Simulation of friction-induced vibrations using elastic multibody models

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Abstract

Simulation of friction-induced vibrations still represents a challenging topic for engineers. These oscillations are present in many day-to-day applications and they can yield, among others, uncomfortable sound emission or unpredictable mechanical excitations. Examples of such phenomena are found on the squealing of brakes, the chattering of a cylinder being manufactured on a spindle or the scraping of chalk on a blackboard. Since the 1960s, the problem of disc brake squeal, see Figure 1, has arisen as particularly challenging for the automotive industry [1].

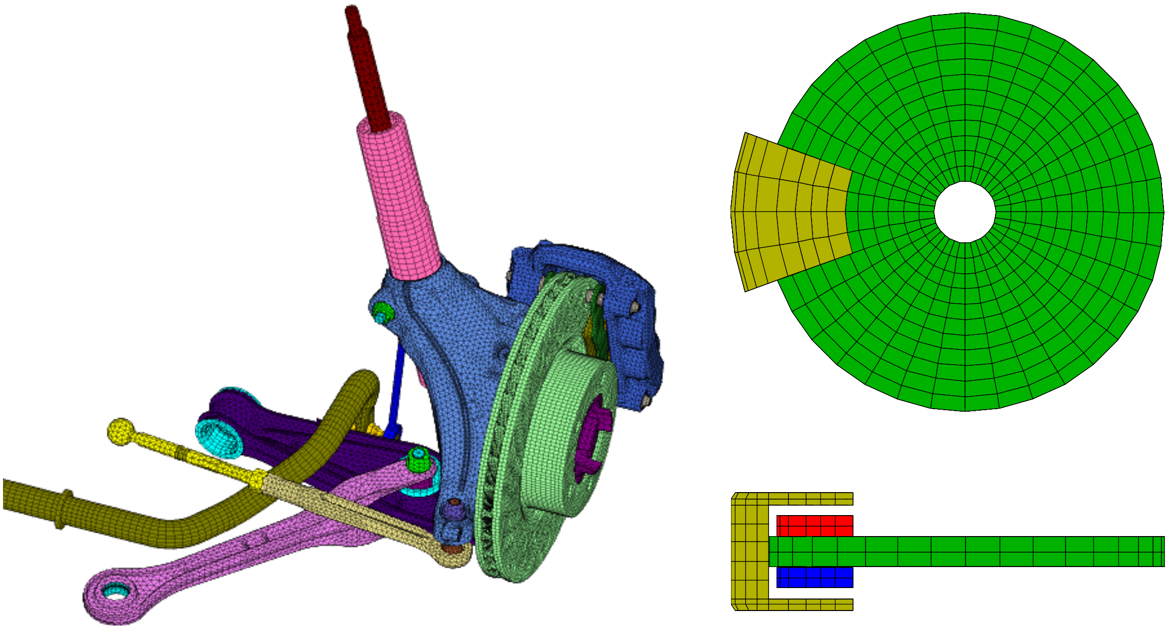

Figure 1: Examples of brake systems.

In order to detect the instabilities, commonly investigations in the frequency domain are performed. A very well-known procedure is the method of complex eigenvalue analysis [2]. This method is based on the linearization of the nonlinear equations of motion around a working point, which is afterwards classified as stable or unstable depending on the real part of the provided complex eigenvalues. However, the method tends to overestimate the number of unstable frequencies found in experimental investigations and does not predict the displacements since the delivered complex eigenmodes are normalized.

In scope of calculating the magnitude of these deformations, time domain investigations are a necessary but expensive solution. On a first attempt, integrating large finite-element (FE) models over time is neither promising nor affordable because of long calculation times [2]. At this point, using elastic multibody systems (EMBS) based on the floating frame of reference approach [3] is advantageous because large nonlinearities resulting from rotation and contact can be efficiently coupled with small linear deformations. Moreover, this approach fits well to the usual process chain in mechanical design and benefits from the widespread and detailed FE modeling of components.

Contact modeling between interacting bodies plays a decisive role, too. A master-slave approach with a penalty-factor formulation is applied by coupling the contact module proposed in [4] with the EMBS program Neweul-M^2. As a result, penetration of slave nodes into master faces and corresponding normal contact forces are calculated. Furthermore, the interface is extended to include slave and master nodal velocities, tangential directions and different friction laws which permit adding tangential contact forces to the system. In between, a rough detection algorithm manages an efficient handling of slave and master nodes and triggers signals that interrupt time integration. In this way, contact pairs or even multibody systems itself are updated and new time investigations with new contact situations are restarted.

Due to this last issue, contact also plays a major role in the creation of elastic bodies. When system switching is performed, new elastic coordinates are added which are related to the set of modes used to project the system matrices into the modal space. Concerning its application, the multibody preprocessing tool MatMorembs allows the combination of constraint modes at the contact interface with modal or more advanced reduction methods.

In this paper, an illustrative example of a brake system composed by disc, lower and upper pads and caliper is investigated, see Figure 1. By means of elastic multibody dynamics and the presented contact modeling, computationally efficient time integrations are performed and the amplitudes of the oscillations for a number of operational parameters are predicted. In the resulting phase diagrams, the creation of a stable limit cycle for a low friction coefficient is identified, see Figure 2. This way, conclusions on the stability of the system are drawn and a new criterion for quantifying the squeal propensity of a system affected by friction-induced vibrations is proposed.

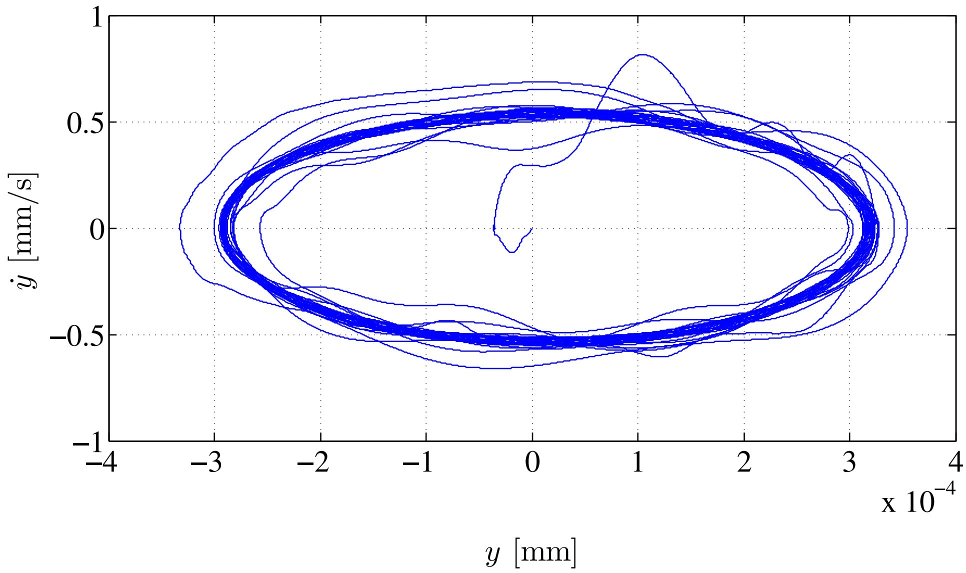

Figure 2: Caliper motion, stable limit cycle for friction coefficient $\mu = 0.1$.

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