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# Design & Development of Robust Control for Paper Making Headbox System

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**Abstract: The objective of this paper is to control pulp total head & pulp stock level of a paper making headbox system. A physical modeling of headbox is made based on a general laws of control. Due to the wide range variations of pulp stock and dilution water in the headbox , the system dynamics change considerably. The different strategies for total head and stock level control are presented in this paper. The controller design is based on a combination of kalman observer along with optimal linear quadratic Gaussian (LQG) controller. Kalman filter is used to design an observer that estimates desired states and state feedback controller gain is estimated using LQG or using linear quadratic criterion. The state controllers improves the regulation performance. LQG/LTR robust control strategy which reduces the uncertainty & compared with PID controller commonly used in industry. The LQG/LTR robust control strategy improves the performance of the system.**

**Keywords: Linear quadratic Gaussian (LQG/LTR), kalman, state space model, headbox.**

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## I- INTRODUCTION

Robust control is used to analyze and design MIMO system with uncertain parameters. If the control system meets its performance and stability objectives in the presence of all noises or model uncertainty then the system is said to be robust. The paper machine head box is a subsystem of paper making process. This is complex and non linear system in nature due to interaction of parameters like stock level, stock flow, total head, jet velocity, wire speed, air flow, and consistency of the stock. But in present investigation total head, stock level, air supply and stock supply parameters are considered. The modeling of head box is not possible in the presence of all parameters and disturbances or noises. The robust control is only choice to model the system in the presence of disturbances. So, system needs advance control strategy i.e. linear quadratic gaussian(LQG)/loop transfer recover(LTR). In this paper, the classical controller (PID) and LQG are considered to analyze the performance of head box MIMO system.

## II- PAPER MAKING HEADBOX

Headbox is a subsystem of paper making process. Headbox delivers the pulp stock uniformaly on the weir in the cross & machine direction. It plays an important role to control basis weight of the pulp. The head box with rectifier rolls without over flow in a multi grade paper machine is chosen for control purpose. Stock is fed to the head box with a fan pump which is also used as main control device for the total head. The stock level in the pond is controlled using an air caution is adjusted with a constant speed air pump and four control valves. Over all transfer function is given by reference [1] Fig.1 shows MIMO configuration to control total head and stock level in a head box system of a paper mill.

