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ULTRASOUND METHOD TO EVALUATE THE FORCE IN BOLTED JOINT
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MSc. Rafael Carlucci Tavares
USP – Universidade de São Paulo
e-mail: rafael.carlucci@yahoo.com.br

Abstract. *The present study aims to investigate the method that estimates the force exerted by the screw on bolted joint, proposing a possible replacement of the conventional load cell. Based on the pulse-echo ultrasonic technique, the wave propagation time in a rectified screw is checked before and after being subjected to a normal load. The time difference related to the measured force by loaded cell was performed after applying the tightening torque on the fixation elastic region. Additionally, the screw samples were rectified at their parallel ends and the ultrasonic apparatus was magnetically coupled under the screw using water-based gel as a coupling, thereby verifying the time shift of the echo signal that is detected by a threshold amplitude of that signal. Moreover, the pulse-echo flight time in the isotropic medium was the object of the study to relate to the force measured in a cell that measures force (kN). Using equipment that basically is formed by cell of longitudinal and torsional load with electronic transduced torque wrench to define the gradual tightening, the time difference of the ultrasonic pulse was caused by a longitudinal effort after a tightening torque applied in the elastic region of mechanical resistance of the screw in the simulated joint. According to formulas at ISO16047, this equipment is currently used to check the friction of threaded elements and the numerous possibilities of contact surfaces, such as nuts and bolts. This method could evaluate the loosening force through a remote monitoring on bolted buildings, specifically bridges, oil and gas pipelines, wind energy towers, vehicles, engines, mats, maintenance of equipment, etc.*

Keywords: *Ultrasound, echo-pulse, force, load, bolt, nut.*

1. INTRODUCTION

In engineering fastening processes, the force that the screw generates in the fastening after an applied torque is what makes the assembly joint. Nevertheless, in bolted joints, what ensures the fastening is the force that the bolt exerts on the parts acting together with the friction to avoid loosening of the fastening element. As a result, the bolts and nuts generally have tabular torques for each application, however, it is necessary to ensure that the workloads based on the calculations of the loading loads do not cause relative movements among the components, nor do not exceed the resistance limit of the material, and they do not overtighten the screw.

After applying improper torque, the friction influence among different materials and coatings can compromise the desired union strength in a way that compromises project safety. Thus, the work aims to make an investigation study related to the screw force on the union of bolted joints with the aid of the ultrasound technique. The ultrasound, through the pulse-echo technique, allows to establish a direct measurement of the screw length before and after tightening, considering only the difference of the wave propagation time in the medium. Since the screw elongation is a critical factor during tightening, once it is generally desired to keep it in an elastic regime or close to the elastic-plastic area, measuring the tightening force using a fast and reliable method becomes very useful.

The use of the ultrasound pulse echo technique offers a method of measurement that is complementary to the use of the torque wrench, which only offers a direct torque measurement without considering other combined efforts from the friction among joining and parts.

With the advent of automation, graphical analysis of the tightening can be performed, however construction variables such as the part flow that is being tightened, or the tool that is being plasticized, both can be wrong.

Specific normalized tests are used to determine the critical limit of screw failure caused by these combined forces as a function of torque x angle, but with each application change, there is a latent need to rework the tests and reproduce this new scenario. Nevertheless, this is not always feasible in practical engineering situations or fault analysis. The ultrasound technique (TOF-Time of flight) can contribute as an analysis tool to assist phenomena interpretation that is taking place in the bolted joint (figure 1).

In figure 1 (a) a representation of the part still without tightening can be seen, positioned in a way that will suffer a tension on the demarcated region and the propagation of the ultrasonic pulse represented by the red arrow. Figure 1 (b) shows the difference in the length of the end, in red, although the tension is in the region lk, with the same transmitted ultrasonic pulse, but the displacement time is higher, once the difference between the final and initial length has been changed.

