Abstract

When suspended payloads are moved in a material handling environment pendulum-like oscillations are naturally introduced. This presents a problem any time especially when expensive and/or delicate objects are moved. In a steel industry environment objects have to be placed in tight locations after finishing up of rolling. Typically an object (rolled coil) is lifted by a hook on the end of a cable, creating pendulum that is free to swing in a transit condition. This swinging motion makes remote positioning of casks and barrels difficult to control precisely which is potentially destructive to facility equipment and to other storage containers. Typically, a crane operator moves objects slowly to minimize induced swinging and allow time for oscillation to dampen, maintaining safety but greatly decreasing the efficiency of operations. By employing proper algorithm or by the choice of proper drive it is possible to dampen the oscillations predictive called residual vibration[1]. Using damped-oscillation control algorithm [2] is one method of solving this problem. Residual vibrations resulting from the motion of the crane can not only be expensive to deal with but also dangerous. Standard practice in crane operation is to allow the pendulum swing to die out before working with the moved object. Considering the size of these cranes and the length of the pendulum, this could take a very long time. This situation lends itself to a more intelligent control system. Reducing these residual vibrations, even if not eliminating them, could save substantial wasted man-hours and create a safer working environment. This paper demonstrates the possibility of implementing an feedforward technique on a gantry crane robot model. Input shaping [3] is the technique of feedforward mode wherein the impulses are convolved with an arbitrary reference input to control the desired outputs or states of a system. This technique has been used in very limited situations. A Crane system is idealized as material handling industrial robot for experimentation. The model is tested under a steel environment using LABVIEW and PID algorithm

Key Words Damping, adaptive control, input Shaping
I INTRODUCTION

The use of gantry cranes in steel environments requires limitation of both the swing during the motion and the residual oscillation. Experienced crane operators attempt to eliminate the residual sway by causing a deceleration oscillation which cancels the oscillation induced during acceleration, or they may brush the payload against obstacles to damp out the oscillation. If a computer controller is utilized and cable swing is considered in the control design, the time-optimal commands which results in zero residual vibration can be generated. Hoisting of the load during the slew increases the difficulty of generating the control because the system frequency is time-varying. Optimal controls based on a nonlinear model are even more difficult to generate. One method for developing optimal controls divides the motion into five fundamental sections. The optimal control for each section is then derived and pieced together by satisfying boundary conditions. Even when optimal commands can be generated, implementation is usually impractical because the boundary conditions (the move length) must be known at the beginning of the move. When feedback is available, adaptive controllers and combination open and closed loop control is possible. In this paper the feedforward control technique of Input Shaping is investigated. Input Shaping is easier to derive and implement than time-optimal control schemes and does not require the feedback mechanisms of closed-loop and adaptive controllers. Rather than attempt to obtain exactly zero residual vibration (which is impossible on real machines), the version of Input Shaping described here may yield non-zero, but low levels of sway[4]. The test bed was a simulated model of a gantry crane. The control of the system was developed entirely with a Motorola HC11. Five main functions of the HC11 parallel I/O, serial I/O, timers, interrupts, and the pulse accumulator were used. A PC interface added to the system to mimic an interface that might be provided to the operator of the crane. In real time operation it provides information about the state of the crane such as the length of the pendulum and the motion of the trolley. Increasing the information provided to the operator is intended to help his ability to operate the crane safely and accurately. This too, is a feature that has not yet been implemented in industry.

II Residual Vibrations

Fig.1 shows the general modeling of the crane system in which the $\theta$ is the cable angle of displacement. After the movement of displacement the system is left with vibration which goes as sway from the normal plane of motion. This is what we call residual vibration.
III ISSUES LEFT OVER

With the past development the following issues were left over for development:

1) The increments of speed required to have effective control

2) The effect of having the pre-filter tuned to a frequency different from the crane system's natural frequency and

3) Stiction and Coulomb friction effect

Stiction and Coulomb friction are nonlinearities and since transfer function representations are reserved for linear systems only, it uses a physical model with the driving force reduced by a nonlinear friction force. Fig. 2(a) and Fig 2 (b) below shows the variations of residual vibrations with speed and length values.

IV FEED FORWARD TECHNIQUE [5]

The goal is to develop control methods that yield low levels of both transient and residual oscillations and not attempt to obtain exactly zero residual vibration. When zero residual is required, the solution is somewhat difficult to obtain and implement.
V INPUT SHAPING

Fig. 3 shows the Input Shaping which is a feedforward control technique for reducing vibrations in computer controlled machines. The method works by creating a command signal that cancels its own vibration. That is the vibration caused by the first part of the command signal is canceled by vibration caused by the second part of the command.

