Clamp Force based Control for the Tightening Processes of Threaded Fasteners

Clamp Force Estimation with Ultrasonic Measurement

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Abstract

Clamp force-based tightening control has been of interest for a long time in both industry and research. No significant breakthroughs have been made in this area when it comes to the control of dynamic processes. Advances in sensors and signal processing, as well as the development in model-based control enable new approaches for clamp force-based control for tightening processes. Ultrasonic sensors are at a sufficient technology readiness level to enable real-time clamp force estimation which can be used in the control of tightening tools. The goal of the project is to develop new tightening strategies with improved precision with the help of ultrasound signals.

Introduction

The objective of a threaded fastener joint is to keep the joint together when a external force is applied to it. This is done via the clamp force, which is generated during the tightening of the fastener (see Figure 1). In the most common tightening strategies used today torque, torque plus angle, and material yielding are used to estimate clamp force.

Usually, the reference values are determined through look-up tables from various industry norms or by doing a joint analysis. The tightening result is subjected to a large scatter due to variations in friction, speed dependency, mechanical influences, and other disturbances.

From these shortcomings and the attempts to achieve a better process control originates the idea to develop tightening strategies that are directly based on clamp force or which use more accurate clamp force estimators.

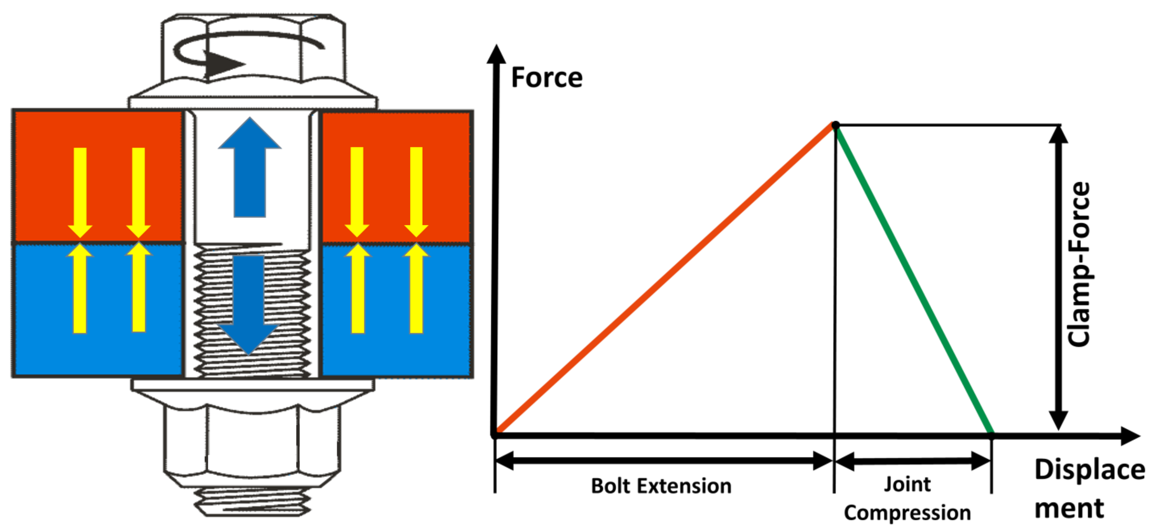

Figure 1. Forces and displacements in a typical bolted joint [from internal presentation] / [from boltscience.com]

State of the Art Tightening Strategies

State of the art in the tightening industry is typically PI-control with speed references. These strategies are parametrized through parameter sets (P-sets). The most common tightening strategies are:

a) **Torque tightening** runs with a defined speed until the shut-off torque is reached. (Figure 2.)

b) **Torque plus angle tightening** works with a defined angle as shut-off parameter. (Figure 3.)

c) **Yield tightening** works with a change in the torque rate as shut off parameter.

