Modeling a Bolted Joint for Dynamic Tightening Simulation and Control

Friction Modeling and Clamp Force Estimation

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Summary

A model for threaded fastener tightening was developed to create an environment to study dynamic tightenings. That model includes components representing friction torques and non-linear displacement-stress relationships.
The behavior for the friction torque model is presented in detail.

A contribution to the long-term goal of clamp force-controlled tightening was made in a Thesis work on clamp force estimation with Kalman Filters. The shown accuracy is above 95%

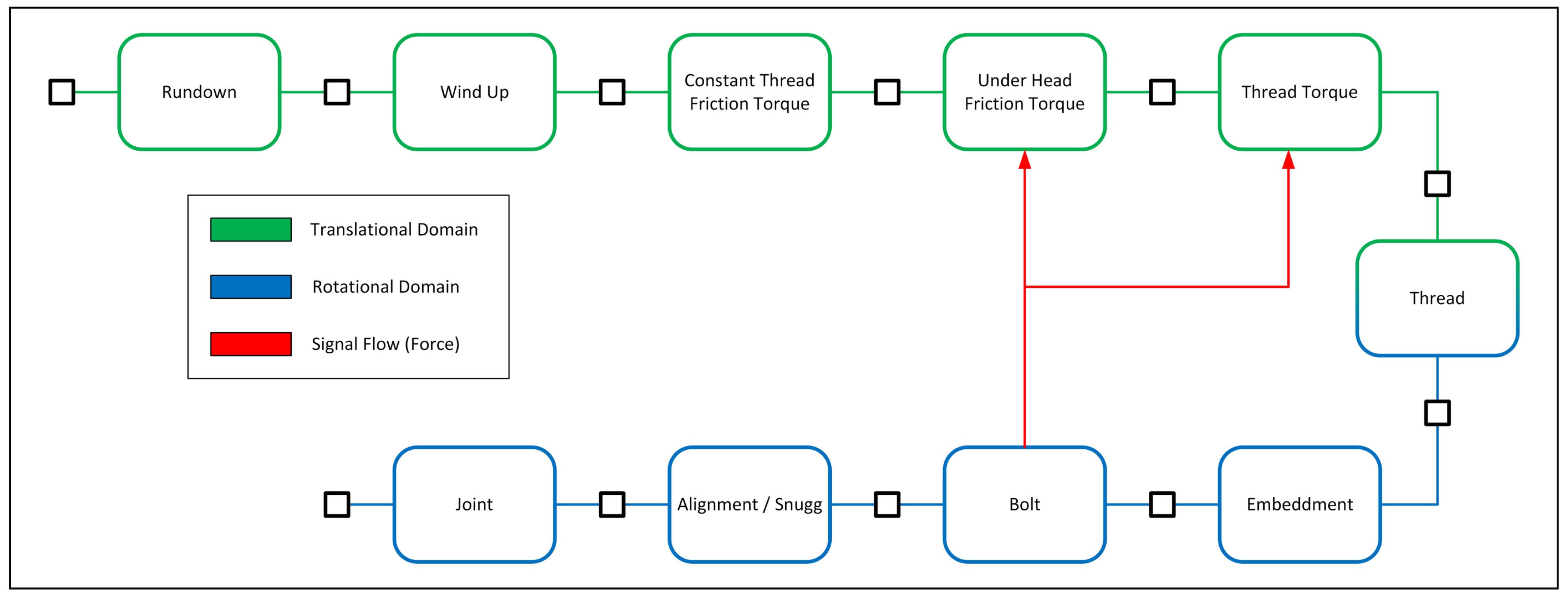

Figure 1. Schematic representation of the simulation model for a bolted joint. Model subcomponents and signal flow.

Figure 3. Typical tightening tool from Atlas Copco, for which more advanced tightening control strategies are desirable. Here a n EVT Tensor SB Tool.

Model for Friction in Threaded Fastener Joints

A model that can be used for the friction components (Under Head Friction and Thread Friction) has been developed to model the friction losses with varying normal force (clamp force in the case of a bolted joint) and angular velocity dependent friction coefficients.

