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Research of Anti-sway System for ARMG Based on Input-shaping Control Method

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Abstract

This paper did research on electric-control anti-sway system with input shaping method, which is different from commonly used closed-loop PID and Fuzzy-logical control. Input shaping technique is a feed-forward control technique that involves convolving a desired command with a sequence of impulses known as "input shaper" to damp motion induced oscillations. Based on Matlab/Simulink the input shaper inside an embedded Matlab-function-block was implemented. By comparision, although the IS-controlled system reaches the desired position later, but swings inside the tolerance zone, which makes it more efficient.

Keywords: Input-shaping; Anti-sway; ARMG; Mathematical Model

1. INTRODUCTION

There are many types of technical solutions for anti-sway systems in container gantry cranes, mechanical and electric-control systems.

The most common way is to use a closed-loop PID control which can be implemented i.e. in PLC controls. Sometimes, Fuzzy-controllers are used in gantry crane controllers, especially to increase its robustness against parameter changes. Input shaping technique is a feed-forward control technique that involves convolving a desired command with a sequence of impulses known as "input shaper" to damp motion induced oscillations. The most common shaper contains only positive impulses.

2. SIMULATION RESEARCH

The crane and load movement shall be simplified as single rope system with a container, described as a concentrated mass. Also there shall be a viscous like damping which is proportional to the rotational speed of the container.

2.1 Mathematical Model

Within the scope of this thesis x is the position of the trolley, x_m and y_m are the positions of the load. M and m are the masses of the trolley and the container. α is the angle between the rope and the y-axis. G and R are the abbreviation for the weight and friction forces. In addition S is the fore of the rope.

The position of the load can be described as:

$$x_m = x + L * \sin(\alpha) \tag{1}$$

$$y_m = -L * \cos(\alpha) \tag{2}$$

For this type of model it is decided to assume the motors as 'strong', this means a free movement of the trolley is not presumed (or is neglected) when the motors are powered and the mass and inertia of the trolley is not considered.

For an experimental model-crane, the above introduced simplified model is accurate enough and useful, but if it is desired to simulate the behavior of a real crane, then the assumption of " strong motors" will not work because of the huge masses of load and trolley. RTG can lift loads up to 40t where the lift system to pick it up also weights about 12t (so the total amount of m is up to about 52t). In compression the trolley is only about 30t. The heavy mass of crane and especially of the load of a real-sized system causes a high moment of inertia. In this case the motors, which are relative small in consideration of the masses, cannot accelerate the trolley immediately and also the deceleration is limited. In the common literature it is often said that gantry cranes are under actuated systems, also because the load mass is much higher than the actuator (trolley-) mass.

Therefore, the most common modelling of two dimensional cranes (as displayed in fig.1), take the trolley mass M as additional degree of freedom under account and uses the external driving force F as system input. This means that also the trolley can move freely and the movement of trolley and load are coupled so, as shown later, also the trolley (but not only the load) swings when i.e. a PID-position controller is used. This type of modelling is used and introduced by most authors, and shall be introduced similarly but without writing every calculation step.

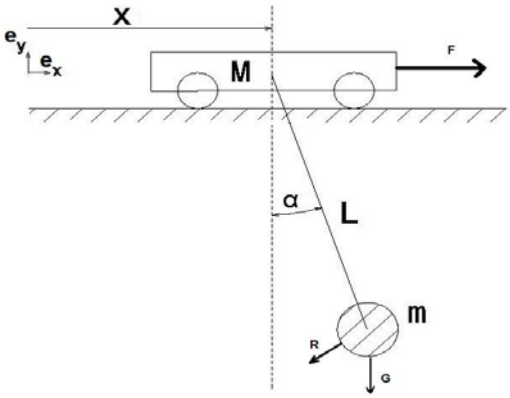

FIG.1 MODEL OF LOAD AND TROLLEY AS 2D- MOVEMENT

For this kind of modulation it is the quasi standard in literature to use the Lagrange formalism to obtain the differential equations of the system respectively its transfer function. Therefore in a first step the positions of the trolley and load mass are written as in equation 1 and 2. Then according to these formulas the kinetic energy of the system is:

$$E_{kin} = \frac{1}{2}(\mathrm{M+m})\dot{x}^2 + m\dot{x}\dot{\alpha}L_0\cos(\alpha) + \frac{1}{2}L_0{}^2\dot{\alpha}^2 \tag{3}$$

