Received: 15 June 2021 | Accepted: 23 September 2021

DOI: 10.1002/pamm.202100064

Consideration of rubber bushings in a multi-body simulation by detailed finite element models

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Within a multi-body simulation (MBS) a three-dimensional FE model is employed to represent the nonlinear properties of rubber bushings. This is implemented via a sequential force-displacement coupling between the two solvers. For a first material modelling approach of the elastomer, the modified Neo Hooke model is used in conjunction with the generalized Maxwell model. Later, however, a physically motivated material model will be used. First results for a single-mass oscillator are presented and show the general functionality of the coupled approach. Since the use of FE models in MBS causes a significantly higher computational effort, it is necessary to realize the coupling between FEM and MBS as efficient as possible, which is also a future task.

1 Introduction

Vibration isolators for passive vibration reduction, made of elastomer materials (so called rubber bushings), are used in a wide range of technical systems in different designs. Their application mainly ensures the fulfilment of both objective (e.g. service life) and subjective (e.g. comfort) quality characteristics. When developing such systems, the multi-body simulation is utilized to determine the system behavior in an early phase of the product development process. In addition to the mass properties, the behavior of the overall system is essentially specified by the stiffness and damping properties of the individual components and their mutual interactions. Thus, when simulating multi-body systems, it is highly relevant to consider the characteristics of the bushings in detail in order to achieve a reliable model prediction, e.g. with regard to resonance frequencies or vibration amplitudes. However, elastomer-based vibration dampers cannot be described via simple constitutive laws due to their strongly non-linear material properties. This is why one-dimensional rheological models representing arbitrary number of components are often used, in order to model the non-linear material behavior determined in unidirectional experiments. However, most rubber bushings show significant stiffness changes under multi-axial loading [2, 3], which cannot be reproduced by using one-dimensional rheological models. One approach to overcome this is the use of more complex material models, which are implemented numerically by means of the FEM and can reproduce the material behavior under multi-axial load. Furthermore, the FEM allows to reduce the parameterization effort by transferring the model parameters to further geometries and load amplitudes. To this end, this contribution outlines an approach that will be expanded in the future in order to exploit the potentials mentioned.

2 Simulation model

2.1 Solver coupling

The solver coupling between the MBS-model and the FE-model is established by a force-displacement coupling. For this purpose, the kinematic quantities of defined markers (see Fig. 1) are calculated in each time step and applied to a node set of the FE model. The bushing is fixed at the lower end, so that reaction forces and moments can be calculated on the basis of a constitutive law with the applied kinematic quantities.

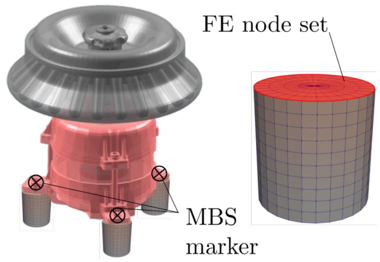

Fig. 1: Full simulation model of a centrifuge with three rubber bushings

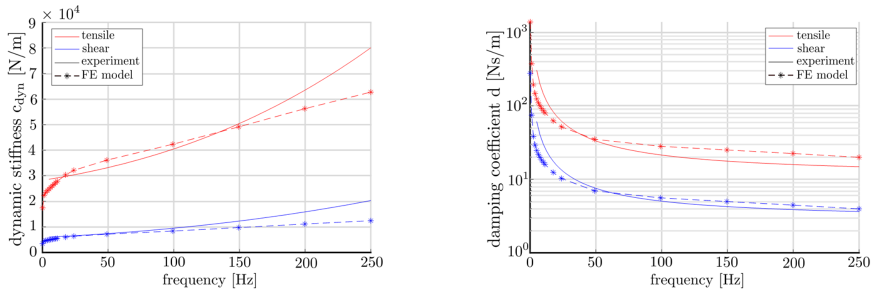

Fig. 2: Comparison between simulation and experiment for the frequency dependent properties (left: dynamic stiffness, right: damping coefficient)

Neglecting the inertia properties of the rubber bushings, the FE analysis is performed transiently using the simple Euler backward method. Subsequently, the resulting reaction forces are added to the vector of the right-hand side to continue the

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time integration of the multi-body model. This sequential process is repeated in each time step, if necessary with several corrector steps, so that one can speak of a fully implicit solver coupling [1].

