Experimental and Numerical Looseness Detection and Assessment in Flanged 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 the timely detection of which can prevent the imposition of heavy financial losses and in some cases injuries. There are conventional methods for detecting this fault and each of them has its own drawbacks. For instance, torque control methods have high error of measurement, impedance-based measurement methods; have high expenses, and vibration or ultrasonic methods 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 can detect and assess looseness of flanged joints with high precision through the measurement of the intensity of the vibrational and ultrasonic signals modulation applied to the structure. This paper was an attempt to investigate the efficiency of the Vibro-Acoustic modulation method in the detection and evaluation of flanged joints numerically and experimentally. For this, a laboratory sample composed of two pipes connected with flanged joints is employed. It is revealed that this method can detect bolt looseness with 12.5% precision. In addition, the effect of parameters such as ultrasonic and vibrational frequency, amplitude of applied torque, sensors and actuators position, as well as excessive increase of torque have been examined and the method precision in the studied structure has been estimated.

KEYWORDS

Structural Health Monitoring; Smart Structures; NDT; Vibro-Acoustic Modulation; Bolted Joints.

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Introduction

According to the published articles in recent years, VAM method has often been used in the detection of defects such as cracks, delamination, and defects stemming from erosion, decay or impact [1-4]. In this paper, the efficiency of VAM method in the diagnosis and evaluation of loose bolt are investigated numerically and experimentally. Flanged joint of the two pipes connected with eight M16 bolts and nuts to each other are modeled in ABAQUS according to the specifications of laboratory sample, and the location and intensity of loose bolt is detected by this method. In addition, the effect of parameters such as the frequency of ultrasonic and vibrational excitation, the location of the sensor and actuator, the intensity of torque applied to the bolts, excessive increase of torque increase and method precision on the structure are estimated. The laboratory sample comprised of two pipes with 5 mm thickness, 250 mm diameter, and 1200 mm length connected with two flat flanges, eight bolts and nuts to each other . A one-Hertz DC electric motor is used to create a mechanical to the structure by 3-blades with 250mm diameter. Given the sensitivity analysis of the parameters affecting the performance of VAM method requires that the vibrational frequency change, a DC driver has also been employed through which 0.5-1.5 Hz vibration frequencies can be applied. The sensors and actuators connected to the setup were of the PZT piezoelectric type. The piezoelectric elements, with the help of silver adhesive, are located on the sides of the flange and correctly between the bolts and the nuts. The upper and lower element played the role of the ultrasonic actuator and sensor respectively. According to 898-1 ISO, the torque applied to bolts and nuts in the setup bolts and nuts were regulated at the standard level by digital torque meter SK11060118. Low frequency Flaw Detector acted as the sender of ultrasonic waves to the actuator and the structure subsequently. Owon-VDS2064, connected to a desktop computer, acted as the oscilloscope; additionally, it contributed to the storage of modulated signals on the computer. After wards, these signals were processed by MATLAB.

Results

As shown in figure 1, if the modulation index is plotted for different sensor-actuator locations for 50% looseness, it is quite considerably observed that the modulation index value is maximums for locations 45 and 56. This means that the loose bolt is located in location 5. In fact, as sensors and actuators are closer to the loose bolt, due to the short distance between two flange surfaces, acoustic impedance between the two levels will cause vibrational and ultrasonic waves passing the modulated surface, and the calculated modulation index value increases. Another point worth mentioning is the difference between the values obtained from the experimental and the numerical analyses. In general, all values obtained from numerical simulations are lower than those obtained from empirical experiments due to the nonlinearity of the actual samples used in the experiments. In other words, surface smoothness, support conditions, etc., are assumed to be ideal in the modulation of numerical analysis, whereas in the actual case, these parameters were not ideal and these differences led to an increase in the nonlinear wave behavior when passing through the flanged surfaces that is reflected in the form of signal modulation.

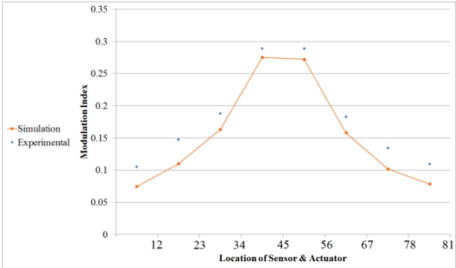

Figure 1 Modulation index at different sensor-actuator positions at 50% looseness

Another point to bear in mind is that increasing the applied torque does not always decrease the modulation index value. As shown in figures 2 and 3, excessive applied torque has had a negative effect leading to an increase in the modulation index value. In fact ,when excessive torque is imposed on the bolt, the stress field is formed around the bolt which causes nonlinear behavior of the wave passing through the field due to the acoustoelastic effect. This behavior will be illustrated in the form of modulation.

As shown in Figures 4 and 5, as vibration frequency increases, the index value for different looseness will also generally increase. In addition, the effect of increasing the vibrational excitation frequency is greater, and the modulation index value will have a greater increase when the bolt looseness intensity is higher. As shown in Figures 6 and 7, the overall behavior of the indices in relation to the fluctuations of the ultrasonic frequency is the same as their behavior against the vibrational excitation frequency fluctuations . Compared to the sensitivity analysis of the vibration excitation frequency, this sensitivity analysis reveals that ultrasonic frequency fluctuations have a much smaller effect on the modulation index than vibrational excitation frequency fluctuations.

