On the Impact Test Methodology for the Quick Estimation of Natural Frequency of the Mechanical Systems

Phuoc Vinh Dang, Nhu Thanh Vo, Hoai Nam Le, Anh Duc Pham, Thanh Nghi Ngo, and Le Anh Doan

Abstract The identification of natural frequency of machinery is a very important phase during the design, fabrication and testing process of any mechanical systems. This paper represents the experimental methodology for quick determining of natural frequency of a system by means of impact test. In this test, two kinds of sensors are used for the test, namely accelerometer and loadcell. The former is installed directly on the tested machine while the latter is built-in the hammer. Acquired signal from these sensors are analyzed and performed the Fast Fourier Transform (FFT) algorithm to get the transfer function. Then the natural frequencies of the system can be estimated. Besides, the corresponding coherences are also evaluated in order to evaluate accuracy of the results. This methodology is quite simple, less time consuming and very reliable for the natural frequency calculation.

Keywords Impact test · Natural frequency · Fast fourier transform · Coherence

P. V. Dang (✉) · N. T. Vo · H. N. Le · A. D. Pham · T. N. Ngo
Department of Mechanical Engineering, The University of Danang—University of Science and Technology, 54 Nguyen Luong Bang Street, Da Nang, Vietnam
e-mail: dpvinh@dut.udn.vn

N. T. Vo
e-mail: vnthanh@dut.udn.vn

H. N. Le
e-mail: lehoainam@dut.udn.vn

A. D. Pham
e-mail: ducpham@dut.udn.vn

T. N. Ngo
e-mail: ntnghi@dut.udn.vn

L. A. Doan
Department of Mechanical Engineering, The University of Danang—University of Technology and Education, 48 Cao Thang Street, Da Nang, Vietnam
e-mail: dlanh@ute.udn.vn

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1 Introduction

Determining the natural frequencies of any rotating machineries from both rotating and stationary reference frames is very essential to prevent the resonance phenomenon which could lead to the unusual operation of the machine, or even cause critical damages of the machines [1].

Resonance phenomenon leads to increasing significantly the amplitude of vibration of system and resulting the damage of system. The well-known Tacoma Narrows bridge [2] is a typical example of the resonance. In 1940, its main span collapsed into the Tacoma Narrows as a result of aeroelastic flutter caused by a 42 mph (68 km/h) wind. The bridge collapse had lasting effects on science and engineering. The event was presented as an example of elementary forced resonance, with the wind providing an external periodic frequency that matched the natural structural frequency.

The resonance identification in a system can be obtained by means of some methodologies. After design phase by using the Solidworks or Inventor, the natural frequencies can be calculated easily. However, those methods are impossible or very difficult for the available systems or machines. For this reason, the impact test was introduced and applied widely not only for the mechanical systems [3, 4] but also for the civil systems [5]. Besides, based on the natural frequency identification, some dynamic characteristics of the system can be obtained such as model shape, transfer function [6–10].

This paper presents the natural frequency identification of the system using the impact test. A small rotating machinery test rig with a rotating shaft with two disks are used. Some accelerometers and one built-in loadcell in the hammer are used to perform the tests. Acquired signals from these sensors will be analyzed and processed by MATLAB. Next, the natural frequencies of the systems can be calculated quickly. The coherence is also considered to evaluate the accuracy of the test.

2 Experimental Setup

Figure 1 shows the photo of the test rig using for the impact test. Three accelerometers are attached to the three different positions of the system. Figure 2 shows the position of these three sensors. One accelerometer is put on the disk (A2); one accelerometer is attached to the bearing housing (A1) while another sensor is on the rotating shaft (A3). The force will be applied on the shaft by the hammer (Fig. 2).

All the signals are acquired by using the NI 9234 of the National Instrument (Fig. 3). The specifications of the sensors, hammer and NI 9234 are listed in Table 1.

Figure 4 shows the time history of the signal acquired from the hammer and the corresponding accelerometer A2 in one arbitrary test. Note that some test with a double hit can be occurred (see Fig. 5b), it is necessary to ignore this kind of test in order to obtained the best result.