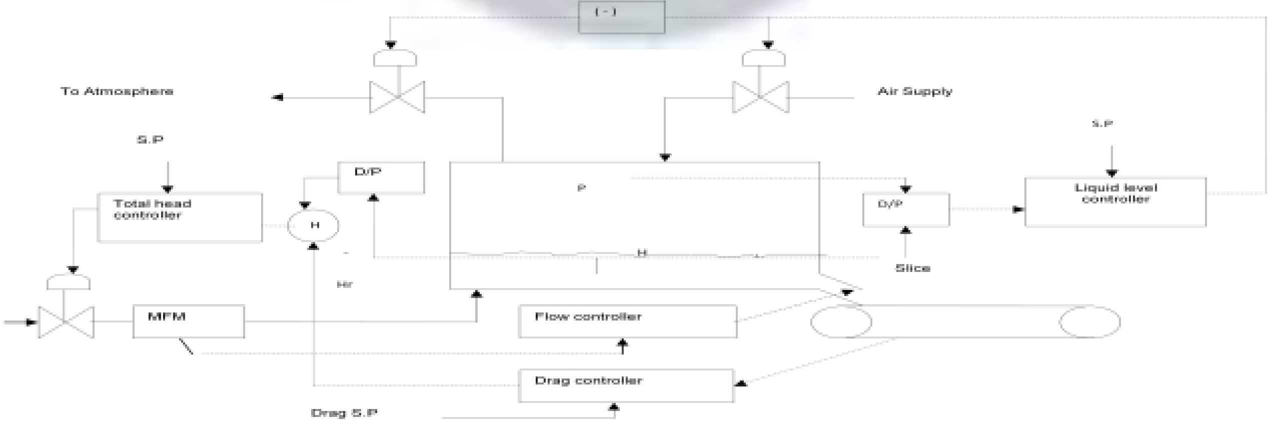


Fig.1 Pressurized air cushion head box

The process flow diagram of pressurized air cushion headbox is shown in Fig. 1. It is complex in nature. The air pressure, total head , stock flow and the stock level parameters are associated with it and interact outputs in case of MIMO( multivariable input & multivariable output). There are two conditions: drag & rush condition. When the conveyor belt speed is high & the pressure inside the headbox is less then the drag with each other. The total head control is based on the output of drag controller. A turbulence is also situated inside the headbox to mix the pulp and dilution water. Air supply valve and stock supply valve are inputs & the total head and stock level are condition will be created. And when the conveyor belt speed is slow and the pressure is high then the rush condition will be created. The main purpose of headbox is to maintain the rush and drag ratio.

## III– MODEL DEVELOPMENT

**Development of PID controller:** PID controller provides a controlling action according to the error between measured variable and the desired set point. The controller tries to minimize the error in outputs by adjusting the controller parameters i.e proportional gain, integral time & derivative time. The transfer function of total head is suggested by Nissinen[6].

$$y1 = \frac{0.528e^{-6s}}{2.2s+1} * u1 + \frac{1.2539s+.063}{30.051s^2+17.79s+1} * u2 \quad (1)$$

The transfer function between total head ($y_1$) & air supply valve ($u_1$) is:

$$\frac{y1}{u1} = \frac{.528-1.584s}{6.6s^2+5.2s+1} \quad (2)$$

And the transfer function between total head ($y_1$) & stock supply valve($u_2$)

$$\frac{y1}{u2} = \frac{1.2539*s+.063}{30.051*s^2+17.79*s+1} \quad (3)$$

Simulink model of the headbox system with PID controllers have been developed on matlab simulink toolbox. The controllers are tuned automatically, shown in Fig. 2 & 3.

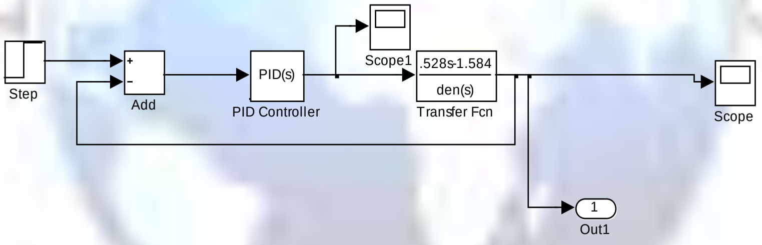


**Fig.2 Simulink model of PID controller for $y_1/u_1$**

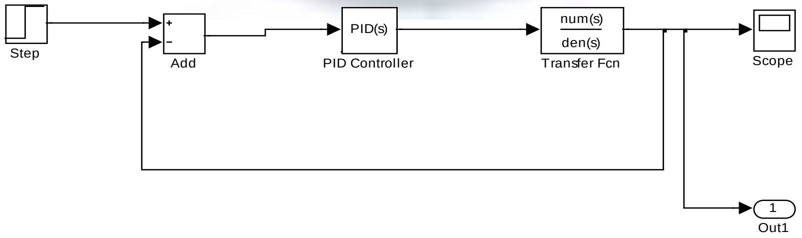


**Fig. 3 Simulink model of PID controller for $y_1/u_2$**

**Development of LQG controller:** Robust controller for MIMO system of head box (total head & stock level) has been developed on the basis of state space model as mentioned in equation (2) & (3). One can calculate state space variable i.e. A,B,C,D for the dynamics as mentioned in equation (1).Pade's approximation theorem is used for linearization, the equation (2) becomes

$$\frac{\mathrm{y1}}{\mathrm{u1}} = .528 * \frac{(1-3\mathrm{s})}{(2.2\mathrm{s}+1)*(1+3\mathrm{s})}$$

$$\frac{\mathrm{y1}*\mathrm{x1}}{\mathrm{x1}*\mathrm{u1}} = \frac{.528-1.584\mathrm{s}}{6.6\mathrm{s}^2+5.2\mathrm{s}+1}$$

