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Short Communication

Coherence measurement for early contact detection between two components

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Abstract

In process and power plants, there are several structural components which may come in contact with the neighbouring components over a period of time. For example, the coaxial tubes often used for conveying hot fluids, where the detection of contact between the tubes at an early stage is important for safety and performance considerations. The paper presents the observation on the coherence behaviour for the detection of early contact based on the simple laboratory experiments.

1. Introduction

In vibration analysis, the ordinary coherence between two vibration signals is defined as [1]

$$\mathrm{Coh}(\gamma^2) = \frac{|S_{xy}(\omega)|^2}{S_{yy}(\omega)S_{xx}(\omega)}, \tag{1}$$

where $S_{xx}(\omega)$ and $S_{yy}(\omega)$ are the power spectral densities of two signals, $x(t)$ and $y(t)$, and $S_{xy}(\omega)$ is their cross-power spectrum at an angular frequency (ω). The coherence between two signals indicates the degree to which two signals are linearly correlated at a given frequency. In experimental modal analysis [2], coherence is a well-known tool for assessing the linear correlation between the structural responses $x(t)$ due to a given input excitation $y(t)$ to the structure when

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processing the data in the frequency domain to extract the modal parameters—natural frequencies, modal damping, and mode shapes. The following can also be inferred about the coherence:

(a) Coherence (Coh) is close to unity means the response is linearly correlated to the input excitation.
(b) In general, measurement of structural responses and input are contaminated with noises (generated due to measuring instruments or/and structures) which may cause reduction in coherence.
(c) Coherence reduces due to nonlinear relation between response and input.
(d) Coherence reduces when the response is due to extraneous inputs.

In general, nonlinear systems in structural dynamics could be of several types. The most common nonlinear systems observed in practice are of two types—structures with nonlinear (cubic) stiffness and/or damping model [3–8], and structures with bilinear stiffness in system like breathing of crack particularly seen in rotating shaft [9–14]. Several methods have been suggested by researchers to identify the nonlinearity in the structural systems [3–8]. However in rotating machines, the breathing of crack in a cracked shaft during its rotation is detected by the presence of 2× (two times rotor speed) component in the shaft responses during machine normal operation and run-down [9,12]. Sinha and Friswell [15] have simulated the presence of 2× component in the response of a free–free beam with the breathing of a crack when excited at half the beam natural frequency. So most of the studies and observations have not used the coherence defined in Eq. (1) for detection of nonlinearity. However there are several stationary structures used in plants, which may come in contact with neighbouring components, for example, two coaxial tubes generally used in process and power plants [16], where detection of such contact at early stage is important. Hence a simple laboratory experimental set-up consisting of two such components separated by a small gap is presented here. The nonlinear interaction between the two components has been studied. An interesting observation made on the coherence measurement during the modal tests with different gap is reported here.

2. Modal testing

The schematic of the laboratory setup is shown in Fig. 1. The setup consists of a 2 m long steel tube (OD = 25.4 and ID = 22.4 mm) mechanically clamped at both the ends and a helical spring of very low stiffness at the centre of the tube. The location of the low frequency exciter with a long stroke length and the response measuring accelerometer is shown in the figure. The shaker armature was fitted with a force sensor. The tube was filled with number of steel balls to reduce the first mode frequency to be covered by the excitation frequency range of the shaker.

For the modal test, multi-sine signal in the frequency band of 2–10 Hz was given to the shaker to excite the tube in its first bending mode. The measured force and response data were simultaneously processed on FFT analyser. Since the signal generation and processing was on the analyser, data processing error in the analysis is not expected. Different modal tests were conducted by adjusting the gap between the tube and the spring. The excitation level was kept

