Application of Damping Enhanced Component Mode Synthesis to the Finite Element Floating Frame of Reference Formulation

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Introduction

The harsh environment of a fusion tokamak vessel means that maintenance of important components must be performed remotely using robot manipulators [4]. For instance, in the future DEMOnstration fusion power plant, one component that will have to be regularly maintained is the approximately 80-tonne heavy, 12-meter-long breeding blanket [4]. When a large, slender structure, such as the blanket, is subject to displacements, it will inevitably distort, deflect, and vibrate [4]. One part of obtaining realistic models of the blanket's behavior during remote handling is the inclusion of damping effects. Research from the sub-structuring literature suggests that using enhanced Component Mode Synthesis methods, which include damping effects within the transformation itself, leads to lower eigenvalue errors for dynamic systems with arbitrary (non-proportional) viscous damping [1]. Motivated to investigate effective modelling approaches, in this work, the damping enhancement method presented in [1] is applied to a flexible multibody problem with arbitrary viscous damping, modelled using a Finite Element Floating Frame of Reference Formulation (FE-FFRF) [5].

Method

The damping enhancement method in [1], which is appropriate for underdamped systems, is applied to the Craig Bampton (CB) transformation and is described by Eqn. 1:

$$\begin{bmatrix} \boldsymbol{u_B} \\ \boldsymbol{u_I} \end{bmatrix} \approx \begin{bmatrix} \boldsymbol{I} & \boldsymbol{0} \\ \boldsymbol{\Psi_{IB}} & \boldsymbol{\Phi_D} \end{bmatrix} \begin{bmatrix} \boldsymbol{u_B} \\ \boldsymbol{\eta} \end{bmatrix} \tag{1}$$

where $\boldsymbol{\Phi_D}$ are damped modes, $\boldsymbol{\Psi_{IB}}$ are static constraint modes, $\boldsymbol{\eta}$ are modal amplitudes, and $\boldsymbol{u_B}$ and $\boldsymbol{u_I}$ are the boundary and internal elastic degrees of freedom respectively. The normal modes in the standard CB transformation are replaced with damped (complex) modes $\boldsymbol{\Phi_D}$. These damped (complex) modes are obtained by transforming the second order system into state space form and solving the state space eigenvalue problem [1]. The transformation is displacement based, and this allows for straight-forward implementation using standard flexible multibody formulations like the FE-FFRF.

The presence of rigid body modes in the static constraint modes $\boldsymbol{\Psi_{IB}}$ would lead to coordinate redundancy when modelling the flexible bodies using the FE-FFRF. To eliminate these rigid body modes, appropriate reference conditions should be applied and included within the transformation. Recent work of [3] describes a methodology that includes reference conditions in the standard CB transformation. This methodology is therefore extended to obtain a damping enhanced transformation that works in the context of the FE-FFRF.

The damped transformation in Eqn. 1 is applied to the planar flexible double pendulum example presented in [3]. Both links are flexible and are modelled using the FE-FFRF with Euler-Bernoulli beam elements. The system is modelled using the Augmented Multibody Formulation with Baumgarte's stabilization and solved using ode23t in MATLAB. An arbitrary, non-proportional, damping matrix is constructed using the approach described in [2].

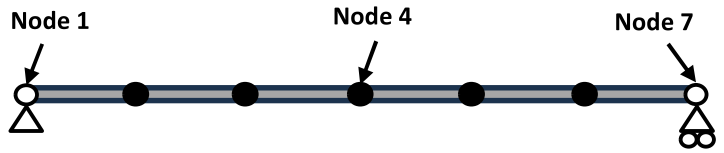

Figure 1 – Application of Reference Conditions on Link 2

Simulation Results

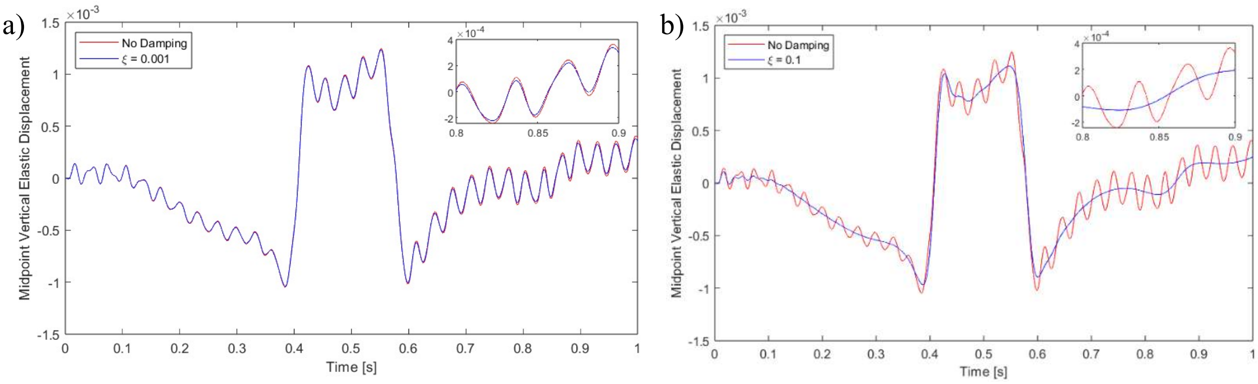

Figure 2: a) Damping Ratios of 0.001 b) Damping Ratios of 0.1

The reference conditions applied to the second link are shown in Figure 1. It can be seen in Figure 2a) that in cases with low damping, the transformation reduces to the undamped results. Increasing the damping ratio value leads to suppression of the vibrations as shown in Figure 2b) and the flexing behavior at around 0.4 s is still captured by the damped transformation. The results in Figure 2, are obtained by including the middle node (Node 4) degrees of freedom in $\boldsymbol{u_B}$.

Conclusions

The damping enhanced transformation can be applied to flexible multibody systems with arbitrary viscous damping. However, from our investigations, the selection of $\boldsymbol{u_B}$ is important. In the standard CB transformation, any selection of $\boldsymbol{u_B}$ will give appropriate results. This is not the case with the damped transformation, where the selection of $\boldsymbol{u_B}$ can significantly affect the behavior of the results. The results in Figure 2 seem to indicate that when high flexing occurs in a particular area, $\boldsymbol{u_B}$ in the damped transformation should include nodes in the high flexing area – in this case Node 4.

Acknowledgements

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