Chapter 1
Stabilization and Control of Mechanical Systems with Backlash

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ABSTRACT

Backlash is one of several discontinuities found in different kinds of systems; it can be found in actuators of different types, such as mechanical and hydraulic, giving way to unwanted effects in the system behavior. In this chapter, three different control approaches are derived to stabilize mechanical systems in which this phenomenon is present in the actuators of the system. First, an independent joint control approach when backlash is found in the actuators is derived; then a PI loop shaping control design implementing a describing function to find the limit cycle oscillations and the appropriate control gain is developed. Finally, an optimal controller for mechanical systems with backlash is derived, obtaining the optimal control law and oscillations frequency when this nonlinearity is found implementing a describing function to model the backlash effects.

1. INTRODUCTION

Backlash is a phenomena found in different kinds of actuators such as mechanical and hydraulic, generally it occurs when the contact of two mating gears do not match and this give way to many unwanted effects provoking problems to the whole mechanical system. Thus some authors have proposed several solutions respect to the control and stability issues of these systems with input nonlinearities; taking in count that is not a trivial task due to the complexity of the model, traditional control strategies fail in most of the cases, and therefore it is necessary to design nonlinear control strategies or implement modified traditional ones. The objective of this book chapter is to explain diverse control strategies for

systems with this kind of nonlinearity. The intention is to show some nonlinear control techniques that have been developed and propose different approaches to solve this problem.

Robust and output feedback controllers (Barreiro & Baños, 2006; Azar & Serrano 2014; Azar & Serrano 2015 a,b; Azar and Zhu 2015; Zhu and Azar 2015; Mekki et al. 2015; Vaidyanathan et al. 2015; Vaidyanathan and Azar 2015a, b, c, d) are some approaches that has been used for decades taking in count that most of the mechanical systems are nonlinear and multivariable, thus these techniques are explained as a preamble for some novel control procedures developed for the stabilization of mechanical systems with this kind of nonlinearity. Adaptive backlash control is another control strategy developed by some authors; this approach has the advantage of cancelling the backlash effects using a backlash inverse model (Tao & Kokotovic, 1993; Tao & Kokotovic, 1993; Tao & Kokotovik, 1995, Zhou, Er, & Wen, 2005; Jing & Wen, 2007; Guo, Yao, Chen, & Wu, 2009). The implementation of optimal nonlinear controller with backlash is another different approach to solve this problem, in which an optimal control law is found to keep the system about the equilibrium point by the use of the Riccati equations (Tao & Ma, 1999; Tao, Ma, & Ling,2001). Sometimes, this problem is solved by using a deadzone or hysteresis model of the backlash, even when this approach is not so accurate it yields acceptable control performances (Ma & Yang, 2008; Ahmad & Khorrami, 1999). Other authors propose an input-output stable controllers using an H_∞ and L_∞ approach to deal with the backlash nonlinearity (Barreiro & Baos, 2006; Bentsman, Orlov, & Aguilar, 2013). Intelligent control (Azar and Vaidyanathan 2015a,b) is a good choice for the design of efficient control strategies, some authors have proposed different control approaches with this characteristic as explained in (Jang, Lee, Chung, & Jeon, 2003) where a fuzzy controller (Azar, 2010) is designed by modeling the backlash nonlinearity and suppressing the unwanted effects yielded by this phenomenon. This control strategy is suitable when this discontinuity is found in mechanical and other kinds of systems due to the estimation properties of the intelligent controller allowing the designer to conceive an efficient control system. There are several mechanical and mechatronics systems that possess backlash nonlinearities, in this chapter some control strategies for n degrees of freedom robotics and multibody systems are developed and analyzed starting with the derivations of the dynamic equations obtained by the Euler Lagrange formulation, including the backlash nonlinearity, then some control strategies are obtained for the control and stabilization of these models under the effects of input backlash. The effects of backlash is common in the above mentioned systems, considering the contact of different actuators and sensors specially gears; this is a non desirable characteristic that yields unwanted effects, so it is necessary to devise controllers that deal with this kind of feature in the design process. The second section of this chapter is devoted to depict the different kinds of backlash models found in literature; these models are explained and analyzed because it is necessary to obtain an adequate discontinuity model before the controller design process. The kinds of mathematical models that can be implemented could be approximate and accurate models (Nordin & Gutman, 2002), so the designer could select an appropriate mathematical model for the controller design. In this section, the inverse backlash model is explained in detail, although it is not implemented in the proposed control strategies of this chapter, it is important to cite this model because is very useful in the design of adaptive and intelligent controllers (Jang, Lee, Chung, & Jeon, 2003).The intention of this chapter is to elucidate three kinds of control approaches when backlash is present in the actuators, to show how to deal with this nonlinearity by independent or multivariable control of the mechanical systems. These approaches are done by frequency domain and state space control techniques with their respective analysis as explained in each of the following sections. An independent control approach of mechanical

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