Vibro-Impacts of a Piecewise-Linear System with a Clearance

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Abstract. Vibro-impacts are commonly observed in various engineering systems as a consequence of clearances they possess. Many of these systems can be modeled as single-degree-of-freedom piecewise-linear systems excited by force fluctuations. Starting from a rattling gear pair example, such an equivalent piecewise-linear system will be defined and non-dimensionalized in this study. A piecewise-linear solution technique will be used to solve the equation of motion. Parameter sensitivity studies will be presented to map the overall dynamic response as well as showing various bifurcation routes amongst periodic and chaotic motions representing different types of vibro-impact motions. A gear pair test set-up will be used to demonstrate some of the predicted vibro-impact motions revealed by the bifurcation diagrams.

Introduction

Mechanical systems subjected to clearance type nonlinearities exhibit a rich spectrum of nonlinear phenomena. Resultant vibro-impact dynamic behavior can be viewed in two groups. In the first group, piecewise-linear system is excited at frequencies near its natural frequency $\omega \approx \omega_n$ where ω is the excitation frequency and ω_n is the natural frequency of the system. Even under a high mean force F_m that creates a large contact deflection compared to the alternating force F_a (i.e., $F_m \gg F_a$), such excitations can cause nonlinear resonances with coexisting of multiple motions due to separations of contact surfaces, yielding softening type frequency responses [1,2]. The second group of vibro-impact motions, which is the focus of this study, occurs when a system with clearance is subjected to large force fluctuations compared to mean load. In contrast to first group, F_m is not large enough to overcome inertia forces due to F_a at frequencies far away from the natural frequency $\omega \ll \omega_n$, and thus the contact cannot be maintained. This constitutes a different contact loss mechanism than the resonant type vibro-impacts of the first group. Motions in this group are chaotic or periodic of chattering type high frequency impacts occurring at ω_n as well as slower dynamics imposed by ω [3,4].

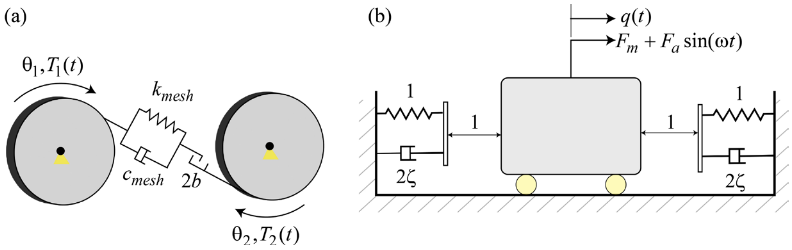

Figure 1: (a) A gear pair dynamic model (b) the equivalent translational vibro-impact model.

Perhaps one of the most common examples of piecewise-linear systems of practical importance is a gear pair whose torsional dynamic model is shown in Fig. 1(a). As for a gear pair, many real-life systems with clearances can be shown to be governed by the system of Fig. 1(b) [5].

Current literature lacks a comprehensive theoretical treatment of vibro-impact motions, especially when F_a of the external force is comparable to F_m and $\omega \ll \omega_n$. Accordingly, this paper aims at studying the vibro-impacts of the system shown in Fig. 1(b) through detailed parametric studies to demonstrate various periodic and chaotic motions and bifurcations between them. A gear rattle test set-up will be employed at the end to show some of these vibro-impact motions experimentally.

Results and Discussion

Detailed parameter studies performed on e piecewise-linear oscillator of Fig.1(b) revealed basins containing various chaotic impacting and $P(m,n)$ type periodic motions with m and n being the number of impacts and period of the motion compared to excitation period, respectively. Further, well-structured bifurcations were observed between $P(1,n)$ and $P(1,n+1)$ motions separated by bands of chaotic motions. At the end, measurements from a gear pair test rig were shown to follow these bifurcations as mean load is varied.

References

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