Chapter 97
Stabilization of Mechanical Systems with Backlash by PI Loop Shaping

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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. PI loop shaping control design implementing a describing function to find the limit cycle oscillations and the appropriate control gain is developed. Therefore a frequency domain approach is implemented for the control of nonlinear system of any kind such as robotics, mechatronics, other kind of mechanisms, electrical motors etc. Finally, in order to corroborate the theoretical background explained in this article, the stabilization of a cart-pendulum system with the proposed control strategy is shown.

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 on the systems 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 article 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.

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Control theory have a manifold variety of applications in many fields of science and engineering (Azar 2012; Azar & Serrano, 2015a,b,c,d; Azar & Serrano, 2014; Azar & Vaidyanathan, 2015a,b,c; Azar & Zhu, 2015; Mekki.et al., 2015; Vaidyanathan et al., 2015a,b,c; Vaidyanathan & Azar, 2015a,b,c,d; Zhu & Azar, 2015). Robust and output feedback controllers (Barreiro & Baños, 2006; Mousa et al. 2015; Mnasser et al. 2014; Ben Hariz et al. 2014; Bahgaat et al. 2014) 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). There are several mechanical and mechatronics systems that possess backlash nonlinearities, in this article a PI H_∞ loop shapìng strategy 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 the PI H_∞ loop shapìng strategy is 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. Some backlash mathematical models can be implemented for the design of the PI loop shaping controller, 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 strategy of this article, 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 multivariable PI H_∞ loop shaping design for mechanical systems with backlash is proposed in this article is implemented due to their frequency domain characteristics; therefore it is suitable for the implementation of the backlash describing function model to analyze the limit cycles due to the backlash effects. This approach is done by implementing the coprime factorization of a linearized model following the loop shaping design procedure and it is based on the work of (Azar & serrano, 2015a). The PI H_∞ control strategy shown in this article consists in implementing two weighting functions as a pre compensator and post compensator considering the linearized model of the nonlinear dynamics of a mechanical systems according to their frequency domain properties. One of the main issues overcame in this study, is that the backlash nonlinearity is modeled implementing a describing function, something that it not only allows to ease the design of the proposed control strategy, this kind of nonlinearity model allow us to find the limit cycles frequencies and periods. The describing function approach consists in the implementation of Fourier series to obtain a linear model of the backlash and other nonlinearities and due to its properties, this model is used in this article in order to obtain a feasable loop shaping controller design. In this article it is also explained a frequency analysis for this kind of mechanical systems using the Nyquist and the positivity criterion in order to analyze the stability properties of this kind of systems, something that is an important contribution of this article. Finally, the stabilization of a cart-pendulum system implementing the proposed control strategy is shown corroborating the effectiveness of this approach.