International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 1 Issue 3, May - 2012

Optimization of Dynamics Parameters and the Effect of Sway Angles in Hydraulic Crane Hook

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ABSTRACT: - *The present scenario focuses on crane hook suffers by sway angle due to the pendulum motion of payload, to put hold on the sway angle, to increase the efficiency and user friendly approach. Here the paper presents the design of anti-sway controller brake system for hydraulic floor crane by studying the parameters like mass & length and by the use of mathematical models & equation like Lagrange's equation to achieve the equation of motion was optimized then automatically or self actuating anti-sway controller system was designed. Synchronized algorithm for the practical correct and excellent use of hydraulic floor crane for loading and unloading the goods. The result of this mathematical model shows the effect of mass and length if changed then sway angle is optimized.*

KEY WORD:-*Crane System, Lagrange's Equation, Crane hook, Weigh Sensor, Payload, Sway Angle and Mathematical Model.*

INTRODUCTION:-

Firstly in today's world the use of floor crane is going wide sprayed and this use is directly related with two parameters firstly the efficiency Secondly user friendly approach. The floor cranes use are many like domestic, industrial Construction site etc. While going through all this we observe major lacuna in the hook of the crane. This lacuna is the sway angle. We call this sway angle as lacuna because while lifting, transportation & placing the load, then hook of hydraulic floor crane play the major role that will put direct impact on the above said parameter i.e. user friendly approach and efficiency. This sway in the hook of the crane will slow down the working of the crane & decrease the efficiency on the other hand the driver has to keep acute vision during the motion of the crane. To put all this problem on hold this antis-sway controller system for the hook of the crane is designed by learning the optimization of dynamic parameters of crane hook and the effect of sway angle in hydraulic floor crane. Recently designed cranes are larger and have higher lifting capacities and travel speeds. To achieve high productivity and to comply with the safety requirements, these cranes require effective controllers such as anti swing controls. Inertia forces due to the motion of the crane can induce significant payload oscillations. If the oscillations of the payload can be constrained using an appropriate method, there will be a number of benefits such as having greater yield and safety margin, enabling higher operating speed, enhancing work quality and creating greater throughput for a given installed capacity. Besides, most actual systems are influenced by noise and external disturbances including crane.

PROBLEM BACKGROUND:- Among the several of types of cranes, hydraulic cranes are the mainly used.They are used for loading, unloading and transporting the load. One of the most essential problems in the cranes is wavering of the payload which is produced by various factors arising mostly from the crane maneuvers and motions of the crane's components forperforming the desired operations. Payload influence slows down the movement and transmission of the payload process because extra time is required to let the pendulum motion come to a stop.

HYDRAULIC FLOOR CRANE:-

Figure (1) Computer Model for Hydraulic Floor Crane

METHODOLOGY:-

SYTEM MODELLING FOR HYDRAULIC CRANE:-

Figure 1 shows the schematic system of a crane. It is consist of two boom (Main boom and Auxiliary boom) two hydraulic cylinder. The mathematical model for this hydraulic crane are shown figure 2. With their hook rotation and payload rotation various direction. Before analyzing the dynamic motion of hook parameter of the crane into a mathematical model, a number of assumptions are introduced, so that the crane model can be simplified.

Assumptions for Mathematical Model

1) The payload and crane hook (only) are supposed to have simultaneous motion in determining the equation of motion.
2) A hydraulic floor crane with two booms and two hydraulic cylinders is considered to create a mathematical model.
3) In this model the effect of crane motion in straight rotation of hook steering and movement of payload is considered for deriving the equation of motion.
4) The entire motion of hook and payload considered as general plane motion due to crane movement.
5) The mass of hook is considered as point mass and length of payload (L_p) considered weightless.
6) (L_p) has displacement in X, Y and Z direction but hook length (L_h) displace in X and Z direction only.
7) Neglect the effect of air resistance on the movement of hook and payload.

