Vibration attenuation of dynamic systems using multiple motion constraints

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Abstract. In this study, the dynamics and vibration transmission behavior of an impact oscillator with multiple motion constraints are investigated. The main sub-system is excited by an external harmonic force. A semi-analytical harmonic balance method and a time-marching method are used for the determination of system response. The effects of the constraint properties on the dynamic performance as well as the force transmission characteristics are examined.

Introduction

Contact nonlinearities exist in the operation of many dynamical systems, e.g., tooling machinery, drilling machines, roller bearings, meshing gears, etc [1]. The components may be engaged with each other during the motion. The contact interaction will change the physical properties of the assembly and will significantly influence the system performance [2]. The impact oscillators comprising constraint have been widely accepted as a representative model to study the nonlinear dynamic behaviour in the systems with clearance. In past research, the dynamics of impact oscillators were extensively investigated. However, very few studies were reported on the application of multiple constraints on the vibration attenuation design of dynamic systems, e.g., suppressing the vibration of propulsion shafting on board. This research investigates a multiple-degree-of-freedom impact oscillators considering multiple motion constraints. The equations of the motion of the system in a matrix form are

$$\begin{bmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{bmatrix} \begin{Bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \end{Bmatrix} + \begin{bmatrix} c_1+c_2 & -c_2 & 0 \\ -c_2 & c_2+c_3 & -c_3 \\ 0 & -c_3 & c_4+c_3 \end{bmatrix} \begin{Bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{Bmatrix} + \begin{bmatrix} k_1+k_2 & -k_2 & 0 \\ -k_2 & k_2+k_3 & -k_3 \\ 0 & -k_3 & k_4+k_3 \end{bmatrix} \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} + \begin{Bmatrix} f_1 \\ f_2 \\ f_3 \end{Bmatrix} = \begin{Bmatrix} f_0 e^{i\omega t} \\ 0 \\ 0 \end{Bmatrix}, \quad (1)$$

where f_1, f_2 and f_3 denote the constraint forces act on the masses, respectively. The solutions of these equations can be determined by a harmonic balance approximation method and validated by the numerical integration method.

Results and discussions

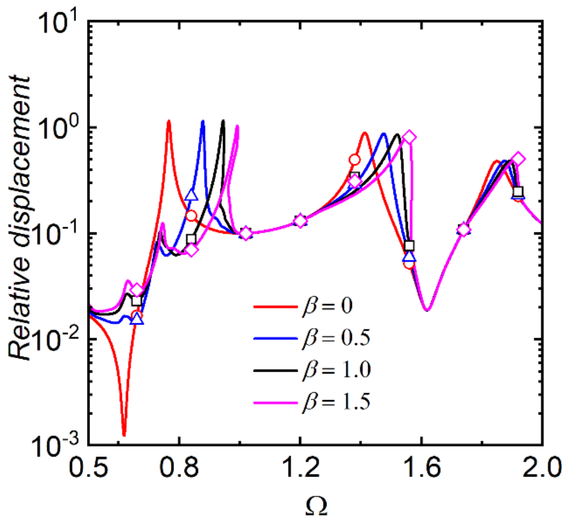

Figure 1: Relative displacement response between two subsystems.

Figure 1 show that the constraints can provide a hardening effect on the frequency response of the system. A higher constraint stiffness will further extend the transmissibility curves to the high frequencies, resulting in multiple solutions and super-harmonic components. This research facilitates further power flow analysis (PFA) on the vibration transmission and dissipation mechanism from the energy viewpoint. In this way, a deeper understanding of the vibration transmission behavior within the systems with clearance contact can be achieved, which will benefit the improvement of vibration attenuation designs for such systems.

References

[1] Dai W., Yang J., Shi B. (2020) Vibration Transmission and Power Flow in Impact Oscillators with Linear and Nonlinear Constraints *Int J Mech Sci* **168**:105234.

[2] Dai W., Yang J. (2021) Vibration transmission and energy flow of impact oscillators with nonlinear motion constraints created by diamond-shaped linkage mechanism *Int J Mech Sci* **194**:106212.