And the potiential energy is:

$$E_{pot} = -mgL_0\cos(\alpha) \tag{4}$$

It is obvious that this formulation do not consider a hoisting movement of the rope. The Lagrange Equation is given as:

$$L = E_{kin} - E_{pot} \tag{5}$$

This is used for the Lagrange formulas as:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{x}}\right) - \frac{\partial L}{\partial x} = F \tag{6}$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\alpha}}\right) - \frac{\partial L}{\partial \alpha} = 0 \tag{7}$$

As it can be seen from equation 6, the system input is for this model the trolley driving force (in contrast to the simplified model where the trolley speed, respectively the motor voltage, is the input). 6 and 7 with 3 and 4 give two coupled differential equations as:

$$F = (M+m)\ddot{x} + ml\ddot{\alpha}\cos(\alpha) - \dot{\alpha}^2\sin(\alpha) \tag{8}$$

$$0 = \ddot{x}\cos(\alpha) + l\ddot{\alpha} - g*\sin(\alpha) \tag{9}$$

These equations are highly nonlinear and shall be linearized around the zero position of the load-pendulum. The TAYLOR- linearization used for equations 8 and 9 gives:

$$F = (M + m)\ddot{x} + mL_0\ddot{\alpha} \tag{10}$$

$$0 = \ddot{x} + L_0\ddot{\alpha} + g\alpha \tag{11}$$

This can be rewritten as:

$$\ddot{x} = g\alpha\frac{m}{M} + \frac{1}{M}F \tag{12}$$

$$\ddot{\alpha} = -\frac{g}{L_0} * \frac{m+M}{M} - \frac{1}{L_0 M}F \tag{13}$$

According (but slightly modifiyed by ignoring the friction) to Hertkorn this can be rewritten in state space form

$$\dot{x} = Ax + Bu \tag{14}$$

$$y = c^T x \tag{15}$$

By defining x as the state vector $x = \begin{bmatrix} x \\ \dot{x} \\ \alpha \\ \dot{\alpha} \end{bmatrix}$[3]. y symbolize the position of the load as: $y = x_m = x + L_0 * \sin(\alpha)$ or (as further used) linearized: $y = x_{mlin} = x + L_0\alpha$. Finally the state space-representation of the linearized model is:

$$\dot{x} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & g\frac{m}{M} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -\frac{g}{L_0} * \frac{m+M}{M} & 0 \end{bmatrix} x + \begin{bmatrix} 0 \\ \frac{1}{M} \\ 0 \\ -\frac{1}{L_0 M} \end{bmatrix} F \tag{16}$$

