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Modeling and Control of MIMO Headbox System Using Fuzzy Logic

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Abstract:
The Headbox plays an important role in pulp supply system with sheet forming in paper making process. The air cushion headbox is a nonlinear & strong coupling system. In the air cushion headbox system there were two important parameters which include total head and the stock level for improving pulp product quality. These two parameters make this system MIMO output system so for this a decoupling controls strategy was required for interaction between these two control loops. In this paper fuzzy tuned PID control scheme is proposed for controlling the nonlinear control problem in air cushion headbox after the system being decoupled. An attempt has been made for comparison between classical (PID) and fuzzy tuned PID controller. It concludes that the fuzzy tuned PID controller is found most suitable for MIMO system in terms of obtaining steady state properties. The effects of disturbances are studied through computer simulation using Matlab/Simulink toolbox.
Keywords: Multi-input multi-output (MIMO), Fuzzy Logic controller (FLC), Relative gain array (RGA)

I. INTRODUCTION

In the present trend, the most of the industries are controlled with the help of advance process control strategies. It includes artificial intelligence, adaptive, optimal, & robust control. In this paper, artificial intelligence approach has been taken, particularly fuzzy logic control strategy. Fuzzy logic control is found most suitable for complex system, ill defined & nonlinear system. The air cushion headbox is the subsystem of paper making process. It delivers the pulp over the conveyor belt in cross & machine direction. There are various parameters like level of stock, total head, flow of pulp, speed of conveyor belt, air pressure inside the headbox, flow of dilution water associated with it. So, it is not possible to control individually parameters. Due to all these parameters, headbox is complex system [1]. The dispersion degree of fiber in the head box and the regularity of pulp flow in the stock inlet of air cushion headbox decided the sheet quality of finished paper. In the headbox system there were two important parameters which include total head and the stock level for improving pulp product quality. The existing single loop control strategy could not perform adequately due to interaction between the two control loops. A decoupling control strategy was required for interaction between these two control loops [6]. In the proposed work, Systems with more than one actuating control input and more than one sensor output may be considered as multivariable systems or MIMO. The control objective for multivariable systems is to obtain a desirable behavior of several output variables by simultaneously manipulating several input channels. A possible approach to multivariable Controller design is to reduce the problem to a series of single loop controller design problems. There are several MIMO systems but here air cushion type headbox used as a MIMO system.

II. DESIGN ASPECTS OF FLC

In the proposed work fuzzy logic controller is designed for tuning the parameters of PID controllers (K_p K_i K_d) in order to control the output of MIMO system.

Structure of Fuzzy Logic Controller

The fuzzy logic controller consists three main stages fuzzification, rule base and defuzzification Fig- 1.

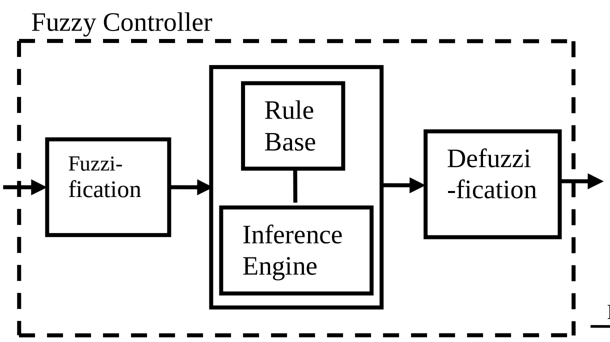

Fig 1: Fuzzy logic controller

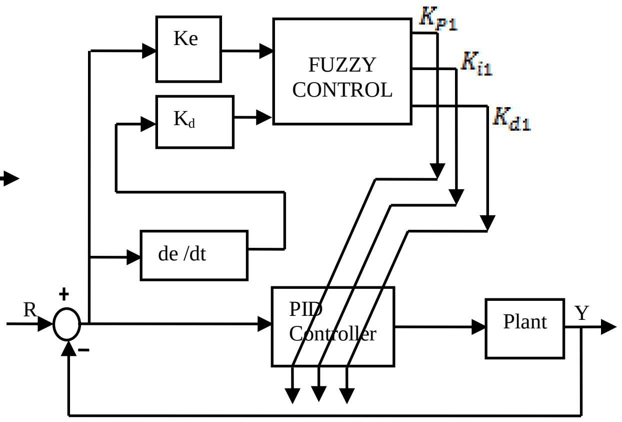

Fig 2: Fuzzy tuned PID controller

III. FUZZY PID SELF TUNING

The basic structure of the PID controller is described in the following equations

$$U^{PID} = K_p e + K_i \int edt + K_d \frac{de}{dt} \quad (1)$$

$$U^{PID} = K_p \left(e + \frac{1}{T_d} \int edt + T_i \frac{de}{dt}\right) \quad (2)$$