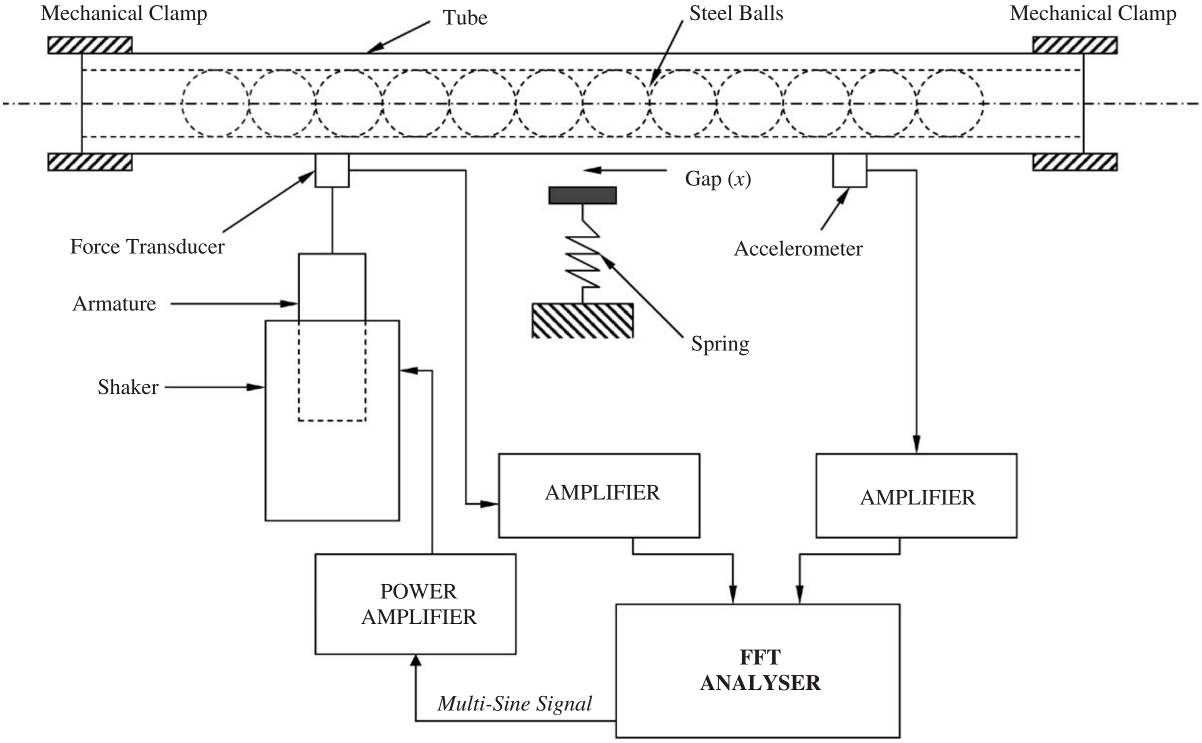

Fig. 1. Schematic of a simple experimental setup.

constant for all the tests. Fig. 2 gives the measured frequency response function (FRFs) and the coherence (Eq. (1)) of the modal tests. Note that the tube behaves as a linear system for the level of excitation given by the shaker. The nonlinearity in the tube response was introduced by interaction with a spring which was achieved by adjusting the gap between them. The following observations are made.

Initially the gap (x) was kept large so that the tube does not interact with the spring during the modal test. The first mode of the tube was identified at 6.0 Hz and the coherence between the force and the response is close to 1.0 as shown in Fig. 2(a). This indicates that the system is linear and the noise in the measurement is close to zero.

Then the gap (x) was adjusted such that the tube experiences just *touch and go* contact with the spring during the modal test. The introduction of such a small *make and break* nonlinear interaction between the tube and the spring results in marginal increase in frequency (6–6.125 Hz) but the coherence drops to 0.62 just at the tube frequency (see Fig. 2(b)).

The gap was further reduced and the modal test was repeated. The *make and break* nonlinear interaction was present. It has been observed that the frequency further increased to 6.25 Hz but there was improvement in the coherence (0.83) as shown in Fig. 2(c).

Now the spring was slightly pre-stressed so that there was no *make and break* nonlinear interaction during the modal test. The system returns to the linear behaviour. As can be seen from

