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$$u = -10x_1 - 13.4966x_2 + 31.2263x_3 + 7.8037x_4 \quad (18)$$

This compensated system is considered to an optimal system which results in a minimum value for the performance index. The simulation of this compensated system is done in the next section.

This section discusses about the design of a stable control system for the overhead crane based on quadratic performance indexes. The main advantage of using the quadratic optimal control scheme is that the system designed will be stable, except in the case where the system is not controllable. The matrix 'P' is determined from the solution of the matrix Riccatti equation. This optimal control is called the Linear Quadratic Regulator (LQR).

The optimal feedback gain matrix k can be obtained by solving the following Riccatti equation for a positive-definite matrix 'P'.

$$A^T P + PA - PBR^{-1}B^T P + Q = 0 \quad (19)$$

$$\text{Let } Q=\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (20)$$

$$R = [0.01] \quad (21)$$

Tuning of Q and R matrix, we get P matrix.

$$P=\begin{bmatrix} 1.4775 & 0.5833 & -0.7804 & 0.1206 \\ 0.5833 & 0.7484 & -1.2736 & 0.1499 \\ -0.7804 & -1.2736 & 5.9359 & -0.1955 \\ 0.1206 & 0.1499 & -0.1955 & 0.1057 \end{bmatrix}$$

$$k = R^{-1}B^T P \quad (22)$$

$$u = -10x_1 - 13.4966x_2 + 31.2263x_3 + 7.8037x_4 \quad (23)$$

This control signal yields an optimal result for any initial state under the given performance index.
In LQR the cost function which is to minimized is

$$J = \int_0^\infty (X^T QX + U^T RU)\,dt \quad (24)$$

The two matrices Q and R are selected by design engineer by trial and error. Generally speaking, selecting Q large means that, to keep J small. On the other hand choosing R large means that the control input u must be smaller to keep J small One should select Q to be positive semi definite and R to be positive definite. This means that the scalar quantity $X^T QX$ is always positive or zero at each time t. The Q & R matrix is tuned by trial & error method. The trial & method is done by MATLAB coding's. The best value of the Q & R matrix is calculated by checking the step response of the system (with LQR).

7. Simulation Results

MATLAB software package is used to determine the response of the system. The Simulink model of the system with optimized values of PD and PID controller is created in MATLAB. Tuning of the Q & R matrix is done by separate coding. The regulation of position and swing angle is determined with tuning of Q & R matrix and the tracking of the crane also determined. The Simulink model of the system is developed.