$$y = \begin{bmatrix} 1 \\ 0 \\ L_0 \\ 0 \end{bmatrix} x \tag{17}$$

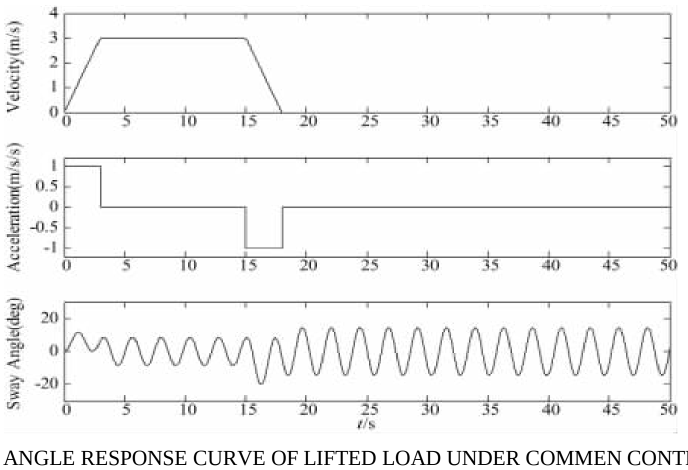

FIG.2 SWAY ANGLE RESPONSE CURVE OF LIFTED LOAD UNDER COMMEN CONTROL SIGNAL

2.2 Introduction into Command Shaping

In application, trolley is usually controlled under trapezoidal speed mode, and its corresponding acceleration is square-wave single pulse signal. Because acceleration signal has the same harmonic wave component with natural frequency of the system, so, after acceleration or deceleration course of the trolley, the sway response angle ϕ of the lifted load shall be like fig.2, which is obviously cause disadvantage to crane operation.

Input shaping is a feed forward open loop control method. It manipulates a desired input-control signal for improved system behavior, concrete to avoid swing, without a feedback of the actual systems output. The origin of this control scheme is the so called ‘Posicast control’.

A slightly damped system, like an overhead gantry crane, is stimulated to vibrations by every input command i.e. impulse or step commands. As shown in fig. 3 the Idea of Inputshaping is to use a smart second (or several further) input commands to create new oscillations. The vibration (blue) is compensated by a second vibration (green) to the resultant movement (red). Vibration one and two are caused by impulses (depicted as bars).

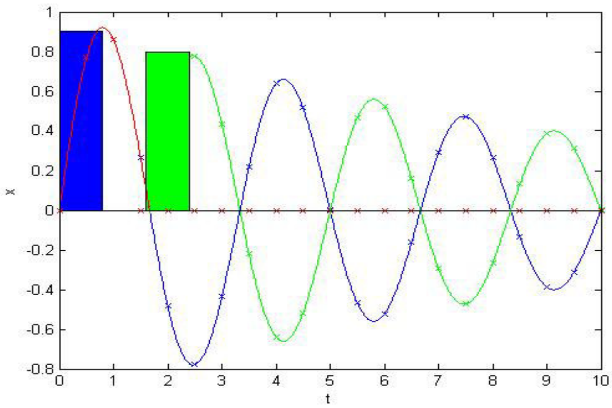

FIG. 3 THE PRINCIPLE OF INPUT SHAPING

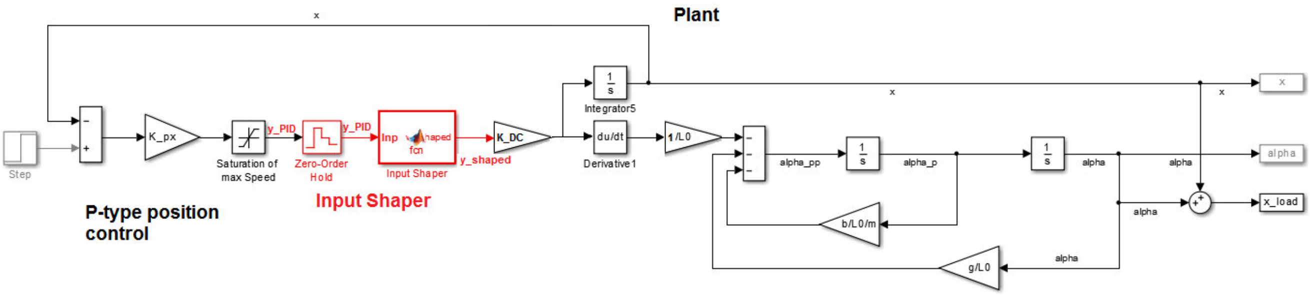

FIG. 4: SIMULINK BLOCK-DIAGRAM OF THE MODEL WITH INPUT SHAPING METHOD.

