IMPROVED FAULT DETECTION IN A ROTATING SHAFT BY USING THE ELECTROMECHANICAL IMPEDANCE METHOD

A. A. Cavalini Jr, D. S. Rabelo, D. D. Oliveira, R. M. Finzi Neto, V. Steffen Jr

LMEst - Laboratory of Mechanics and Structures, Federal University of Uberlândia, School of Mechanical Engineering, Av. João Naves de Ávila, 2121, Uberlândia, MG, 38408-196, Brazil.
E-mail: aacjunior@mecanica.ufu.br

Abstract: The aim of this paper relies on the correct detection of incipient faults in rotating shafts by using the so-called electromechanical impedance method. Basically, this structural health monitoring technique - SHM monitors changes in the electric impedance of piezoelectric transducers bonded to the host structure, through specific mathematic equations, the so-called damage metrics, to detect damage. Previously, experimental tests were performed in a horizontal rotor in which PZT patches were bonded along the host structure. Although successful, the obtained results shown to be susceptible to changes in the environment and machine temperatures. Aiming at overcoming the limitations faced, in this contribution a compensation technique is tested.

Keywords: fault detection, electromechanical impedance method, temperature compensation, rotating shafts.

1 Impedance based structural health monitoring

The detection and identification of incipient cracks in shafts of rotating machines under operating condition is one of the most challenging problems in the field of rotor dynamics. The techniques based on vibration measurements are recognized as promising SHM tools (Structural Health Monitoring). Previously, incipient damages were detected in a rotating shaft (17 mm diameter) by using the so-called electromechanical impedance method (Cavalini Jr, Finzi Neto, Steffen Jr, 2014). Through piezoelectric material sensor-actuators (PZT patches; 12 mm *x* 6 mm), the electromechanical impedance was determined.

For non-rotating structures, the impedance based SHM technique was first proposed by Liang, Sun, and Rogers (1994). As mentioned, this technique uses small PZT patches to monitor changes in the structure that may occur due to the appearing of damage. When the PZT patch is bonded to the structure and an electric voltage is applied, generally 1V, a strain is produced. Using a high excitation frequency, if an incipient damage was grown in the system, changes can be observed in the measured impedance signatures. The structural integrity assessment is made based on the comparison of impedance signatures measured before and after the occurrence of damage. In this sense, the so-called damage metrics is calculated. The deviation of the correlation coefficient (CCD) is the mostly commonly used metric.

$$CCD = \frac{1}{n}\sum_{i=1}^{n}\frac{\left[\mathrm{Re}\left(Z_{1i}\right)-\mathrm{Re}\left(\bar{Z}_{1i}\right)\right]-\left[\mathrm{Re}\left(Z_{2i}\right)-\mathrm{Re}\left(\bar{Z}_{2i}\right)\right]}{S_{Z1}S_{Z2}} \tag{1}$$

where $Z_{1,i}$ is the impedance of the transducer measured under healthy condition, $Z_{2,i}$ is the impedance for the comparison with the baseline measurement at frequency interval i. The over bar represents mean impedance values, while S_{Z1} and S_{Z2} represent standard deviations.

2 Temperature compensation procedure

For a fixed selected frequency range, the horizontal e vertical shifts can be considered uniforms. This feature allows us to separate the temperature effects. In order to compensate the vertical shifts, a global average difference from two signals (1: *baseline* and 2: test measurement) is calculated as shown in equation 2:

$$\Delta_v = \frac{1}{n}\left[\sum_{i=1}^{n}\mathrm{Re}\left(Z_{2,i}\right)-\sum_{i=1}^{n}\mathrm{Re}\left(Z_{1,i}\right)\right] \tag{2}$$

where Δ_v is the vertical shift and n is the number of frequency points. The frequency shift is obtained through an iterative routine until the maximum deviation CCD (ideally 1) is obtained (Park et al., 1999).

3 Experimental application

Figure 1 shows the test rig used in the application of the SHM technique proposed by this work, i.e., the detection of incipient transverse cracks in rotating shafts by using the electromechanical impedance method. The first two critical speeds are approximately 1685 rev/min (28.1 Hz) and 5430 rev/min (90.5 Hz). Additionally, a schematic arrangement with each of the five patches bonded to the system is shown (frequency bandwidths used for the PZT patches were, approximately, 165 to 180 kHz).