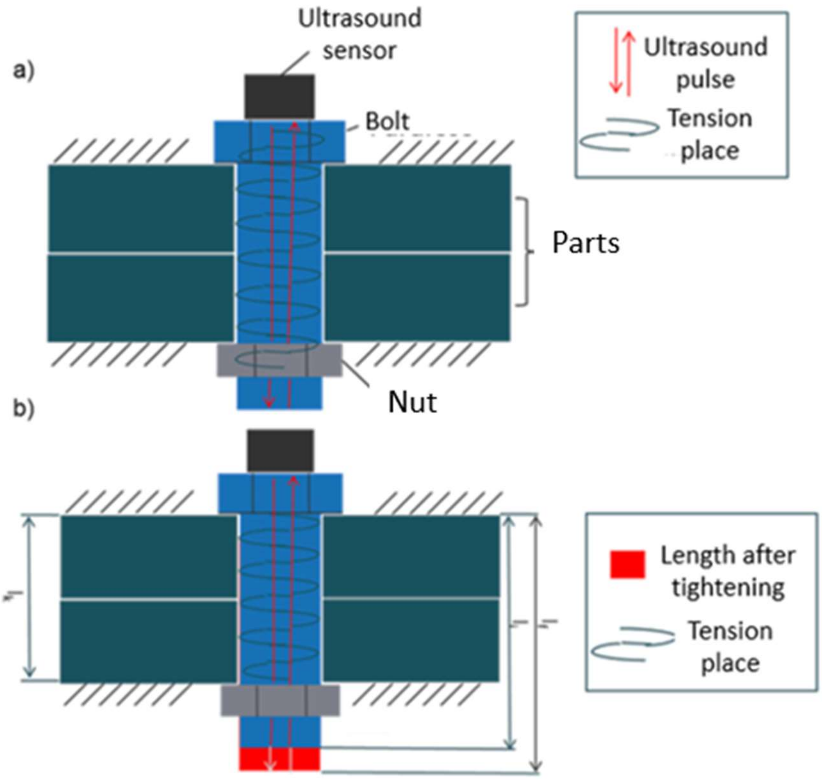

Figure 1. Schematic representation of the region on voltage and measurement using ultrasound.

Knowing the actual elongation of the bolt, it is possible to better control the tightening force required by the design irrespective of the friction between the parts, whose also vary due to of the complexity of the phenomena inherent in the mechanisms and surfaces that cause friction. In this sense, the work proposed to investigate the use of pulse-echo ultrasound technique to be used as a criterion for controlling the force after the tightening of bolted joints.

Thus, there is a direct relationship among the material's elastic constants, the propagation velocity of the longitudinal and the material's transverse waves. Considering the dependence relation among “Lamé modulus”, "shear" and "Poisson's ratio" constants.

The present study might be accompanied by remote monitoring for prevention of disasters in bolted joint face off different engineer areas.

Considering the commodity of pipeline fixed by bolts, this monitoring is useful for leakage prevention and assembly assurance by the loosening force on bolt, but the personal monitoring can also be used:

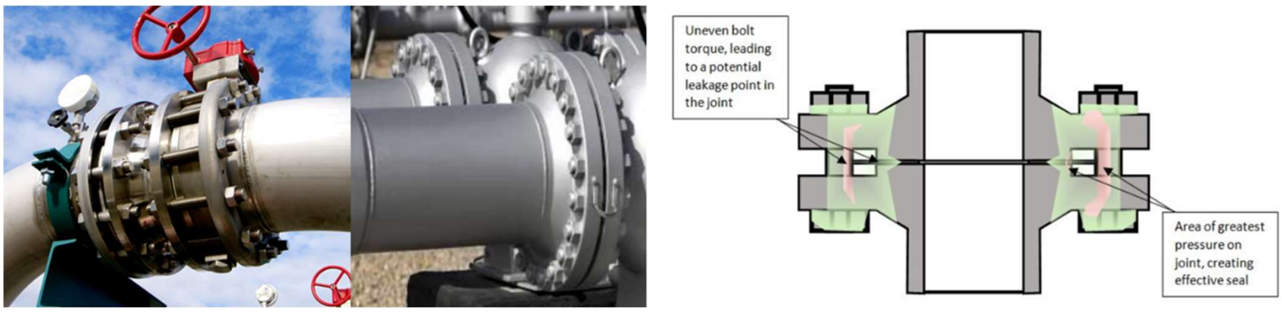

Figure 2: Pipeline structures with bolted joint and explanation of leakage.

2. YOUNG´S MODULUS AND POISSON COEFFICIENT´S

The modulus of elasticity is the ratio of the deformation in the direction of the load to be applied, in the elastic region, and this is the maximum tension that supports the material without suffering permanent deformation. This relationship was defined as Young's modulus (E).

