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Combination of input shaping and radial spring-damper to reduce tridirectional vibration of crane payload

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ABSTRACT

The input shaping technique alters the human-operator commands to reduce the payload oscillation. A single radial spring-damper can simultaneously produce three dampings to suppress the tridirectional vibration of a crane payload. Combination of input shaping and radial spring-damper can be a sensorless approach to reduce the vibration induced by both operator commands and external disturbances. A numerical simulation of a boom crane is carried out to clarify the effectiveness of each component in the combination. An experiment of a laboratory boom crane is presented to show the effect of radial spring-damper.

1. Introduction

Cranes occupies a crucial role within industry. The improvement of cranes operational effectiveness can be extremely valuable. However, the payload suspended by cables is highly flexible in nature. Payload oscillation induced by motions of the support unit or external disturbances, such as wind is a major limitation.

The techniques proposed for anti-swing crane control include feedforward and feedback control. The feedback techniques generate the control command based on the crane measurements [1–7]. The fuzzy control [8], adaptive control [9], and predictive control [10] have been studied for the crane with parametric uncertainties and external disturbances. However, because almost all the cranes are operated by human, the feedback technique can causes the fundamental conflict between human and computer. To reduce the payload swing, the input command is adjusted continually by both human operator and feedback controller, which can cause unexpected conflict motions [11–15]. The feedforward techniques, on the other hand, modify the command before sending to the crane motors. The input shaping, a typical open-loop technique, is implemented by convolving a series of impulse, called the input shaper, with the reference command [11–15]. Although do not require the sensors, the input shaping cannot counteract disturbances or initial conditions due to its open-loop nature [16,17]. A recent comprehensive review of both feedback and feedforward control of crane can be found in Ref. [18].

The rather more conventional passive damping systems are introduced to control the payload swinging in some recent studies [19,20,21]. The radial spring-damper is a typical type of passive system can be used in anti-sway crane control [20,21]. It works in the principle of nonlinear Coriolis damping. The radial spring-damper is mounted in-line, between

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the crane hook and the payload. Practically, the large payload weight should be the problem for introduction of additional mechanical device. However, in fact, some suppliers [22,23] supplied device called Passive Heave Compensation, which is the cylinder filled with gas, used to absorb shock in the crane's cable. This can be modeled as a combination of gas spring and gas damper. The problem of mechanical stress in spring can be avoided for this type of radial spring-damper.

In comparison with the feedback control, the passive approach has limited effectiveness. However, the passive system is simple in application and can be used as a secondary system to improve main control systems. Obviously, the technique does not rely on sensors should be the combination between the passive systems and the input shaping techniques.

The purpose of this paper is to introduce a combination of radial spring-damper with input shaping technique to control the tridirectional vibration of the crane payload induced by both human operators and initial conditions. Tridirectional vibration includes the vibration of tangential sway, radial sway and cable tension. The paper reveals that a single spring-damper system can simultaneously produce three dampings for those three vibrations. Each of three driving commands to a boom crane can be shaped for each of payload's degree of freedom. The paper includes two main parts. First, the effect of input shaping and radial spring-damper are clearly explained. Then the effectiveness of the combination is verified numerically and experimentally.

2. Problem statement

The concept of combination of input shaping and radial spring-damper to reduce the tridirectional vibration of a crane payload is shown in Fig. 1.

If the command from the crane operator is sent directly to the motor to move the crane, the oscillatory response is induced. Instead of that, the operator command is convolved with a series of impulses, called the input shaper, before sending to the motor. The general input shaper can be diagrammatized as shown in Fig. 2.

In Fig. 2, the gain blocks correspond to the impulse amplitudes, A_i while the time delay blocks correspond to the impulse time locations. In this paper, for the demonstration purpose, two simplest input shapers are considered: the zero vibration (ZV) shaper and the zero vibration and derivative (ZVD) shaper [13]. They are represented as:

$$ZV = \begin{bmatrix} A_i \\ \Delta_i \end{bmatrix} = \begin{bmatrix} 0.5 & 0.5 \\ 0 & \pi/\omega \end{bmatrix} \tag{1}$$

$$ZVD = \begin{bmatrix} A_i \\ \Delta_i \end{bmatrix} = \begin{bmatrix} 0.25 & 0.5 & 0.25 \\ 0 & \pi/\omega & 2\pi/\omega \end{bmatrix} \tag{2}$$

where ω is the natural frequency of the system modeled as a second order harmonic oscillator. A major advantage of the input shaping technique is that they do not require the sensors. However, they are lack the ability to handle external disturbances or initial conditions. In Ref. [20], a radial spring and damper is proposed to limit the free vibration induced by initial

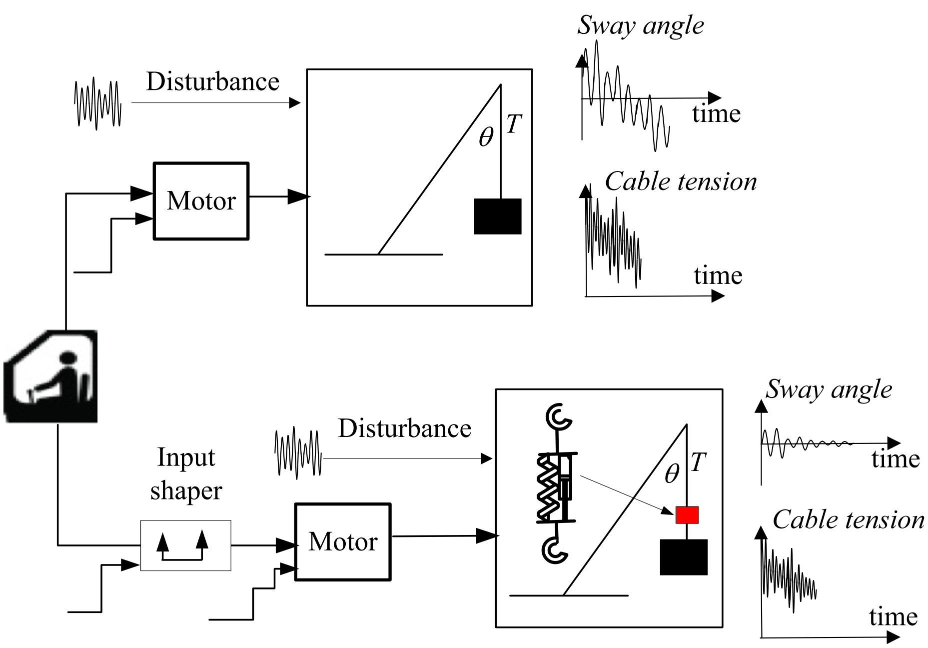

Fig. 1. Combination of input shaping and radial spring and damper.