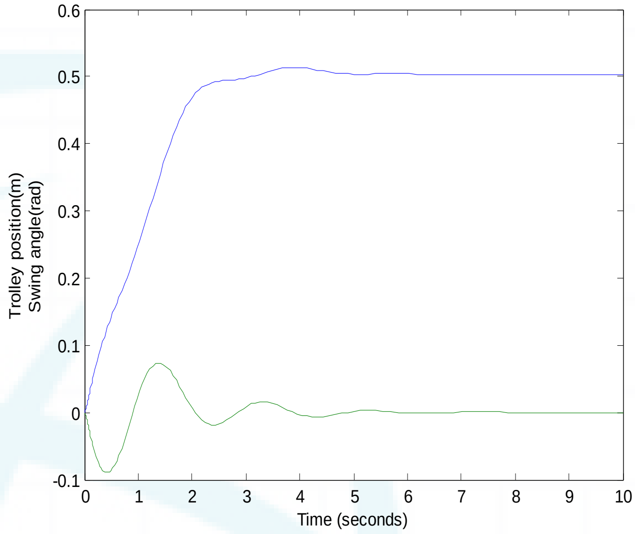

Figure 2: Position and swing angle control using PD and PID controller

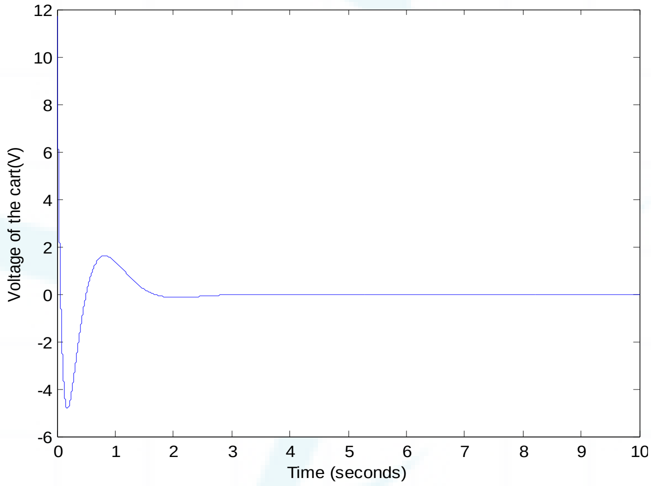

Figure 3: Voltage of the cart

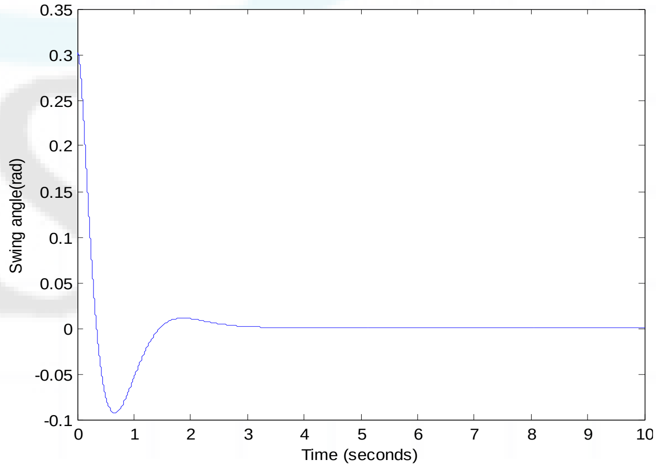

Figure 4: Swing angle of the crane

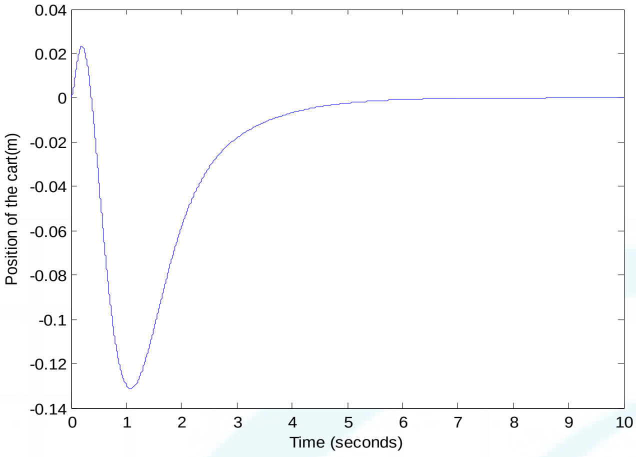

Figure 5: Position of the cart

The figure 2 shows the position and swing angle control using optimized values for Kp, Ki, Kd, Kps and Kds which are the proportional, integral and derivative gains for position control and proportional, derivative gains for anti-swing control. From figure 3, figure 4 and figure 5, the system is regulated at 2 sec, 3 sec and 5 sec respectively and the system consists of small no of overshoot and undershoot when compared to PD and PID controller. The system is precisely regulated at this condition.

8. Conclusion

In this paper a state variable feedback system was designed for the overhead crane to achieve the desired system response. Also, an LQR system was designed for the crane which results in a minimum value for the performance index. This optimal controlled system results in a minimum value for the performance index. Also, the control law given by equation (18) yields optimal result for any initial state under the given performance index. Both the transient and steady state response of the system is improved with LQR controller. This design based on the quadratic performance index yields a stable control system for the overhead crane.

9. Future Scope

From the foregoing analysis, disturbance is not introduced into the system. A tuned Linear Quadratic Gaussian controller eliminates the disturbance affect into the system. A noise signal is added in the system and compare the response of the with tuned LQR controller.

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