The transversal deformation that occurs in the material subjected to longitudinal load is measured by the Poisson's coefficient (ν). This coefficient is related to the Young's modulus and calculated in relation to the orthogonal direction of the deformation, and when the material is compressing the direction, orthogonal there is expansion, but when the material is stretched the orthogonal sense is contraction.

The formula of the Young modulus is (Adamowski,2004):

$$E = \frac{\sigma}{\varepsilon} \quad (1)$$

The coefficient of deformation (ε) is expressed by the final length ratio (lf) minus the initial length (li) of the part divided by the initial length (Tavares,2017):

$$\varepsilon = \frac{l_f - l_i}{li} \quad (2)$$

Thus, the stress (σ) is the force (F) exerted on the part area (A) (Fonseca,2005):

$$\sigma = \frac{F}{A} \quad (3)$$

And finally, the Young (E) module can be written as (Tavares,2017):

$$E = \frac{F.l_i}{A.(l_f - l_i)} \quad (4)$$

Considering the calculation method of the pulse-echo velocity of the ultrasound, the constant velocity of the medium and the final propagation time greater than initial propagation time of the body subject to normal traction, as well as the force variable (F) as a function of modulus of elasticity in normal loading and the difference of the variable initial time (ti) and final time (tf), it can be seen as:

$$F = \frac{E.A.(t_f - t_i)}{t_i} \quad (5)$$

For steels, the modulus of constant elasticity E = 207 GPa, and the Poisson coefficient ν = 0.30 (REEDY JR., 1997).

3. EXPERIMENTAL PROCEDURE

The experiment below was based on a device with electronic torque wrench, torque transducer, load cell and ultrasound pulse echo system evaluating the "time of flight" (TOF) (Kinsler,1999) method measured in μs with mono element ultrasound transducer.

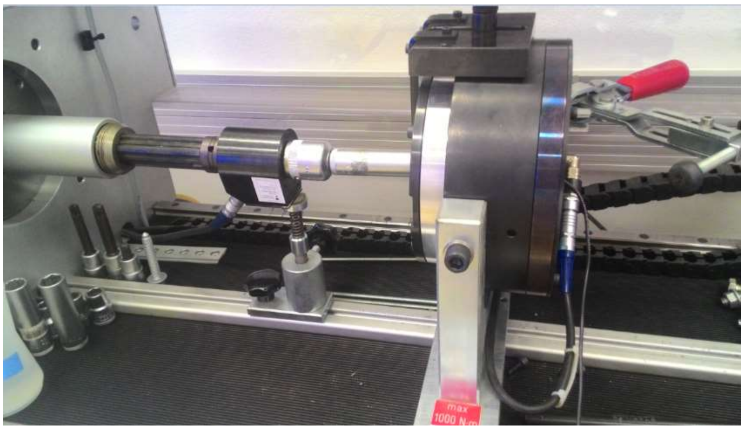

Figure 3: Screw positioning with ultrasonic transducer with nut and socket for test (ISO16047, 2005).

In the line graph below, the tightness until the test screw is run can be checked to assure the test in the elastic area refine of the tightening (Nm), and thus, both can verify the region of load (kN) for the test.

