated at the beginning to make the analysis easier and more reliable. The data was processed first in a normalization step and then in a shift step. In the first step, the profile data was adjusted to a mean value of zero. There were three groups of data along the feed direction. The shifting adjusts the three groups of data so that the profiles all start at the same position, e.g., in the valley in the profiles. Then the space domain data is transformed to the frequency domain by FFT.

The FFT is an efficient algorithm for computing the discrete Fourier transform (DFT) of a sequence. The FFT returns the DFT of signals, computed with a fast Fourier transform algorithm. In the algorithm, the FFT decomposes the long series of Fourier transforms into a short series of Fourier transforms, using the fastest Fourier transform in the West (FFTW)[9] Matlab.

To further enhance the FFT analysis results, the surface profiles are reconstructed using wavelets on both approximate and detailed levels. The wavelet reconstruction splits the surface profile into an approximate curve and detailed noise.

3 Results and Discussion

The workpiece topography generated by hard turning is affected by the feed rate, macro tool geometry, micro tool geometry (tool wear), and machine tool vibrations, etc. The frequency components of the profile correspond to these factors. There is always a constant frequency for any cutting conditions, which is the reciprocal of the feed rate. The high frequencies can be related to the micro tool geometry (tool wear) and the machine tool vibrations. Since the experiments were conducted with a new cutting tool, the differences caused by the cutting tool geometry will be ignored in the discussion.

The frequency plots of the surface profiles generated by the two machines are shown in Figs. 2-5 for various feed rates.

