# Reduction of friction torque in a revolute joint by superposed vibrations

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In this study, the effect of the superposition of oscillations on the friction characteristic in a revolute joint is investigated. The bolt is modelled as a multibody-oscillator with multiple friction contacts, where two bodies are excited, while one mass lies on a transversally moving surface. The dynamical behavior is analyzed numerically and the results depict a massive reduction of the friction force at the natural frequencies of the underlying linear system.

**Keywords:** friction reduction, revolute joint, transversal vibration, superposition of oscillations

## 1. Introduction

In special cases, a lubrication of a revolute joint is not possible due to constraints of the construction. Nevertheless, the joint should be low-friction and satisfy high demands concerning precision. This combination can lead to undesired break-away effects and therefore to bad performance and controllability, which is a common problem in systems with dry friction. One attempt to suppress this behavior is the superposition of oscillations. In detail, a bolt is excited to longitudinal vibrations, which is to reduce the effective friction force in circumferencal direction at a bushing sitting in the middle of the bolt. This study aims to investigate the influence of longitudinally excited oscillations on the friction force in contact with prescribed transversal motion.

## 2. Methods

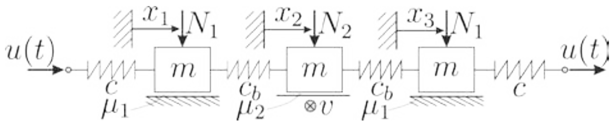


Figure 1: Mechanical model of the system

The bolt is modelled as a three-mass-oscillator with a friction contact at each mass, cf. Figure 1. The excitation is realized by piezo elements, which are equal to an external spring-force excitation with given displacements $u(t)$. The friction force is modelled as Coulomb friction with constant coefficient $\mu$. For the base of mass 2, a transversal motion $v = const.$ is prescribed, displaying the relative motion due to the rotation of the joint.

2.1. Basic equation

Utilizing the symmetry of the system, the equation of motion can be simplified to

$$\vec{x}_r'' + \begin{pmatrix} 1+\gamma & -1 \\ -2 & 2 \end{pmatrix}\vec{x}_r + \begin{pmatrix} r_1 \operatorname{sgn} x_1' \\ r_x \end{pmatrix} = \gamma \begin{pmatrix} u(\tau) \\ 0 \end{pmatrix}. \quad (1)$$

The parameter $\gamma$ gives the ratio of $c/c_b$ and $r_i = N_i \mu_i / c_b$. The force $r_x$ is the component of the friction force in $x$-direction $r_x = r_2 x_2' / \left({x_2'}^2 + v^2\right)^{\frac{1}{2}}$. The dimensionless time $\tau = \omega_0 t$ is referenced on $\omega_0^2 = c_b/m$. The excitation is given by $u(\tau) = \hat{u}\cos(\Omega\tau)$. The magnitude of interest is the $y$-component of the friction force

$$r_y = r_2 v / \left({x_2'}^2 + v^2\right)^{\frac{1}{2}}. \quad (2)$$

2.2. Numerical Scheme

A Runge-Kutta-method of order 4 with error estimator order 5 is used to solve the equation for various excitation frequencies $\Omega$ using homogenous initial conditions. To divide between sliding and sticking, event functions are implemented.

2.3. Results

Figure 1 shows the mean friction force $\bar{r}_y$ during one period of the excitation for a given parameter set. The graph depicts two distinct minima at the natural frequencies of the underlying linear system at $\Omega_1 = 0.56$ and $\Omega_3 = 1.79$. The second natural frequency $\Omega_2 = 1.22$ is not observable, as this mode is not excited due to an anti-resonance. For low and high excitation frequencies, there is no reduction in the friction force.

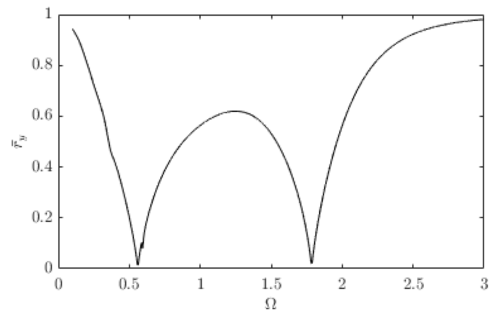


Figure 1: Mean friction force for $v = 1$, $\hat{u} = 6$, $\gamma = 0.5$, $r_1 = r_2 = 1$.

## 3. Discussion

In the presented model, a significant reduction of about 98% of the friction force is observed. From Eq.(2) one can see that the velocity $x_2'$ of mass 2 influences the friction force of interest. At the natural frequencies of the linear system the amplitudes of the displacement and the velocity are maximal. This explains the minima of the mean friction force at these points.

However, experimental results [1] show that the reduction is much smaller, which implies that this model overestimates the effect. This leaves the necessity to improve the model under investigation.

## 4. References

[1] Kapelke, S., "Zur Beeinflussung reibungsbehafteter Systeme mithilfe überlagerter Schwingungen", KIT Scientific Publishing, 2019, Karlsruhe.