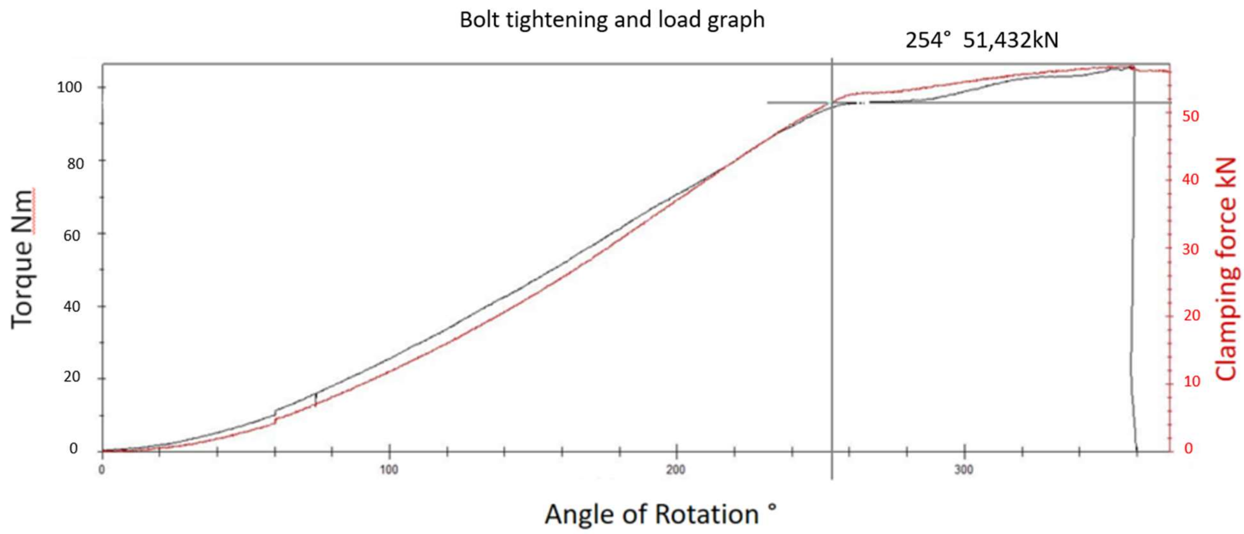

Figure 4: Test drive torque x load of yeld point of the screw.

Using an electronic torquemeter, the incremental clamping was performed 1 in 1 kN and the ultrasound propagation time threshold was measured up to 40 kN.

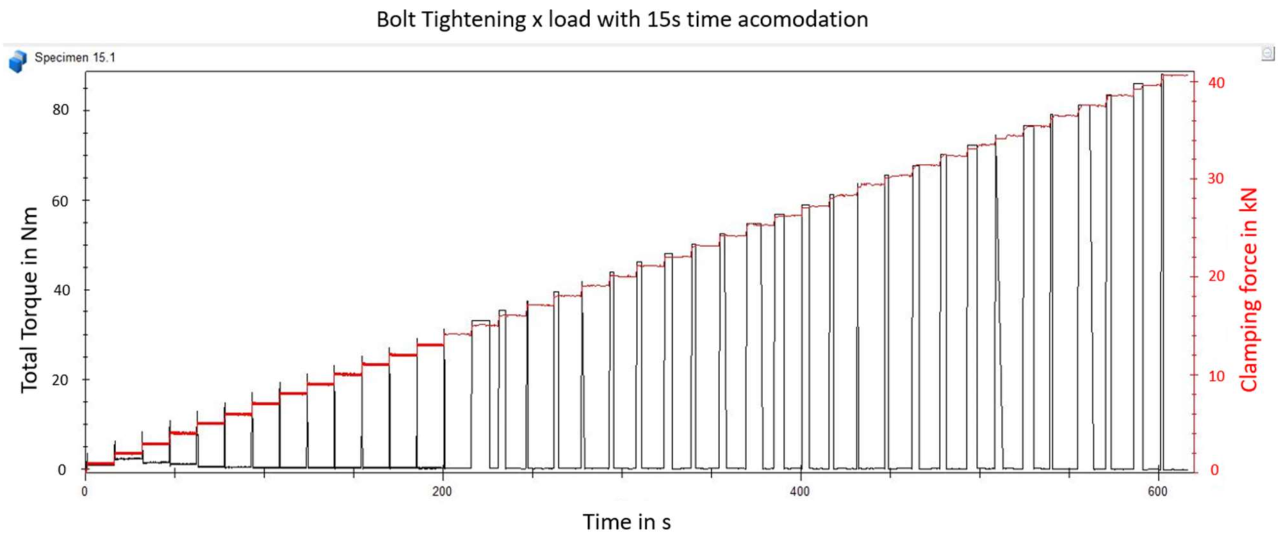

Figure 5: Measurement from 1 in 1 kN to 40 kN.

