نشریه مهندسی مکانیک امیرکبیر

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(10) (2021) 661-664
DOI: 10.22060/mej.2019.15707.6185

Looseness Detection and Assessment of Flange Type Joints Using Vibro-Acoustic Modulation Method

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ABSTRACT: Flanged joints' looseness is among the common causes for the failure of industrial structures with flanged joints such as wind turbines or transmission line pipes the timely detection of which can prevent the imposition of heavy, financial losses and in some cases property damage. Conventional methods for detecting this fault, such as torque control methods, have high error of measurement, or impedance-based measurement methods, have high expenses, or vibration or ultrasonic methods which lack accuracy due to the use of linear phenomena in fault detection. Vibro-acoustic modulation method is one of the nonlinear fault detection methods that detect and evaluate looseness of flanged connection with high precision through the measurement of the intensity of the vibrational and ultrasonic signals modulation applied to the structure. Although the published papers in recent years have often identified the cracking, delamination, or corrosion and decay of parts using this method, in this paper the efficiency of the vibro-acoustic modulation method in the detection and evaluation of flanged joints of simulated wind turbine towers has been numerically investigated by defining an index for modulation intensity and bond relaxation. Then, the effect of parameters such as ultrasonic and vibrational frequency, amplitude of ultrasonic and vibrational stimulation, sensors and actuators position, as well as preload force, on the method performance has been studied. Finally, in order to reduce the simulation time in ABAQUS software, the modeling of the neural network was performed using MATLAB software and the obtained results were compared with numerical results.

Review History:

Received: Jan. 27, 2019
Revised: Apr. 18, 2019
Accepted: Jun. 16, 2019
Available Online: Jun. 25, 2019

Keywords:

Nondestructive testing
Fault detection
Looseness detection
Vibro-acoustic modulation
Impact modulation

1- Introduction

Vibro-acoustic modulation method is one of the non-destructive nonlinear methods that has attracted researchers' attention in recent years [1]. In this method, as shown in Fig. 1, the ultrasonic signals (high frequency) and vibration (low frequency) stimulate the connection simultaneously and, in case of any looseness in the connection, a modulation in the structure response will be clearly observable by measuring of which the amount of looseness in the connection can be estimated [2-5].

The method of Vibro-acoustic modulation has often been used in the detection and evaluation of cracks in industrial structures, and except for a few articles that proved the method's efficiency in detecting the looseness of simple static bolt. In this paper, along with the modeling of a flange connection of a turbine tower with twelve bolts and nuts, the efficiency of the Vibro-acoustic modulation method in the detection and evaluation of flange connection bolt has been numerically investigated. In addition, the effect of parameters such as ultrasonic and vibrational excitation frequency, ultrasonic and vibrational stimulation amplitude, location of sensors and actuators, as well as preloading force on the method's performance has been studied [5-9].

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2- Numerical Simulation and Methodology

As shown in Table 1 and Figs. 2 and 3, a flange joint consisting of twelve nuts and bolts has been utilized to model the flange joint of the wind turbine tower, connecting two parts of the turbine tower of 2 meters in diameter. The tower body as well as the bolts and nuts are all considered to be made of steel, and no material or intermediate part between the two flanges is considered. In this occasion, at each run of the program, the vibrating signal obtained from the turbine performance is applied as a transverse force to the upper tube of the tower at a frequency of 3 Hz; simultaneously, the ultrasonic harmonic signal, for instance, with the help of actuator 1 at a frequency of 150 kHz stimulates the system and the responses are received with the help of 12 sensors located on the other side of the flange. This process is repeated for every single operator, and there will be 144 responses per sensor for each ultrasonic stimulation applied by each operator. If investigated in the Fourier space, modulated signals will exhibit sidebands around the ultrasonic frequency.

3- Results and Discussion

As mentioned above, the method of Vibro-acoustic modulation, due to the nature of its non-linearity, has not only more precision compared to other conventional methods, such as ultrasonic methods, impedance-based measurement methods or vibration-based methods but also impose relatively low costs on inspectors due to the simplicity of inexpensive required equipment. In addition, it was observed that when

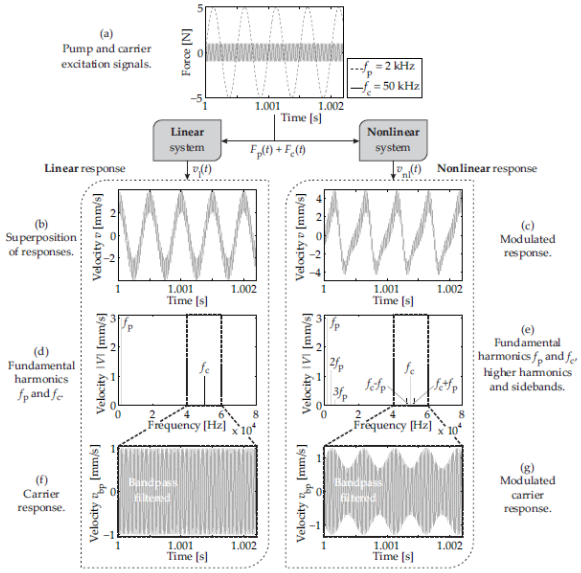

Fig. 1. Comparison of received signals from healthy and faulted structures [5]

