DESIGN OF ROBUST CONTROLLER FOR MULTIVARIABLE PAPER MAKING APPROACH FLOW SYSTEM

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ABSTRACT

The objective of this paper is to design & robust control of the multivariable i.e. ash flow rate and flow rate of retention aid of approach flow system of paper making process. A robust controller has been designed with five inputs and two outputs for the same. The controller design is based on kalman observer along with optimal linear quadratic gaussian (LQG). Kalman filter is used to design an observer that estimates desired states and state feedback controller gain using LQG or linear quadratic criterion. Paper concludes that the LQG robust control strategy improves the stability & performance objectives of an approach flow system in the presence of disturbances.

Keywords: Approach flow system, Linear Quadratic Gaussian, kalman filter, state space model.

I. INTRODUCTION

Robust control is used to design and analyze multivariable 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 robust control system is more useful for nonlinear and complex processes. The present trends in most of the industry like paper industry need such system. The paper making process starts from raw material to finished product i.e. paper. One of the subsystems of paper making process i.e. approach flow system is very complex and nonlinear. It is difficult to control. The approach flow system extends from the machine chest to the headbox slice. Occasionally, certain stock chests and refiners may also be considered part of the approach flow system. It has several parameters like flow of stock, flow of air, consistency, level of stock, & dilution water flow to control. So it is difficult to control individual parameter in the presence of disturbances, the robust control is only choice to model & control the system. System needs advance robust control strategy i.e. linear quadratic Gaussian (LQG). In this paper, the LQG is designed to control & analyze the performance of multivariable approach flow system.

II. PAPER MAKING APPROACH FLOW SYSTEM

The approach flow system starts with fan pump or term "approach flow system" refers to fan pump loop where in the paper making furnish is metered, diluted, mixed with any necessary additive, screened and cleaned before being discharge onto the paper machine wire. This system extends from the machine chest to headbox slice lip. Certain stock chests, refiners, bleding chest consistency regulator , flow control devices, magnetic flow meter,

basis stock valve, may be considered as the part of approach flow system. The screens function mainly to remove contamination and defloc the fibers, while centricleaners are designed to remove debries [4]

In the following figure the stock is pumped by primary fan pump to a series of centri-cleaners and then again to vacuum treatment and screening operation. Then comes the headbox that stores the stock for further processing. The approach flow system is as shown in the figure 1.
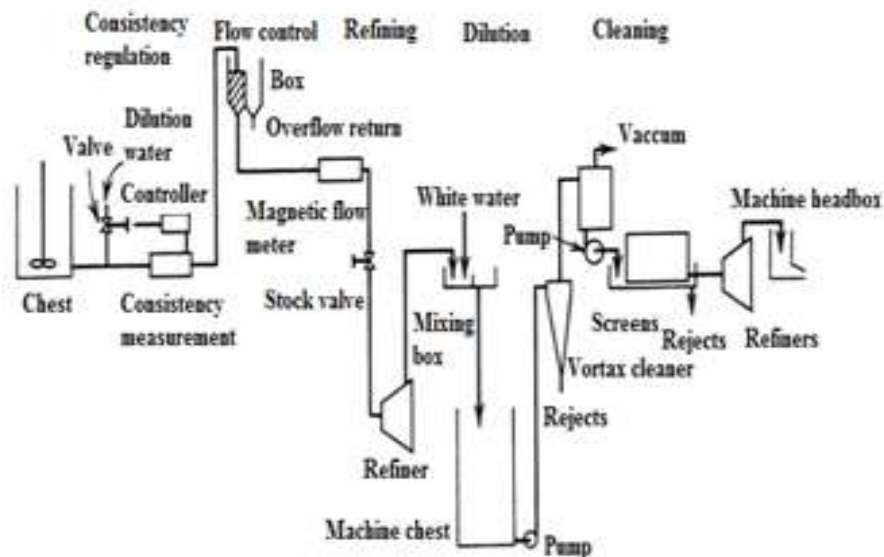

