GEAR DRIVE SIMULATIONS WITH FRICTION AND HIGHER ORDER ANSATZ FUNCTIONS USING ELASTIC MULTIBODY MODELS

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High quality gear drives play a crucial role in many devices such as in combustion engines of cars, see Fig. 1, ships, as well as in wind turbines. In order to analyse and predict performance and durability of these devices, accurate predictions of contact forces are necessary. Similarly, the ability to evaluate transmission errors and accelerations is a prerequisite for a broad range of applications like noise predictions. To that end, deformations, stresses, and forces can be analysed using numerical simulations. Such simulations usually rely on linear finite elements analyses (FEA). This approach, however, is computationally very expensive. The resulting long simulation times for multiple gear rotations, present a major disadvantage of this approach.

Instead, rigid body descriptions using multibody simulations (MBS) can be used. Yet, this approach can be inaccurate for forces and accelerations and contact forces estimated using MBS have to rely on a heuristic force-displacement law [1]. Even when this law is appropriate, elastic effects, such as a gear's tooth-bending as shown in Fig. 2, are not taken into account. This typically leads to an overly stiff system with highly over-estimated contact forces and accelerations. Being able to represent elastic effects, elastic multibody systems (EMBS) offer a good compromise between FEA and rigid MBS descriptions.

A further issue for both EMBS and FEA is mesh generation. Generating a usable hexahedron mesh for industrial applications often requires many hours of work. In contrast, tetrahedron ("tet") meshes can be created automatically and reliably using fast algorithms. A significant drawback of linear tetrahedron meshes is their overly stiff and hence inferior performance due to shear locking. This issue can be overcome by using tetrahedron finite elements with quadratic ansatz functions. The resulting description is locking-free and mesh generation can be reliably automated.

As a remedy to: i) the long simulation times of FEA ii) the inaccuracy inherent whilst using rigid MBS descriptions iii) the issue of automatic meshing, we propose using an EMBS description with quadratic tetrahedron meshes. Consequently, this work investigates the contact description in normal and tangential direction in gear drives with elastic multibody models and higher-order ansatz functions.

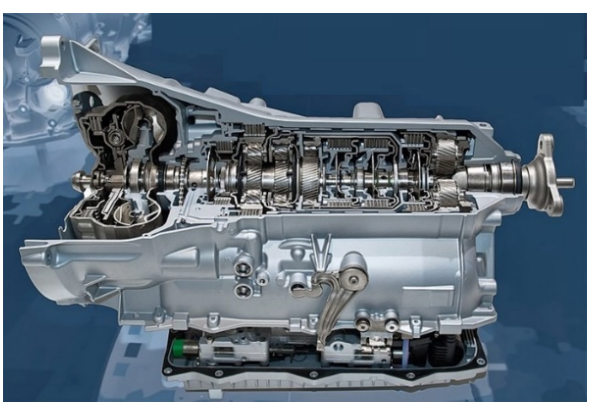

Fig. 1: Gear drives in an automatic transmission (C) Stefan Krause, Free Art License

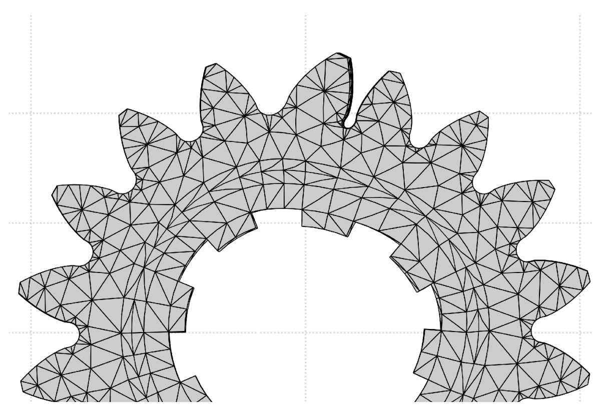

Fig. 2: Gearing simulation. A visualization of the magnified deformation upon contact is shown with visible tooth bending.

Computations are performed with the in-house program Gear Train Module (GTM), which provides a tool-chain for EMBS simulations of gear trains using a floating frame of reference approach and elastic gear models that are reduced with combinations of modal shape functions and so-called static mode shapes, see [2, 3]. A newly implemented contact routine provides contact normal forces for transient simulations with ten-node tetrahedron elements. Furthermore, stress recovery and visualization for quadratic elements is performed. First, contact candidate nodes are located using pairs of flank nodes. Then, their precise location in local element coordinates is found iteratively. From this, a penalty force is computed with an integration point to surface contact. In this step it is important to take the tooth bending flexibility into account, otherwise the contact force is over-estimated see Fig. 3. The resulting force is then projected onto the elastic mode shapes and used in time integration. Next, stress can be recovered in two main steps. In a pre-processing step, so-called stress modes, which define stress components for each node and mode according to the bodys model order reduction, are assembled. The final stress is then calculated in a post-processing step by superposition of the stress modes according to the elastic coordinates values.

The described approach enables accurate simulations with dynamic loads for multiple gear rotations. Obtained contact pressure distributions may then be used for exmaple in load capacity analyses [4].

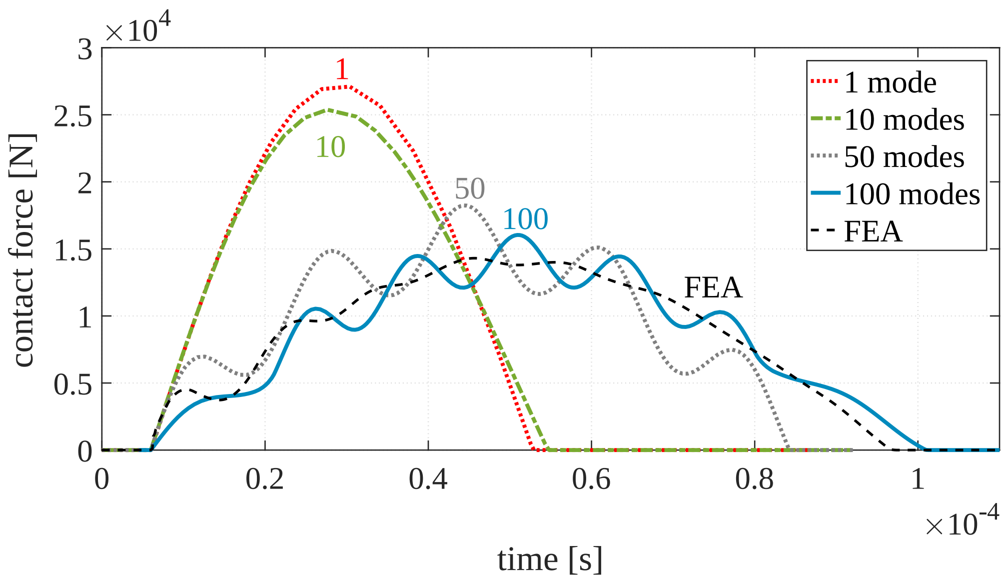

Fig. 3: Calculated normal force for different sizes of modal truncation.

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