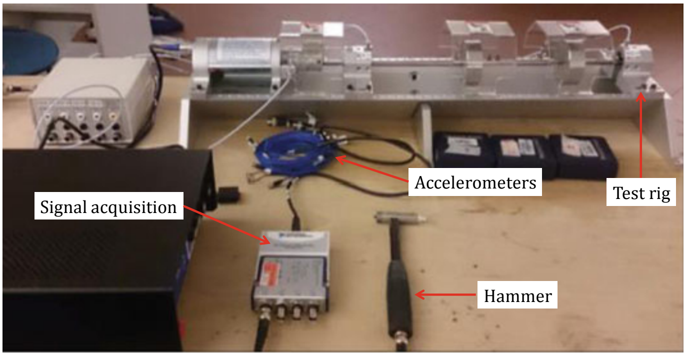


Fig. 1 Photo of the test rig

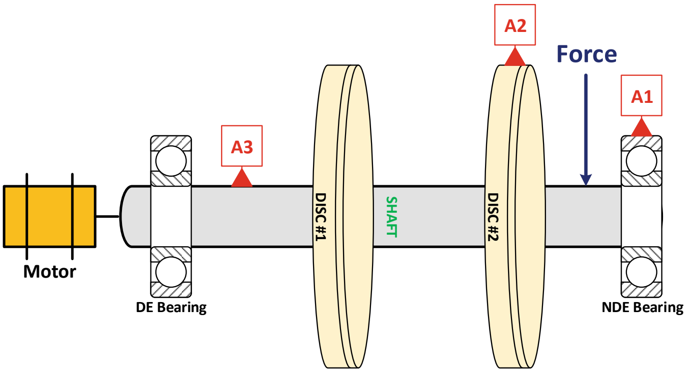


Fig. 2 Experimental setup

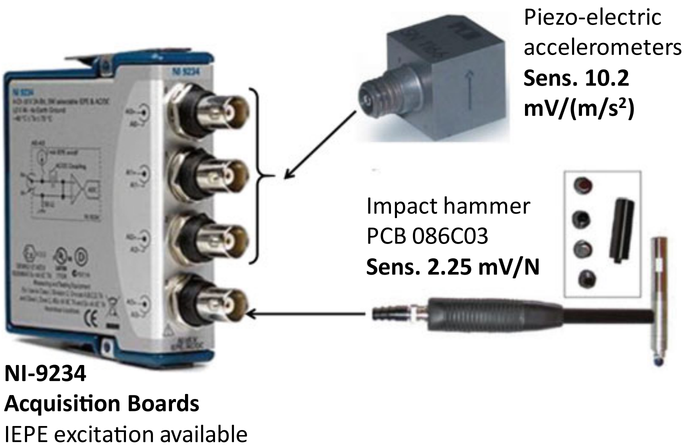


Fig. 3 Devices for the experimental test: NI-9234 boards, accelerometer and hammer

Table 1 Specifications of acquisition devices

Accelerometer		
	Model	PCB Model 333B30
	Working frequency (Hz)	0.5–3000
	Resolution (mV/(m/s^2))	10.2
	Output	IEPE
	Resonance frequency (kHz)	≥40 kHz
	Weight (g)	4.8
Hammer		
	Model	086D05
	Resolution (mV/N)	0.23
	Range (N pk)	±22240
	Weight (kg)	0.32
NI Board		
	Model	NI 9234
	Differential Channels	4
	Resolution	24
	Sampling rate (kS/s)	51.2
	Bandwidth (kHz)	23.04