Fig.1 Flow Diagram of Approach Flow System

III. MULTIVARIABLE INPUT MULTIVARIABLE OUTPUT (MIMO) MODEL

The dynamic model can be an essential tool in the designing & analysis new system process variables. In this present work, the approach flow system with five inputs such as reel speed U_1, thick stock flow rate U_2, ash flow rate U_3, flow rate of retention aid U_4, and ash fraction in thick stock U_5 and two outputs Y_1 (bone dry weight) and Y_2 (bone dry ash weight) has been modeled. The ash fraction in thick stock depends upon the extent of mixing of raw materials in the machine chest and magnitude is changed according to the paper grade. For this reason the ash fraction is considered as an input variable. The lower-order transfer functions can be expressed as [1].

$$Y_1 = \frac{-0.05242}{1.253s+1}U_1 + \frac{0.005675\,e^{-1.8}}{1.572s+1}U_2 + \frac{0.07373\,e^{-0.8751}}{1.294s+1}U_3 + \frac{0.1322s+0.009898\,e^{-0.9865}}{13.82s^2+4.19s+1}U_4 + \frac{0.9e^{-1.8}}{10s+1}U_5$$

.. (1)

$$Y_2 = \frac{-0.01008}{3.427s+1}U_1 + \frac{0.001334e^{-1.3}}{14.23s+1}U_2 + \frac{0.05274}{1.92s+1}U_3 + \frac{0.1322s+0.009898\,e^{-0.9865}}{13.82s^2+4.19s+1}U_4 + \frac{35.53e^{-1.3}}{1.608s+1}U_5$$

….. (2)

The state space model for the plant is given as

$\dot{X}$=Ax+Bu

Y= Cx+Du

Where A, B, C, D are expressed as

$$A= \begin{pmatrix} -0.7728 & 0 & 0 & 0 \\ 0 & -0.5208 & 0 & 0 \\ 0 & 0 & -0.3032 & -0.2894 \\ 0 & 0 & 0.2500 & 0 \end{pmatrix}$$

$$B= \begin{pmatrix} 0.2500 & 0 \\ 0.0625 & 0 \\ 0 & 0.0625 \\ 0 & 0 \end{pmatrix}$$

$$C = \begin{pmatrix} 0.1567 & 0 & 0.0153 & 0.0185 \\ 0 & 0.0617 & 0.0153 & 0.0185 \end{pmatrix}$$

$$D = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$$

IV. DESIGN OF ROBUST CONTROL

Robust control is a branch of control theory that explicitly deals with uncertainty in its approach to controller design. It is used to analyze and design MIMO system with uncertain parameters. There are several techniques to design robust controller for any systems or processes. But LQG technique is found more efficient [2]. LQG is related with uncertainty of the linear system which is disturbed by additive white Gaussian noise. LQG is the combination of linear quadratic regulator (LQR) & kalman filter. 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 (LQG) has been designed and developed for the approach flow system.

4.1 Linear Quadratic Regulator (Lqr)

System dynamics i.e. a set of linear differential equations and the cost described by a quadratic function is called the Linear quadratic (LQ). The LQR is an important part of the LQG (linear quadratic gaussian). For designing the robust controller, the following steps have to be follow, but firstly approach flow system i.e. continuous system is described in state space model in a continuous-time linear manner.

$$\dot{X}= Ax+Bu$$

A cost functional or performance index, J is also defined for system dynamics

$$J=\int_0^\infty (x\,'Qx + u\,'Ru)dt$$

The feedback control law that minimizes the value of the cost function i.e.

$$u= -Kx$$

$$K=R^{-1}B^{T}P$$

Where, A, Characterizing matrix =n×n

x, State vector = n×1,

B, State vector = n×p

u, State vector = p×1

Q, Cost weighted matrix

R, Control weighted matrix,

K, LQR gain

And P is found by solving the continuous time algebraic Riccati equation.

$$A^TP+PA-PBR^{-1}B^TP+Q=0$$

4.1.1 Steps for designing LQR

1. Define the state space model for ash stock flow rate & flow rate of retention aid of an approach flow system (Matlab Command: tf2ss)

2. Define state-cost weighted matrix Q for LQR based on number of states and multiply with gain.

3. Define control weighted matrix R for LQR based on number of inputs.

4. Design LQR, the MATLAB command is

   $[K_c,S,E]=lqr(A,B,Q,R)$

   where K_C LQR gain, S riccati's coefficient, E eigen values . The result is

$$K_c = \begin{pmatrix} 18.7231 & 6.0246 & 0 & 0 \\ 0 & 0 & 21.0172 & 18.2047 \end{pmatrix}$$

4.2 Kalman Filter Or Linear Quadratic Estimator

The Kalman filter is an optimal estimator of the state of processes which satisfies the following points.