$$J\dot{\omega} = \tau_{in}(t) - \tau_{out} - \tau_{frict}(\omega, t)$$

$$\mu(\dot{\omega}) = \tanh(c_0\omega)\left(c_1 + c_2|(\omega)| + c_3 e^{(-c_4|\omega|)}\right)$$

$$\tau_{frict} = C_F(t)\mu(\omega)r$$

Inputs : ω, τ_{in}, C_F Outputs : τ_{out} Losses : τ_{frict}

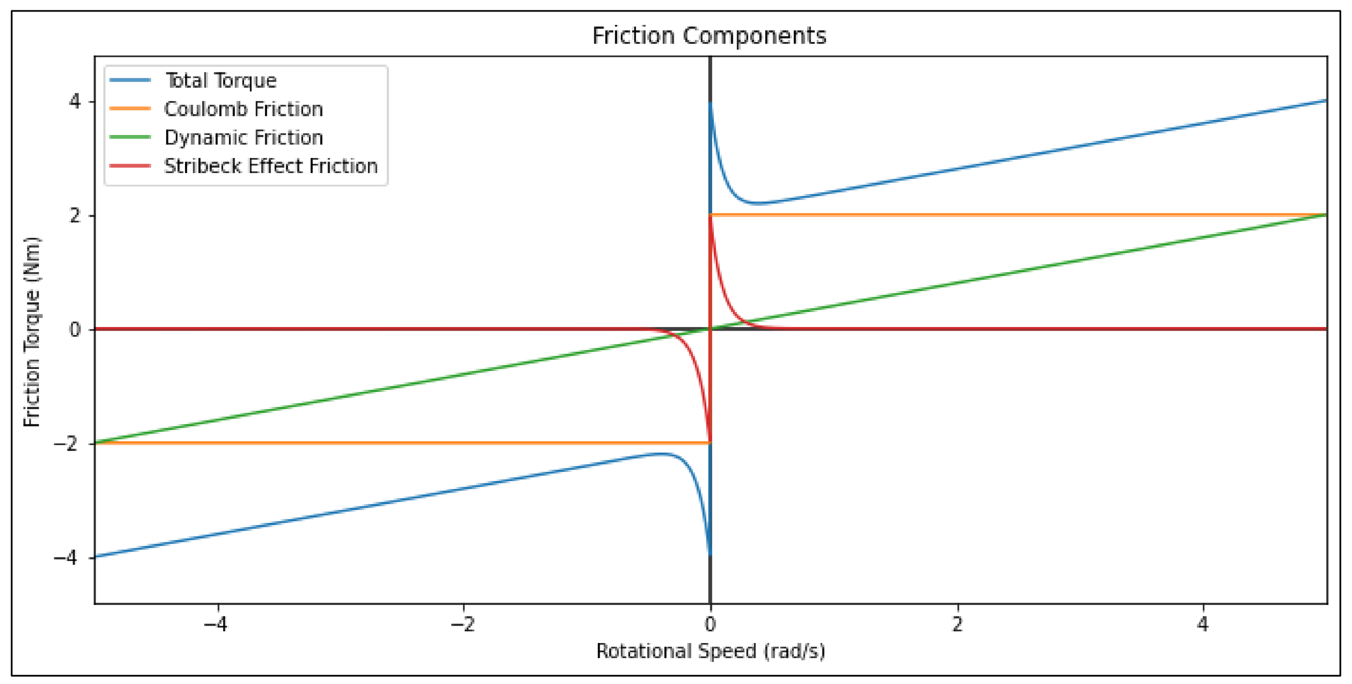

Figure 2. Friction torque according to the friction model. Torque components divided in the share of coulomb friction, dynamic friction and Stribeck friction.

Use Cases for Joint Model and Friction Studies

The joint model is expected to give a better understanding of the tightening dynamics and thus open possibilities for advanced tightening strategies, such as model based control, optimal tightening or simulation-based parametrization of tightening programs, known as P-sets.

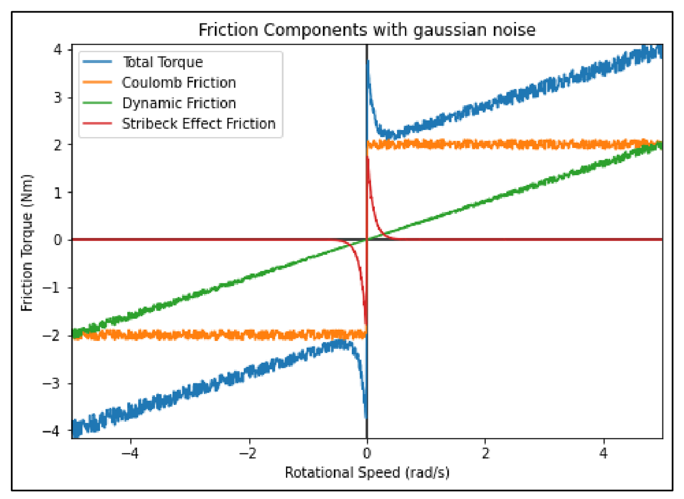

Figure 4. Friction torque components under the assumption that the base friction is subject to gaussian noise.