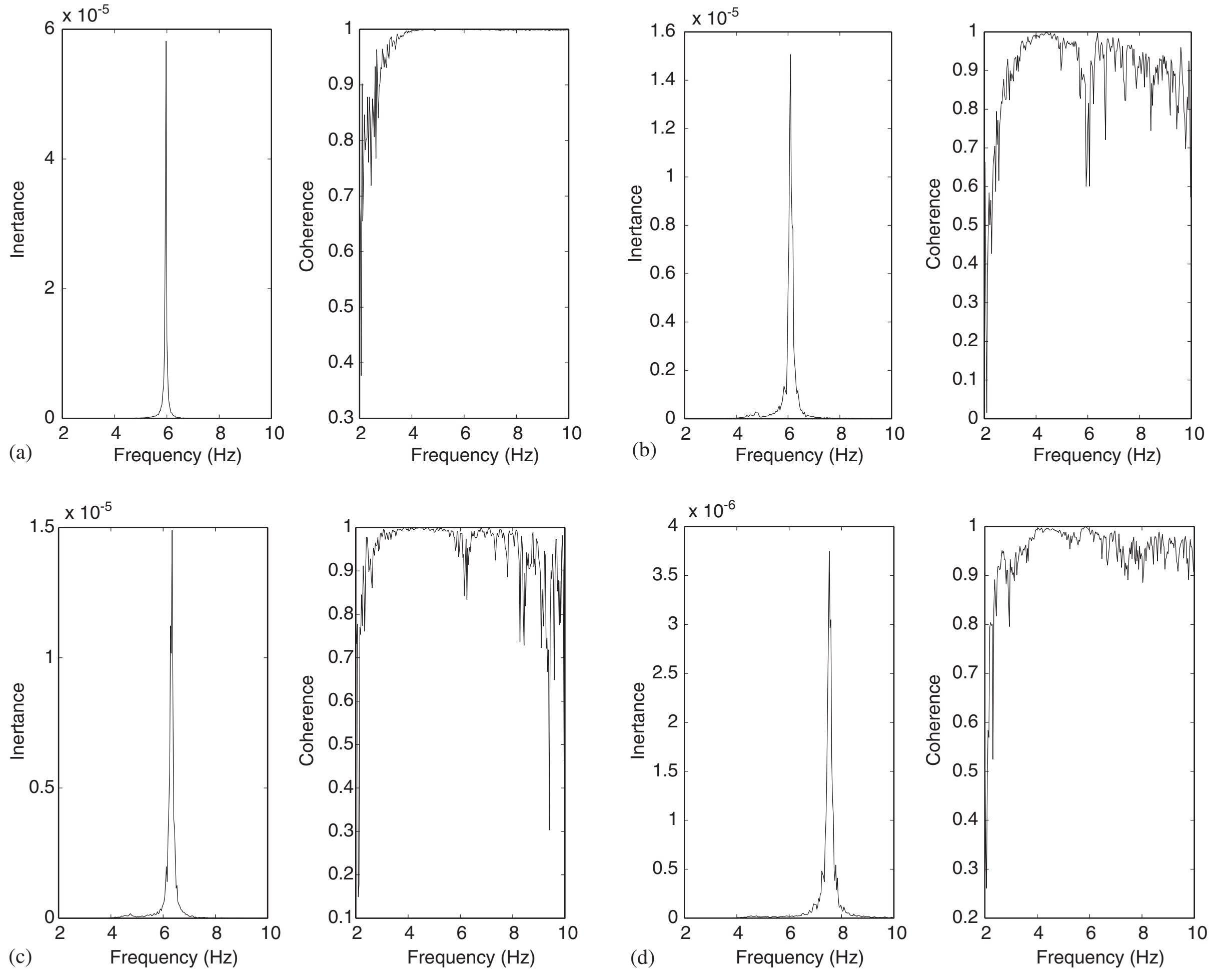

Fig. 2. Measured FRFs and Coherence: (a) no contact, (b) just make and break (touch and go), (c) strong make and break, and (d) permanent contact between tube and spring.

Fig. 2(d) there is significant increase in the natural frequency (7.65 Hz) and the coherence is again close to 1.0.

3. Discussion and comments

The nonlinearity in the present system is different from the nonlinear system generally discussed in earlier studies. The experimental observation of the dynamic behaviour of a simple beam behaving as a *linear system to make and break type nonlinear system to again a linear* system is presented. The decrease in the FRF amplitude at the resonance frequency for noncontact to positive contact between the tube and the spring with increase in the frequency value is observed.

These features are expected and well known. The first decrease and then increase in the coherence also indicates the system behaviour moving from a nonlinear to a linear response. This discerning feature of sharp drop in coherence at resonance due to make and break nonlinear interaction particularly for just *touch and go* condition holds promise as a potential diagnostic tool. Such observation can be exploited for detecting early contact between two components.

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