Investigation of sway angle characteristics in gantry crane system by PSD analysis

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ABSTRACT – This paper attempts the investigation of the 2D-gantry crane system which focused on the sway angle characteristics via Power Spectral Density (PSD) analysis. The dynamic model of the nonlinear gantry crane system is derived by using Lagrange Equation. The system is simulated in MATLAB environment and the result is presented in the form of time and frequency domain. A comparative assessment of the various payload mass and rope length of the system performance is assessed and discussed.

1. INTRODUCTION

Gantry crane is important in the transportation industry for loading and unloading load. The control objective of this system is to move the trolley to a desired position as fast and accurate as possible without causing any immoderate sway at the final target position. In transportation industry, speed is required as the priority issue as it translates into productivity and efficiency of the system. However, controlling the crane manually by human will tend to excite sway angles of the hoisting line and degrade the overall performance of the system. At very low speed, the payload angle is not significant and can be ignored, but not for high speed condition. The sway angle become larger and hard to settle down during movement and unloading [1]. Besides, the effect of increasing the hoisting will degrade the performance of sway angle. This is very severe problem especially in the industries which requires small of sway angle with time taken for the transportation is short and high safety.

2. DYNAMIC MODEL STRUCTURE

In this section, a dynamic model of nonlinear gantry crane is formed. Assuming the dynamic model has the characteristics that the trolley and payload are connected by a massless, rigid link as in Figure 1 and the parameter of the system is shown in Table 1.

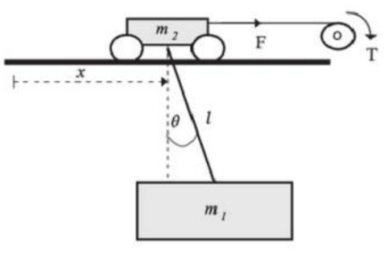

Figure 1 Dynamic model structure of gantry crane [2]

Table 1 Parameters of the dynamic gantry crane model structure [2]

Parameters	Values
Payload mass (m1)	0.5 to 50 kg
Trolley mass (m2)	5 kg
Rope length (l)	0.5 to 1.5 m
Gravitional (g)	9.81 ms^{-2}
Friction (B)	12.32 Nsm^{-1}
Resistance (R)	2.6
Torque constant (Kt)	0.007 NmA^{-1}
Electric constant (Ke)	0.007 $Vsrad^{-1}$
Radius of pulley (rp)	0.02 m
Gear ratio (z)	0.15

From the previous study [2], it shown that Lagrange Equation are frequently used to derive the model of the gantry crane system. Therefore, Lagrange equation is chosen for mathematical modeling of the system where L, T and P represent Lagragian function, kinetic energy and potential energy.

$$L = T - P \tag{1}$$

The kinetic energy and potential energy of the whole system are:

$$T = \frac{1}{2}m_1\left[\dot{x}^2 + l^2\dot{\theta}^2 + 2\dot{x}l\dot{\theta}\cos\theta\right] + \frac{1}{2}m_2\dot{x}^2 \tag{2}$$

$$P = -mgl\cos\theta \tag{3}$$

Constructing Equation (2) and (3) by using Lagrange Equation as in Equation (4) where qi and Qi represent independent generalized coordinate and nonconservative generalized coordinate.

$$\frac{d}{dt}\left[\frac{\partial L}{\partial \dot{q}_i}\right] - \frac{\partial L}{\partial q_i} = Q_i \tag{4}$$

The following equations of motion for trolley position (Equation 5) and payload sway (Equation 6) can be obtained as:

$$(m_1 + m_2)\ddot{x} + m_1 l\ddot{\theta}\cos\theta + 2\dot{x}l\dot{\theta}\cos\theta + B\dot{x} - m_2 l\dot{\theta}^2\sin\theta = F \tag{5}$$

$$m_1 l\ddot{x}\cos\theta + m_1 l^2\ddot{\theta} + m_1 gl\sin\theta = 0 \tag{6}$$

The force in the Equation (7) is derived from the DC motor at the trolley to be substituted in Equation (5).

$$F = \frac{VK_t z}{Rr_p} - \frac{K_e K_t z^2}{Rr_p^{\ 2}}\dot{x} \tag{7}$$

The equation of the position and sway in the overall system is in the equation (8) and (9). In this paper, only sway part will be focused.

$$\ddot{x} = \left(\frac{VK_t z}{Rr_p} - \frac{K_e K_t z^2}{Rr_p^{\ 2}} \dot{x} - B\dot{x} - m_1 l \ddot{\theta} \cos\theta + m_1 l \dot{\theta}^2 \sin\theta \right) \left(\frac{1}{(m_1 + m_2)} \right) \quad (8)$$

$$\ddot{\theta} = \left(\frac{1}{m_1 l^2} \right) \left(m_1 l \ddot{x} \cos\theta + m_1 g l \sin\theta \right) \quad (9)$$

3. SIMULATION

Figure 2 shown the design with the development of position and sway as in Equation (8) and (9) respectively in Simulink.