Taking the denominator part

$$\frac{\mathrm{x1}}{\mathrm{u1}} = \frac{1}{6.6\mathrm{s}^2+5.2\mathrm{s}+1}$$

$$6.6\mathrm{s}^2 * \mathrm{x1} + 5.2\mathrm{s} * \mathrm{x1} + \mathrm{x1} = \mathrm{u1}$$

Taking inverse Laplace transformation

$$6.6 * \ddot{\mathrm{x}}1(\mathrm{t}) + 5.2 * \dot{\mathrm{x}}1(\mathrm{t}) + \mathrm{x1}(\mathrm{t}) = \mathrm{u1}(\mathrm{t})$$

$$\begin{bmatrix} \dot{\mathrm{x}}1 \\ \dot{\mathrm{x}}2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -.1515 & -.7878 \end{bmatrix} * \begin{bmatrix} \mathrm{x1} \\ \mathrm{x2} \end{bmatrix} + \begin{bmatrix} 0 \\ .1515 \end{bmatrix} * \mathrm{u1} \qquad (4)$$

Taking the numerator part

$$\frac{y1}{u1} = .528 - 1.584s$$

$$.528x1 - 1.584sx1 = y1$$

Taking inverse Laplace transform

$$.528x1(t) - 1.584 * \dot{x}1(t) = y1'(t) \qquad (5)$$

Put u1=0

$$\frac{y1}{u2} = \frac{1.2539*s+.063}{30.051*s^2+17.79*s+1}$$

$$\frac{y1*x3}{u2*x3} = \frac{1.2539*s+.063}{30.051*s^2+17.79*s+1}$$

Taking the denominator part

$$\frac{x3}{u2} = \frac{1}{30.051*s^2+17.79*s+1}$$

$$30.051 * s^2 * x3 + 17.79 * s * x3 + x3 = u2$$

Taking inverse Laplace transformation

$$30.051 * \ddot{x}3(t) + 17.79 * \dot{x}3(t) + x3(t) = u2(t)$$

$$\begin{bmatrix} \dot{x}3 \\ \dot{x}4 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -.3328 & -.5919 \end{bmatrix} * \begin{bmatrix} x3 \\ x4 \end{bmatrix} + \begin{bmatrix} 0 \\ .3328 \end{bmatrix} * u2 \qquad (6)$$

Taking the numerator part

$$\frac{y1}{x3} = 1.2539s + .06$$

$$y1 = 1.2539 * \dot{x}3 + .063 * x3$$

$$y1''(t) = .063 * x3(t) + 1.2539 * x4(t) \qquad (7)$$

The sum up of equation (4) & (6)

$$\begin{bmatrix}\dot{x}1\\ \dot{x}2\\ \dot{x}3\\ \dot{x}4\end{bmatrix}=\begin{bmatrix}0 & 1 & 0 & 0\\ -.1515 & .7878 & 0 & 0\\ 0 & 0 & 0 & 1\\ 0 & 0 & -.3328 & -.5919\end{bmatrix}*\begin{bmatrix}x1\\ x2\\ x3\\ x4\end{bmatrix}+\begin{bmatrix}0 & 0\\ .1515 & 0\\ 0 & 0\\ 0 & .3328\end{bmatrix}*\begin{bmatrix}u1\\ u2\end{bmatrix}$$

And the sum up of equation (5) & (7)

$$\begin{bmatrix}y1'\\ y2''\end{bmatrix}=\begin{bmatrix}.528 & -1.584 & 0 & 0\\ 0 & 0 & .063 & 1.2539\end{bmatrix}*\begin{bmatrix}x1\\ x2\\ x3\\ x4\end{bmatrix}$$

## IV- LINEAR QUADRATIC GAUSSIAN

LQG related with uncertainty of the linear system which is disturbed by additive white Gaussian noise. LQG is the combination of kalman filter with linear quadratic regulator (LQR). LQG control applies to both linear time invariant system as well as linear time varying system. In this work an advance controller i.e. linear quadratic Gaussian with loop transfer recovery (LQG/LTR) control for robust controller have been designed and developed in the head box plant.