Correlating the time difference of the screw without loading and with the loads applied, the following linear regression is resulted:

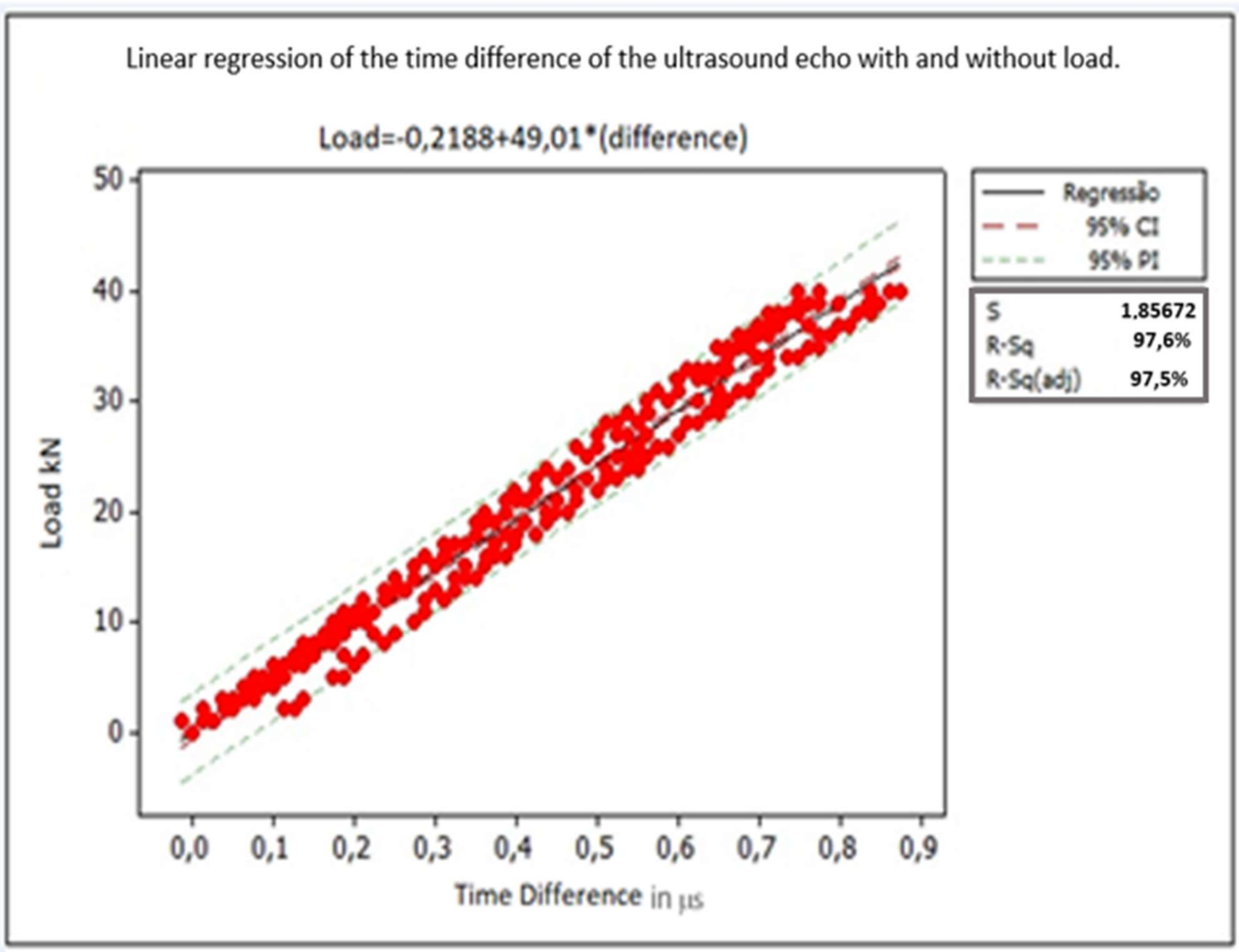

Figure 6: Regression line of the difference between the initial and final ultrasound time in μs and the respective applied load

According to this measurement a standard error of approximately 2kN for the load can might be considered, according to the expression of the line, time difference of the amplitude 3, and the applied load, it can be obtained a quadratic residue of 98%.

4. CONCLUSIONS

This study showed that there is a linear relationship between the screw propagation time and the clamping force, by the study presented is around 97% accuracy compared to a known load cell measuring equipment, this technique can be applied in conjunction with manual, electronic and pneumatic clamping tools to meet the desired torque force regardless of the frictions of the bolted joint.

With this technique it is also possible to check the loss of tension of the tensioned fastener element in the elastic region.

The technique used to determine the arrival of the echo was based on a threshold of the amplitude of the echo signal. The use of time in multiple echoes, in this case, the third echo, improved the signal-to-noise ratio in obtaining the time of propagation of waves inside the screw.

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