A Study on Load Vibration Control in Crane Operating

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Abstract : *In the offshore crane system, the requirements on the operating safety are extremely high due to many external factors. This paper describes a model for studying the dynamic behavior of the offshore crane system. The obtained model allows to evaluate the fluctuations of the load arising from the elasticity of the rope. Especially, in this paper, the authors design control system in which just winch rotation angle and rope tension are used without load position information. The controller design based on input-output feedback linearization theory is presented which can handle the effect of the elasticity of the rope and track the load target trajectory input. Besides that, a full order observer is designed to estimate unknown states. Finally, By the experiment results, the effectiveness of proposed control method is evaluated and verified.*

Key words : *Load Position, Rope Dynamics, Input-Output Feedback Linearization, Offshore Crane System*

1. Background

In actual crane operation, a load moving process is not easy due to residual vibration which is an inherent problem of the offshore crane systems. Therefore, many control strategies have been proposed to obtain good work performance [1,2,3]. In these studies, rope dynamic characteristics are not considered and the proposed control methods require knowledge of complex control theories. In this paper, a dynamic model for the fixed crane structure and the extendable rope is derived. The rope stiffness is a representative one of them which should be carefully treated in modeling based on input-output linearization theory.

2. Problem Statement

The main object of the crane work is moving the load in vertical direction. To make a desirable solution for considered issue, we use the pilot model as illustrated in Fig. 1.

In this paper, the transfer function of motor-winch system is estimated by the Matlab Identification Toolbox software.

$$J_w \ddot{Z}_w + d_w \dot{Z}_w + k_w Z_w = T_{in} - r_w T_{dis} \quad (1)$$

where Z_w is the rope length, $T_{dis} = k\Delta L$ is a disturbance torque, $T_{in} = \eta v$ and u denotes the control input.

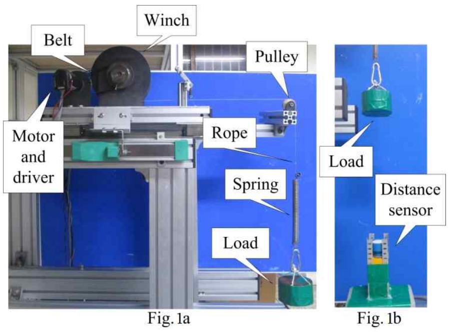

Fig. 1. Photos of experimental apparatus.

According to Moon et al. [4], the parameters of rope are time-varying and strongly depend on rope length. The load motion dynamics is represented by Eq. (2) based on Newton/Euler method.

$$m(\ddot{Z}_w + \ddot{\Delta L}) + \frac{\beta A_r}{Z_w + L_0}\dot{\Delta L} + \frac{e_r A_r}{Z_w + L_0}\Delta L = 0 \quad (2)$$

3. Controller Design

A state-space model of the system shown in Eq. (3). The authors propose the control method based on an input/output feedback linearization theory.

$$x = \left[Z_w \ \dot{Z}_w \ \Delta L \ \dot{\Delta L} \right], \begin{cases} \dot{x} = f_{(x)} + g_{(x)} v \\ y = h_{(x)}, t \geq 0 \end{cases} \quad (3)$$

where

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$$f_{(x)} = \begin{bmatrix} x_2 \\ -\frac{k_w}{J_w}x_1 - \frac{d_w}{J_w}x_2 - \frac{r_w e_r A_r}{J_w(x_1+L_0)}x_3 \\ x_4 \\ \frac{k_w x_1 + d_w x_2}{J_w} + \frac{r_w e_r A_r}{J_w(x_1+L_0)}x_3 - \frac{e_r A_r x_3 + \beta A_r x_4}{(x_1+L_0)m} \end{bmatrix} \quad (4)$$

$$g_{(x)} = \left[0 \ \frac{\eta}{J_w} \ 0 - \frac{\eta}{J_w}\right]^T, \ h_{(x)} = x_1 + x_3 + L_0 \quad (5)$$

However, the parameters e_r and β of the rope used in the experiment are difficult to measure. The authors assume that the damper constant d is neglected for control law. And a spring with the stiffness k_r is inserted between the end of rope and for the convenience, the authors try to introduce an observer for estimating the necessary dynamic motions such as load position or displacement etc. Because it may be impossible to measure the motions due to the irregular types of the loads.

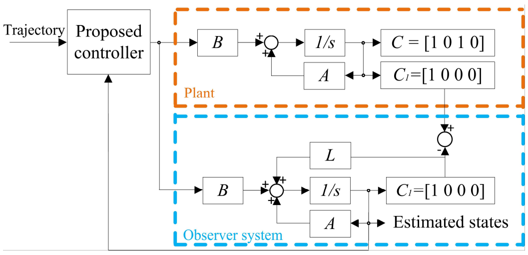

Fig. 2. Observer structure.

The control law is derived via the input-output feedback linearization method and written as follows:

$$v = \frac{\frac{k_w Z_w + d_w \dot{Z}_w}{J_w} + \left(\frac{r_w k_r}{J_w} - \frac{k_r}{m}\right)\hat{\Delta L}}{\frac{\eta}{J_w}} + \\ + \frac{y_{ref}^{(4)} - k_0 e_{error} - k_1 \dot{e}_{error} - k_2 \ddot{e}_{error} - k_3 e_{error}^{(3)}}{\frac{k_r}{m}\frac{\eta}{J_w}} \quad (6)$$

4. Experimental Results

With 2 types of the input trajectory, the effectiveness of proposed controller is evaluated by PID and Observer-based control method.

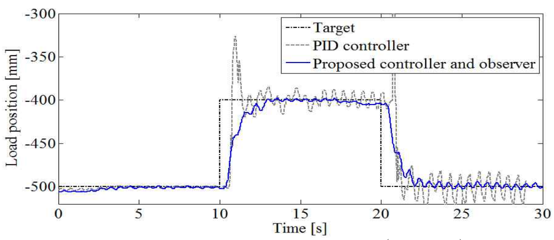

Fig. 3. Experimental result (case 1).

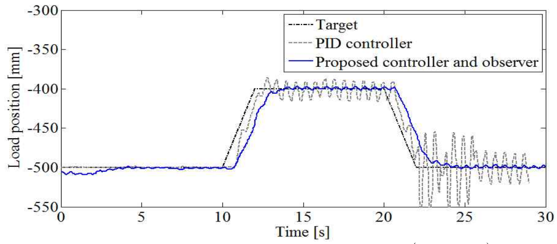

Fig. 4. Experimental result (case 2).

In Fig. 3, the observer based control method can not give good tracking performance (blue-solid line). Especially, in the steady state, vibrated motion is appeared. As the second try, as in Fig. 4, we can find out more improved transient responses for all control methods.

5. Conclusions

The paper proposed a nonlinear control strategy for controlling load position of a crane system under effecting of the elasticity of the rope. Experimental results showed that the proposed controller make the controlled system track the reference target exactly without undesirable motions in the steady state, especially without information of load motions.

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