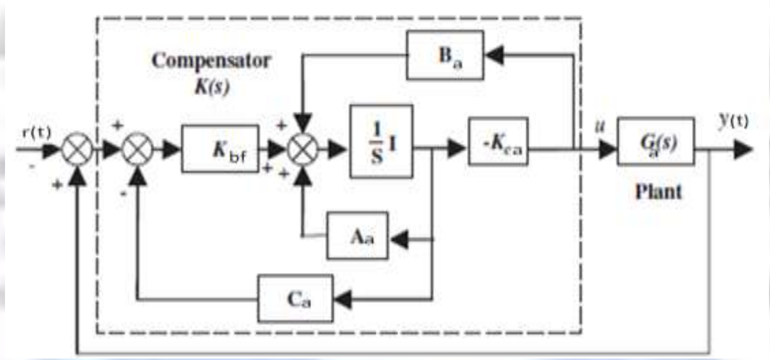


**Fig.4 Diagram of LQG/LTR**

The corresponding state-space representation of the plant can be described as follows:

$\dot{x} = Ax + Bu$

$y = Cx + Du$

where,

$$A=\begin{bmatrix}0 & 1 & 0 & 0\\ -.1515 & .7878 & 0 & 0\\ 0 & 0 & 0 & 1\\ 0 & 0 & -.3328 & -.5919\end{bmatrix}$$

$$B=\begin{bmatrix}0 & 0\\ .1515 & 0\\ 0 & 0\\ 0 & .3328\end{bmatrix}$$

$$C=\begin{bmatrix}.528 & -1.584 & 0 & 0\\ 0 & 0 & .063 & 1.2539\end{bmatrix}$$

D = [0]

**Performance analysis:**

The simulation results for the total head(y1) and air supply valve (u1) & the total head (y1) and stock supply valve (u2) are shown in Fig.5 & 6 respectively. The results show high peak overshoot of the order of, high rise time and a large settling time.

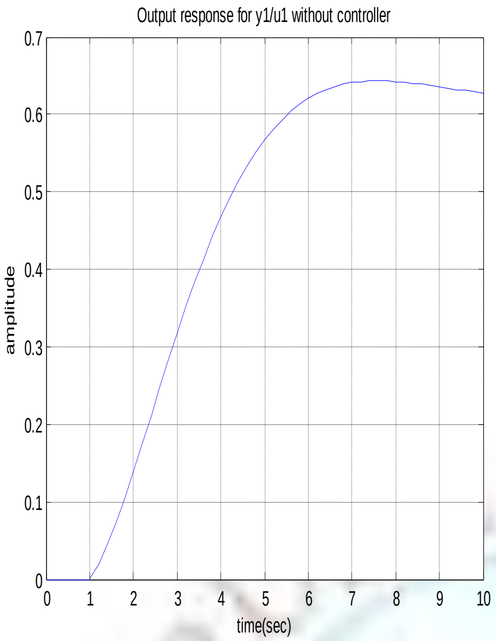


**Fig.5. Response of the simulink model for total head**

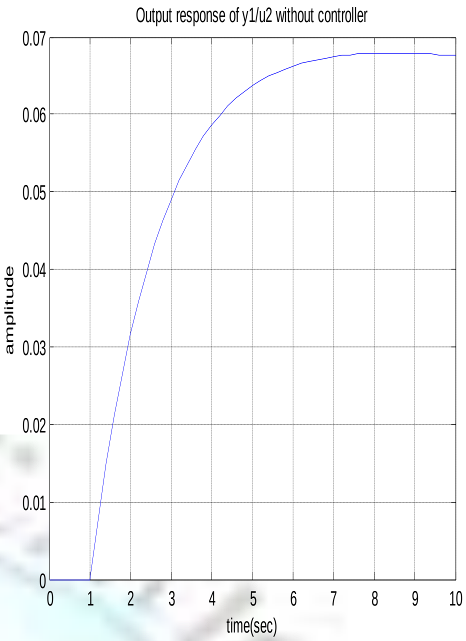


**Fig.6. Response of the simulink model for total head**

Fig.7 & 8 show the responses of the system using PID Controller between y1/u1 & y1/u2. The system is then tuned with a conventional PID tuner, the responses become stable. Steady state for the system is achieved.