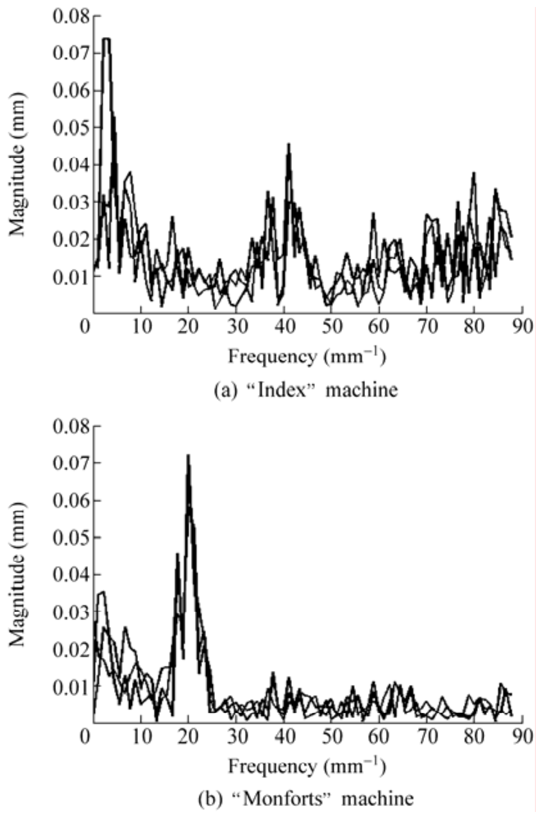

Fig. 2 Frequency feature of the profiles for a feed rate of 0.05 mm/r

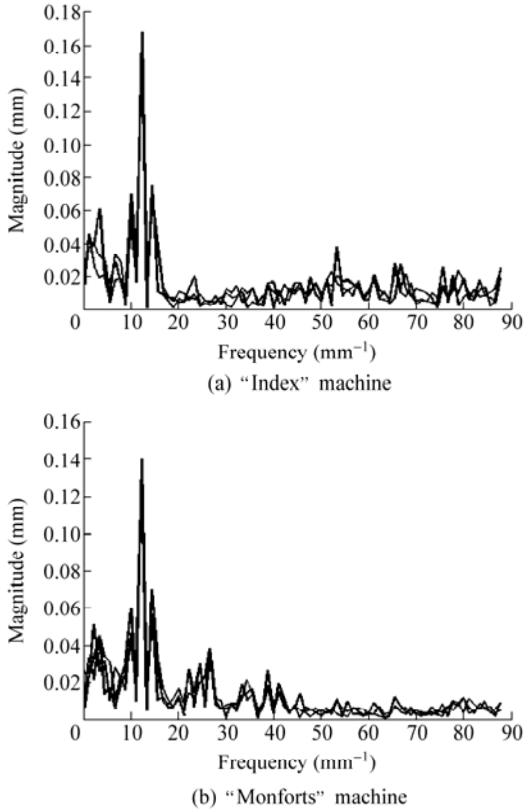

Fig. 3 Frequency feature of the profiles for a feed rate of 0.08 mm/r

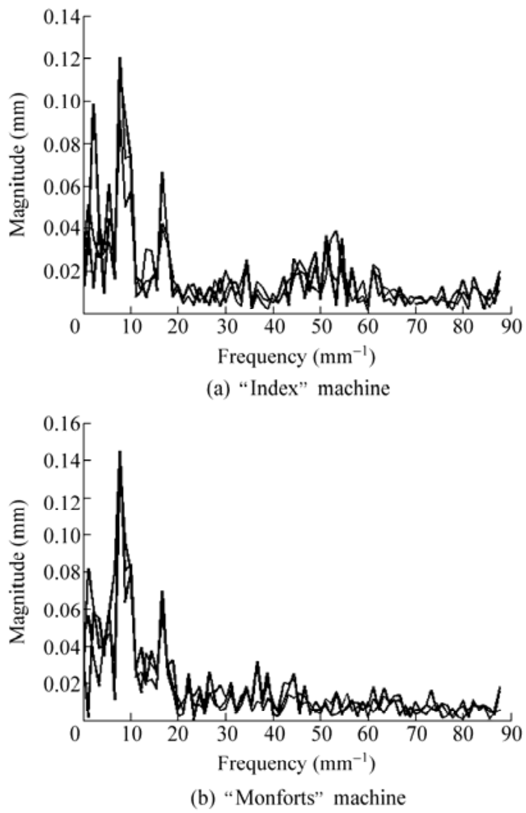

Fig. 4 Frequency feature of the profiles for a feed rate of 0.12 mm/r

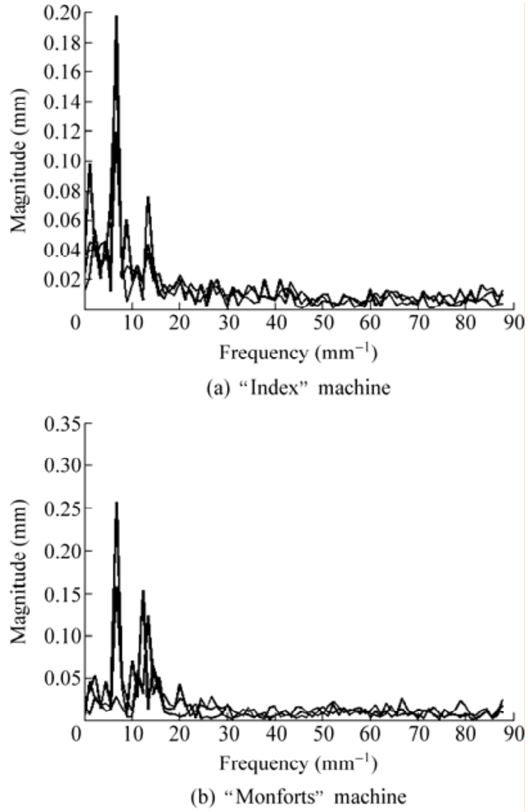

Fig. 5 Frequency feature of the profiles for a feed rate of 0.15 mm/r

The plots show that the surface profiles generated by “Monforts” machine have less high frequency components than the ones generated by the “Index” machine especially at low feed rates (0.05 mm/r), which reflects the better rigidity performance of the “Monforts” machine.

At the low feed rate (0.05 mm/r), the frequency features of the surface profile were on the two quite different machines (Fig. 2). On the “Index” machine, the feed frequency (1/0.05=20) does not have a large amplitude while many high frequency components appear at irregular frequencies.

The approximate reconstruction of the profile in Fig. 6 shows the de-noised topography.

The approximate reconstructions of the profile, especially the fifth level reconstruction show that for the surface profile generated by the “Index” machine, the machine tool vibrations offset the cosine shape of the feed rate period which tends to hide the feed rate related frequency component. In addition, the vibrations generate many small waves with high frequencies. This “noise” is found in the wavelet detail construction in Fig. 7.