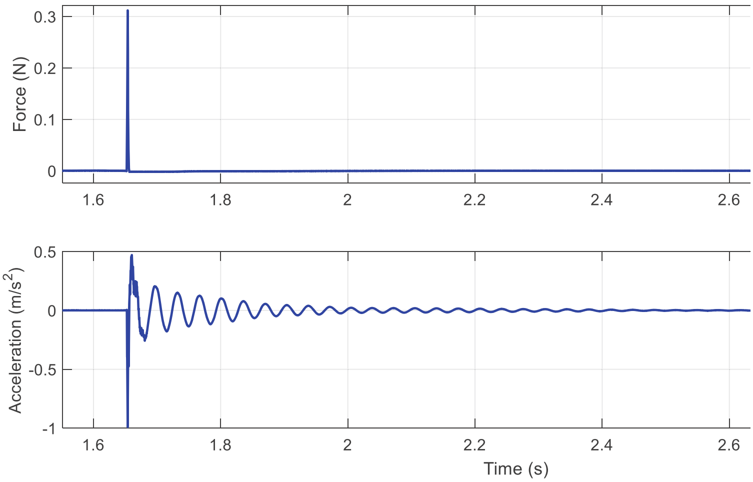


Fig. 4 Time history of the signal of hammer and accelerometer A2

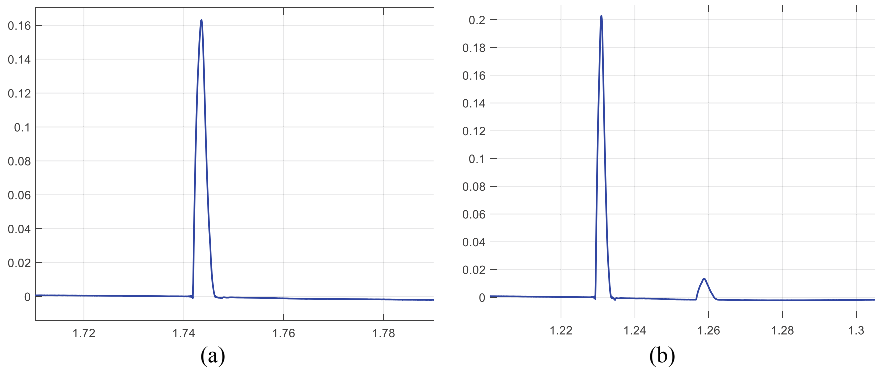
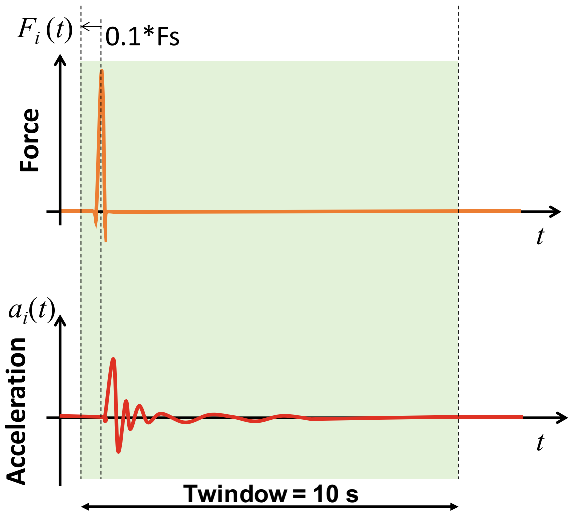


Fig. 5 Time history of hammer signal in **a** good test and **b** double test

Acquired signal will be pre-processed before the analysing. The experimental test is performed many times (10 times in this paper) in order to reduce the noise. The time history of the applied force is different for each test. For this reason, the signal must be filtered to make sure that time history of the signal of all test will be identical. The following steps are the procedure of the signal filtering:

1. Perform the test with the sampling frequency Fs of 10 kHz in 15 s (t). The acquired signal length will be $t \times F_s = 150{,}000$ points.
2. Identification of time in which the force is applied. It is clearly that the applied force will be maximum in this time (Fig. 6). This moment can be used for the reference time.

Fig. 6 Filter the signal in order to avoid leakage and null information



3. From this position, a time window of 10 s is applied for all signal of hammer and accelerometers to avoid the leakage and null information.