If a computer controller is utilized and cable swing is considered in the control design the time optimal command which results in zero residual vibration can be generated. Hoisting of the load during slew increases the difficulty of generating the control because the system frequency is time varying. Optimal control based on a non-linear model are even more difficult to generate. Even when optimal commands can be generated, implementation is usually impracticable because the boundary conditions (move Length) must be known at the beginning of the move.

VI SHAPER DESIGN ALGORITHM

1. Pick a Shaper length (deceleration period)
2. Select a desired limit on the percentage residual vibration amplitude
3. Require the vibration to be below V at the lowest possible frequency (the longest cable length)
4. Perform an optimization which maximizes the frequency range over which the residual amplitude be kept below V. The output of the optimization is an input shaper and the maximum suppressed frequency.

If the frequency range covers the entire workspace, then terminate the algorithm. Otherwise start at step 3 and replace ū1 with ūh. The product of the algorithm is one or more fixed duration shapers which can be used to suppress vibration throughout the workspace.

VII DESIGN FOR FIXED DURATION SHAPERS

For a mode of natural frequency ū and damping ratio ă this percentage vibration is given by

\[ V(\ddot{u},\ddot{a}) = e^{-\ddot{u} \omega t} [C(\dot{u},\ddot{a}) + S(\dot{u},\ddot{a})] \] .. (1)

where,

\[ C(\dot{u},\ddot{a}) = A_1 e^{\ddot{u} \omega t} \cos(\dot{u} - \omega \ddot{a} t) \] .. (2)

\[ S(\dot{u},\ddot{a}) = A_2 e^{\ddot{u} \omega t} \sin(\dot{u} - \omega \ddot{a} t) \] .. (3)
\( A_i \) and \( t_i \) are the amplitudes and time locations of the impulses and \( n \) is the number of impulses in the input shaper. Because (1) is a function of the impulse amplitudes and time locations it can be used to design an input shaper which will limit the residual vibration to some small value, \( V \) at the mode described by \( \dot{u} \) and \( \phi \).

**VIII DOUBLE PID CONTROL**

The PID control rule is very common in control systems. It is the basic tool for solving most process control problems. The PID controllers are usually standard building blocks for industrial automation.

\[
\dot{u}(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} (e(t))
\]

The most basic PID controller has the

where \( \dot{u}(t) \) is the control output and the error, \( e(t) \), is defined as \( e(t) = (\text{desired value} - \text{measured value}) \) of quantity being controlled. The control gains \( K_p \), \( K_i \), and \( K_d \) determine the weight of the contribution of the error, the integral of the error, and the derivative of the error to the control output. These gains will dictate the response of the closed-loop system to initial conditions and inputs. There are a number of tuning methods for PID controllers. Some of them are based on transient response experiments some other are based on frequency analysis. In the crane system under consideration, the quantities for PID control are the cart position and pendulum angle. The pendulum-cart control system containing two PID controllers. The first operates based on the angle of the pendulum and the second operates based on the position of the cart. The outputs of the PID controllers are added to produce the final control value for the D/A converter, and as a result the output motor torque. A schematic of the proposed double PID control system for the pendulum-cart system is shown in Fig.4. The proposed controller is then constructed in a Simulink block diagram and used to control the pendulum system as described below.

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**Fig 4 Double PID Controller**
The PID controller contains a built-in digital filter. It receives 8 inputs:

- x(1): Filtered PV, which will be further filtered in the built-in digital filter.
- x(2): Setpoint.
- x(3): The proportional gain Kp.
- x(4): The integral gain Ki.
- x(5): The derivative gain Kd.
- x(6): Time.
- x(7): If it is 1, then use PID control action, otherwise use manual CO value.
- x(8): Manual CO value.

where PV — Process Variable; SP — Set Point; CO — Controller Output.

Fig. 5(a) shows the simulated response of the controller output. Fig. 5(b) is the flowchart of the input shaper. Fig. 5(c) is the Simulink model, and Fig. 5(d) is the software interface under LABVIEW.
X CONCLUSION

When considering the effectiveness of the input shaping scheme in reducing residual vibration, one must realize that it is impossible to completely eliminate all oscillations, primarily due to modeling approximations and an imperfect representation of the system dynamics. Therefore, a better indication of system performance is the amount that the swing amplitude is reduced by added an input shaper. Because small swing angles can result in considerable movement of the payload with a sufficiently long cable, direct measurement of the swing angle as a means of verification of the success of the input shaper is impractical. However, since the magnitude of the swing angle is so drastically reduced when input shaping is used, the benefits of input shaping on the simple pendulum system are readily apparent with the naked eye. One limitation of the control scheme implemented on the pendulum system is the requirement of zero initial conditions and no external disturbances. Furthermore, the feed-forward technique of input shaping necessitates a fairly accurate model of the system dynamics.
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