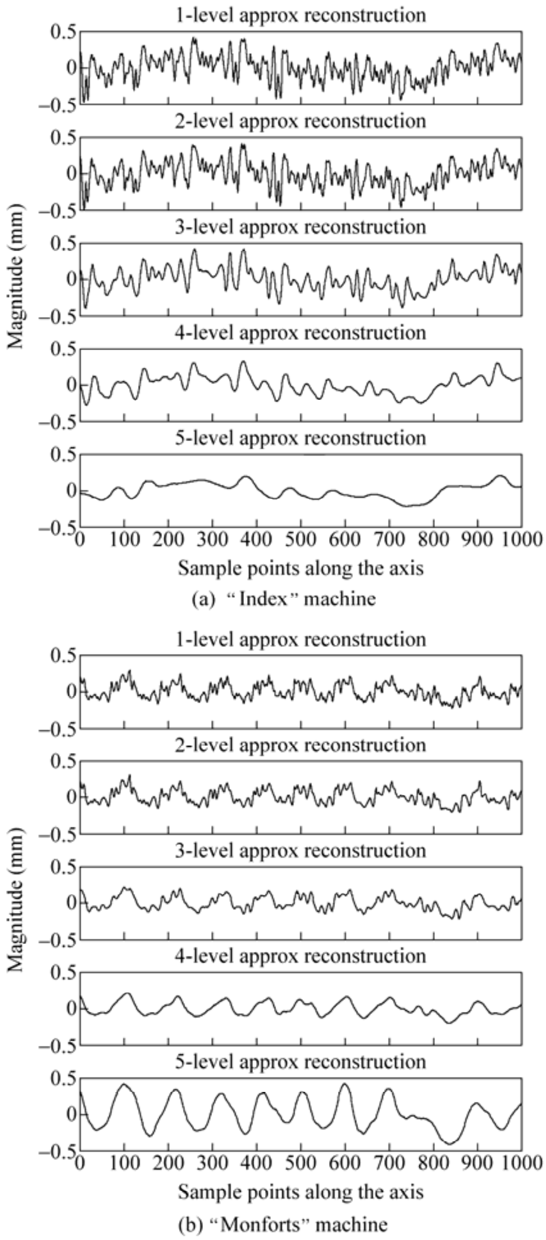

Fig. 6 Approximate reconstructions of the surface profile for a feed rate of 0.05 mm/r