3 Signal Processing

All cut signal will be converted from time domain to frequency domain before evaluating the transfer function. Note that:

- Input and output signal in time domain is signal from loadcell $x^P(t)$ and accelerometer $y^P(t)$, respectively; with p is the number of test ($p = 10$).
- $x^P(t)$ and $y^P(t)$ in the time domain will become $X^P(f)$ and $Y^P(f)$ in the frequency domain.

In order to calculate the transfer function of input/output, the auto spectrum G_{xx} and cross spectrum G_{yx} need to be identified using the Eq. (1):

$$\begin{aligned} G_{xx}(f) &= X^p(f)^* \cdot X^p(f) \\ G_{yx}(f) &= Y^p(f)^* \cdot X^p(f) \end{aligned} \tag{1}$$

where $Y^p(f)$ and $Y^p(f)^*$ is the complex vector and complex conjugate vector of the output. These vectors can be defined as:

$$\begin{aligned} Y^p(f) &= a + ib \\ Y^p(f)^* &= a - ib \end{aligned} \tag{2}$$

Because the test was repeated 10 times, the average auto spectrum and average cross spectrum are:

$$\begin{aligned} \overline{G}_{yx} &= \frac{1}{P}\sum_{p=1}^{P} Y^p(f)^* X^p(f) \\ \overline{G}_{xx} &= \frac{1}{P}\sum_{p=1}^{P} X^p(f)^* X^p(f) \end{aligned} \tag{3}$$

The transfer function between input and output H_1 is defined as:

$$H_1(f) = \frac{\overline{G}_{yx}(f)}{\overline{G}_{xx}(f)} \tag{4}$$

To evaluate the accuracy of the result, the coherence of the transfer function is obtained as:

$$\gamma_{xy}(f) = \frac{\left|G_{xy}(f)\right|^2}{G_{xx}(f) \cdot G_{yy}(f)} \quad (5)$$

Note that the amplitude of $\gamma_{xy}(f)$ will be from 0 to 1 in which "1" number shows that the result is absolute reliable while the "0" one presents the opposite result.

4 Experimental Results

4.1 *Transfer Function*

The transfer function H_1 and the corresponding phase between input and output of three accelerometers A1, A2, A3 in a frequency range of 0–200 Hz are shown in Figs. 7, 8 and 9, respectively. From Figs. 7, 8 and 9, it can be identified that the first and second natural frequency of the system is approximately 28 and 118 Hz. In order to validate these results, some preliminary tests in this test rig were performed. At each housing bearing, two accelerometers (P1 and P2) are installed in the vertical and horizontal direction (X and Y). Then, the shaft was run-up from 0 to 4000 rpm. The signal acquired from these accelerometers were applied the FFT functions to change signal from the time domain to the frequency domain. It is clearly to see from Fig. 10 that the first and second natural frequency of the system is about 30 and 120 Hz.

However, the transfer function obtained from A1 is not clear as those of A2 and A3. This can easily be explained due to the position of A1. Look at back the Fig. 2, the A1 is installed on the bearing housing whilst the A2 and A3 are installed on the

