Advanced Prediction Based Control Strategy Application On A Paper Machine Headbox

Juneja Pradeep Kumar, Ray A.K., Mitra R.

ABSTRACT

Head box is the part of the paper machine whose primary function is to deliver a uniform dispersion of fibers in water at the proper speed through the slice opening to the paper machine wire. The modern headbox has many attributes which are highly significant for all papermakers. Uniformity of flow, absence of streaks and large eddies, head box stability and ease of operation are features which are requirements for all paper grades. Consistency in a headbox is a very important parameter in paper mills in its various stages of operations. Without the knowledge of consistency it is not possible to optimize productivity with optimal quality. One of the most important aspects in the design of consistency controller is to make sure that the dilution water added is well mixed with the stock before reaching the consistency sensor. It is possible to control consistency on the basis of either a sample taken from the main stream or by making the appropriate measurement directly in the main channel of flow.

In the present paper, a multivariable, linearized, state space model of a paper machine headbox is selected for control of consistency and liquid level in headbox of a paper machine using the advanced control strategy called Model Predictive Control. Model Predictive Control (MPC) does an explicit use of a model to predict the process output along a future time horizon. It performs the calculation of a control sequence to optimize a performance index. It is based on receding horizon strategy, so that at each instant the horizon is moved towards the future involves the application of the first control signal of the sequence calculated at each step.

Introduction

The main function of the paper machine [1] is to form the paper sheet and then remove water from the sheet by means of vacuum, pressing, and evaporation. The paper machine is divided into two main sections referred to as the wet-end and dry-end. The sheet is formed in the wet-end on a continuous synthetic fabric (wire), which also allows water to drain from the forming sheet. Additional water is removed by passing the sheet through the wet press, which compresses a water absorbing fabric against the paper sheet.

One of the most important sub processes in the paper machine is the head box. The intent of the head box is to generate a steady flow of pulp to the wire, which is important for the quality of the paper. A simplified illustration of a pressurized head box is given in Figure 1.

Headbox stock level is controlled to maintain proper holey roll emersion and to prevent large level variation for practical reasons. This is control on a single loop basis by controlling the padding air and vent control valves.

Indian Institute of Technology Roorkee, Department of Paper Technology Saharanpur Campus, Saharanpur-247 001

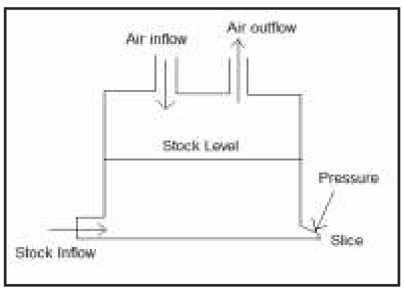

Figure 1 : A simplified illustration of Pressurized Headbox

These valves are usually arranged so that the headbox pad can be controlled with a positive pressure or under vacuum. Since actual headbox level is less critical than total head, level is used to control the slower responding padding air and vent control valves.

The headbox must not only spread out the stock evenly across the width of the machine at the correct speed and angle, but must level out cross-currents, machine direction velocity gradients, and consistency variations as shown in figure 2.

Headbox level is usually sensed by a D/P cell with one side sensing pressure at the bottom of the box and the other the pressure in the air pad at the top. The output of the D/P cell goes to level controller. Liquid level is most commonly controlled by conventional pneumatic, analog hardware with PI action. Controller tuning is usually by manual cut-and-try methods, unless decoupling of liquid level from total head is being attempted, whereupon, digital controllers are used and sophisticated identification and tuning procedures are required.

Usually, the dilution water from various sources is always added to the thick stock immediately before fan pump and then led to flow to a consistency sensor, and then to the other equipments of approach flow system including Headbox. A feedback signal is obtained from the consistency sensor which is transmitted to the consistency controller through transmitter.

A comparator is used in the loop to compare the set point and measured variable to produce an error which goes to the controller to determine an appropriate position of the valve controlling the flow of dilution water to the stock immediately ahead of the pump. The value of the dead time for consistency control depends upon type of the process, loop design and location of sensor.

