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ScienceDirect

Procedia Engineering 199 (2017) 477–482

Procedia Engineering

www.elsevier.com/locate/procedia

X International Conference on Structural Dynamics, EURODYN 2017

Measurement of rotating beam vibration using optical (DIC) techniques

Ahmed Yashar[a,*], Neil Ferguson[a], Maryam Ghandchi Tehrani[a]

[a]Institute of Sound and Vibration Research, University of Southampton, Southampton SO17 1BJ, UK

Abstract

In this paper, an experimental study is presented to validate a dynamic model of a rotating beam. The majority of existing vibration instrumentation is typically wired to an acquisition system through a connection using slip rings. An issue is the inherent signal to noise and the reliability of slip ring electrical connections. Herein, an experimental test rig is designed to overcome these issues. In addition, the rig is conceived to incorporate capabilities such as applying variable rotational speed using a variable frequency driver and provide vertical base excitation input to the centre of the rotation using a linear bearing. The tests are performed using random excitation on the fixed end of the rotating cantilever beam to excite the flapwise modes of the beam. The responses are then measured optically using a single high-speed camera, and the images are post-processed using a digital image correlation (DIC) method. This non-contacting optical method is used to extract the deflection of the beam as a function of time. The frequency response functions are then obtained from the measured responses. The modal frequencies are estimated and compared with numerical simulations to validate a Rayleigh-Ritz and FE numerical model for different rotational speeds.

Keywords: Rotating beam; Image correlation; Image processing; flapwise vibration;

1. Introduction

Rotating cantilever beams are widely applied in engineering applications, such as in wind turbines, in helicopter blades and in turbomachinery applications. The vibrational characteristics of beams become considerably different when subject to rotation. Numerical approaches to study the phenomena have been widely published [1–3]. However, there are much fewer experimental investigations because of the difficulties in performing the tests. One of the principal obstacles is attaching and connecting instrumentation to the rotating structure. Furthermore, the additional mass of any transducers can also affect the behaviour of the structure. To overcome these issues, in this paper a new digital image processing method is developed to obtain the natural frequencies and final time domain response of a rotating beam. The new non-invasive method is based on measuring the beam deflection optically.

* Ahmed Yashar. Tel.: +44-(0)2380-59-4930-24930 ; fax: +44-(0)2380-59-3190.
E-mail address: amiy1g14@soton.ac.uk

1877-7058 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the organizing committee of EURODYN 2017.
10.1016/j.proeng.2017.09.052

2. Experimental design

An experimental test rig was designed incorporating a controllable high rotational speed and vertical base excitation. The foundation of the design should be rigid enough to avoid frequency interference between the specimen and the foundation. To achieve these requirements a test rig was designed as shown in Figure 1. This design comprises five main parts. A steel foundation, a high-speed air-cooled controllable motor that provides a speed range between 0-24000 rpm, a variable frequency drive (VFD) to control the rotational speed and a rotational hub.

This design was optimised using vibration analysis in FE. The estimated beam natural frequencies, covering the fundamental, second and third mode are between 8-500Hz and the test rig foundation is about 850Hz, which is much higher than the specimens' frequencies.

The rotating hub assembly allows the introduction of a vertical excitation to the base of the rotational beam as shown in the Figure 2, where the four shafts have the ability to slide in the linear bearings. This vertical excitation was achieved using an electrodynamic shaker, which excites the beam in a flapwise direction at its base.

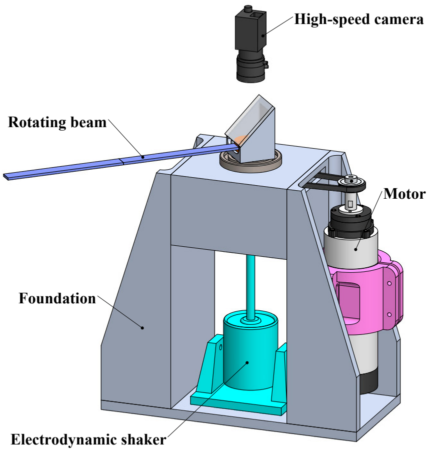

Fig. 1: Experimental test rig with single high speed camera and mirror.

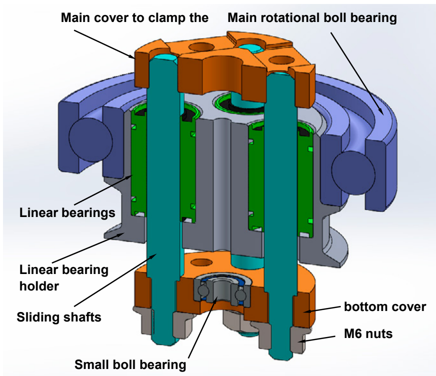

Fig. 2: Section view of rotating hub assembly.

3. Digital image correlation

Digital Image Correlation (DIC) is a pattern tracking method and it is designed to recognise and track a special density of grey levels [4]. To achieve this task, specimen typically are painted with two contrast colours such as black and white as shown in the Figure 3. This pattern should be random and the size of the black points should not be less than three pixels to avoid pixel aliasing. In this paper, three different markers were used instead of the speckles for the purpose of tracking the tags using a simple MATLAB image processing algorithm; a commercial DIC software package was used for comparison with the results. These three markers are a 10mm diameter circle black point, three 2mm diameter black points and five 2mm diameter black points as shown in Figures 3(b)-(d), respectively.

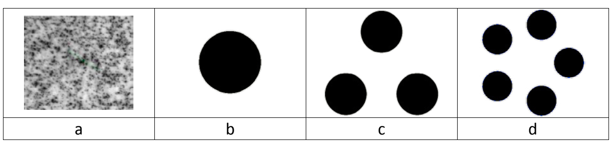

Fig. 3: Illustration of the (a) Speckles and (b-d) Marker patterns.