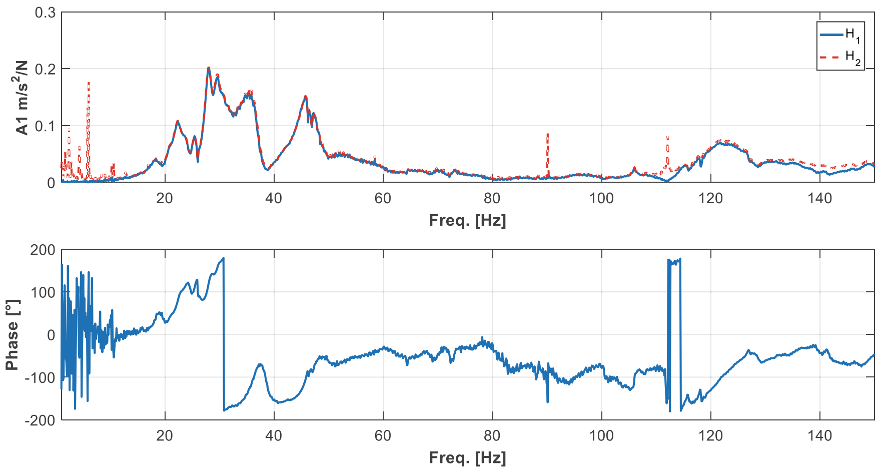


Fig. 7 Transfer function and phase versus frequency of A1

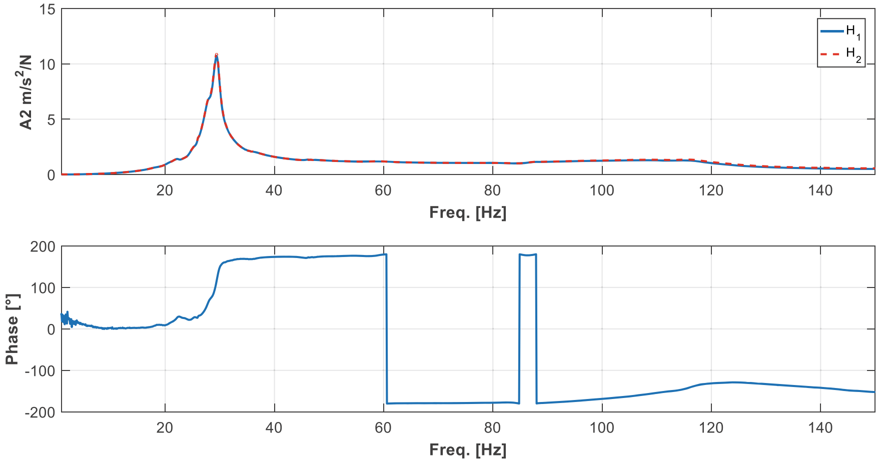


Fig. 8 Transfer function and phase versus frequency of A2

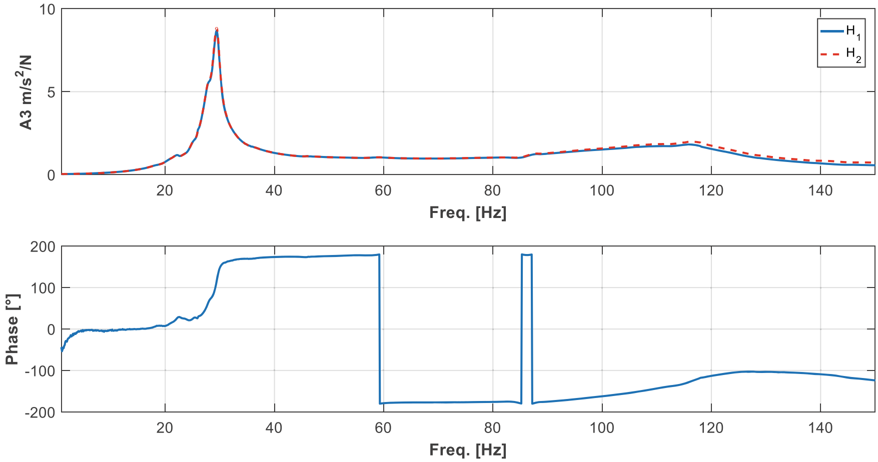


Fig. 9 Transfer function and phase versus frequency of A3

disk and shaft. So, the acceleration acquired from A1 is very small and the vibration at this position can be neglected. This also explains why the amplitude of transfer function of A1 is very small (maximum of 0.2 $m/s^2/N$) and only equals to 1/50 that of A2 (maximum of 10 $m/s^2/N$).

Besides, the transfer function of A2 is larger than that of A3 (maximum of 8.5 $m/s^2/N$). This probably is due to the position of the applied force is closed to the A2.