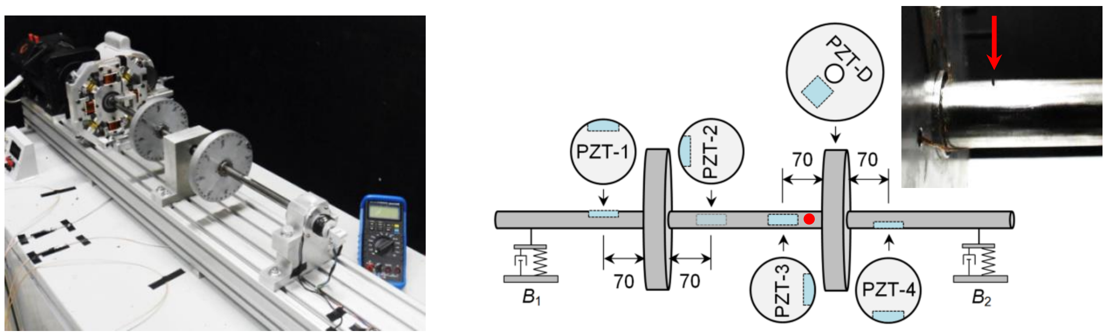

Figure 1: Test rig used in this application and the distribution of the PZT patches along the machine.

A saw cut was performed along the shaft cross-section by using a thin machining disc to simulate a crack. This was done at a location about 15 mm from one of the discs (55 mm from PZT-3; region delimited by the discs; see the details in figure 1). The machining work formed a "crack" of approximately 0.5 mm thick and 2.5 mm depth (about 15 % over the shaft diameter).

Figure 2 shows the impedance signatures obtained for the rotor without and with damage (PZT-4), considering the rotor as being previously balanced and operating at 1200 rev/min. Note that the differences between the impedance signatures becomes smaller with the application of the temperature compensation approach, leading to a more consistent damage detection approach (see the details of the first peak related with each impedance signature).

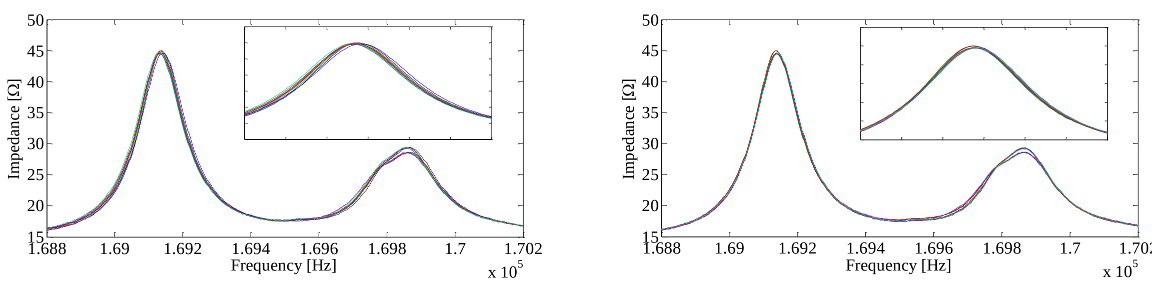

Figure 2: Uncompensated and compensated impedance signatures measured by using PZT-4.

Acknowledgments

The authors are thankful to the Brazilian Research Agencies FAPEMIG, CAPES and CNPq (INCT-EIE) for the financial support provided for this research effort.

References

Cavalini Jr AA, Finzi Neto RM, Steffen Jr V (2014) Fault detection in a rotating machine by using the electromechanical impedance method. In: XXXIIth Conference and Exposition on Structural Dynamics, IMAC 2014, Orlando, FL, USA.

Liang C, Sun FP, Rogers CA (1994) Coupled electromechanical analysis of adaptive material systems: determination of the actuator power consumption and system energy transfer. Journal of Intelligent Material Systems and Structures 5(1):12-20.Park G, Kabeya K Cudney HH, Inman DJ (1999) Impedance-based structural health monitoring for temperature varying applications. JSME International Journal 42(1): 249-258.