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Force identification in bolts of flange connections for structural health monitoring and failure prevention

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Abstract

Force identification in bolts of flange connection is not only important to preserve the structure integrity but also to understand how does it works or even improve code procedures. Due to the relaxation phenomenon it becomes even more important in case of compressed bolts. In this paper a bolted flange connection was examined during static tensile test. Four of six bolts were equipped with washer load cells. Alternatively some bolts were equipped with piezoelectric transducers (actuator and sensor) in order to measure signals of elastic waves. It was noted that the load increasing causes changes in the signals measured. Principal components analysis was used for dimensionality reduction of measured signals. The aim of this study was to investigate the use of elastic waves and artificial neural networks for the purpose of force identification. Examples of preliminary results have shown that force in each bolt may be estimated with relatively good accuracy.

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Keywords: Force prediction; artificial neural networks; structural health monitoring; flange connection

1. Introduction

Force measurement in bolts is important in many industrial and engineering applications. Most often they are carried out during laboratory tests of prototype connections to study the behaviour of their individual components. The second area are non-destructive tests (NDT) and structural health monitoring (SHM) systems which enhance

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safety and reliability of structures. There exists also a group of joints where a level of pretension force influence the strength of a slip resistance connection. In this case, pretension force changes over time may become a very important issue, especially in cyclically-loaded constructions such as bridges, telecommunication towers or wind turbines.

One of the major problems with the use of bolted joints is the precision of tightening method selected to achieve an accurate preload level. Insufficient preload of bolts is a frequent reason of bolted joint failures. There are few main tightening methods used to control the preload of a threaded fastener. Of course they differ in terms of accuracy. For everyday purposes the clamping force can be approximated by measuring the tightening torque (±25%), whereas the highest accuracy is achieved using strain gauges or ultrasonic sensing (±1%). The force in a single bolt can be estimated using commercial solutions like ultrasonic load monitoring devices. Measurement uncertainty of washer like strain or piezoelectric load cells is about ±10%. Some of them were compared by Fric et al. (2015). Unfortunately, their price can not be possibly neglected and thus in long term research conducted strain gauges are used, either glued onto the bolt or fitted inside the bolt shank.

In this paper a new idea of the force identification was proposed. It takes advantage of the elastic wave propagation phenomenon which are introduced and measured by piezoelectric transducers. Nazarko and Ziemiański (2016) have used this idea in the field of structural health monitoring and non-destructive damage detection in various materials. Chaki and Bource (2009) have studied guided ultrasonic waves to monitor the stress levels in steel strands.

Laboratory tests were performed on several bolts of a flange connection mounted in a static test machine. It was noticed that force changes influence signals measured by sensors. It was reflected also in principal components calculated, which are often used to compress the signals, see for example Nazarko (2013) or Chen et al. (2017), where also the other signal compression methods are compared. The obtained patterns data base was then used for the training of Artificial Neural Networks (ANNs). Preliminary obtained results showed that ANNs are able to predict the force in bolts with reasonably well accuracy.

2. Force monitoring in bolts

Reliable bolt tension measurement contributes to safe and reliable operation of any critical systems. There are several solutions on the market that enable the measurement of forces in bolts. The first group of devices, known as an ultrasonic bolt tension monitor, is designed to measure elongation produced by tightening a threaded fastener. The measurement is achieved by determining the change in the transit time of an ultrasonic shock wave along the length of the fastener as the fastener is tightened. The on board microcomputer automatically interprets this measurement to display the time (nanoseconds), elongation, load, stress, or strain from stretching a fastener.

Measuring elements like electro-resistive strain gauges can be integrated into a bolt. It turns a bolt into a bolt sensor, which can measure the fastening force while working as a bolt. Smart bolts can measure developed tension in a fastener with a distinct colour spectrum.

Washer/donut type load cell belongs to the second group of devices. It is used for press-in force measurement. A load cell is a sensor or a transducer that converts a load or force acting on it into an electronic signal. This electronic signal can be a voltage change, current change or frequency change depending on the type of load cell and circuitry used.

Bolt may become loose with the passage of time, especially under vibration circumstance. Bolt loosening can be dangerous in some particular applications like bridge construction, hosting equipment, steel structure plant, construction machinery, etc. Thus, it become important to verify bolt forces (or pretension forces) during periodic inspections, damage detection or structural health monitoring of such structures.

The idea proposed in this paper takes advantage of the elastic wave propagation phenomenon. Two piezoelectric transducers (single or placed in two stacks) can be used to excite and to measure signals. The most convenient way of measuring is probably placing the transducers on one side of the screw, but they can use in both a pulse-echo as well as a pitch-catch configurations. It can be expected that even relatively small change in a bolt force will affect the signals measured (its time of flight, amplitude, frequency, etc.), what was confirmed by Kim and Hong (2009)