 1. They can be modeled by a linear system

 2. The measurement and the process white noise have zero mean gaussian distributions.

It is characterized by the state equation and the measurement equation, shown in eqn. (3) & (4) respectively.

$$\dot{X} =Ax+Bu+GW \qquad (3)$$

$$Y=Cx+V \qquad (4)$$

Under these conditions, knowing the input and the output of the system, the Kalman filter provides an optimal estimate of the state of the process 'x', by minimizing the variance of the estimation error and constraining the average of the estimated outputs .

G represents the process noise, W is the white noise, C is the transition matrix that maps the process state to the measurement, and V represents the measurement noise.

4.2.1 Steps for Designing Kalman Filter in Matlab

 1. Define the state space model for ash stock flow rate & flow rate of retention aid of an approach flow system (Matlab Command: tf2ss

 2. Define the process noise gain matrix 'G' relating the process noise to the state variables.

 3. Define Rn is the auto-covariance of v for kalman based on number of inputs.

 4. Define auto co- varience matrix Qn of process disturbances is assumed to be equal to the number of states variables.

 5. Design kalman filter using Matlab

   $[K_f,P,E] = lqe(A,G,C,Qn,Rn);$

Where K_F = Kalman Gain, P is the steady state estimation error auto covariance matrix which solves the associated Riccati equation & E is the eigan values of kalman filter.

$$K_f = 1.0e\text{-}05 * \begin{pmatrix} 0.1014 & -0.0000 \\ -0.0000 & 0.0592 \\ 0.0174 & 0.0174 \\ 0.650 & 0.0650 \end{pmatrix}$$

4.3 Linear Quadratic Gaussian

The Linear Quadratic Gaussian (LQG) control is to design a control law that only requires the measurable information such that when it is applied to the given plant, the overall system is stable and the performance index is minimized.

In time-invariant dynamic system case both matrix Riccati differential equations may be replaced by the two associated algebraic Riccati equations. The matrix K_f, matrix K_c, and system matrix [A, B, C] are now used to construct the LQG controller [2].

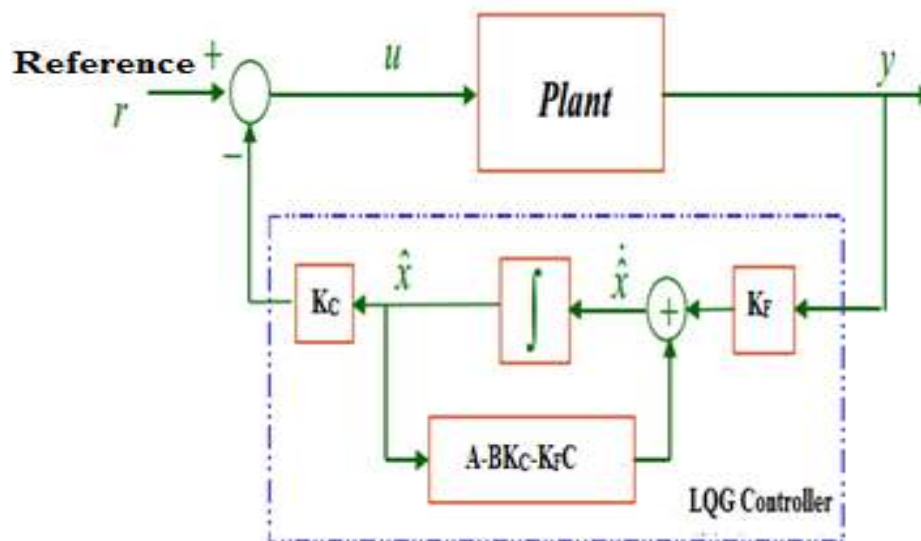$$K(s) = K_c \left[sI - A + BK_c + K_f\ C \right]^{-1} K_f$$

Fig. 2 LQG control loop

4.3.1 Steps to Design LQG Controller

1. Design LQR control(defined in previous section) .

2. Design kalman filter for the approach flow system.

3. Define LQG Control law i.e

$$K(s) = K_c \left[sI - A + BK_c + K_f\ C \right]^{-1} K_f$$

Where A= A-BK$_c$-K$_f$C

B=K$_f$;