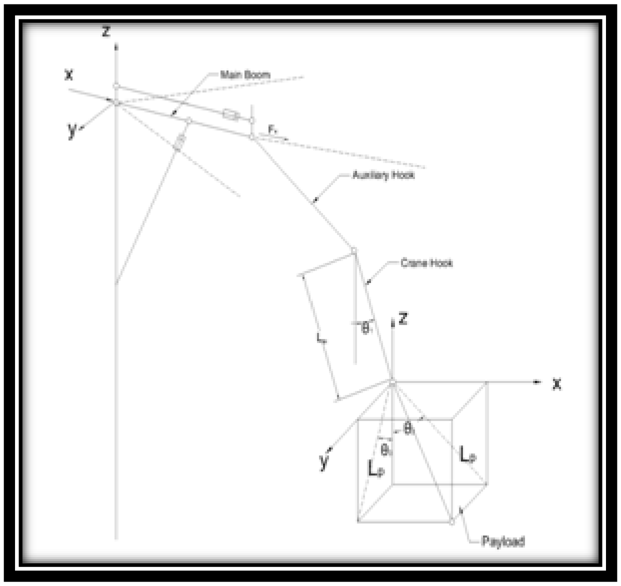


Figure (2) Mathematical Model for Hydraulic Floor Crane

FORMULATION FOR DYNAMIC PARAMETERS AND SWAY ANGLE:-

Firstly we are derived the equation of motion for the payload and crane hook by using Lagrangian equation. It is a scalar procedure which is starting from the scalar quantities of kinetic energy, potential energy and express in generalized coordinates. It is given as:

$$\frac{d}{dt}\left[\frac{\partial L}{\partial \dot{q}_i}\right]-\left[\frac{\partial L}{\partial q_i}\right]=F_i \quad [1]$$

Where, L = T – U
T = Total Kinetic Energy,
U = Total Potential Energy
F_i = Non potential Forces,

q_i = Generalized Coordinates

$\dot{q}_i$ = Velocity Coordinates

So, $$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right)-\left(\frac{\partial T}{\partial q_i}\right)+\frac{\partial U}{\partial q_i}=Q_i$$ **[2]**

Here, $q_1=\theta_1, q_2=\theta_2, q_3=\theta_3, q_4=x$

EQUATION OF MOTION FOR PAYLOAD AND HOOK:-Displacement of payload in X, Y and Z direction

$$x_p = L_p \sin\theta_2 + L_h \sin\theta_1 + x \quad [3]$$

$$Y_p = L_p \sin\theta_3 \quad [4]$$

$$Z_p = L_p \cos\theta_2 + L_h \cos\theta_1 + L_p \cos\theta_3 \quad [5]$$

Displacement of hook in X and Z direction

$$X_h = L_h \sin\theta_1 + x \quad [6]$$

$$Z_h = L_h \cos\theta_1 \quad [7]$$

So the resultant velocity vector for payload and hook is given as

$$V_p^2 = \dot{x}_p{}^2 + \dot{y}_p^2 + \dot{z}_p{}^2 \quad [8]$$

$$V_h^2 = \dot{x}_h{}^2 + \dot{y}_h{}^2 + \dot{z}_h{}^2 \quad [9]$$

Total kinetic energy (K.E.) is

$$T = T_p + T_h \quad [10]$$

Where, K.E. for payload

$$T_p = \frac{1}{2}m_p v_p^2 + \frac{1}{2}I_p\dot{\theta}_2^2 + \frac{1}{2}I_p\dot{\theta}_3^2 \quad [10.a]$$

And K.E. for hook

$$T_h = T_2 = \frac{1}{2}m_h v_h^2 + \frac{1}{2}I_h\dot{\theta}_1{}^2 \quad [10.b]$$

So

$$T=\begin{bmatrix} \frac{1}{2}m_p\left[[L_p\theta_2\cos\theta_1+L_h\dot{\theta}_1\cos\theta_1+\dot{x}]^2+[L_p\dot{\theta}_3\cos\theta_3]^2+[-L_p\dot{\theta}_2\sin\theta_2-L_h\dot{\theta}_1\sin\theta_1-L_p\dot{\theta}_3\sin\theta_3]^2\right] \\ +\frac{1}{2}I_p\dot{\theta}_2+\frac{1}{2}I_p\dot{\theta}_3^2+\frac{1}{2}m_h\left[[\frac{1}{2}L_h\dot{\theta}_1\cos\theta_1]^2+[-\frac{1}{2}L_h\dot{\theta}_1\sin\theta_1]^2\right]+\frac{1}{2}I_h\dot{\theta}_1^2 \text{............}[11] \end{bmatrix}$$

Total Potential Energy (P.E.) is

$$U = u_p + u_h \quad [12]$$

Where, P.E. for payload

$$u_p = m_p g[L_p\cos\theta_3 + L_p\cos\theta_2 + L_h - L_h\cos\theta_1]$$

P.E. for hook

$$u_h = m_h g[L_h - L_h\cos\theta_1]$$

So

$$U = m_p g[L_p\cos\theta_3 + L_p\cos\theta_2 + L_h - L_h\cos\theta_1] + m_h g[L_h - L_h\cos\theta_1]..[13]$$

