A system-level bushing joint parameter identification approach using flexible multibody models

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Bushings are a key component in the proper operation of mechanical systems, ranging from vehicles to production machinery. These bushings have a high impact on the dynamic loads and vibrations transferred through the system. Due to their high importance, an accurate characterization of these components is key in the design and monitoring of mechanical systems. However, in practice this characterization for operationally representative boundary conditions and load cases is completely lacking. Experimental parameter identification methods exist, but these are typically limited to isolated identification on dedicated test rigs. On the other hand, a fully (nonlinear) finite-element model is typically not available either. In this work, we therefore propose a technique for identifying bushing parameters in-situ using system-level measurements and (flexible) multibody models.

The (flexible) multibody models proposed in this work contain two types of joints:

- Ideal joints, described with a Lagrange multiplier formulation, for those connections where negligible flexibility is expected;
- Flexible joints, added as a generalized force term in the equations of motion. This allows to represent bushings as well as imperfect joints (e.g. with clearance).

The identification process for the bushing parameters $\mathbf{p}$ is based on a nonlinear least-squares optimization between a measured $\mathbf{h}_{meas}$ and simulated $\mathbf{h}_{sim}$ system response:

$$min\,|\mathbf{h}_{meas} - \mathbf{h}_{sim}|_2 \quad \text{for} \quad \mathbf{p} \in \mathbb{R}_{+}^{n_p}. \tag{1}$$

In this work, the considered responses can be a combination of positions, velocities, accelerations, and forces recorded on the machine. In order to solve this optimization problem the Broyden–Fletcher–Goldfarb–Shanno (BFGS) algorithm is employed.

The gradients of the response over time are required for this BFGS algorithm. In order to limit the computational load, we propose to employ the adjoint variable method for computing these gradients of the simulation with respect to the desired parameters. This approach increases the implementation complexity with respect to finite differences or direct differentiation method, but enables a computational cost independent of the number of parameters to be identified. This makes it very well suited for large systems of which a large number of parameters need to be identified [1]. The drawback of this method is that it is not straightforward to implement and the need to have access to underlying variables in the equations of motion, including their derivatives.

The proposed approach has been implemented in an in-house object-oriented Matlab multibody code. The underlying flexible multibody formulation employed is a novel approach called the flexible natural coordinate formulation (FNCF) [2]. This formulation is a combination of the floating frame of reference (FFR) and the generalized component mode synthesis (GCMS) method and results in a constant mass and stiffness matrix with quadratic constraint equations. The specific equation structure obtained through the FNCF formulation drastically reduces the complexity of the adjoint variable method as the simulation derivatives can be readily obtained and are of limited order.

The proposed bushing identification approach is numerically demonstrated on an academic double mass-spring-damper system, shown in Fig. 1, which is implemented in a general multibody framework. The bushings are modeled by the Kelvin-Voigt model, represented by a spring and damper in parallel. In this example the signal x_2 will be used for the identification of the bushing parameters. The reference response is generated from a simulation with the correct stiffness and damping parameters. For the initialization of the identification, the parameters are divided by a factor two. The convergence of the identified response to the reference for the different iterations, is shown in Fig. 2. The accompanying identified parameter values per iteration are shown in Figs. 3– 4.

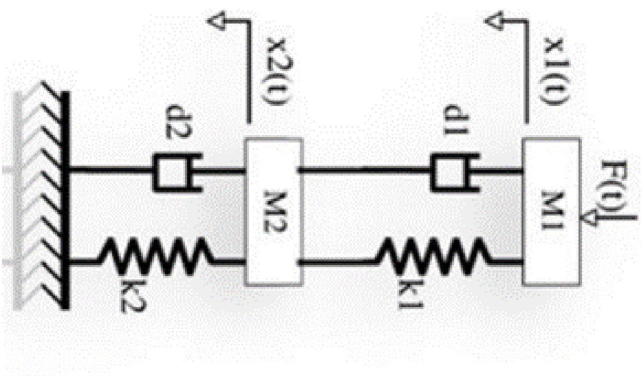

Fig. 1: Double mass-spring-damper system

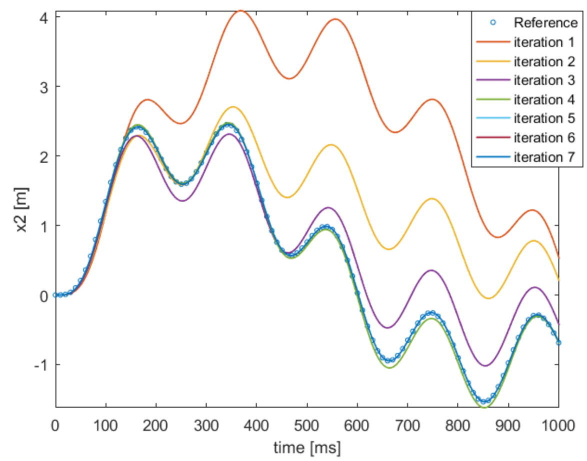

Fig. 2: Response per iteration

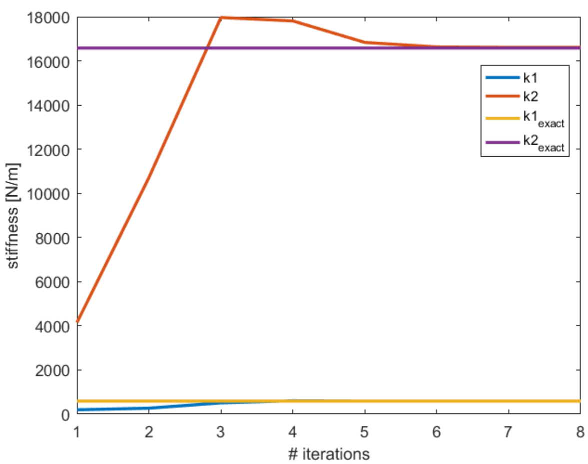

Fig. 3: Stiffness parameters per iteration

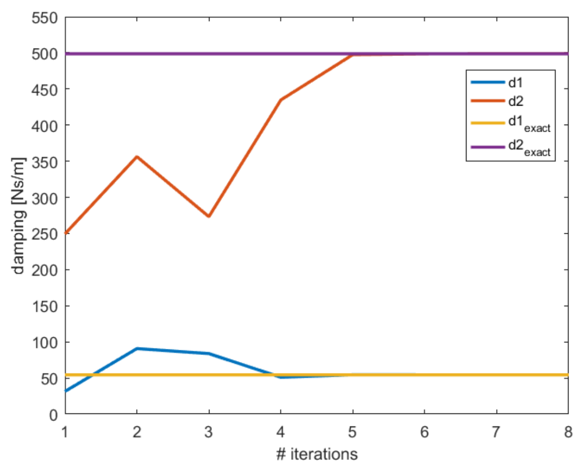

Fig. 4: Damping parameters per iteration

References

[1] A. Saltelli, K. Chan, and E. Scott, *Sensitivity Analysis*. Wiley, 2009.

[2] M. Vermaut, F. Naets, and W. Desmet, "The dual flexibility (df) formulation: A novel flexible multibody formulation resulting in quadratic system equations," in *Joint International Conference on Multibody System Dynamics*, May 29 – June 3, Montreal, Canada 2016. Abstract No. 241.