Structural Dynamics Characterization of a Deep-Hole Drill through Modal Analysis including Torsional Modes

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Abstract
In this paper a systematic approach for identifying the torsional modes of slender drills with an adapted method is presented. In a first step, an established experimental modal analysis is performed using a single-beam laser vibrometer. By comparing the results to a numerical modal analysis, the mode shapes of all natural frequencies including the torsional modes can be obtained. Based on this knowledge, an adapted experimental method using a rotational laser vibrometer is developed to verify the simulation and identify the respective mode shapes reliably.

1 Introduction
The deep-hole drilling process is affected by its high-dynamic characteristics due to the high-flexible tool. Figure 1 pictures the 235 x 4 mm drill that is analysed in this paper. For the purpose of optimising this complex system, it is necessary to understand its dynamic characteristics. In the analysis of the dynamic process forces and torques two essential effects stand out. First, the rotation of the tool excites oscillations on the rotary frequency and its higher harmonics. Second, a dominant 3900 Hz vibration can be found. Since the cutting forces in drilling include high tangential components, it can be assumed that this is a torsional natural frequency. To obtain a structural dynamic characterization of the tool including the mode shapes modal, testing is commonly used [1]. However, these conventional methods are not able to identify the torsional modes of slender drills reliably.

2 Modal Testing
In order to determine its dynamic characteristics, the deep-hole drill to be investigated is clamped in the main spindle of the TBT deep-hole drilling machine as
shown in figure 5. In a first step, a conventional experimental modal analysis is performed. Due to the high flexibility of the drill, it is only possible to apply the force excitation with an Impact Hammer near to the clamping sleeve. The displacement response is measured at defined points along the drill shaft in sequence using a Polytec single-beam laser vibrometer system, mounted on an adapted axial-carrier. By assembling and analysing the excitation and response signals using the LMS Test.Lab system the frequency response functions, the normal frequencies and the respective mode shapes are obtained. In figure 2 an exemplary frequency response function is compared to the appropriate frequency response function calculated from an adequate finite-element model. The accordance in frequency is very high at all modes, similar to the mode shapes except for the 3900 Hz vibration. This assumed torsion mode shape cannot be identified in the measurement due to its motion orthogonal to the laser beam. Additionally there is another mode near to this 3900 Hz mode, therefore it is very important to research into this frequency range with a different approach.

3 Adapted Measuring Technique

Thus, in the second step, the analysis is focussed on the first tangential mode. Therefore both a tangential excitation and a tangential displacement measurement have to be applied. Consequently, a set-up with falling balls is implemented as depicted in figure 3. To ensure an impact with constant impulse excitation in order to average the signals, a pipe is mounted on the set-up to guide the balls to the impact point. To measure the tangential displacement a Polytec rotational vibrometer system OFV-4000 is used [2]. This system that is based on two parallel laser beams with the
distance of 8 mm evaluates the difference of the separately analysed laser signals thus the lateral motion is neglected and the tangential motion is separated. Since the diameter of the drill (4 mm) is too small to apply the rotational laser directly on it, a light-weighted attachment is set on the top of the drill as depicted in figure 4. Thereby the small torsional amplitudes are amplified. The change in the system due to the additional mass is compensated in the numerical model subsequently. To avoid that the measured signal contains large amounts of the adjacent mode, the attachment is positioned at its nodal point.

Figure 3: Tangential impact excitation with falling balls

Figure 4: Attachment to measure tangential motion

The signals are evaluated by an HP Dynamic Signal Analyzer 35665A. In figure 6, the resulting amplitude spectrum in the range of the torsional mode is plotted. In contrast to the conventional excitation method, the torsional mode now is distinguished from the adjacent modes reliably.

Figure 5: Measurement concept: Falling balls impacting on the drill excite a torsional motion that is measured with a rotational vibrometer
4 *Simulative verification*

In order to verify the measurement results, the set-up is mapped to a numerical model including the measurement attachment. A numerical modal analysis is performed and the results are compared to the findings of the new measurement method, as can be seen in figure 6. The simulated and the measured frequency coincide within an error of 0.1%.

![Amplitude spectrum](image1)

**Figure 6:** Amplitude spectrum

![Torsional mode shape](image2)

**Figure 7:** Torsional mode shape

In the next step the measurement attachment is removed in the numerical model and a modal analysis is performed. The results are compared to the outcome of the conventional experimental modal analysis. Since the results coincide, the 3900 Hz vibration is identified certainly as the torsional mode that is illustrated in figure 7.

5 *Conclusion and Outlook*

A systematic approach for identifying the torsional modes on slender drills with an adapted method was presented. In order to obtain the modal parameters additionally, the excitation force has to be known precisely. Hence the focus of the next improvement steps for the presented measurement and analysis method will be the development of a suitable excitation method using an electro-magnetic transducer for example.

**References:**