Putting the value of derivative of K.E. and P.E. from equation [11] and [13] in Lagrange's equation. So linear equation in term of angular acceleration (as variable) of hook and payload are given blow:

Let

$$A_1 = Sin\theta_1, A_2 = Sin\theta_2, A_3 = Sin\theta_3$$
$$B_1 = Cos\theta_1, B_2 = Cos\theta_2, B_3 = Cos\theta_3$$
$$C_1 = Sin2\theta_1, C_2 = Sin2\theta_2$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\theta}_3}\right)-\left(\frac{\partial T}{\partial \theta_3}\right)+\frac{\partial U}{\partial \theta_3}=0$$

$$\ddot{\theta}_3[L_pB_3+L_p^2A_3^2+I_p]+\ddot{\theta}_2m_p[L_p^2A_2A_3]+\ddot{\theta}_1m_pL_hL_pA_1A_3+\ddot{x}[0]=V_3$$

[14]

Where,

$$V_3 = m_p\dot{\theta}_3[C_3L^2{}_p - L_pA_3] + \dot{\theta}_2{}^2m_pL^2{}_pA_3B_2 + \dot{\theta}_1^2L_hL_pm_pA_1A_3 + m_pgL_pA_3$$

Similarly,

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\theta}_2}\right)-\left(\frac{\partial T}{\partial \theta_2}\right)+\frac{\partial U}{\partial \theta_2}=0$$

$$\ddot{\theta}_3[m_pL_p^2A_2A_3]+\ddot{\theta}_2[m_pL_p^2B_2^2+m_pL_p^2A_2^2+I_p]+\ddot{\theta}_1[m_pL_pL_h][B_1B_2+A_1A_2]+\ddot{x}[m_pL_pB_2]=V_2$$

[15]

Where

$$V_2 = -\dot{\theta}_3^2 A_2 B_3 m_p - \dot{\theta}_1[m_p L_p L_h B_1 A_2 - m_p L_p L_h A_1 B_2] + \dot{\theta}_1\dot{\theta}_2 B_1 m_p - \dot{\theta}_3\dot{\theta}_2 m_r (B_2 A_3 - L_p^2 A_3 B_2)$$
$$+\dot{x}\dot{\theta}_2 m_p L_p A_2 + \theta_2 m_p L_p^2 A_2 B_2 + \theta_2 L_p^2 m_p B_1^2 + \dot{\theta}_1 L_p L_h m_p B_1^2 + \dot{x} L_p m_p B_1$$

Similarly

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\theta}_1}\right) - \left(\frac{\partial T}{\partial \theta_1}\right) + \frac{\partial U}{\partial \theta_1} = 0$$

$$\ddot{\theta}_3[m_p L_h L_p A_1 A_3] + \ddot{\theta}_2[A_1 A_2 + B_1 B_2] m_p L_p L_h + \ddot{\theta}_1 L_h[m_p A_1^2 + \frac{m_h}{4} B_1^2 + \frac{m_h}{4} A_1^2 + I_h]$$
$$+\ddot{x} m_p L_h (A_1 + B_1) = V_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [16]$$

Here

$$V_1 = -\theta_3^2 (A_1 B_3 m_p) - \dot{\theta}_2^2 m_p [L_p^2 A_1 B_1 + L_p L_h (B_1 A_2 +) A_1 B_2] - \dot{\theta}_1^2 m_p L_h^2 L_1 + \dot{x} m_p L_h A_1$$
$$+\dot{\theta}_1\dot{\theta}_2 M_p L_p L_h (2A_2 B_1 + B_2 A_1) - \dot{\theta}_1\dot{\theta}_3 L_h L_p B_1 A_3 (m_h - m_p) - \dot{x}\theta_1 m_p L_h (B_1 A_1) + \dot{x}\theta_2 m_p L_p A_1$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{x}}\right) - \left(\frac{\partial T}{\partial x}\right) + \frac{\partial U}{\partial \theta} = F_x$$

$$[0]\ddot{\theta}_3 + \ddot{\theta}_2[m_p L_p B_2] + \ddot{\theta}_1[m_p L_h A_1] + \ddot{x}[m_p - m_1] = V_x \; [17]$$

