Multiharmonic forced response analysis of a torsional vibration isolator using a nonlinear quasi-zero stiffness approach

Sebastian Willeke, Michael Steidl, Norbert Reinsperger, and Stephan Bohmeyer
Hasse & Wrede GmbH, Technology & Innovation department, Georg-Knorr-Straße 4, 12681 Berlin, Germany

Abstract. The forced response of a nonlinear coupling element featuring an angular displacement range with quasi-zero stiffness (QZS) is studied numerically by means of multiharmonic simulations. The paper focuses on the development of an iterative simulation procedure for the prediction of torsional vibration isolation. It is based on the multiharmonic balance method and an alternating frequency time domain approach in combination with a numerical continuation of the sought solution branch using a predictor-corrector scheme. The simulation procedure is validated against time domain solutions for a single degree of freedom oscillator. A parametric study regarding the excitation torque amplitude, the amount of damping, the degree of isolation as well as the static offset from the nominal operating point is conducted. Finally, the procedure is applied to the torsional vibration analysis of a generic internal combustion engine. The results indicate a potential reduction of torsional drive train vibrations by up to 93 % using the QZS isolation principle.

Introduction

Various engineering applications comprise drivetrains which consist of rotating shafts transmitting the driving torque from a powering unit. Torsional vibrations due to torque fluctuations may result in undesired noise emission or lead to severe damage of the drivetrain's components. Besides established countermeasures like damped vibration absorbers, a passive isolation concept using a nonlinear coupling element with quasi-zero stiffness (QZS) is proposed, see Fig. 1. By connecting a linear coupling element with a positive rotational stiffness ($k_{\mathrm{lin}} = \mathrm{const.} > 0$) in parallel to a nonlinear coupling element ($k_{\mathrm{nl}} = k_{\mathrm{nl}}(\varphi)$) with a rotational negative stiffness (RoNeSt), a QZS region is obtained at a static angular displacement φ_{stat}. By this means, the QZS coupling maintains its main purpose, i.e. the transmission of a static torque T_{stat}, and, in addition, provides an optimal vibration isolation due to a negligible dynamic coupling stiffness at its nominal operating point.

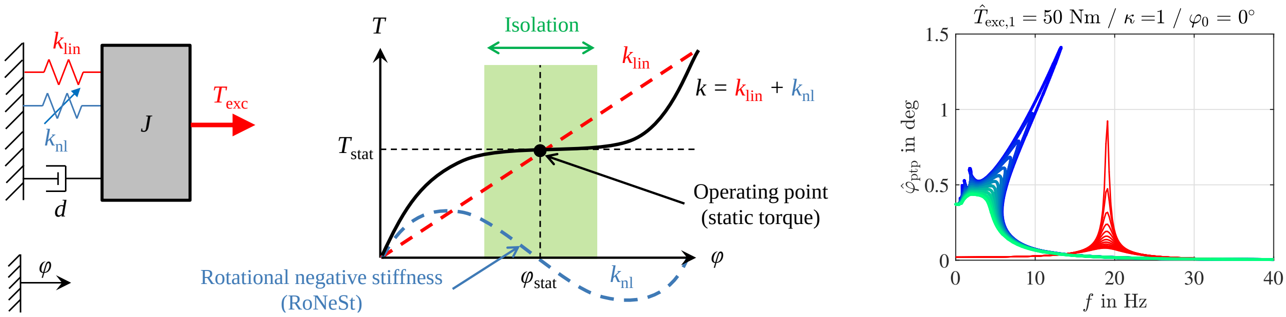

Figure 1: Torsional quasi-zero stiffness isolator (left) and nonlinear forced response for various damping levels (right)

Numerical forced response analyses of QZS isolators indicate a significant reduction of vibrations over a wide frequency range. They are, however, often limited to the fundamental vibration harmonic and neglect higher-order terms. Therefore, this paper presents a simulation procedure based on the multiharmonic balance method which employs an alternating frequency time domain approach in combination with a pseudo-arclength continuation method using a predictor-corrector scheme, see [1, 2].

Results and discussion

A comparison of the simulation outcome with time domain results shows that the procedure is able to accurately predict the isolator's multiharmonic response including unstable regions of the solution branch. Furthermore, it benefits from a reduced computational cost compared to the corresponding steady-state time domain simulations. A parametric study reveals a strong nonlinear response behavior for increased displacement amplitudes. Despite a variation of the excitation torque amplitude, the response reduction due to the torsional vibration isolation is maintained, but the response mitigation strongly depends on the degree of isolation. The latter is used to define a static stability limit. The consideration of a mismatch between the static operation point and the isolator's nominal conditions deteriorates its torsional vibration isolation capabilities. Finally, the exemplary application of the simulation procedure for the torsional vibration analysis of an internal combustion engine reveals a significant potential to reduce drivetrain vibrations by up to 93 % using torsional vibration isolation.

References

[1] Cardona, A., Coune, T., Lerusse, A., Geradin, M. (1994): A multiharmonic method for non-linear vibration analysis. *Int. J. Numer. Meth. Eng.* **37(9)**, 1593-1608.

[2] Seydel, R. (2009): Practical Bifurcation and Stability Analysis. Springer.