Measuring of drill bit vibration by laser Doppler methods

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Measuring of drill bit vibration by laser Doppler methods

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Abstract. The beginning of the drilling process was measured on the drill bit by laser Doppler interferometric methods. The measurements of the velocities were based on the Doppler effect. An LDV (Laser Doppler Vibrometer) device was used to measure the translational vibrations, and then the torsional vibrations (angular velocity changes) of the drill bit were investigated by an LTV (Laser Torsional Vibrometer) device. The time series and frequency spectra were also analysed.

1. Introduction
One of the most common cutting operations is drilling. It occurs particularly often in the aerospace industry and vehicle industry sectors, where it can represent up to 30-40% of the working procedures. Because of its productivity and other beneficial properties, the twist drill is the most frequently applied tool [1]. In order to obtain adequate production quality, the parameters of the tool and its environment must be set to appropriate values. The drill has several technical parameters, such as point angle, chisel edge angle, cutting lip length, helix angle, etc., which in different ways affect e.g. the cutting force. At the same time, the RPM and feed rate set on the machine, or even the design of the machine itself all have a direct effect on the quality of the boreholes. Figure 1 below shows some borehole images from the drilling experiments that we carried out earlier. It is a common characteristic for all of them that the discontinuous pattern observable on the machined surface was caused by self-excited vibrations. (It is worth to note the odd number of the recurrence pattern!)

Consequences similar to the above can be the result of the whirling vibration of the tool, which contains the twisting or lateral oscillations, or both oscillations at the same time.
Understanding the phenomena behind machining is not only needed for the setting of the cutting parameters, but it is an essential safety interest as well. The simplest way to do this is to continuously monitor the process, i.e. the cutting forces, the cutting temperature, and the vibrations that develop on the tool. The acquired signal can have information about tool life, quality of cutting and defects in the workpiece.

Laser measuring instruments are often used to measure rotating bodies in industrial environments [2,3]. Nowadays we can also find them within the research projects in connection with metal cutting. Without the demand of completeness, we can mention an example for milling research [4], or turning studies [5].

In spite of the foregoing, the laser Doppler drilling studies are not too common in the literature [6,7,8]. Most of the instruments used during drilling are not laser equipment, but devices that measure some other physical parameters, such as torque or force. However, when these devices are used, most of the time special clamping, structural alterations are necessary. As opposed to this, the laser measurement technology - with its non-contact intervention - could provide a truer picture about the process.

2. Circumstances and methods

The measurements were performed on a DMG CNC general lathe in the workshop of the Department of Machine Tools, Institute of Machine Tools and Mechatronics. We chose a general twisted drill bit from Tivoly, contained 5% Co content (DIN338) with a diameter of 12.0 mm. Its point angle is 130˚, and its cutting edge ratio is 1/3-2/3 (1/3 of the cutting lip remained).

Throughout these measurements the workpiece (or the tool) was rotated at 825 RPM. In case of the workpiece with Fe490-2 material quality, we did not prepare pilot bore before drilling. This was not necessary because of the point thinning of the cut chisel edge. The feed rate was \( f_z = 0.1 \text{mm/rotation} \). We kept the machining speed (i.e. the RPM of the main spindle) low. In the course of the drilling process the tool arrives to the defined depth (3 mm), then it immediately comes back to the starting position. It only stays here just for a moment (few ms), and the operation sequence of the drilling is closed with the moving of the tool to the reference point. Most of the experiments lubricant fluid was used only to a limited extent (minimal quantity lubrication). It was justified by tool-material pairing also. During experimentation, several sets of measurements were made with various circumstances; however, in this article we describe only a few ones in detail.

The translational and the torsional vibrations were examined by laser interferometric methods. To monitor the process, we used two different non-contact measuring devices applied one after the other. We measured the lateral vibrations of the drill bit from the point outside of the workplace, using the LDV that was mounted on its own tripod (figure 2a). In this case the drill bit was standing, while the workpiece and the chuck were rotating. Although for such circumstances an axial alignment error may occur between the axis of the drill and the axis of the rotating workpiece, it has the advantage that the rotation of the tool does not have any effect on the measurement. By the investigations performed with the LTV (figure 2b) we observed the RPM changes of the drill bit. However, during these experiments - although the instrument is capable of measuring the angular speed changes of a stationary object as well [9] – the drill was rotating and the workpiece was standing. This setup also had the advantage that we could avoid the axis misalignment problem between the workpiece and the tool.