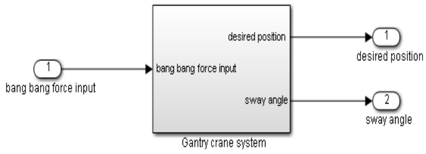

Figure 2 Gantry crane system block model

4. RESULTS AND DISCUSSION

The performances of the sway angle are analyzed in Power Spectral Density (PSD). PSD is a measure of a signal power intensity in the frequency domain to identify oscillatory signals in time series data and verify their amplitude. It is also states at which frequency ranges variation is strong and that might be quite useful for further analysis. There were three sets of mass had been tested in payload section which were 0.5 kg, 1.0 kg and 1.5 kg. The performance of the sway sway is analyzed in PSD. Based on Figure 3, when the payload mass is 0.5 kg, the PSD is at the normalized frequency of 0.2.44 π rad/sample. When the mass is tested with 1.0 kg, it shows that the PSD is at 0.2500 π rad/sample which is higher than 0.5 kg. Then, the test is continued with 1.5 kg of payload mass. It shows that the frequency created at 0.2578 πrad/sample. Table 2 shows the summarize of the response in the frequency domain with various of payload mass.

Figure 4 shows that when the payload mass is 0.5 m, the PSD shows the normalized frequency of 0.2734 π rad/sample. When the rope length is tested 1.0 m, it shows that the frequency is 0.1953 π rad/sample which is lower than 0.5 m. Lastly, when the system is tested to 1.5 m of rope length. It shows that the frequency created at 0.1563 π rad/ sample. Table 3 shows the summarized of the response in the frequency domain with various of rope length.

5. CONCLUSIONS

Investigation of the sway angle characteristic for a dynamic model of gantry crane system with variation of payload mass and rope length has been presented. The model structure of the gantry crane system is developed using Langrage Equation and simulated with bang-bang force input. The response of the sway angle has been obtained and analyzed in both time and frequency domain. From these findings, it is useful and important in the development of controller for 2-D gantry crane system in order to minimize the sway angle and also able for the trolley to reach the target position.

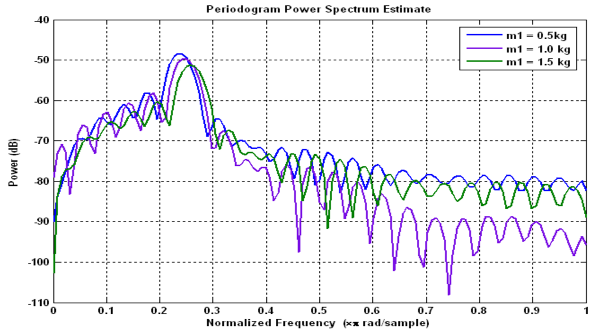

Figure 3 Response in the frequency domain of several of payload mass

Table 2 Summarize of response in the frequency domain with several of payload mass

Payload mass, m1 (kg)	Power, (dB)	Normalized frequency (πrad/sample)
0.5	-48.41	0.2344
1.0	-49.75	0.2500
1.5	-51.23	0.2578

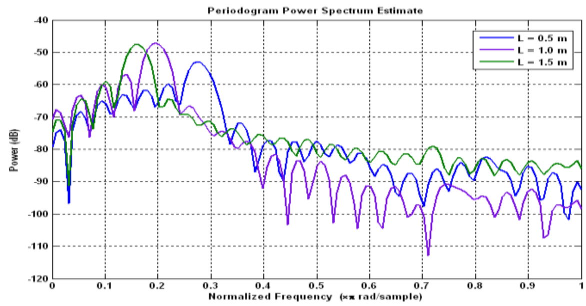

Figure 4 Response in frequency domain of various of rope length

Table 3 Summarize of response in frequency domain with several of rope length

Rope length, l (m)	Power, (dB)	Normalized frequency (π rad/sample)
0.5	-52.89	0.2734
1.0	-47.08	0.1953
1.5	-47.78	0.1563

6. REFERENCES

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