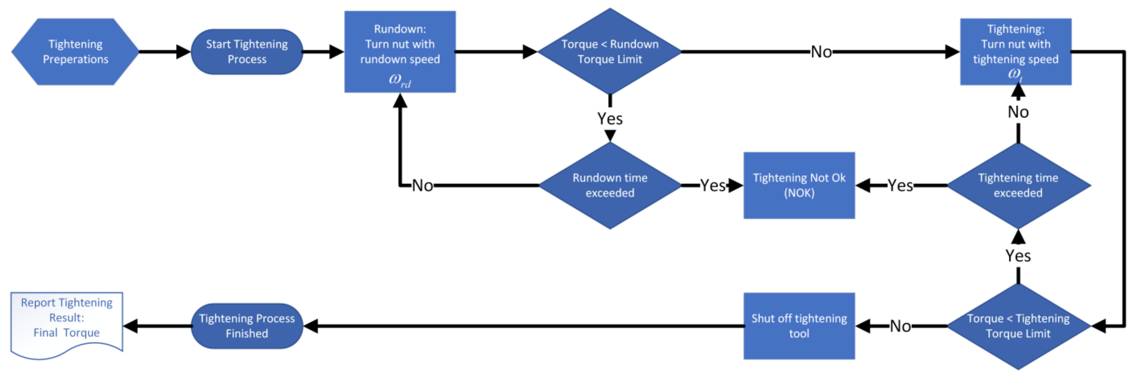

Figure 2. Conventional tightening process with torque as a control parameter

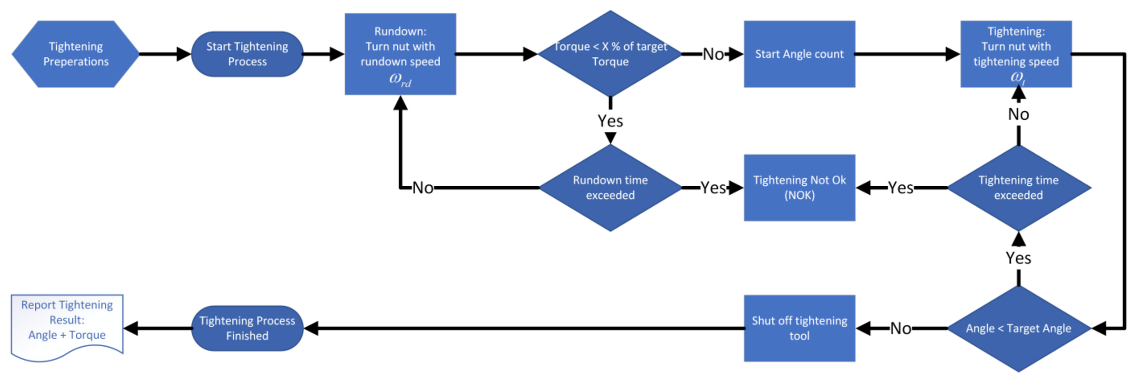

Figure 3. Conventional tightening process with torque and angle as a control parameter

Problem Formulation

The achieved clamp force in a tightening process is subject to scatter to a large extent. Therefore, many threaded fastener joints are over-dimensioned and the actual clamp force in a joint is seldom known.

Hence there is a need for more accurate clamp force control in tightening processes.

A target is to develop tightening strategies that use better models for clamp force estimation or measure clamp force directly.

Clamp Force based Tightening Strategies

The goal of the project is to develop tightening strategies that can use ultrasound waves to measure the elongation of threaded fasteners under load, which is directly related to clamp force. In the elastic region, where Hooke's Law can be applied, the elongation can be used as a performance measure. An example of such a strategy can be seen in Figure 4.

