Active Sway Control of a Gantry Crane by an Electrical Ducted Fan

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Sway reduction is very vital in a nonlinear oscillatory system such as a gantry crane. In this paper, a new design is proposed for active sway control of a gantry crane using an electrical ducted fan. The thrust force developed by the motor is used to cancel out payload oscillation. A dynamic model of the crane with a ducted fan is derived and simulated using Matlab. Performance of the proposed technique is investigated for a crane subjected to initial sway and an external force input. In addition, cases with different payloads and cable lengths are also studied. Simulation results show satisfactory performance of the fan-controlled system in eliminating the payload sway. The proposed design can also handle changes in payload and cable length. A main advantage of this approach is that it does not require modeling of the crane in real time experiments.

1. INTRODUCTION

Vibration control is crucial in flexible structures where their movement produces undesired vibration. Although flexible systems are lighter and faster than rigid ones, their motion-induced vibration is a drawback that limits their applications. In order to reduce the system vibration, several control approaches have been proposed by researchers. These include, active control of a grinding machine,[1] adaptive control of a drill string,[2] active vibration control of a ring-stiffened cylindrical shell[3] and active vibration control of smart plates.[4]

Gantry cranes are flexible structures that are commonly used in material handling systems in factories, warehouse, shipping yards, and nuclear facilities where heavy loads must be transferred from a specific place to a desired location. However, the crane movement induces undesirable payload sway.[5] This undesired load swing negatively influences the productivity and causes a drop in efficiency, load damages, and even accidents. Speed is a focal point in industries as it translates into the productivity and efficiency of the system. However, fast maneuvers tend to excite sway angles of the hoisting line, and this can result in a higher residual sway that degrades the overall performance. At very low speeds, the payload sway is not important and can be ignored. Nevertheless, at a higher speed, these sway angles become larger and significant and cause the payload difficulty in settling down when unloading. The overall system performance will be affected when significant sway angle of the payload occurs during and after the movement of a gantry crane. This is a very severe problem, especially for applications in the industries that require high positioning accuracy, small swing angle, short transportation time, and high safety.[6]

A number of techniques have been proposed for control of gantry cranes. The control objective is to move the trolley to a required position as fast as possible with low payload oscillation. The control algorithms can be categorized into feed-forward and feedback control strategies. The feed-forward control strategy mainly involves command shaping techniques and optimal control. An approach in command shaping techniques known as input shaping has been proposed and has received considerable attention in vibration control.[7] An input shaping technique for reduction of the residual vibration of a gantry crane has also been proposed.[8,9] The closed-loop control algorithms include linear quadratic regulator (LQR) technique, state feedback, and nonlinear control. The LQR technique is utilized to track the reference trajectories,[10] the state feedback control strategy is used to hoist, stabilize, and delivery the payload[11] and a nonlinear control scheme incorporating parameter adaptive mechanism is utilized to ensure the overall close-loop system stability[6] have been proposed by researchers. On the other hand, an acceptable system performance without payload sway that accounts for system changes by developing a hybrid controller consisting of both feed-forward and feedback control techniques has been successfully implemented on a gantry crane.[12]

Although many control strategies have been applied on different type of cranes to reduce the payload sway, no work has been conducted on the direct control of the payload sway. Several researchers have used ducted fans to control the swinging payloads, such as spy cameras[13] and indoor service robots.[14] In this paper, a new sway control strategy is proposed that utilizes an electrical ducted fan to directly control the payload sway of a gantry crane. The thrust force of an electrical ducted fan, installed on top of the hook, can be used to significantly reduce residual sway. The proposed technique can handle initial sway, external disturbances and changes in payloads and cable lengths.

2. DYNAMIC MODEL OF A GANTRY CRANE

The gantry crane can be considered as a simple cart and pendulum system.[12] Figure 1 shows a schematic diagram of a trolley and payload system considered in this study. M, m, l, b, d, F_e, x, and θ represent trolley mass, payload mass, cable length, coefficient of payload friction, coefficient of trolley friction, external force, trolley displacement, and angular displacement of payload, respectively. Table 1 shows the system parameters used in these investigations.

There are several methods to derive the mathematical equations that represent the trolley and payload system. In this work, Lagrange's equation is used to derive the mathematical expression for the model. The system has two numbers of independent generalized coordinate, namely trolley displacement x and angular displacement of payload oscillation. The