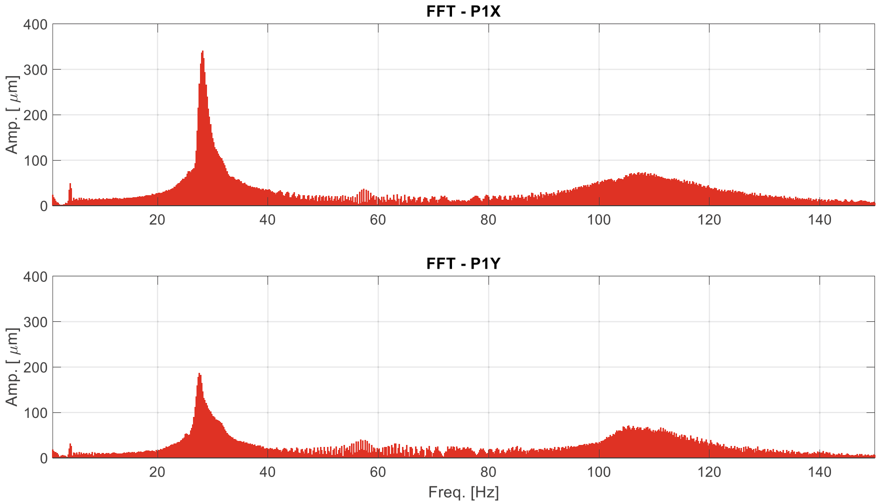


Fig. 10 Signal from two accelerometers in the frequency domain

4.2 *Coherence*

From the coherence of three accelerometers A1, A2 and A3 in Fig. 11, the accuracy of the results from three accelerometers can be assessed.

It can be seen that the coherences of transfer function of A2 and A3 are almost 1. It can be concluded that the first and second natural frequency of the system is about 28 Hz and 118 Hz, respectively.

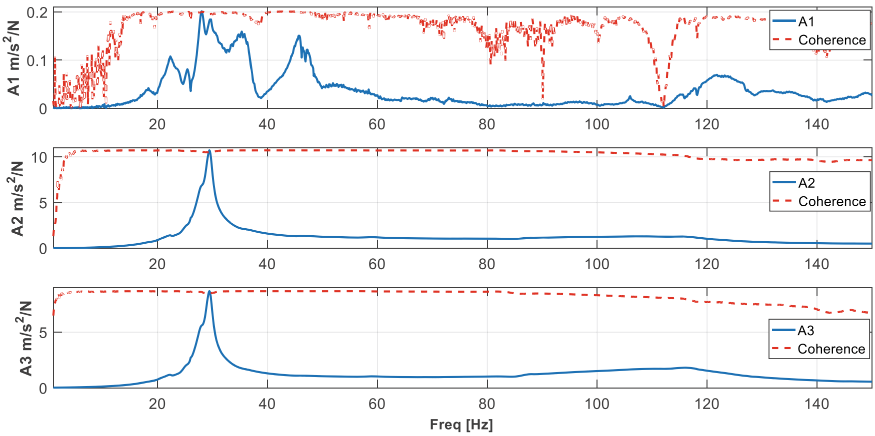


Fig. 11 Coherence of three accelerometers

For the A1, the value of coherence is not stable in the considered frequency range, especially the coherence is very small at the frequency of 10 and 115 Hz. So, it is better to avoid the result from A1. It can be inferred that the position of accelerometer in the impact test should be not at the fixed location such as bearing housing.

5 Conclusions

This paper represents the methodology of natural frequency identification of system by means of impact test. This method is quite simple, less time consuming and provide good result.

Some accelerometers are installed on the tested system to give the acceleration when a force is applied from a hammer with a build-in loadcell. The test is repeated in several times to get the average result. The transfer function in then evaluated in the frequency domain. The coherence is also considered to re-check the accuracy of the result.

From the transfer function of three accelerometers in accordance with the coherence, it can be concluded that the first and second natural frequency of the system is about 28 Hz and 118 Hz, respectively. It also infers that the position of accelerometer in the impact test should be not at the fixed location such as bearing housing.

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