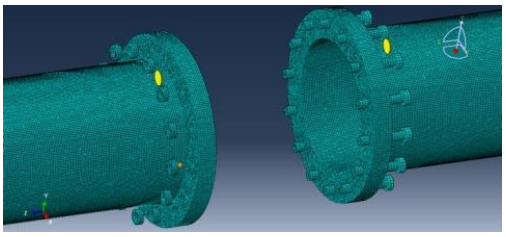

Fig. 2. Simulated flanged joint in ABAQUS

Table 1. Simulation parameters of valuation

Physical Parameters	
The diameter of tower pipes	2 meter
The material of the pipes	Steel
Flange thickness	5 cm
Nuts and bolts number	12
The material of nuts and bolts	Steel
The internal diameter of nuts and bolts	5 cm
Type of Piezoelectrics	PZT
Stimulation Parameters	
Ultrasonic frequency	150 kHz
The vibrational frequency of the turbine performance	3Hz
Ultrasonic stimulation amplitude	50 N
Vibrational stimulation amplitude	100 N
Axial force applied to the loose joint	500 N
Axial force applied to other joints	1000 N

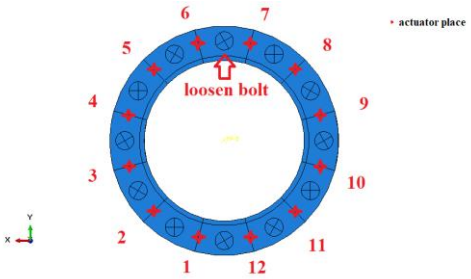

Fig. 3. Location of sensors and actuators in simulated flanged joint

the connection becomes loose, the vibrations occurring at the junction during ultrasonic wave propagation will cause modulation which can be detected well by the Vibro-acoustic modulation method.

There are significant parameters that can influence the effectiveness of the method, the most notable among which are ultrasonic and vibrational frequency, vibrational and ultrasonic wave amplitude, sensors, actuators, and vibrations. As stated before, the more ultrasonic and vibrational frequencies are closer to the natural frequencies of the structure, the more method efficiency will be; however, in general, increasing the ultrasonic frequency will reduce the relative looseness index, while increasing the vibrating frequency will result in a slight increase in the looseness index. The behavior of the index of relaxation versus increasing the amplitude of ultrasonic and vibrational stimulation is approximately the same and will increase in both cases. Moreover, the proximity of the actuator to the bolt and nut as well as the sensor's distance will result in a better performance of the Vibro-acoustic modulation technique in detecting and evaluating the looseness of the joints.

References

[1] S.M.Y. Nikravesh, M. Goudarzi, A Review Paper on Looseness Detection Methods in Bolted Structures, Latin American Journal of Solids and Structures, 14(12) (2017) 2153-2176.

[2] V. Y. Zaitsev, A. Sutin, I.Y. Belyaeva, V. Nazarov, Nonlinear interaction of acoustical waves due to cracks and its possible usage for cracks detection, Modal Analysis, 1(3) (1995) 335-344.

[3] V. Zaitsev, P. Sas, M. Wevers, Nonlinear modulation methods of structural damage detection based on dissipative nonlinear effects, in: Proceedings of the International Seminar on Modal Analysis, KU Leuven; 1998, 2001, pp. 233-242.

[4] V. Kazakov, A modulation crack-detection technique: I. Instrumental method of implementation, Russian Journal of Nondestructive Testing, 42(11) (2006) 709-716.

[5] T.H. Ooijevaar, Vibration based structural health monitoring of composite skin-stiffener structures, PhD Thesis, Universiteit Twente, (2014)

[6] D.M. Donskoy, A.M. Sutin, Vibro-acoustic modulation nondestructive evaluation technique, Journal of

intelligent material systems and structures, 9(9) (1998) 765-771.

[7] M. Meo, U. Polimeno, G. Zumpano, Detecting damage in composite material using nonlinear elastic wave spectroscopy methods, Applied composite materials, 15(3) (2008) 115-126.

[8] F. Amerini, M. Meo, Structural health monitoring of bolted joints using linear and nonlinear acoustic/ ultrasound methods, Structural health monitoring, 10(6) (2011) 659-672.

[9] M.Goudarzi, S. M. Y. Nikravesh, Looseness Detection and Assessment of Flange Type Joints Using Vibro-Acoustic Modulation Method, in: 8th International Conference on Acoustics and Vibration, Iran (Tehran), 2018 (In Persian).