Where e is the error. Conventional PID controller is the sum of three different control actions. A PID controller has three adjustable or tuning parameters: K_p, K_i, K_d. The Proportional action can reduce the steady state error, Integral action will eliminate the steady state and Derivative action will improve the closed loop stability. The relationships between these three control parameters are:

$$K_i = K_p / T_i \quad (3)$$

$$K_d = K_p * T_d \quad (4)$$

Where T_i and T_d are integral time and derivative time respectively. In this work the controller has two inputs and three outputs for tuning the PID controller using Fuzzy logic approach. For the controller design, error and rate of change of error are used as an input to the self tuning and gains are as outputs. The fuzzy logic is adding to the conventional PID controller to tune the parameters of the PID controller on line according to change of error and rate of change of the error.

The proposed fuzzy self tuning PID [4] controller which is designed for controlling the process of the plant is shown in Figure 2.

IV. HEADBOX MIMO MODEL

The head box with rectifier rolls and 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 Nissinen et al [2]. Figure 3 shows MIMO configuration for control of total head and stock level in a head box control system in a paper mill.

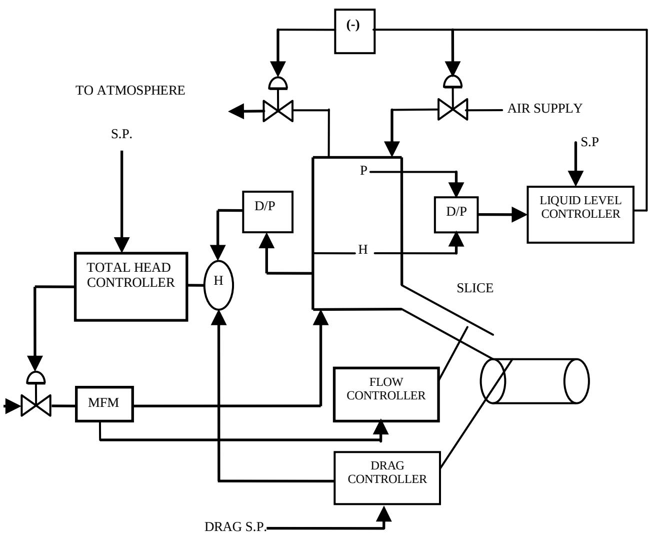

Fig 3: Pressurized air cushioned head box

$$Y_1 = \frac{0.528\, e^{-6s}}{2.2s+1} u_1 + \frac{(1.2539s + 0.063)}{(30.051s^2 + 17.79s + 1)} u_2 \quad (5)$$

$$Y_2 = \frac{(0.0205s+0.0001)e^{-1.5s}}{(43.6s^2+s)} u_1 - \frac{(0.0007)e^{-2s}}{s} u_2 \quad (6)$$

Where u_1 and u_2 are two inputs which are fan pump speed and control air valve respectively and Y_1 and Y_2 are the outputs of process which are total head and stock level respectively.

For determining the interaction between inputs and outputs, there are several methodologies for the same. In this paper Relative gain array has been introduced. A relative gain array (RGA) defines the steady state open loop gain and closed loop gain, k_{ij}.

$$\zeta = \frac{k_{12}\,k_{21}}{k_{11}\,k_{22}}$$

Equation 5 & 6 results

$$\zeta = -0.017045$$

As
$$\lambda_{11} = \lambda_{22} = 1/1-\zeta$$
$$\lambda_{11} = \lambda_{22} = 0.9832$$
$$\lambda_{12} = \lambda_{21} = 1-\lambda$$
$$\lambda_{12} = \lambda_{21} = 1-0.9832 = 0.0167$$

thus the RGA for 2x2 system is given by

$$\lambda = \begin{bmatrix} \lambda & 1-\lambda \\ 1-\lambda & \lambda \end{bmatrix}$$

$$\lambda = \begin{bmatrix} 0.9832 & 0.0167 \\ 0.0167 & 0.9832 \end{bmatrix}$$

Here λ is called the relative gain parameter.
So from above calculation the value of λ tends to 1 so that opening and closing of loops has no effect on each other so that 1-1 and 2-2 pairing is recommended. Therefore, decoupling is required for MIMO system.