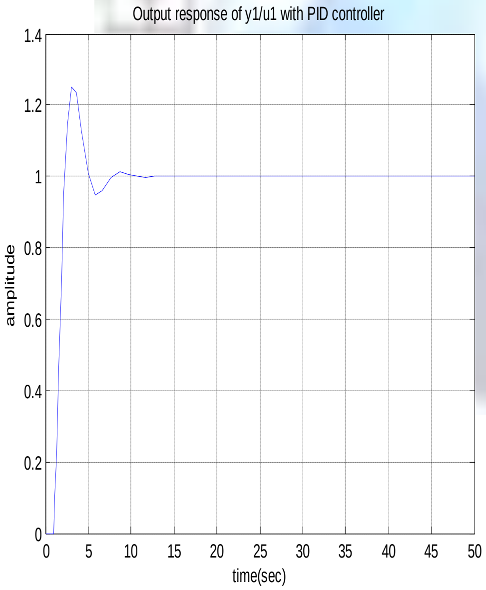


**Fig. 7. Total head response after PID controller**

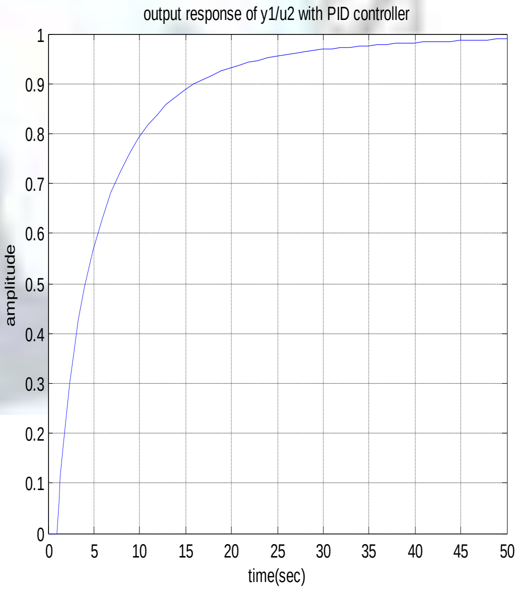


**Fig. 8. Total head response after PID controller**

The responses of MIMO systems for controlling the total head using LQG controller is shown in figure 9. between y1/u1 in which phase margin is 74.84 deg. and gain margin is infinite & Fig.10 between y1/u2 in which phase margin is 86.1 deg. and gain margin is 73.7 dB. And the Fig.10 & 11 show the step response.

