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A novel torsional exciter for modal vibration testing of large rotating machinery

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Abstract

A novel exciter for applying a dynamic torsional force to a rotating structure is presented in this paper. It has been developed at IPP in order to perform vibration tests with shaft assemblies of large flywheel generators (synchronous machines). The electromagnetic exciter (shaker) needs no fixture to the rotating shaft because the torque is applied by means of the stator winding of an electrical machine. Therefore, the exciter can most easily be applied in cases where a three-phase electrical machine (a motor or generator) is part of the shaft assembly. The oscillating power for the shaker is generated in a separate current-controlled DC circuit with an inductor acting as a buffer storage of magnetic energy. An AC component with adjustable frequency is superimposed on the inductor current in order to generate pulsating torques acting on the rotating shaft with the desired waveform and frequency. Since this torsional exciter does not require an external power source, can easily be installed (without contact to the rotating structure) and provides dynamic torsional forces which are sufficient for multi-megawatt applications, it is best suited for on-site tests of large rotating machinery.

Keywords: Torsional exciter; Electromagnetic shaker; Rotordynamics; Mechanical testing; Torsional vibration; Modal analysis

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1. Introduction

Electromagnetic exciters for testing vibration properties of rotating structures were already proposed 60 years ago [1]. The first electromagnetic exciters were mainly developed for testing propellers without the necessity of using aircraft engines and to provide a vibration generator which simulates the rotary and vibratory stress of normal operating conditions while permitting a more satisfactory control or variation of the vibratory stress in accordance with different desired test conditions. The vibration generator consisted of a single-phase alternating-current motor, thus utilising the characteristic of this type motor to reduce the motor torque to zero twice within each cycle of the alternating load current. The application of motor torque pulsations in single-phase motors was also proposed in experimental procedures for investigating torsional vibration in small air-conditioning units [2]. In this test procedure the fan motor was set up to act as a torsional exciter. This solution is attractive because modal vibration tests can be performed on site, without having to install an additional torsional exciter, e.g. a hydraulic exciter system [3]. Since both proposed electromagnetic exciters utilise the torque characteristic of a single-phase induction machine, they are not suited for an application to large electrical machinery which generally requires the application of three-phase machines. In three-phase electrical machines at balanced operation, the instantaneous power at each winding connected to the phases R, S, and T can be described by Eq. (1). The underlined parts of the equation do not contribute to the resulting torque transferred to the rotor. Therefore, the total active power transmitted by a three-phase electrical machine does not have a pulsating torque characteristic like a single-phase induction machine so that the test procedures proposed in [1,2] cannot be applied.

$$\begin{aligned}
P_R(t) &= u_R(t)\cdot i_R(t) = \hat{u}\cos(\omega t+\varphi)\cdot\hat{i}\cos\omega t \\
&= \frac{\hat{u}\cdot\hat{i}}{2}[\cos\varphi(1+\underline{\cos 2\omega t) - \sin\varphi\sin 2\omega t}],\\
P_S(t) &= u_S(t)\cdot i_S(t) = \hat{u}\cos\left(\omega t+\frac{2\pi}{3}+\varphi\right)\cdot\hat{i}\cos\left(\omega t+\frac{2\pi}{3}\right)\\
&= \frac{\hat{u}\cdot\hat{i}}{2}\left[\cos\varphi\left[1+\underline{\cos 2\left(\omega t+\frac{2\pi}{3}\right)}\right]\underline{-\sin\varphi\sin 2\left(\omega t+\frac{2\pi}{3}\right)}\right],\\
P_T(t) &= \frac{\hat{u}\cdot\hat{i}}{2}\left[\cos\varphi\left[1+\underline{\cos 2\left(\omega t+\frac{4\pi}{3}\right)}\right]\underline{-\sin\varphi\sin 2\left(\omega t+\frac{4\pi}{3}\right)}\right],
\end{aligned} \tag{1}$$

where P_{RST} is the instantaneous power at each winding; u_{RST} the winding voltage; i_{RST} the winding current; ω the angular network frequency and φ the phase shift between u_{RST} and i_{RST}.

The study and test of the dynamics of systems in which at least one part rotates with significant angular momentum is most relevant for large rotating machinery [4]. Testing of large rotating components poses significant practical difficulties in measurements and excitations. The different excitation techniques fall in two basic classes—transient excitation (free vibration) and continuous excitation (forced vibration). Since the rotating motion of the impact site is likely to cause errors in the measurement of frequency–response functions [5], a harmonic (continuous) excitation device is preferable for testing large or complex rotating structures. In cases where a hydraulic