Model predictive control is a mature technology in the petroleum and chemical industries. However there are very few applications in the pulp and paper industry. It has several advantages over classical control techniques such as dynamic decoupling. The same algorithm can be used for a wide variety of multivariable

Table 1 :MPC controller design parameters

Tuning parameter	Value
Controller sampling time (t_c)	2
Prediction horizon (P)	10
Control horizon (M)	2
Coefficient of Fs weight	0
Coefficient of Fs rate weight	0.1
Coefficient of Fw weight	0
Coefficient of Fw rate weight	0.1
Coefficient of Lh weight	1
Coefficient of Cf weight	0
Coefficient of Ch weight	1
Duration	15

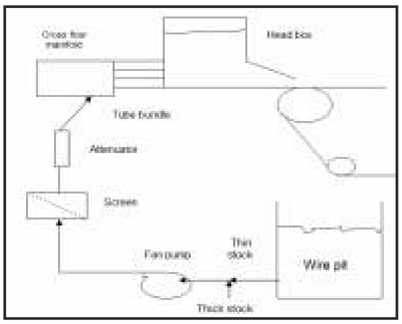

Figure 2 : Headbox

control problems. Process constraints are handled explicitly. Due to its centralized nature, the controller is easier to tune and maintain than a set of interacting PID controllers. In model predictive control, the controller is not a fixed control law but is an optimization problem that is updated and solved every sampling time. Here, prediction of the future plant behavior is used to compute the appropriate control actions and, therefore, the controller requires a dynamic model of the process. Obtaining models that are applicable over the whole operational range of the process may necessitate a considerable amount of identification work. Model predictive control (MPC) is a general methodology for solving control problems in the time domain. Models are used for predicting the process output over a prediction horizon. Control actions are calculated over a control horizon in such a way that the predicted process output is as close as possible to a desired reference signal, and the first control action in sequence is applied in each step.

Literature Survey

The headbox modeling with the help of first principles is done by Mardon (1) and Smith et al (2).

Talvio(3) performed theoretical and experimental studies in to the stability and control of paper machine headboxes, and control system with linear transfer functions.

Waller [4] has made an extensive survey of developments of control of paper making headboxes and their incorporation into forming section. Kumar Prasanna et al [5] has described paper machine control and optimization for different sub system of paper machine loop including consistency control in approach flow and headbox.

Whalley et al [6] addresses the problem of regulating the flow of pulp solution or stock from a fourdrinier paper making machine headbox. A multivariable, time invariant model for a fourdrinier machine headbox is considered. An optimum, minimum control effort strategy is proposed. The headbox model contains a perfect integrator which slowly changes the head box level and hence the output flow rate.

Rao, Bansal, and Ray [7] demonstrated the application of various methods to measure the relevant parameters in a pulp and paper mill emphasizing the status of instrumentation in paper mill with particular reference of paper machine. They have further retreated the selection of instrumentation in terms of cost and added that in paper machine section the measurement and control of headbox temperature along with headbox level are essential.

Nissinen, et. al. (8) studied the feasibility of designing multivariable PI controller for headbox with rectifier rolls without overflow provided with air cushion in a multi-grade paper machine. The system has been considered as multiple input-multiple output instead of single input- single output system. The process dynamics for such system was identified. Based on the process model and the structure of the multivariable PI controller a process simulator was built using Simulink. The simulator was used to test different tuning methods which could be applied to the system.

Several recent publications provide a good introduction to theoretical and practical issues associated with MPC technology. Rawlings [9] provides an excellent introductory tutorial aimed at control practitioners. He presented a more comprehensive overview of nonlinear MPC and moving horizon estimation, including a summary of recent theoretical developments and numerical solution techniques. Mayne, Rawlings, Rao, and Scokaert [10, 11, 12] provide a comprehensive review of theoretical results on the closed-loop behavior of MPC algorithms.

Model Predictive Control, also referred to as Receding Horizon Control and moving Horizon Optimal Control, has been widely adopted in industry as an effective means to deal with multivariable constrained control problems [13].

Results And Discussion

In the present paper, the Paper Machine Headbox model is selected for control of consistency and liquid level using an advanced control strategy called Model Predictive Control.

The condition no. for the process currently under investigation is 4.287 and as we know, the smaller the condition number, the better the conditioning of the matrix.

In the step response, the two manipulated variables affect all three outputs. They have nearly identical effects on Lh. The pairing Fw- Ch exhibits an inverse response.

In the design of MPC for controlling headbox consistency and level in a paper machine, the steady-state error in feed tank consistency is about -0.25 units. It makes it difficult to achieve accurate, independent control of Lh and Ch.

There are only two manipulated variables, so it's impossible to hold three outputs at setpoints. We don't have a setpoint for Fc so we have set its weight to zero. Otherwise, all three outputs would have exhibited the steady state errors.

