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Cutting force measurement from acceleration sensor in milling operation

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Abstract

The purpose of this paper is to propose an alternative method that makes it possible to predict cutting force in milling operations without using expensive dynamometer. The basic idea and the developed method of the alternative cutting force measurement is presented, in which the force is predicted based on measured acceleration signal treated with inverse Frequency Response Function (FRF). The proposed measurement technique is applied on a case study. For validation purpose, the reconstructed result is compared with cutting force measurement by means of dynamometer.

1. Reconstruction of cutting force

In order to thoroughly discover and understand the dynamic behavior of machining processes, an accurate and reliable identification of the resultant cutting force is an important factor [1]. In general, it can be measured accurately by means of dynamometer, although, these sensors are usually quite expensive measurement equipments.

In order to reconstruct the cutting force without dynamometer, the key idea is to capture the system's response and using the Frequency Response Function (*FRF*), which describes the dynamic behavior of the system [2]. The *FRF*, also called transfer function, describes the ratio between the output (resultant vibration $x(t)$) and the input (cutting force $F(t)$) in frequency domain. It is usually determined by modal analysis, typically by means of impact test with modal hammer [2]. Once the *FRF* is known, then the resultant cutting force can be reconstructed as follows:

$$F(t)=\mathcal{F}^{-1}\left\{H^{-1}(\omega)\mathcal{F}\left\{x(t)\right\}\right\} \quad (1)$$

where $H(\omega)$ is the measured *FRF*, while $\mathcal{F}\{\square\}$ and $\mathcal{F}^{-1}\{\square\}$ denote the Fourier and inverse Fourier transformation, respectively.

In practice, the *FRF* and the response are measured as sampled discrete data, therefore, the proposed method can be applied in discrete form as the following steps show:

$$x(t)\xrightarrow{\text{FFT}}\xi(\omega)\xrightarrow{H^{-1}(\omega)}\Phi(\omega)\xrightarrow{\text{IFFT}}F(t) \quad (2)$$

where $\xi(\omega)$ and $\Phi(\omega)$ are the *FFT* of $x(t)$ and $F(t)$, respectively. Note that the reconstructed cutting force is more accurate in lower spindle speed domain, where sufficiently large number of reconstructed points are available since the available bandwidth is usually greater than the relevant bandwidth of the measured *FRF*.