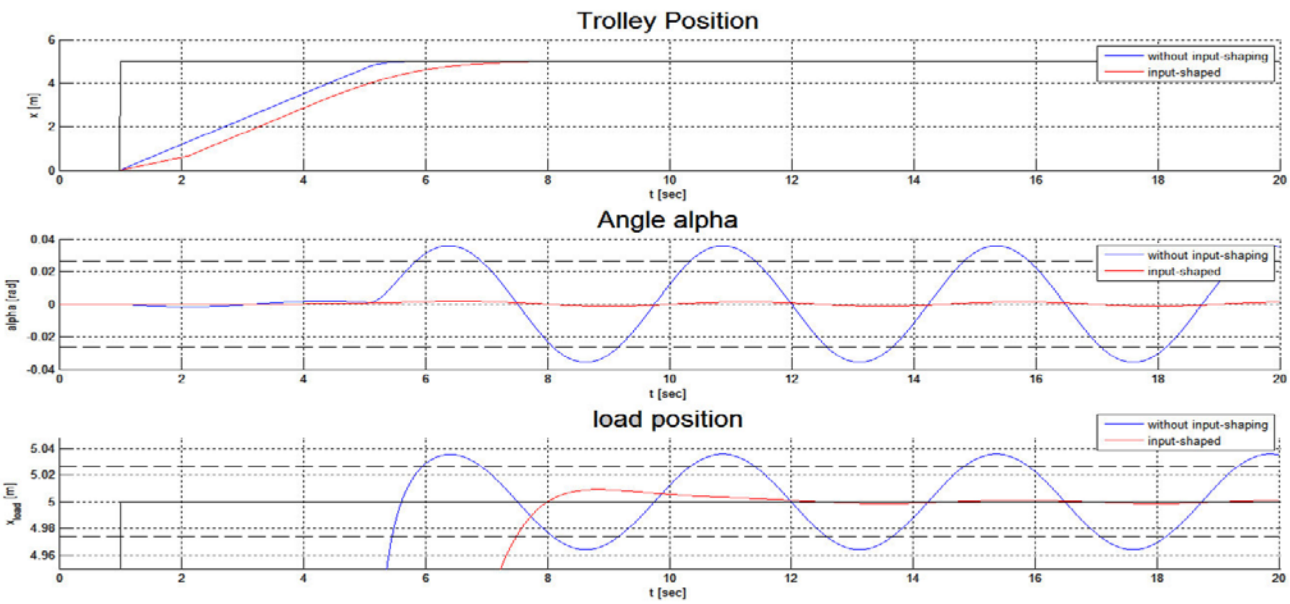

FIG. 5: SIMULATION RESULTS COMPARISON FOR THE SYSTEM WITH AND WITHOUT INPUT SHAPING.

2.3 Development of an Input-shaping Control

Input shaping is a useful method to decrease motion induced swing. Nevertheless, Input-shaping (IS) could not be used alone to run the trolley into a desired position, because it needs either an exact knowledge of the necessary control maneuver for a defined placement, or a feedback control of the trolley position. Within the scope of the topic and of the development of an ARMG a PID-control has been used for the positioning as displayed in figure 4. It has been the efficient way for the simulation with Matlab/Simulink to implement the inputshaper inside an embedded Matlab-function-block which can be programmed with Matlab commands.

Fig. 5 gives the simulation results of a system with and without input-shaping. This shaper is a simple designed approach with two impulses, both with an impulse value of 0.5, at time locations of $t_1 = 0$ and $t_2 = T4$ (T as time for one period of the load swing), so the values are not exact optimal chosen as explained above but the simulation results were already very well.

3. CONCLUSIONS

With the IS-method the end position is reached later than without an input-shaper, due to the two steps divided control signal by the input shaper. This disadvantage is acceptable, because the container of the system without IS reaches the end position earlier but due to its large swing it overshoots outside the tolerance limit. Whereas the IS-controlled system reaches the desired position later, but stays inside the tolerance zone because the resulting angle keeps small in all simulated cases.

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