V. DECOUPLING AND DECOUPLER DESIGN

The above MIMO control problem for total head and stock level can also be solved by partial or full decoupling of loops [1]. In this investigation perfect decoupling has been made as the accurate process transfer function are available. The transfer functions can be used to determine the effect of a change in either u_1 or u_2 on Y_1 and Y_2 as under

$$Y_1 = G_{11}(s)\,u_1(s) + G_{12}(s)\,u_2(s) \quad (7)$$
$$Y_2 = G_{21}(s)\,u_1(s) + G_{22}(s)\,u_2(s) \quad (8)$$

The decoupling control system for MIMO process is shown in Fig 4. By adding additional controllers called decouplers to a conventional multi-loop configuration, the design objectives of reducing control loop interaction can be realized. The decoupler expressions have been described as under

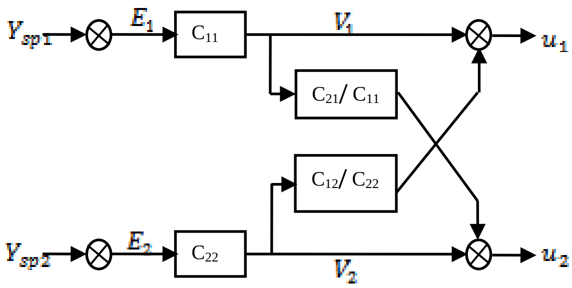

Fig4: A decoupled control system

$$u_1 = V_1 + (C_{12}/C_{22})\,V_2 \quad (9)$$

$$u_2 = V_2 + (C_{21}/C_{11})\,V_1 \quad (10)$$

$$Y_1 = (G_{11} + G_{12}\,C_{21}/C_{11})V_1 + (G_{11}\,C_{12}/C_{22} + G_{12})V_2 \quad (11)$$
$$Y_2 = (G_{21} + G_{22}\,C_{21}/C_{11})V_1 + (G_{21}\,C_{12}/C_{22} + G_{22})V_2 \quad (12)$$

When V_1 affect Y_1 and eliminate the effect of V_2 on Y_1, then
$$(G_{11}\,C_{12}/C_{22} + G_{12}) = 0$$
$$\text{Or } C_{12}/C_{22} = -G_{12}/G_{11} \quad (13)$$

When V_2 affect Y_2 and eliminate the effect of V_1 on Y_2, then
$$(G_{21} + G_{22}\,C_{21}/C_{11}) = 0$$
$$\text{or } C_{21}/C_{11} = -G_{21}/G_{22} \quad (14)$$

The expressions 13 and 14 are for ideal decoupler. One can interpret a decoupler as a type of feed forward controller with an input signal that is manipulated variable rather than a disturbance variable. The corresponding two SISO systems can be obtained by decoupling loops as shown in Fig 5. The overall transfer function is written as under

$$Y_1 = (G_{11} - G_{12}\,G_{21}/G_{22})V_1 \quad (15)$$
$$Y_2 = (G_{22} - G_{12}\,G_{21}/G_{11})V_2 \quad (16)$$

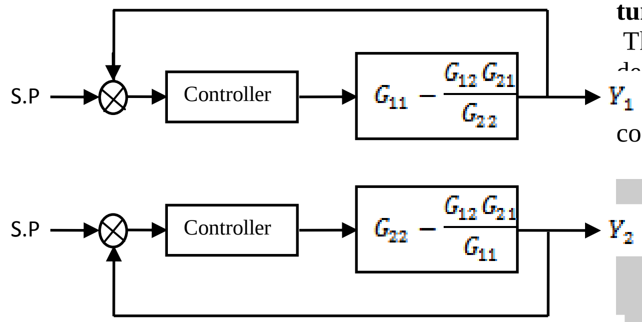

Fig 5: Two SISO System for total head and stock level

The present decoupling appears to be good the independent tuning of each decoupled loop can be easily carried out without detrimental to the stability of the whole system. As the process is approximated as linear, there is no need of using adaptive decoupler whose characteristics change as the magnitude and level of the disturbance imposed upon the system way.

