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Automatic Multisensory Measurement of the Borehole Length during Drilling of Inhomogeneous Materials

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Summary:
Precise borehole length measurements are demanded in manufacturing and surgery, ideally with no additional time but as integrated part of the drilling process. For this purpose, an automatic detection of the material front and back surface position is proposed while monitoring the feed forward. The solution approach is realized by using a multisensory drive train and designing the signal processing for the sensor data fusion. As a result of experimental tests, the approach is validated, demonstrating an automatic measurement of the borehole length during drilling with a measurement uncertainty of 0.17 mm.

Keywords: Drilling, process monitoring, multisensory, composites, measurement uncertainty.

1. Introduction

In bone surgery, the fixation of metal implants on bones with screws requires to drill holes into the bones. Due to the small access to the bone, the borehole length measurement for the correct screw choice is difficult and could be improved by an integrated, automated length measurement during the drilling process.

Sorg et al. [1] published an approach for determining the borehole length when drilling pig bones by using a multisensory drive train and a manual analysis of the signals´ amplitudes in time domain. Guan et al. [2] proposed a method to detect the start and end of drilling in spinal pedicle screws by measuring both force and acoustic emission (AE) signals and processing them through an FFT, in the range of 10 kHz and 15 kHz. Furthermore, a method for the automatic drill breach detection during spine pedicle drilling based on vibroacoustic sensors has been developed by evaluating the spectrograms from the signals and using a neural network [3]. However, an uncertainty analysis for the borehole length was not conducted.

Therefore, the two aims of this paper are designing a signal processing for the automatic multisensory measurement of the borehole length during the drilling in bone-like inhomogeneous materials and determining the achievable measurement uncertainty. Here, the experiments are performed with an inhomogeneous composite material to mimic the structure of a bone.

2. Principle of the solution approach

The technological basis is the multisensory drive train proposed in [1], Fig. 1.

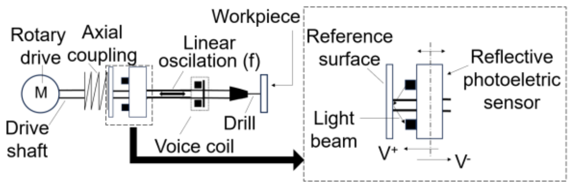

Fig. 1. Multisensory drive train from [1].

The drilling process rotational speed *n* and the feed velocity v_f are controlled and recorded, as well as the axial oscillation frequency *f* excited by a voice coil.

The signals of two integrated sensors (current sensor and reflective photoelectric sensor, RPS) are evaluated for deriving the front and the back surface position of the workpiece from in-process measurements. An additional optical sensor is used to measure the distance between the workpiece´s clamping and a fix structure on the drilling machine, which allows to measure the feed velocity during the process.

The current sensor installed on the rotary drive is used to indirectly measure the torque acting on the drill during the cutting process. The RPS mounted on the output movable shaft measures the relative distance between the sensor and a reference surface fixed on the shaft, which provides a measure for the acting feed force.

3. Experimental results

The experimental results related to the automatic multisensory method for measuring the borehole length are based on a sensor signal analysis, which jointly evaluates the behavior of all sensor signals in time domain, see Fig. 2.

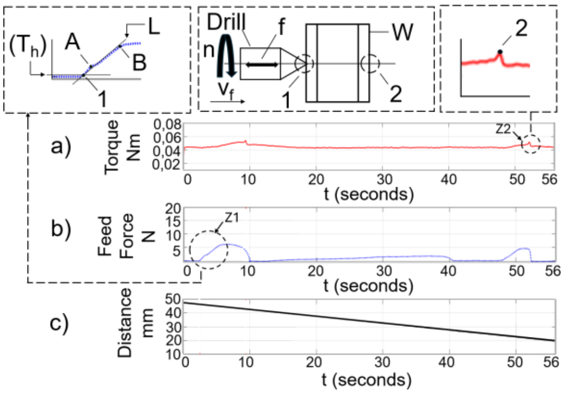

Fig. 2. Automatic multisensory measurement method of borehole length based on time domain signal processing.

Both the torque (Fig. 2-a) and feed force (Fig. 2-b) are obtained by filtering the original measured signals in order to eliminate inherent process noise. The combined analysis of both torque and feed force shows that there is a correlation between these signals. The initial slope observed in the torque and feed force refers to the instant in time in which the drill gets in contact with the workpiece W (material: composite with two PVC external layers and one internal polystyrene rigid foam XPS layer), whereas the drop of both signals noted in the end of the time duration refers to the breakthrough instant of the tool.

The feed force shows a higher sensitivity throughout the drilling process when compared with the torque sensor. This characteristic is used to recognize the initial contact between the tool and workpiece, which is defined by the intersection of the tangential line to the ground noise with an added threshold T_h and the best fit line L from the inflexion point A to the immediate change in curvature B (Fig. 2-b, zoomed view of point 1). The point in time associated with the breakthrough is then determined based on the maximum value shown by the torque signal (Fig. 2-a, zoomed view of point 2) which also matches the feed force signal for the given time instant. The time interval between the detected initial workpiece contact and the breakthrough represents the drilling duration $t_{1\text{-}2}$. The pattern shown by the distance signal (Fig. 2-c) confirms that v_f is constant throughout the drilling process and equals the set value of 0.5 mm/s. By using the combined information from all the sensors, the borehole length L_b is then determined by multiplying the time duration $t_{1\text{-}2}$ by v_f:

$$L_b = t_{1\text{-}2} \cdot v_f \qquad (1)$$

Fig. 3 shows the L_b values achieved when drilling the workpiece by using constant process parameters (n, v_f and f).

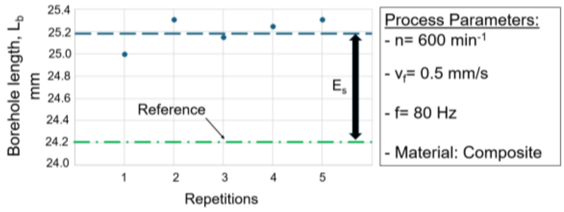

Fig. 3. Automatic borehole length L_b throughout experimental repetitions.

The measured L_b values are distributed around the mean μ = 25.2 mm (blue dashed line) with a small standard deviation σ = 0.06 mm, thus indicating a good precision afforded by the proposed sensor analysis. Considering both the L_b repeatability and the reference system resolution of 0.05 mm as the main sources of errors, and assuming a calibration to compensate for systemic errors, the achieved expanded measurement uncertainty for a confidence level of 95 % amounts to 0.17 mm.

4. Conclusion and Outlook

An automatic multisensory method for the indirect measurement of the borehole length during drilling of inhomogeneous composite material has been presented. The method relies on the evaluation of three different sensor signals to recognize both the initial and the breakthrough positions between the drill and the workpiece. This has resulted in sufficiently precise measurements of the machined borehole length, so that a systematic error dominates that requires a calibration. Therefore, next working steps are the in-depth understanding of the cause-effect chain between the mechanical machining and the sensor signals for improving the accuracy, as well as the investigation of additional sensors regarding their influence on minimizing the achievable total measurement uncertainty of the borehole length.

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