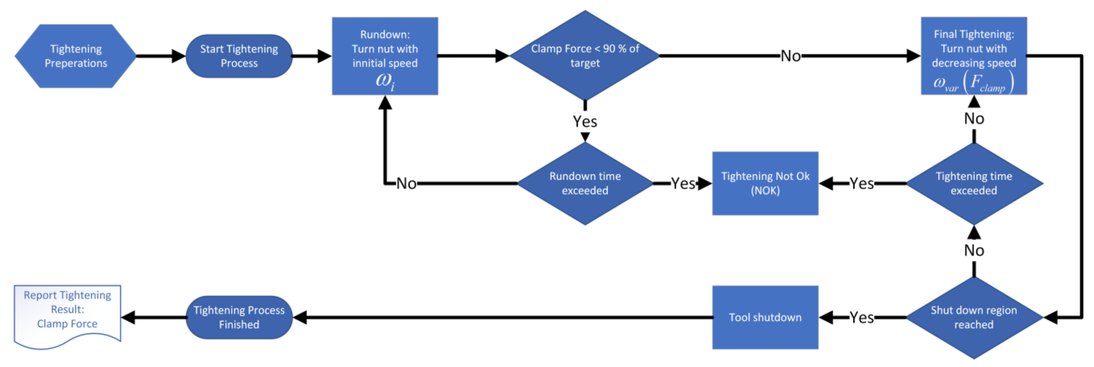

Figure 4. Novel tightening strategy with clamp force as a control parameter

Challenges

It is necessary to further develop methods for clamp force measurements or estimation to use them in tightening tools. The tightening strategies have to be simulated, evaluated and system parameters have to be identified. For doing that, models of the tool and joint are needed, and methods for parameter identification or system identification can be used.

Modeling

The driveline of a tightening tool with the typical components: electrical motor, gearbox, and transmission is similar to the driveline of electric vehicles and can be modeled in a similarly.

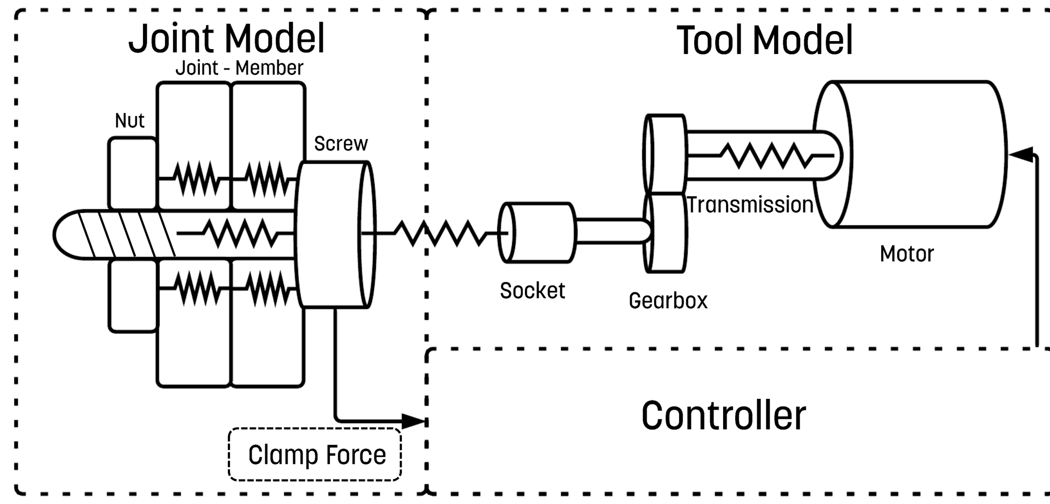

Figure 5. Schematic model of a tool-joint control system

Clamp Force Measurement

It is possible to measure the clamp force through the change in time of flight (TOF) for ultrasound waves in the bolt. This can be utilized in tightening tools in order to use clamp force as control parameter.

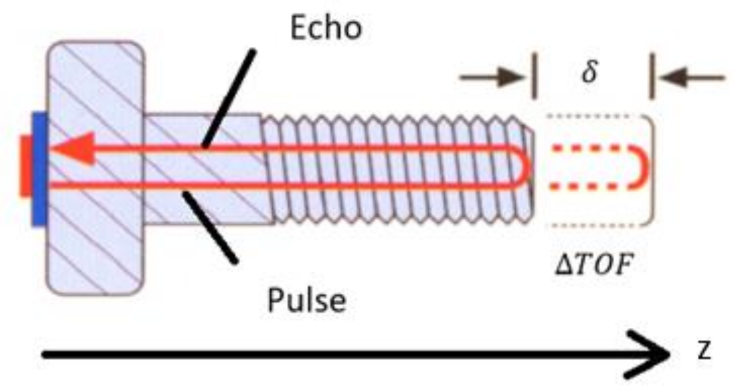

Figure 6. The concept for detection in change in time of flight in stressed bolts [from master thesis]

Publications

[1] G. Hartmann, "Potentials and limitations of ultrasonic clamp load testing," *SAE International, Technical Paper 0148-7191, 2007.*

[2] E. Persson and A. Roloff, "Ultrasonic tightening control of a screw joint: A comparison of the clamp force accuracy from different tightening methods," *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, vol. 230, no. 15, pp. 2595-2602, 2016.*

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