In the SISO system, the above outputs Y_1 and Y_2 are presented as

$$C_{12}/C_{22}=-G_{12}/G_{11}= -0.119\left[\frac{(43.78s^2+22.1s+1)e^{0.6s}}{30.05s^2+17.79s+1}\right] \quad (17)$$

$$C_{21}/C_{11}=-G_{21}/G_{22}= -0.142\left[\frac{(205.5s^2+s)e^{0.5s}}{43.6s^2+s}\right] \quad (18)$$

The above equations are physically unrealizable owing to prediction term e^{s}. The reason for this unfortunate situation is apparent from inspection of G. Because process gain contains time delay, u_2 affects Y_1 sooner than u_1 does. Thus it is impossible to eliminate the undesirable interaction between u and Y completely. The reasonable approximations are as follows.

$$C_{12}/C_{22}= -G_{12}/ G_{11} =-0.119\left[\frac{(43.78s^2+22.1s+1)}{30.05s^2+17.79s+1}\right] \quad (19)$$

$$C_{21}/ C_{11} = - G_{21}/ G_{22} =-0.142\left[\frac{(205.5s^2+s)}{43.6s^2+s}\right] \quad (20)$$

If the time delay in prediction terms has been relatively large, the approximations could result in poor control.

Decoupled SISO model for total head using fuzzy tuned PID controller

The decoupled SISO system model has been designed for controlling the total head of the air cushioned type head box by using fuzzy tuned PID controller as shown in Figure 6.

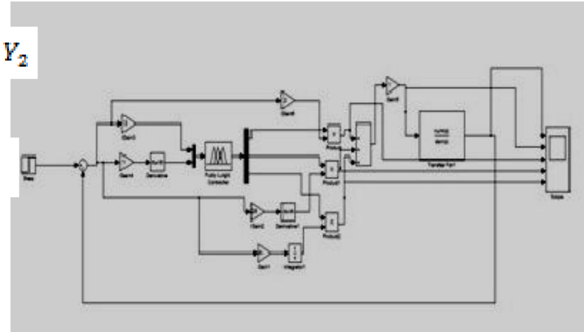

Fig 6: Decoupled SISO model (simulink) for total head using Fuzzy tuned PID controller

Decoupled SISO model for Stock Level using fuzzy tuned PID controller

The decoupled SISO system model has been designed for controlling the stock level of the air cushioned type head box by using fuzzy tuned PID controller as shown in Fig7.

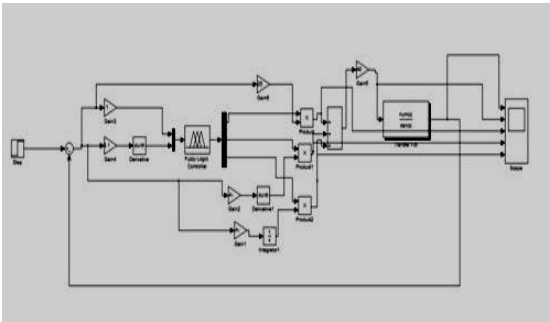

Fig 7: Decoupled SISO model (simulink) for stock level using Fuzzy tuned PID controller

VI.SIMULATION RESULTS & ANALYSIS

(A)Total Head

The response of decoupled SISO system for the controlling the total head using Fuzzy tuned PID controller is shown in Fig 8 in which time is taken on X-axis and total head as output response is taken on Y-axis. The obtained response also shows the variation in Proportional gain, Derivative gain and Integral gain and the analysis is done by calculating the rise time, settling time, peak & overshoot which are shown in table 1.