C=K$_c$

V. RESULT & ANALYSIS

An attempt has been made in this section to analyze data for both the outputs Y_1 (bone dry weight) and Y_2 (bone dry ash weight) & approach flow system with five inputs such as reel speed (U_1), thick stock flow rate (U_2), ash

flow rate (U_3), flow rate of retention aid (U_4), and ash fraction in thick stock (U_5). After finding out the interaction between input & output variables, one can design robust controller to analyze the responses of the bone dry weight (Y_1) with respect to U_3 & U_4, shown in fig.3&4 respectively. The fig.3 shows better settling time, no overshoot but fig.4 reveals maximum overshoot but takes some time to settel the response.
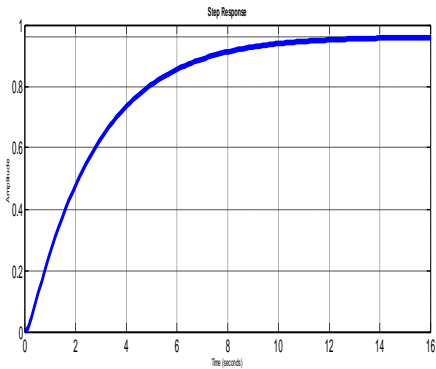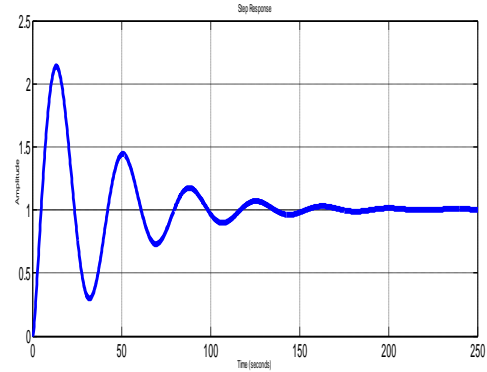

Fig.3. bone dry weight Y_1/U_3   **Fig.4 bone dry weight Y_1 /U_4**
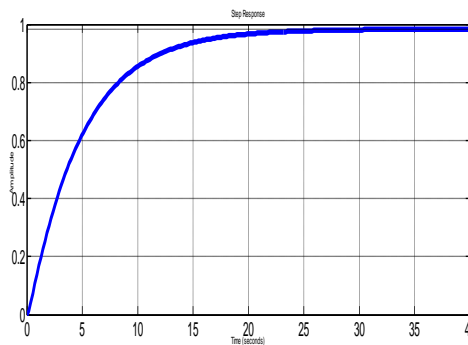

Fig.5 bone dry Ash weight Y_2/ U_3

The bone dry Ash weight Y_2 with respect to U_3 is shown in fig.5, it settles after few seconds. The bone dry ash weight Y_2 with respect to U_4 is shown in fig.6, it exhibits more oscillation but it settles. It's response can improve by adjusting   some LQG parameters.
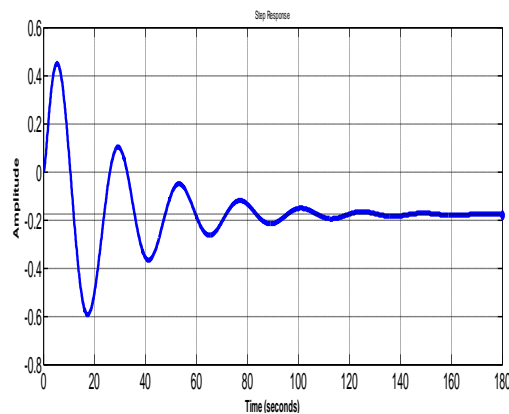

Fig.6 bone dry Ash weight Y_2/ U_4

The dynamic performance parameters like rise time,peak time & settling time for approach flow system shown in table1

Table 1. Dynamic performance parameters

Response	Bone dry weight Y_1/U_3	Bone dry weight Y_1/U_4	Bone dry ash weight Y_2/U_3	Bone dry ash weight Y_2/U_4
Rise Time	5.82 sec	3.47 sec	10.6	**1.05 sec**
Settling Time	**10.4 sec**	166 sec	**19.2**	116 sec
Peak Time	16 sec	15 sec	40 sec	17 ec

VI. CONCLUSION

This paper concludes that bone dry weight and bone ash weight of approach flow system are robust in the presence of disturbances means no effect of any   surrounding parameters.

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