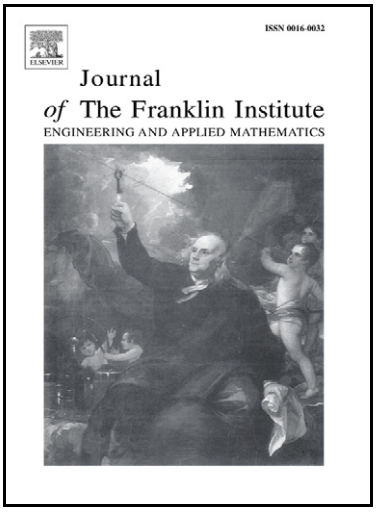

www.elsevier.com/locate/jfranklin

Super twisting control of a parametrically excited overhead crane

Carlos Vázquez, Joaquin Collado, Leonid Fridman

PII: S0016-0032(13)00081-1
DOI: http://dx.doi.org/10.1016/j.jfranklin.2013.02.011
Reference: FI1695

To appear in: *Journal of the Franklin Institute*

Received date: 11 June 2012
Revised date: 3 December 2012
Accepted date: 20 February 2013

Cite this article as: Carlos Vázquez, Joaquin Collado and Leonid Fridman, Super twisting control of a parametrically excited overhead crane, *Journal of the Franklin Institute,* http://dx.doi.org/10.1016/j.jfranklin.2013.02.011

Super Twisting Control of a Parametrically Excited Overhead Crane[☆]

Carlos Vázquez[a,*], Joaquin Collado[b], Leonid Fridman[c]

[a]Department of Control, Engineering Faculty, UNAM, 04510 Mexico, D.F., Mexico
[b]Department of Automatic Control, CINVESTAV-IPN, Av. IPN 2508, 07360 Mexico, D.F., Mexico
[c]Department of Control, Engineering Faculty, UNAM, 04510 Mexico, D.F., Mexico

Abstract

The principal contribution of this note is to avoid the *parametric resonance* effect and attenuate the payload oscillations in an overhead-crane system subject to periodic variations in the base support. Considering an appropriate sliding output with relative degree one, we present the sliding mode control design based on the Super-Twisting Algorithm (STA), ensuring finite time convergence to the desired sliding surface for the linear periodic system with Lipschitz continuous matched and unmatched uncertainties bounded together by their gradients by known functions. The suggested approach also provide chattering phenomenon attenuation. Obtained results are verified experimentally.

Keywords: Sliding mode control, Under-actuated periodic systems, Parametric resonance.

1. Introduction

During the past years, the study of periodic systems has been considered of fundamental interest because periodic variations appear in a wide range of physical systems, see (1). An example of this kind of systems is the ship-mounted crane. Cranes are under-actuated mechanical systems and the acceleration needed to move the trolley induces high oscillations in the load. Furthermore, if the crane is mounted on a ship, the wave-induced motions of the platform may contain significant energy near the natural frequency or twice the natural frequency of the free swinging load, adding the possibility of *parametric resonance*. This kind of instability can be modeled by the Mathieu and Ince equations, which are particular cases of the Hill equation, an important equation in the theory of linear periodic systems, see (2).

Therefore, attenuation of payload oscillations, while at the same time avoiding *parametric resonance*, is a very important control problem for ship-mounted cranes, see (3), (4), (5), (6) and (7). Moreover, in this case, tuning rules for the PID controller are not applicable, see (8) and (9).
Sliding mode control has been shown to be robust and easy to implement, see (10) and (11). Basically, the design consists of two steps:

- First, a suitable sliding surface in the state space is defined such that the system exhibits the desired behavior.
- Second, the appropriate sliding mode enforcement is designed such that the trajectories of the system converge to the sliding surface in finite time.

The sliding mode enforcement requires control signals to commute at a theoretically infinite frequency. Particularly, this is not realizable in the case of electro-mechanical systems like pendulum systems and DC motors. For the purpose of avoiding high frequency oscillations, the STA is a suitable technique which has been proved to be effective in chattering attenuation while at the same time preserving the sliding mode properties, see (12) and (13). For example, in the paper of (14), the STA was successfully applied for an overhead crane on the ground without the presence of wave-induced motions.
In this paper, the crane is modeled as a spherical pendulum attached to a moving support which is parametrically excited. By using the appropriate small angle assumptions, the model results in a time-varying system which is decoupled and symmetric with respect to the traveling and traversing motions of the crane. This model includes two time-varying parameters: the periodic oscillation in the base support and the rope length variation.
With the design of a desirable sliding surface and using the STA, the desired tracking, chattering alleviation, oscillation attenuation and the avoidance of *parametric resonance* are achieved. The design of the sliding surface is inspired by the work of (15) and the robustness of the zero dynamics stability is improved using the method of Hill infinite determinants. The convergence time to the sliding surface is estimated with the recently suggested non-differentiable Lyapunov function approach, see (16) and (17). The obtained results are validated experimentally on a Laboratory Inteco^{TM} 3D crane with a cam mechanism adaptation to produce the parametric excitation.
The paper is organized as follows: The modeling of the parametrically excited crane is presented in Section II. In Section

[☆]This work was supported by Universidad Nacional Autónoma de México (UNAM) under the program POSDOC 2010, PAPIIT 113613, and CONACyT (Consejo Nacional de Ciencia y Tecnología) under grant 132125.
[*]Corresponding author
Email addresses: electroncvaitc@gmail.com (Carlos Vázquez), jcollado@ctrl.cinvestav.mx (Joaquin Collado), lfridman@servidor.unam.mx (Leonid Fridman)