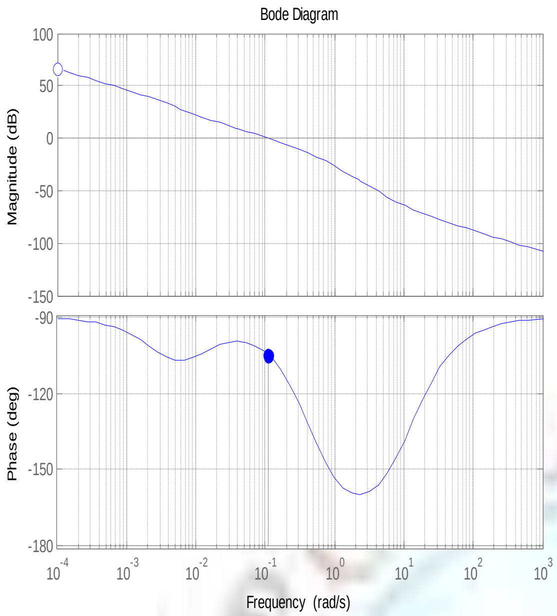


**Fig.9. The bode plot response with LQG**

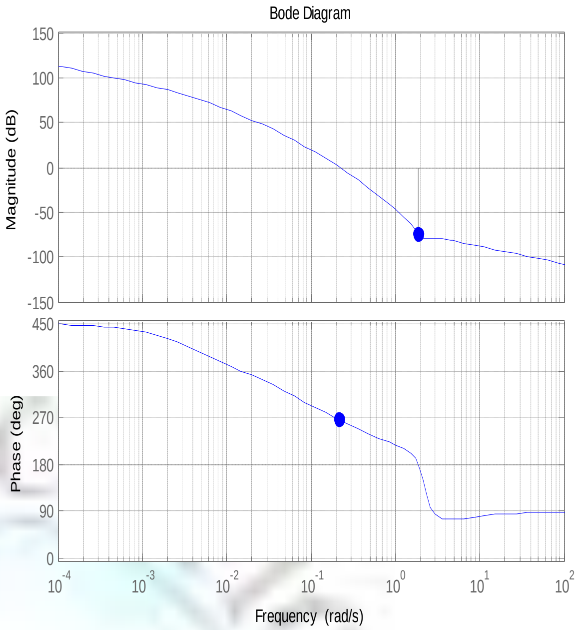
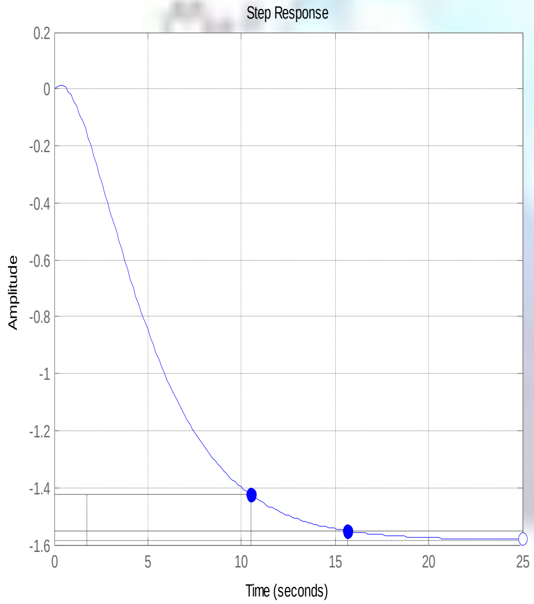


**Fig 10. The bode plot response with LQG**



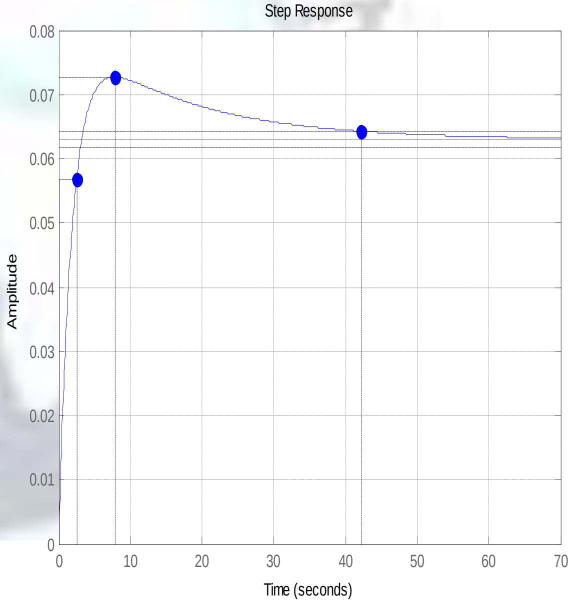


**Fig.11: The step response with LQG ($y_1/u_1$)**

**Fig.12: step response with LQG ($y_1/u_2$)**

## Conclusion

In this paper, we have proposed a robust controller (LQG) & PID for controlling the total head. In the beginning, PID controller reduces the overshoot in the system and make the system faster. LQG controller increases the gain margin and phase margin of the system and makes the system without lack of robustness.

**Table 1.comparison between PID & LQG**

| **Parameters** | **PID ($y_1/u_1$)** | **PID ($y_1/u_2$)** | **LQG ($y_1/u_1$)** | **LQG ($y_1/u_2$)** |
|---|---|---|---|---|
| **Rise time** | 5.26 sec | 142 sec | 8.75 sec | 2.33 sec |
| **Settling time** | 57.1 sec | 166 sec | 15.7 sec | 42.3 sec |
| **Overshoot** | 10.5 % | 8.84 % | 0 | 15.4 % |
| **Gain margin** | 32 dB | 58 dB | Infinity | 73.7 dB |
| **Phase margin** | 42.33 deg | 61.7 deg | 74.84 deg | 86.1 deg |

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