Where

$$V_x = \dot{\theta}_2 m_p L_p L_p A_2 + \dot{\theta}_1^2 m_p L_h A_1$$

Non potential force $F_x = (m_{cr} + m_p)\ddot{x}$

SPECIFICATION: - Assumed parameters for hydraulic floor crane

Table 1:

	Length (In meters)	**Mass (In Kilograms)**	**Moment of Inertia (I)=(mass*length^2) (In Kg. (meters)^2)**
Payload	0.55	2050	620
Crane hook	0.45	8	1.62

FORMATION OF MATRICES:-

The equations of motion are constructed by using Lagrange's equation for angular acceleration ($\ddot{\theta}_1, \ddot{\theta}_2 and \ddot{\theta}_3$), which gives the relation between the mass of and length of the hook which given by equation [15], [16] and [17]. There are four variable so the matrices of 4X4 were constructed for the mass and length of the hook. Now the matrices are form for the mass and length of the hook at the angle of rotation of crane and boom of 30^0 by using the specification of crane. This equation represents the value of angular acceleration related to sway angles ($\ddot{\theta}_1, \ddot{\theta}_2 and \ddot{\theta}_3$).

Mass Matrices for angular acceleration at $\theta = 30^0$

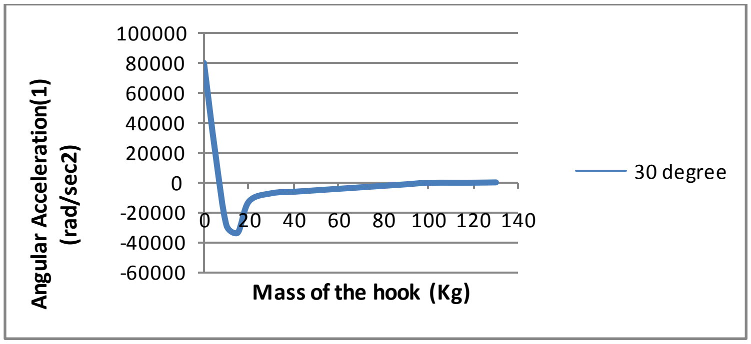
$$\begin{bmatrix} 620 & 0.130 & 0.0618 & 0 \\ 0.0756 & 620.30 & 0.2475 & 0.476 \\ 126.84 & 507.3 & 231.35 + 0.1125 m_h & 1260 \\ 0 & 976.44 & 461.25 & -m_h \end{bmatrix} \begin{bmatrix} \ddot{\theta}_3 \\ \ddot{\theta}_2 \\ \ddot{\theta}_1 \\ \ddot{x} \end{bmatrix} = \begin{bmatrix} 2.877 \\ 0.789 \\ -848.04 + 107\, m_h \\ 1025 \end{bmatrix} \quad [18]$$

Length Matrices for angular acceleration at $\theta = 30^0$

$$\begin{bmatrix} 620.55 & 0.130 & 0.1375 L_h & 0 \\ 0.0756 & 620.30 & 0.55 L_h & 0.476 \\ 281.87 L_h & 1127.5 L_h & 518.12 L_h & 2800 L_h \\ 0 & 976.44 & 1025 L_h & -8 \end{bmatrix} \begin{bmatrix} \ddot{\theta}_3 \\ \ddot{\theta}_2 \\ \ddot{\theta}_1 \\ \ddot{x} \end{bmatrix} = \begin{bmatrix} 2.815 + 0.1375 L_h \\ 0.604 + 0.185 L_h \\ -102 + 3726 L_h + \\ 1775.3 L_h{}^2 \\ 563.75 + 0.275 L_h \end{bmatrix}$$

RESULTS AND DISCUSSION:-

The mass and length matrices show the relation between angular acceleration (sway angle $\ddot{\theta}_1, \ddot{\theta}_2 and \ddot{\theta}_3$) mass and length of the hook. These matrices were solved by using the MATLAB software for different value of mass and length of hook and angle of rotation of boom and crane. The results were shown by drawing the graphs between the angular acceleration and mass and length of the hook at different angle of rotation of crane and boom like 300, 450 and 600. By increasing the mass of the hook then $\ddot{\theta}_1$ began to increases but at 15 kg to 18kg it is decreasing shown in graph (3).