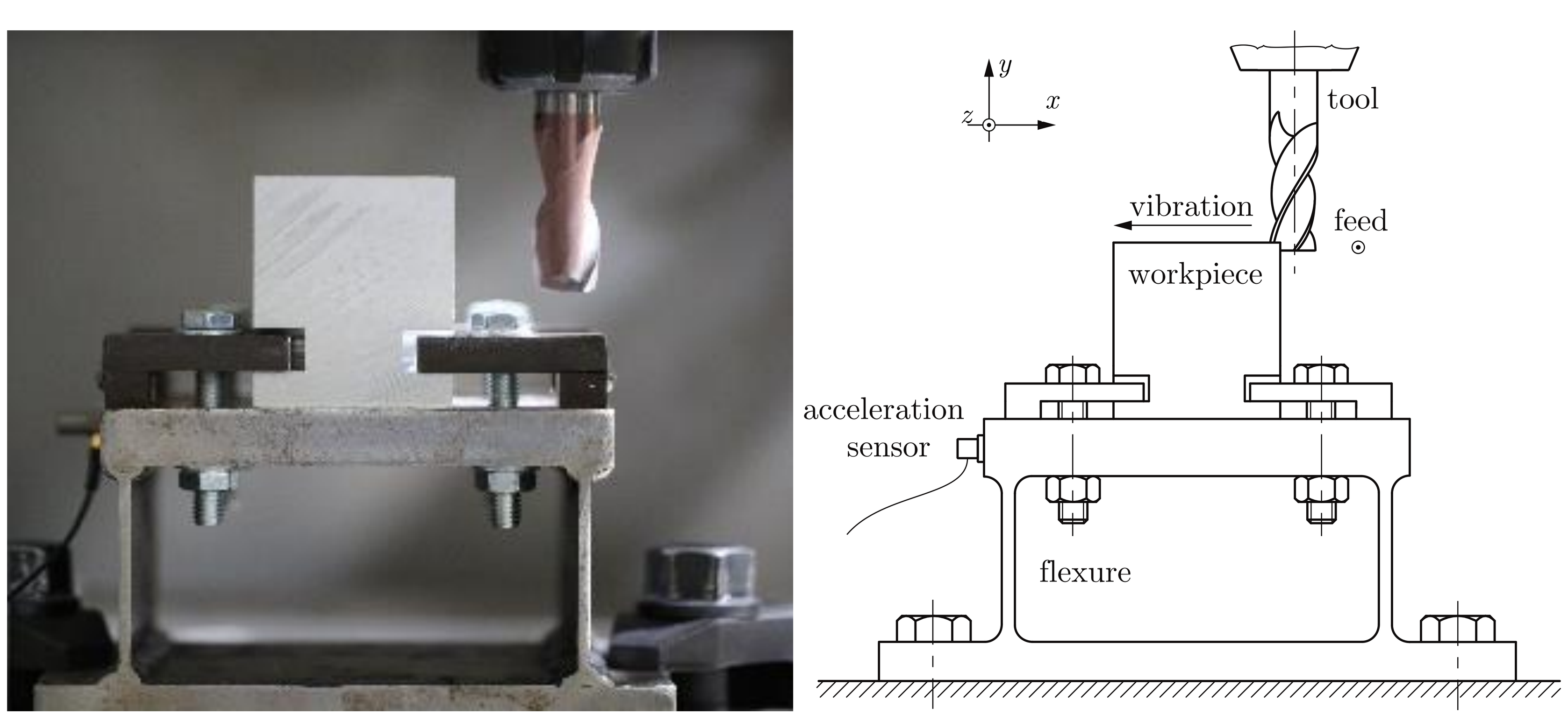

Fig. 1. Schematic figure and experimental setup for milling with single-degree-of-freedom experimental structure.

2. Case study

The measurement technique is applied in a case study during a peripheral down-milling operation. In the experimental procedure, the workpiece (Aluminum 2024-T351) is clamped onto the top of a flexible structure, which was designed to mimic the dynamics of a single-degree-of-freedom system (*SDoF*) (see Fig. 1). The structure is flexible only along *y* direction and can be considered to be rigid in the other directions. The measured *FRF* can be seen in Fig. 2c.

The cutting tests was performed with spindle speed n = 4650 rpm, radial immersion a_e = 2 mm, feed per tooth f_z=0.05 mm/tooth and axial immersion a_p = 2 mm. The TIVOLY P615H endmill had diameter D = 16 mm, number of flutes N = 2, helix angle $\beta=30^\circ$ and rake angle $\kappa=90^\circ$. The response was acquired by NI cDAQ-9178 Chassis with NI 9234 Module at 51.2 kHz sampling rate and PCB 352C23 type acceleration sensor. One time period $x(t)$ and its *FFT* can be seen in Fig. 2a and 2b, respectively. Reconstructed cutting force is plotted in Fig. 2d together with direct force measurement with Kistler dynamometer (9129AA) repeated with the same technological parameters. Note that the difference is in the range of the typical error of force measurement with dynamometers.

3. Conclusion

An alternative force measurement method is proposed which uses only accelerometer sensor and modal hammer. It is capable to measure the resultant cutting force during milling operations directly from vibration measurements without using expensive dynamometer. The efficiency and accuracy of the proposed methodology were validated experimentally in laboratory environment by means of direct cutting force measurement with dynamometer.

