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Controlling coexisting attractors of an impacting system via linear augmentation

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Abstract

This paper studies the control of coexisting attractors in an impacting system via a recently developed control law based on linear augmentation. Special attention is given to two control issues in the framework of multistable engineering systems, namely, the switching between coexisting attractors without altering the system's main parameters and the avoidance of grazing-induced chaotic responses. The effectiveness of the proposed control scheme is confirmed numerically for the case of a periodically excited, soft impact oscillator. Our analysis shows how path-following techniques for non-smooth systems can be used in order to determine the optimal control parameters in terms of energy expenditure due to the control signal and transient behavior of the control error, which can be applied to a broad range of engineering problems.

Keywords: Multistability; Non-smooth system; Impact oscillator; Linear augmentation; Numerical continuation; Optimal control

1. Introduction

Impacting systems are widely found in engineering applications, such as ground moling [1], percussive drilling [2], self-propelled capsule systems [3, 4], where the impacting behavior is a part of the original design, or gearboxes [5], bearings [6], and rotor systems [7], where the impact between mechanical elements is an undesired effect due to wear or defective design. A common feature of impacting systems is that of multistability [8], referring to the coexistence of two or more attractors for a given set of parameter values. From a practical point of view, there are two control issues that are frequently studied in the framework of multistable systems. The first one consists in exploiting the fact that such systems can switch between several operation modes without altering the main system parameters. For example, the direction of motion (forward or backward) of a self-propelled vibro-impact capsule system can be controlled by switching between two coexisting attractors, see e.g. [9]. Another case where multiple coexisting solutions can be advantageous is considered in [2, 10], where the efficiency of drilling applications can be improved by choosing suitable operation modes while maintaining a desired rate of penetration. On the other hand, multistability can also be the source of system malfunctions, specially under the presence of perturbations steering the system to an unwanted operation mode, e.g. drill-string failure due to stick-slip oscillations [11–13], rotor-stator impacts due to imbalance [7, 14]. Therefore, the development of reliable control methods in order to switch between coexisting attractors or suppress some certain unwanted multistable states is crucial.

In the present work, we will study the multistability of a periodically excited oscillator with soft impacts. Such systems are very common to a broad range of engineering applications where the repeated collision of mechanical parts are unavoidable, see for example [5, 15, 16]. In many cases, impacting behavior leads to undesired effects, for instance, reduction of the efficiency and operating life of the

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