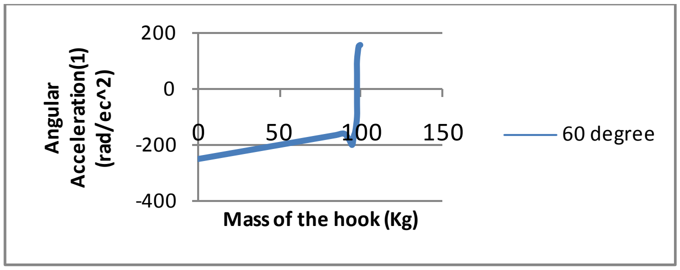
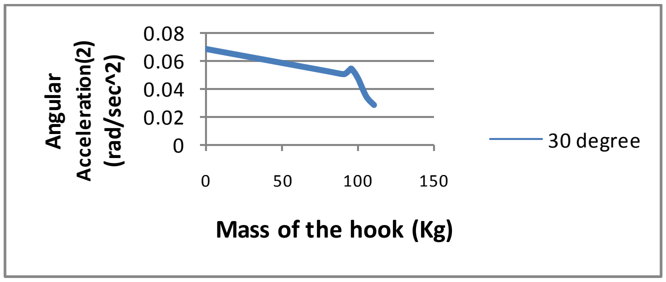


Figure (3) Effect of mass of hook on $\ddot{\theta}_1$



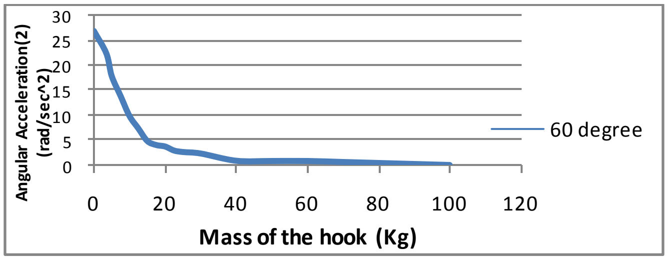
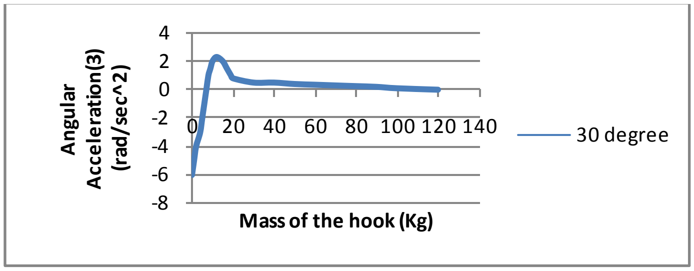


Figure (4) Effect of mass of hook on $\ddot{\theta}_2$



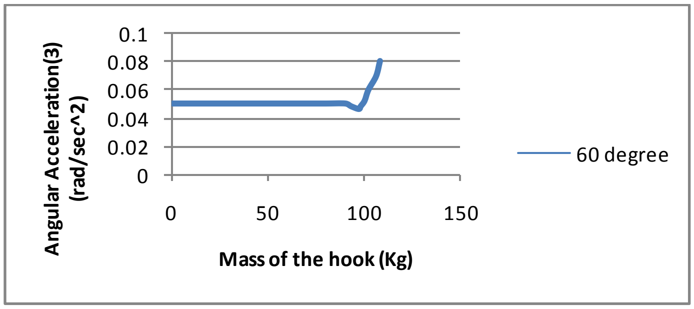
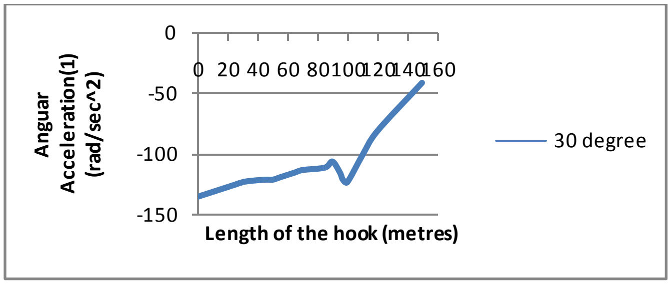