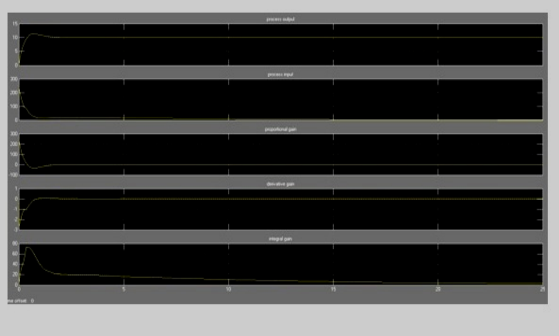

Fig 8: Output response for total head using Fuzzy tuned PID controller

Table.1 Controller Parameters for total head Using Fuzzy tuned PID controller & Conventional controller

Parameters	**Fuzzy tuned**	**PID**
Rise time(sec)	0.41	1.73
Settling time(sec)	1.64	18
Peak time(sec)	0.67	1.08
Overshoot(%)	14	8.47

(B) Stock level

The response of decoupled SISO system for the controlling the stock level using Fuzzy tuned PID controller is shown in figure 9 in which time is taken on X-axis and stock level as output response is taken on Y-axis. The obtained response also shows the variation in Proportional gain, Derivative gain and Integral gain and the analysis is done by calculating the rise time, settling time, peak & overshoot which are shown in table 2.

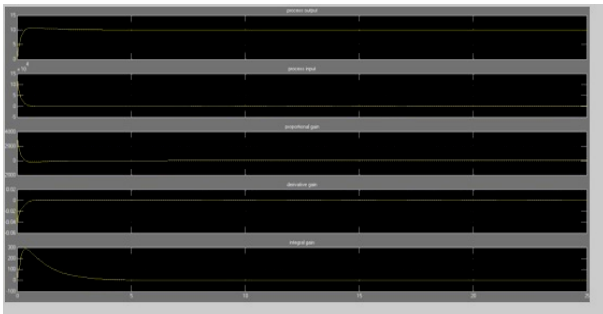

Fig 9: Output response for stock level using Fuzzy tuned PID controller

Table.2 Controller Parameters for stock level Using Fuzzy tuned PID controller & Conventional controller

Parameters	**Fuzzy tuned PID**	**PID**
Rise time(sec)	0.35	1.35
Settling time(sec)	2.24	4.43
Peak time (sec)	0.65	1.06
Overshoot (%)	7.78	6.48

VII.CONCLUSION

The simulation analysis indicates that the control ability of the nonlinear, multivariable complex system increases after using the fuzzy tuned PID controller scheme as compared with classical control approach.

REFRENCES

[1] Kumar Rajesh & A.K.Ray, “Artificial Neural Network modelling and control of retention process in the wet end”. International Journal of Information Technology and Knowledge Management, July-December 2010,Volume 2, No. 2, pp. 259-264

[2] A. I Nissinen, H. N Koivo and T. J Huhtelin, “Headbox control using multivariable PI controller implemented in distributed automation system”, in Control Systems '96, Preprints, Canada: Canadian Pulp and Paper Association, 1996, pp. 95-98

[3] Zhongjun Xiao et al, “study on the NN Decoupling control system of Air-cushioned Headbox” computer and information science vol.2, no. 3 august 2009 .

[4] Maher M.F. Algreer , Yhya R.M.Kuraz, “Design fuzzy self tuning of PID controller for chopper fed DC motor drive”.

[5] Q.Xia et al, “Systematic modeling and deocoupling control of a pressurized Headbox” CCECE/CCGEI’93, 07803-1443-3/93, 1993 IEEE.

[6] J. Fonseca et al, “ Fuzzy logic speed control of an induction motor” Microprocessors and Microsystems 22 (1999) 523–534, 1999 Elsevier Science B.V.

[7] Yan Zhao et al, “Design of Adaptive Fuzzy Controller in Air-cushioned Headbox” , 2010 2nd International Asia Conference on Informatics in Control, Automation and Robotics.

[8] Francisco Vazquez et al, “Tuning decentralized PID controllers for MIMO systems with decouplers”, 15th Triennial World Congress, Barcelona, Spain

[9] D.G. Shnrbaro et al, "Multivariable Nonlinear Control of a Paper Machine Headbox" ,0-7803-1872-2,1994 IEEE
[10] Dr. S.N. Sivanandam, S. N. Deepa, Dr. S. Sumathi, "Introduction to Fuzzy Logic using MATLAB Engineering" , ISBN-10 3-540-35780-7 Springer Berlin Heidelberg New York.