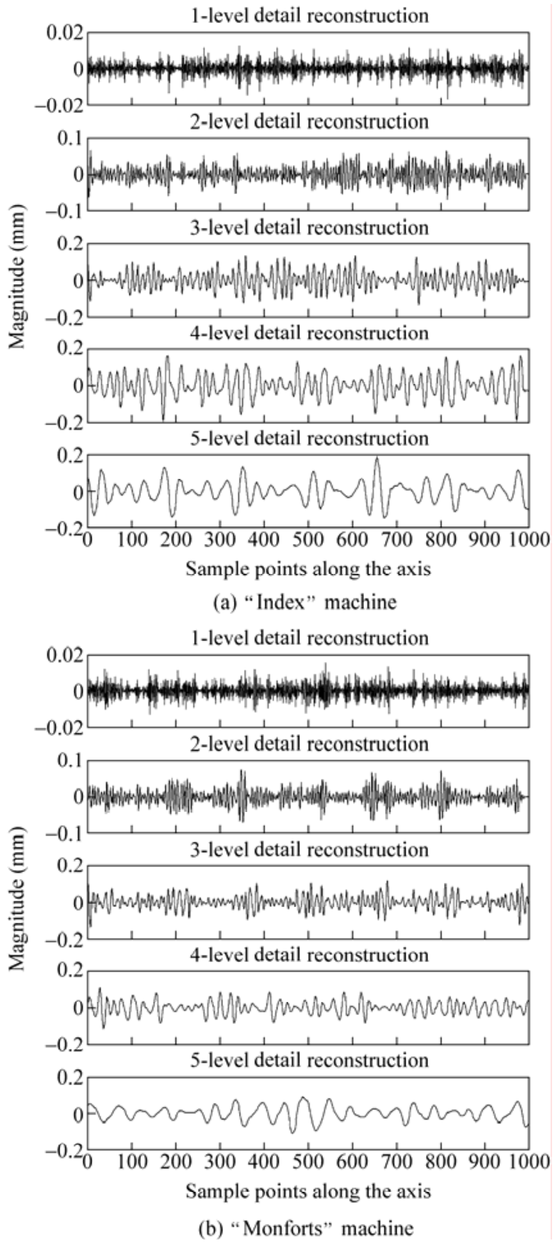

Fig. 7 Detail reconstruction of the surface profile for a feed rate of 0.05 mm/r

The surface profile detail reconstruction shows more noise with larger magnitudes and shorter periods on the "Index" machine. Therefore, the effects of machine vibration are very evident in this feed range and the vibration dominates the surface roughness signal in machines with poor rigidity.

However, as shown in Figs. 3-5, at higher feed rates, the frequency features for the two machines are very similar.

As shown in Fig. 5, for a feed rate of 0.15 mm/r, there are almost no high frequency components on the surface profile generated by the "Index" machine. The approximate and detail reconstructions of the surface profiles in Fig. 8 and Fig. 9 show that the surface profile features generated by the two machines have no significant differences. Therefore, the effect of machine vibrations in the topography can largely be ignored in this feed range.

4 Conclusions

The FFT analysis and Wavelet reconstruction revealed the extent of the effect of machine vibrations on the surface topography at various feed rates. At low feed

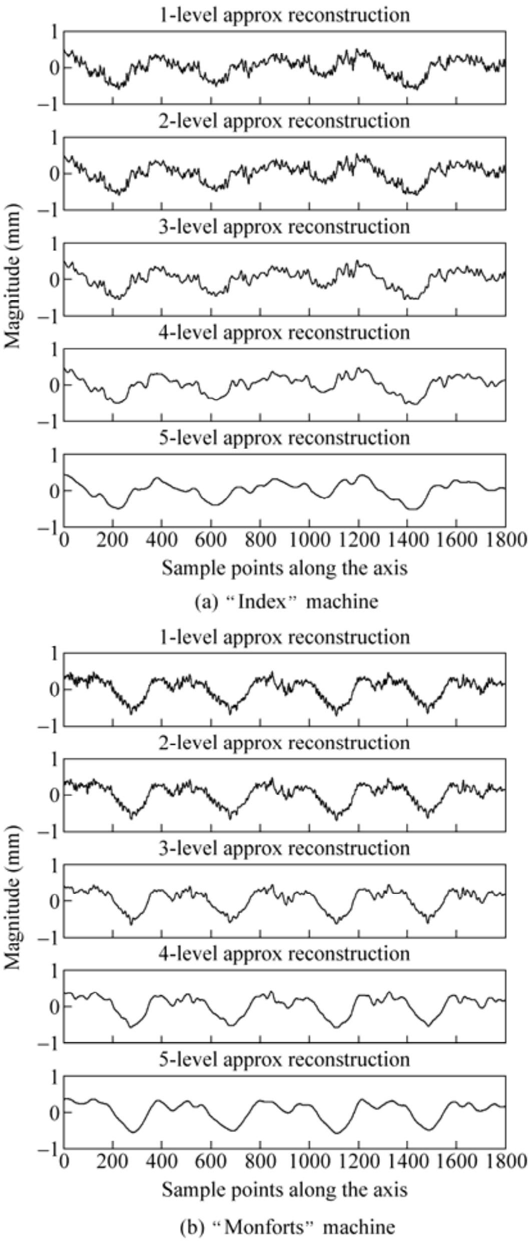

Fig. 8 Approximate reconstruction of the surface profile for a feed rate of 0.15 mm/r