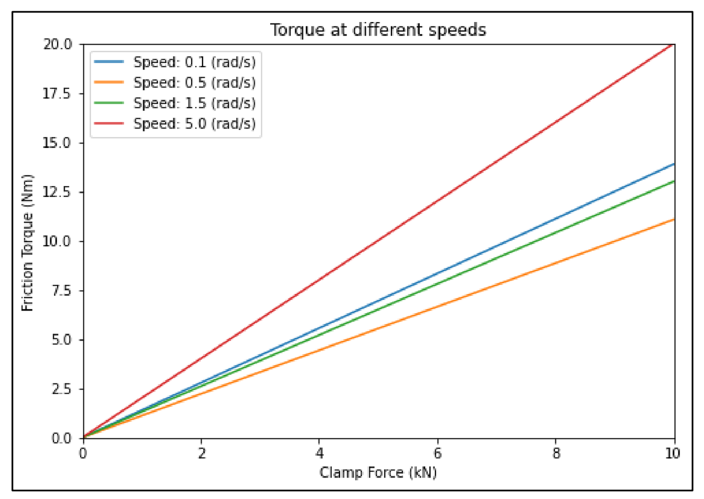

Figure 5. The influence of different angular velocities on the friction torque at changing normal forces

Friction is assumed to constantly change during a tightening. A potential solution for that is additive gaussian noise on the included components. That gives results that are very similar to known friction curves for tightening systems.

The phenomena of stick-slip is a well-known problem when tightening threaded fasteners. That phenomena could also be observed with the given tightening model, even though the model was not specifically designed for that purpose. Further investigations on that topic can contribute to improved control strategies when stick-slip occurs.

Kalman Filter to Estimate Clamp Force

In a Master Thesis the Extended Kalman Filter (EKF) and Unscented Kalman Filter (UKF) for Clamp Force estimation has been evaluated. The result was very promising and showed a deviation of less than 5% at shut off.

More studies will be done for more general cases and on how these algorithms work for online estimation.

Discretized State Space

$$\begin{bmatrix} \omega_{k+1} \\ \theta(k+1) \\ \omega(k+1) \\ \mu_{tot}(k+1) \end{bmatrix} = \begin{bmatrix} \frac{1}{J_{tot}}\left[T - F_c\left(\frac{P}{2\pi} + \mu_{tot}\left(\frac{d_2}{2\cos\alpha} + \frac{D_{km}}{2}\right)\right)\right](1+\epsilon_1)\omega(k)T_s + \theta(k) \\ 0 + \epsilon_2 \\ K\omega t_s(1+\epsilon_3) \end{bmatrix}$$

Observation : $z_k = \omega_k + \delta_k$

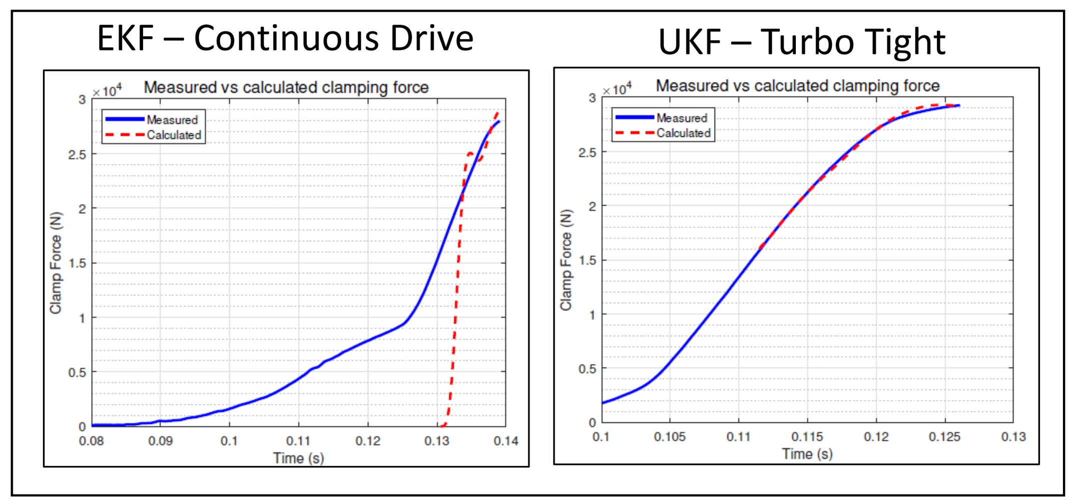

Figure 6. Clamp force estimation with Extended Kalman Filter (EKF) and Unscented Kalman Filter (UKF) for continuous drive and highly dynamic tightenings

Related Publications

[1] Persson, E.V., Kumar, M., Friberg, C., and Dressler, N., "Clamp Force Accuracy in Threaded Fastener Joints Using Different Torque Control Tightening Strategies," SAE Technical Paper 2021-01-5073, 2021, doi:10.4271/2021-01-5073.

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