LDV and LTV devices are well known in the literature. Some publications demonstrate the LDV and LTV detection scheme [6,10,11], so here we do not deal with them.
3. Results and discussion

Figure 3(a,b) shows the time domain representation of the LDV (a) and LTV (b) signal. We can notice, that has some difference between them. Two signals have same characteristics, the values grow along time. But the LTV plot has a relatively permanent phase (about 3.8s-4.38s), where the absolute mean of the signal does not change. This is because this period of the drilling was executed with full diameter of the drill bit. Furthermore, these plots do not really give us a lot of information. Thus we computed short time Fourier transformations, which returned frequencies in the signals as a function of time. Figure 3(c,d) visualize the output of the calculation, and displays the power spectral densities of the measured data. The colors in the spectrogram denote the power levels in the LDV (c) and LTV (d) signals. We have chosen appropriate settings to obtain a good time resolution without losing fitting frequency resolution. We can see here how the frequency of the signals changes as a function of time. The colors in the spectrogram denote the power levels in the measured signal. The blue color depicts low power level and the yellow one depicts high power level. If we closely look at the color pattern on the LDV PSD plot, a blue area is located in the high frequency range at the beginning of the cutting.
The intensity of these frequencies will be more dominant as time goes on. Some of the lower frequencies (for instance around 12 kHz) lose their significance, but some of them (for instance around 5 kHz) increase.

If we take a closer look at the spectrogram of the LTV, in the upper band of the spectrogram that is beyond 20kHz the color pattern is pretty much the same for the entire duration. The color intensity of these signals suggest that the power levels are not so high. So the presence of these components do not add any value to the analysis of the torsional vibration. In contrast to this, based on the color profile, in the lower area we see three or four distinct bands, which change in color. Some of them become wider, and others become thinner. So we need to get rid of the frequency components higher than 20kHz. We can conclude that there is a need to pre-process the LTV signal using a low-pass filter.

We can get a more accurate picture about the exact frequency components, if we make the FFT spectra. The vertical axes named as normalized amplitude, where 1 means the maxima of the FFT signal. On the lower plot, the name of the vertical axis is “synchronized”, because of the differences between the LDV and LTV FFT-lines values, we had to synchronize them to each other, in order to show the FFTs together.

![Figure 4. FFT spectra of the signals from LDV and LTV device (above), common spectra (below).](image)

In the LDV spectrum the lower (at most 1500Hz) frequency components are more significant than the upper frequencies, not only in their numbers, but in their magnitudes as well. In the FFT-spectrum of the LTV signal, however, two higher frequency signals are markedly present: at around 4500Hz and 5700 Hz. From the spectral analysis, we can see that they are both permanently present at the time of metal cutting. At the same time two, even higher frequency oscillations can be recognized (at around 12kHz), out of which, however, one is becoming stronger and the other is becoming weaker in comparison with the others as time goes by.

Nevertheless, both FFT-spectrums agree on having definite peaks in the lowest frequency range. In figure 5, the low frequency part of the two FFT spectra can be seen together, and it is quite visible that some of the components are identical in the two vibrations. We also have to take into account, however, that the LTV signals also contain the noises caused by the pattern of the reflecting surface. The so called pseudo vibrations are the consequence of this, as it has been reported in the literature [12,13].
Figure 5. Low frequency peaks of LDV & LTV FFT

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References
[1] Dudás I, Lierath F and Varga Gy 2010 Környezetbarát technológiák a gépgyártásban, Forgácsolás szárazon, minimális hűtéssel – kenéssel (Budapest: Műszaki Kiadó)
[2] Rothberg S J et. al. 2017 An international review of laser Doppler vibrometry: making light work of vibration measurement Optics and Lasers 99
[3] Castellini P, Revel G M and Tomasi E P 1998 The Shock and Vibr. Dig. 30 6 pp 443–456
[4] Nakagawa H et al 2008 Experimental Analysis of Chatter Vibration in End-Milling Using Laser Doppler Vibrometers Int. J. Aut. Techn. 2 6
[5] Prasad B S, Babu M P 2008 Correlation between vibration amplitude and tool wear in turning: Numerical and experimental analysis Eng. Sci. Technol. Int. J. 20 1
[6] Béres M, Paripás B 2018 Measurements of Vibration by Laser Doppler Method in the Course of Drilling Vehicle and Automotive Engineering 2 (Springer International Publishing AG, part of Springer Nature)
[7] Reddy Y R M, Prasad B S 2017 Analysis of vibration assisted drilling--A base for tool performance evaluation J. Prod. Eng. 20 1
[8] Balajti M, Murthy B S N and Rao M 2016 Optimization of Cutting Parameters in Drilling of AISI 304 Stainless Steel Using Taguchi and ANOVA Procedia Technol. 25
[9] Polytec GmbH RLV-5500 Rotational Laser Vibrometer Datasheet 2017
[10] Béres M, Paripás B 2016 Comparison of two laser interferometric methods for the study of vibrations Vehicle and Automotive Engineering (Springer International Publishing AG, part of Springer Nature)
[11] ed. Drain L E The laser Doppler techique 1980 (New York: Wiley-Chichester)
[12] Rothberg S J, Baker J R and Halliwell N A 1989. Laser vibrometry: pseudo-vibrations J. Sound. Vibr. 135 3, pp 516–522
[13] Martin P and Rothberg S J Methods for the quantification of pseudo-vibration sensitivities in laser vibrometry 2011 Meas. Sci. Technol. 22 035302