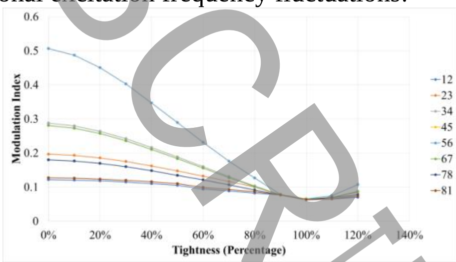

Figure 2 The effect of execcive increase of torque on modulation indexes in different sensor-acutor locations (Experimental Analysis)

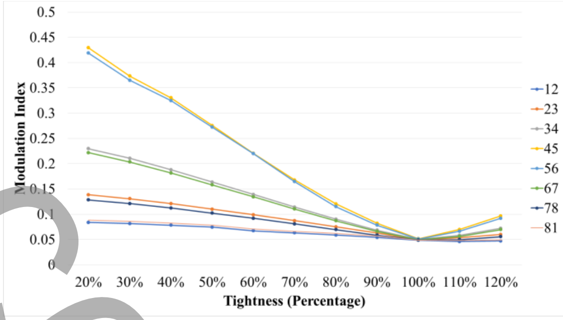

Figure 3 The effect of execcive increase of torque on modulation indexes in different sensor-actuator locations (numerical Analysis)

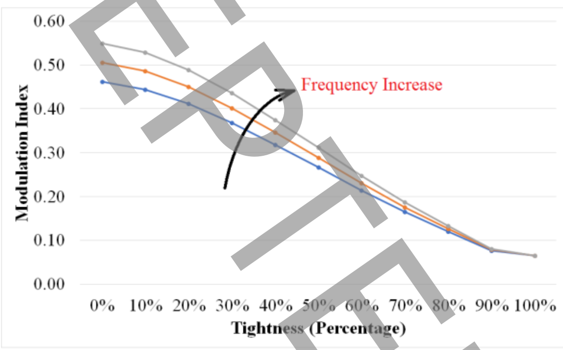

Figure 4 The effect of the vibrational excitation frequency on modulation indexes in sensor-actuator position 45 (Experimental Analysis)

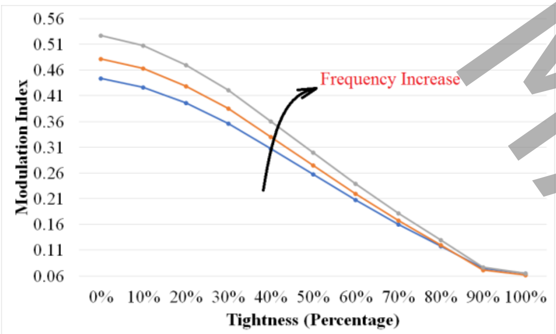

Figure 5 The effect of the vibrational excitation frequency on modulation indexes in sensor-actuator position 45 (Numerical Analysis)

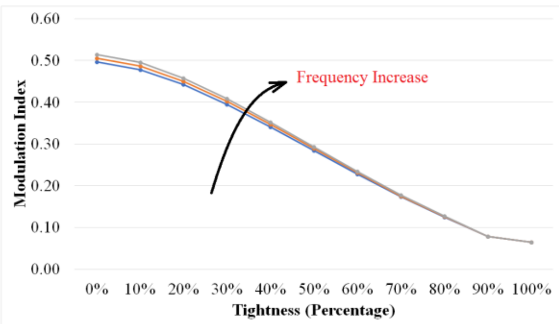

Figure 6 The effect of ultrasonic frequency excitation on modulation indices at sensor-actuator location 45 (Experimental Analysis)

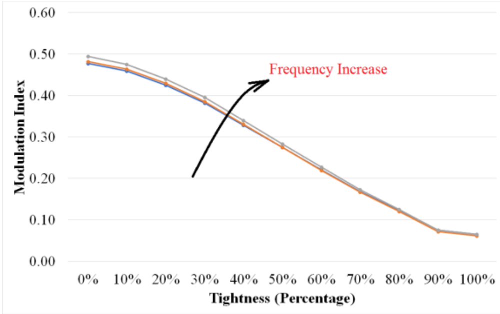

Figure 7 The effect of ultrasonic frequency excitation on modulation indices at sensor-actuator location 45 (Numerical Analysis)

Conclusion

Compared to other looseness detection methods, Vibro-Acoustic vibration method is capable of having higher precision while being simple in implementation. It enables the supervisors to easily design and implement online condition monitoring of flanged joints. This paper investigates the detection and looseness of flanged joints numerically and experimentally. Based on the results, this method competent in looseness detection, intensity and position in flanged joints. The results of experimental tests confirm that the VAM method is capable of detecting up to 12.5% of looseness .The closer the position of the sensor and actuator used in the experiment to the loose bolt, the higher the precision of the method will be. Increasing the amplitude and frequency of vibrational excitation has a positive effect on the ability of the method to detect and evaluate bolt looseness; consequently, the method will be more precise if there are unknown sources of vibration in the system. Although increasing ultrasonic frequency lead to a rise in the modulation index value at different looseness intensities, this effect is very slight and negligible. Increasing the torque applied to the bolt will decrease the acoustic impedance and the modulation index. However, excessive torque will, by itself, cause modulation and increase of the index value due to the acoustoelastic effect.

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