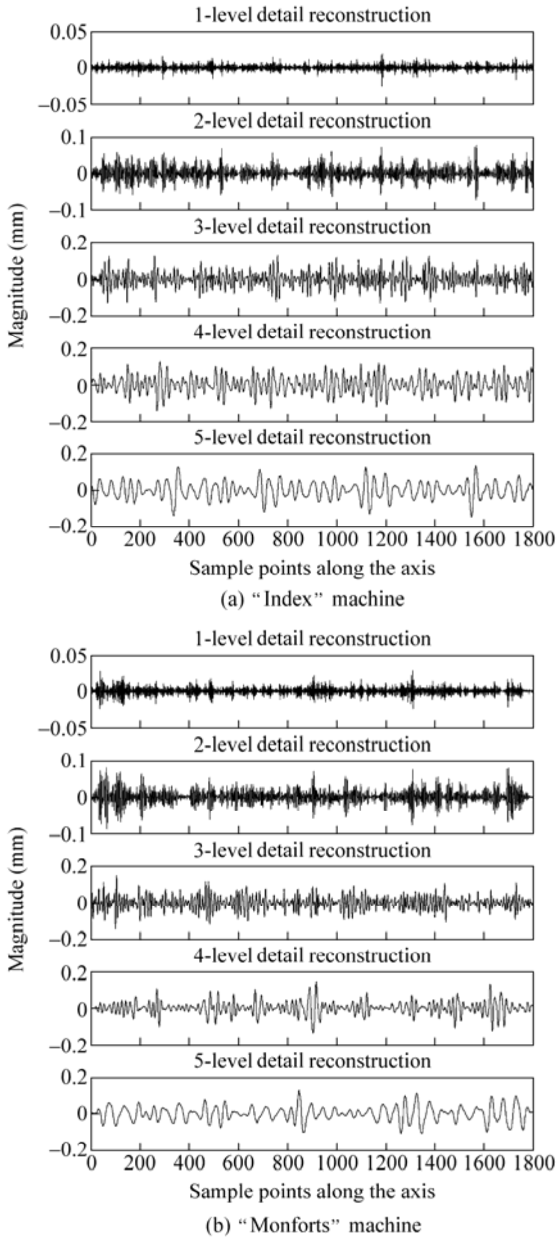

Fig. 9 Detail reconstruction of the surface profile for a feed rate of 0.15 mm/r

rates (0.05 mm/r), machine vibrations significantly influenced the surface topography, generating the dominant roughness on the low rigidity machine. At median or high feed rates (> 0.08 mm/r), the machine vibrations had little impact on the surface topography, with the effect of vibrations at high feed rates (> 0.15 mm/r) being negligible compared to other factors such as tool wear. Note that these surface profile frequency features and the effect of machine vibrations at these feed rates are strongly related to the machine conditions. For example, if two other machines were used, the vibrations may have had more impact at the feed rate of 0.08 mm/r.

Nevertheless, the results indicate that at higher feed rates, machine vibrations have less effect on the hard turning surface profile. In addition, this study shows how FFT and wavelet analyses can be used to analyse surface topographies by hard turning. The approach can also be used to access the influence of macro tool geometry and tool defects. Surface profiles can then be quickly monitored to establish effective quality control.

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Tsinghua Achieves AACSB Accreditation for Business Education

The School of Economics and Management at Tsinghua University (Tsinghua SEM) was recently awarded accreditation by AACSB International (The Association to Advance Collegiate Schools of Business). This makes Tsinghua SEM the first in Chinese Mainland to be accredited for having met the highest standard of achievement in education and research for business schools worldwide.

Tsinghua SEM's bid for accreditation includes the preparation of a self-evaluation report, as well as a peer review. It obtained the AACSB membership in 2002, and applied for accreditation in 2004. Three members of the AACSB review committee from U.S., Europe, and Asia reviewed Tsinghua SEM's comprehensive credentials document and interviewed Tsinghua SEM staff, students, employers, and other stakeholders in March, 2007. As a result of the review team's strong recommendation to AACSB International, the Tsinghua SEM successfully achieves the accreditation after five-year efforts.

The seal of AACSB is a sign that the bearer has earned a superior level of quality distinction among an elite group of peers. It also allows Tsinghua SEM to cooperate with prestigious international b-schools for student and faculty exchange programs - an area in which Tsinghua SEM already has a good track record. Tsinghua SEM's success in accreditation, as the first in Chinese Mainland, signals that Tsinghua SEM qualification has satisfied rigorous international management education standards, which will have a far-reaching impact on China's management education in its internationalization process.

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