2.2 Constitutive modeling

To demonstrate the general feasibility, a classical phenomenological approach to material modeling is used. The hyperelastic material properties of the rubber bushings are represented via the classical Neo-Hooke model with a volumetric/deviatoric split, so that the strain energy can be decomposed into a volumetric and an isochoric part. The viscoelastic or frequency-dependent properties of the bushings are mapped via the generalized Maxwell model considering a prony series with the weighting factors and the relaxation parameters. Quasi-static tensile tests as well as dynamic tensile and shear tests were performed to find suitable material parameters. For this purpose, the dynamic stiffness and the damping coefficient were measured for individual frequencies and the material parameters were adjusted to the experimental data via an optimization algorithm. The results are shown in Fig. 2. It can be clearly seen that with the five Maxwell elements chosen, a trade-off between matching the stiffness or damping properties is required. While there is good agreement between experiments and simulation for the damping coefficient over the entire frequency range, this only applies to the dynamic stiffness for a medium frequency range (approx. 20-150 Hz). This could be remedied by increasing the number of Maxwell elements, but this would be accompanied by a higher parametrization effort and a greater computational cost. However, there also appears an advantage by using the FE model, because the determined material parameters for a tensile load can also be used for the shear load while maintaining the quality of fit (see Fig. 2).

3 Results

Due to the high numerical effort required by considering an FE model within the multi-body simulation, a simplified example in the form of a single-mass oscillator (see Fig. 3) is used to demonstrate the general functionality of the solver coupling. In this process, a mass is excited first with an upwards and then with a downwards frequency sweep (see Fig. 4), while the rubber bushing acts as a spring-damper element. In Fig. 5 the resulting amplitude of the oscillating system is shown. Due to the non-linearity of the bushing, different maximum amplitudes result for the run-up and the run-out, which also occur at slightly different resonance frequencies. For these results, only the frequency-dependent properties of the elastomer were considered in the material model. By taking into account additional effects, we would expect to see a stronger influence on the amplitudes and resonance frequencies. In the future, it is planned to represent such further nonlinear effects by a suitable physical material model [4].

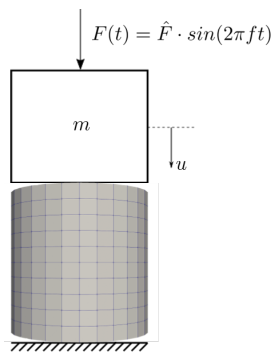

Fig. 3: Single-mass oscillator model

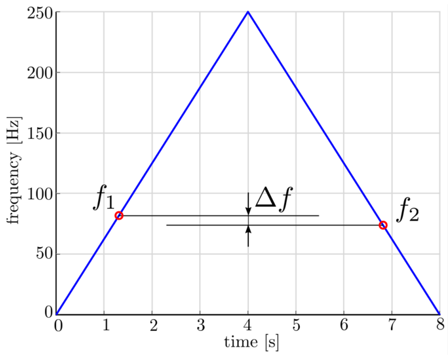

Fig. 4: Applied frequency sweep with different resonance frequencies for run-up and run-out

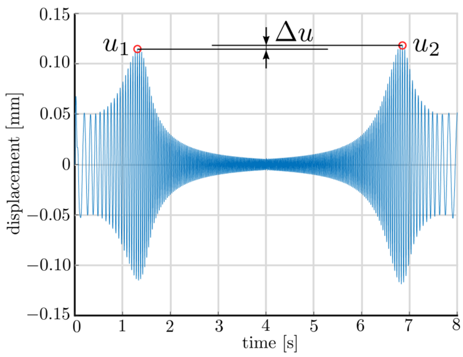

Fig. 5: Resulting displacement of the mass with different maximum amplitudes

Acknowledgements The presented work is part of the joint project “Innovative Simulationsverfahren für die akustische Auslegung von Automobilen”, which is financially supported by the European Union through the European Funds for Regional Development (EFRE) as well as the German State of Saxony-Anhalt. This support is gratefully acknowledged.

Open access funding enabled and organized by Projekt DEAL.

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