Figure (4) Effect of mass of hook on $\ddot{\theta}_3$



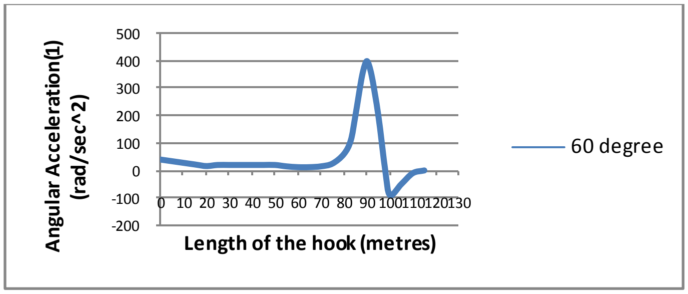
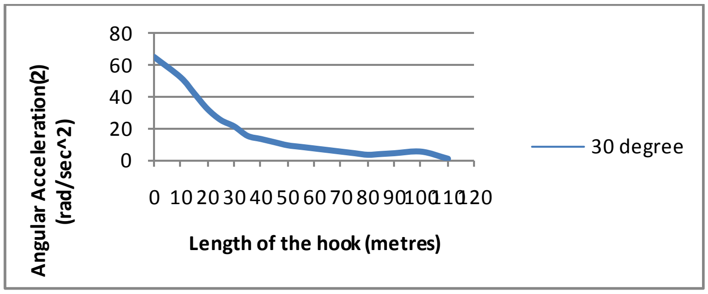


Figure (3) Effect of Length of hook on $\ddot{\theta}_1$



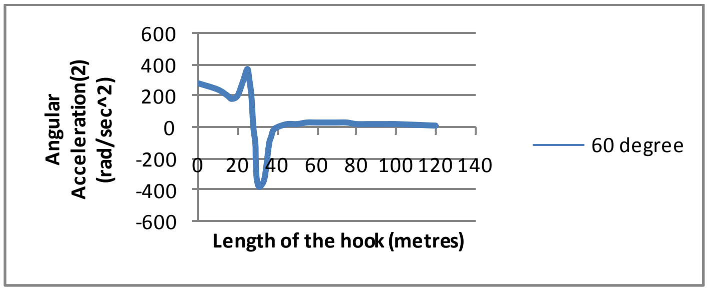
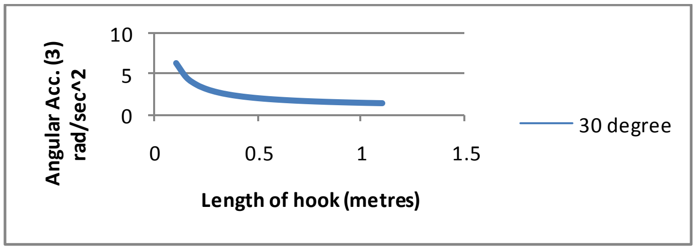


Figure (3) Effect of Length of hook on $\ddot{\theta}_2$



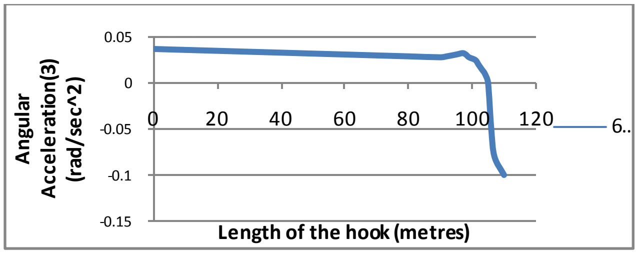


Figure (3) Effect of Length of hook on $\ddot{\theta}_3$

CONCLUSION:-

In this paper the concept shows that the hook of the crane experiences pendulum motion when payload is attached. This motion is optimized by changing the hook parameters like mass and length of hook by framing the equation of motion for the hook and payload of crane using Lagrange's equation for controlling the sway angle of hook and payload. A hydraulic floor crane with 4 degree of freedom to increase the efficiency of floor crane, Straight motion of the crane and rotation of hook and payload was considered, such condition gives the complicated non-linear equations. This equation was converted into mass metrics and length metrics and was solved in MATLAB software accordingly. The assumed mathematical model is used for hydraulic floor crane with two booms and two hydraulic cylinders. The result obtained as shown in attached chart and graph, which shows that while increasing the mass and length of hook, would reduce and optimize the pendulum motion and sway angle of the hook and payload.

NOMENCLATURE:-

Xp , YP and ZP = Displacement of Payload in X,Y and Z direction.

Xh , Yh and Zh = Displacement of Payload in X,Y and Z direction

θ_1 = Angle of rotation of hook in a vertical plain in X direction.

θ_2 = Angle of payload rotation in vertical plain in X direction.

θ_3 = Angle of rotation of hook in an in X direction.

Lp, Lh, mp and mh = Length and mass of payload and hook of a crane

Ip and Ih = Mass moment of inertia for payload and hook

T and U = Total Kinetic and Potential Energy

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