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Shaft instantaneous angular speed for blade vibration in rotating machine

Ahmed A. Gubran, Jyoti K. Sinha *

School of Mechanical, Aerospace and Civil Engineering (MACE), The University of Manchester, Sackville Street, Manchester M13 9PL, UK

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ABSTRACT

Reliable blade health monitoring (BHM) in rotating machines like steam turbines and gas turbines, is a topic of research since decades to reduce machine down time, maintenance costs and to maintain the overall safety. Transverse blade vibration is often transmitted to the shaft as torsional vibration. The shaft instantaneous angular speed (IAS) is nothing but the representing the shaft torsional vibration. Hence the shaft IAS has been extracted from the measured encoder data during machine run-up to understand the blade vibration and to explore the possibility of reliable assessment of blade health. A number of experiments on an experimental rig with a bladed disk were conducted with healthy but mistuned blades and with different faults simulation in the blades. The measured shaft torsional vibration shows a distinct difference between the healthy and the faulty blade conditions. Hence, the observations are useful for the BHM in future. The paper presents the experimental setup, simulation of blade faults, experiments conducted, observations and results.

1. Introduction

Rotating blades are considered as the most common cause of failures in rotating machinery. The blade failure modes normally occur as a result of cracking, high cycle stresses, blade rubbing, blade root looseness, degradation from erosion and corrosion. Therefore, early fault detection is important in reducing blade related failures and hence there is a need of a reliable and simple blade health monitoring (BHM) technique. Sinha et al. [1] recently analyse the in-situ measured vibration data at the bearing pedestals during the steady state and the transient operations in the steam turbines to understand the machine dynamics, and to identify the root cause of the failure of the last stage blades in the low pressure turbines. Al-Bedoor [2] gave the review of different research methods that has been attempted for blade vibration measurements till year 2002. In-situ casing vibration near the last stage of a low pressure (LP) turbine in a steam turbo-generator (TG) set was observed to show the trace of blade resonance only during the fluctuation in the condenser pressure due to change in loads [3]. But such observation contains very limited information and may not be useful for diagnosis. Strain measurement on the blades during the machine operation is another option [4], this is where strain can be measured directly and hence the stress and possibly residual blade life can be estimated [5]. The blade tip time (BTT) has received attention in recent years and it can identify blades with high vibration [4,6]. However both the BTT and the strain measurement methods are intrusive and exorbitant methods. Hence there is a need for reliable and simple but robust method to meet the requirements of the BHM.

* Corresponding author. Tel.: +44 161 3064639; fax: +44 161 3064601.
E-mail addresses: ahmed.gubran@postgrad.manchester.ac.uk, ahmed.gurban1@gmail.com (A.A. Gubran), jyoti.sinha@manchester.ac.uk (J.K. Sinha).

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The use of the encoder in rotating machines is seems to be a common practice to measure the shaft speed. The shaft instantaneous angular speed (IAS) signal from the encoder raw signal based on time-intervals change between successive pulses is nothing but the representing the shaft torsional vibration. This method is generally non-intrusive and non-exorbitant method and now the topic of research for different applications. A few of them include the identification of faulty combustion cylinder(s) in the diesel engines [7,8] using the crank shaft IAS signal and the IAS response of the shaft with fault(s) in rotating machine [9,10]. It has also been reported in the literature that transverse blade vibration is often reflected in the shaft torsional vibration. It was experimentally verified on small rigs, and the mistuning effect on the blade natural frequency was also observed [11,12]. Maynard and Trethewey [13] have also demonstrated the field application on the use of the torsional vibration for tracking crack in shaft and blades. Analytical simulations [14] and Huang and Ho [15] have also shown the potential of the shaft torsional vibration that could be used as the condition monitoring for turbine blades. However, Sinha et al. [16] could not identify the last stage blade resonance during normal operation of a steam turbine in a 220 MW Nuclear Power Plant in India. The transient operation of machine may be useful for such machines. Hence the shaft IAS has been extracted from the measured encoder data during the machine transient operation to understand the dynamics of the blades and to explore the possibility of reliable assessment of the blade health.

A series of experiments were conducted on a test rig with an 8-bladed disc for three different conditions: (1) healthy with mistuned effects, (2) blade root looseness and (3) blade(s) with crack. These conditions are often observed in practice for the rotating machines like steam turbines, gas turbines, etc. and hence the early and reliable detection of the faulty conditions (2) and (3) is important. The extracted IAS signal from the encoder raw data during the machine run-up were then order tracked at the different engine order (EO) speeds so that the presence of the blade resonances, their higher harmonics and dynamics behaviour can be analysed. The measured shaft torsional vibration shows a distinct difference between the healthy and the faulty blade conditions and hence the observations may be useful for the BHM in future. The paper presents the IAS extraction process from the encoder measurement, rig details, blade faults simulations, experiments conducted and the observations on the blade dynamics which may possibly lead to the BHM in future.

2. Instantaneous angular speed (IAS) measurement

An encoder that measures 360 pulses for every complete rotation of a shaft has been used for the present experiment. To aid the understanding of the IAS signal extraction from the measured encoder pulse train, a simplified measurement scheme of the encoder and the pulse train is shown in Fig. 1. The sensor simply measures the gap between each tooth on the gear during its rotation which results in the pulse train of the measured gap voltage with time as shown in Fig. 1. The extraction of instantaneous angular speed (IAS) signal using the pulse train in Fig. 1 is discussed in the following steps.

(i) Each square pulse represents a tooth in the gear of the encoder, hence the difference of times, t_2-t_1, t_3-t_2, ….,$t_{n+1}-t_n$, etc. represents the time interval required to cross the 1st, 2nd, …., nth tooth respectively which is written as

$$\Delta t_n = t_{n-1} - t_n \tag{1}$$

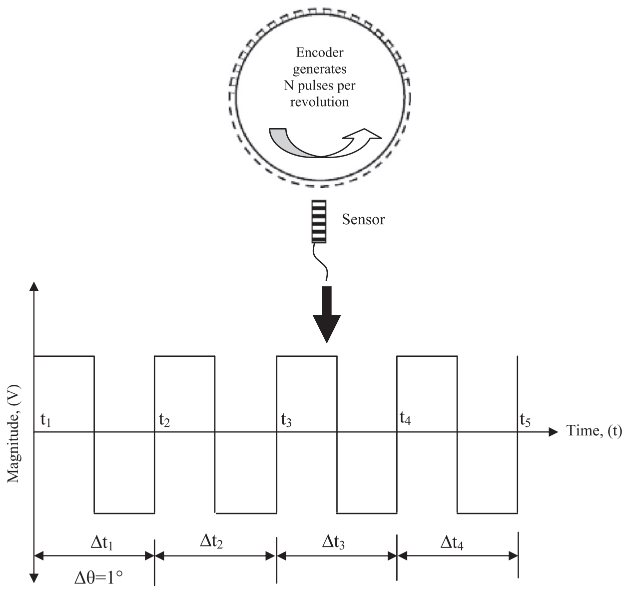

Fig. 1. Pulse train created from shaft encoder.