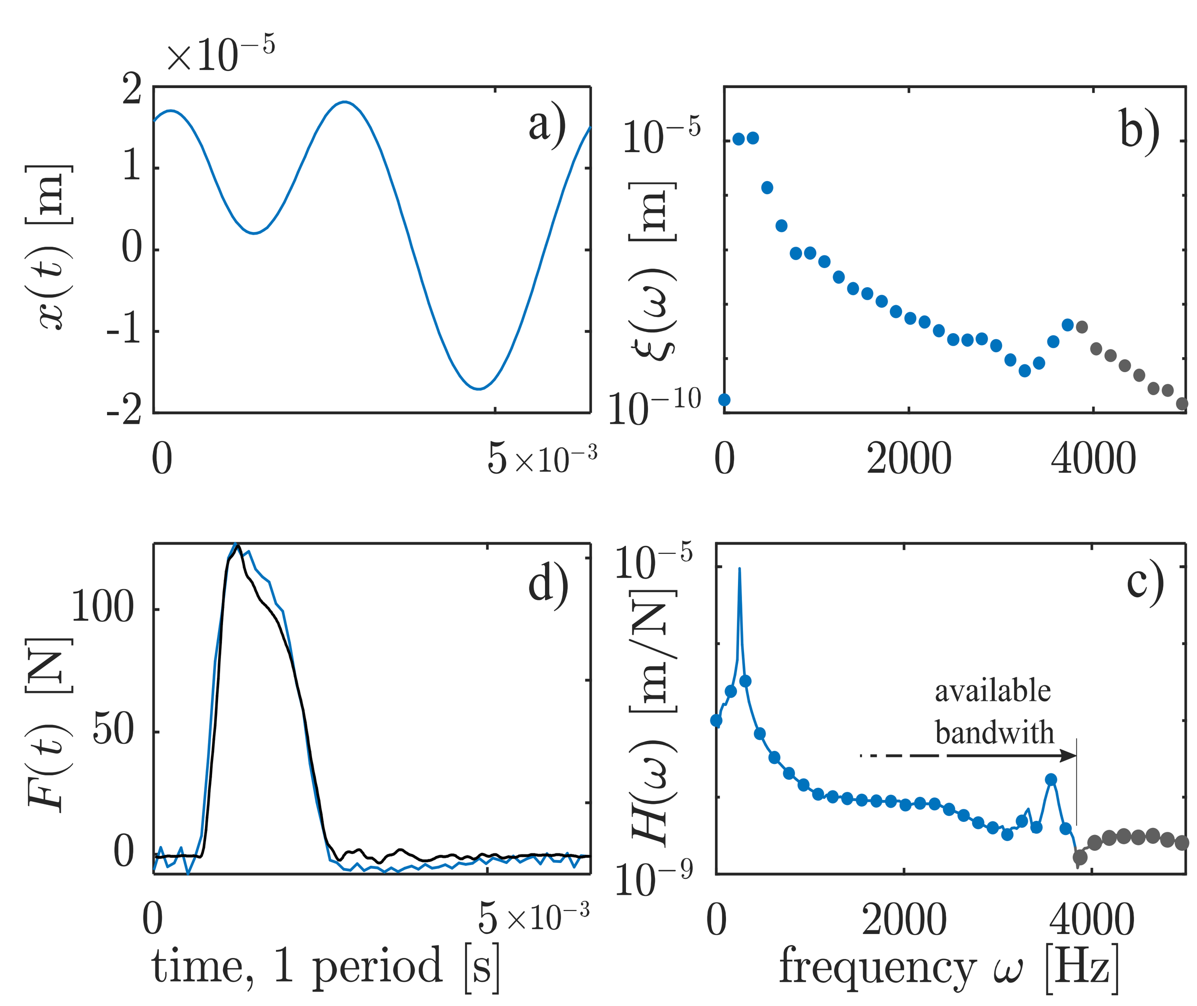

Fig. 2. a) Periodic response during one time period; b) *FFT* of the periodic response; c) measured *FRF* (curve) and interpolated values (dots); d) cutting force reconstructed by acceleration sensor (blue) and measured by means of dynamometer (black).

References

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