Conclusions

The Model Predictive control strategy gives the satisfactory closed loop performance for the consistency

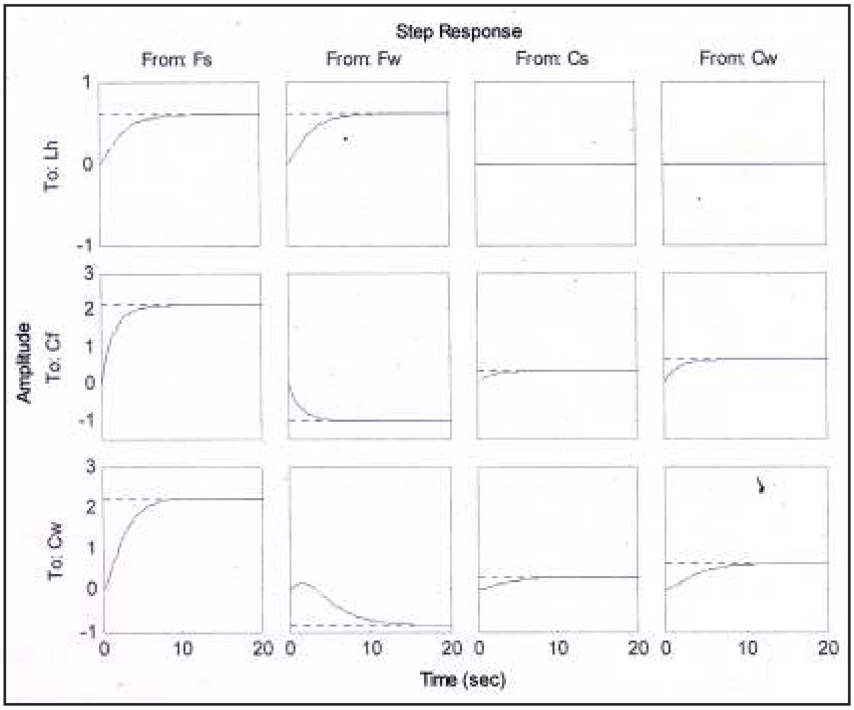

Figure 3 : Step Response

process in a headbox of a paper machine which has a non linear, complex, multivariable, long time delayed dynamics along with interactions in different variables. These features to tackle these problems in MPC controller design strategy make this technique, of prime importance in process industries and makes it an indispensable tool.

Experimental

In the present paper, the Paper Machine Headbox model is selected for control of consistency and liquid level using an advanced control strategy called Model Predictive Control.

Manipulated variables include flow rate of stock entering the feed tank (Fs) and recycled white water flow rate (Fw) Measured disturbance is the consistency of stock entering the feed tank (Cs). Unmeasured disturbance is the consistency of stock entering the feed tank (Cw) and Measured outputs include the headbox liquid level (Lh), feed tank consistency (Cf) and the headbox consistency (Ch). Unmeasured output is the liquid level in the feed tank (Lf). The state variables are : the liquid level in the feed tank, the headbox liquid level, the feed tank consistency, and the headbox consistency.

1) Condition number

The ratio of the largest to the smallest singular value of a matrix is called the condition number, and it is the single most reliable indicator of the conditioning of a matrix.

The steady state gain matrix for this process is

k = 0.6105 0.6105 0 0
2.1270 -1.0317 0.3222 0.6444
2.2091 -0.8532 0.3124 0.6248

and the Singular value decomposition with the help of MATLAB software, yields the following result

p = -0.0913 0.9811 -0.1704
-0.7039 -0.1847 -0.6859
-0.7044 0.0573 0.7075

q = 3.5045 0 0 0
0 0.8173 0 0
0 0 0.00000

r = -0.8872 0.4072 0.2171 0.0000
0.3628 0.9062 -0.2171- 0.0000
-0.1275 -0.0509 -0.4256 -0.8944
-0.2550 -0.1018 -0.8512 0.4472

The condition no. for the process currently under investigation is

Condition no. = 4.287

2) Step response

As clear from figure 4, the present system has rise time of 5.38 seconds when the input is Fs and the output is Lh. It is same when the input is Fw and the output is Lh. It has rise time of 3.49 seconds when the input is Fw and the output is Cf and also when the input is Fw for the same output. The system has rise time of 3.49 seconds when the input is Cs and the output is Cf and also when the input is Cw for the same output. It has rise time of 4.76 seconds when the input is Fs and the output is Cw. It is around 7 seconds for input as Fw and the output as Cw.

From figure 5, it is clear that, the present system has settling time of 9.77 seconds when the input is Fs and the output is Lh. It is same when the input is Fw and the output is Lh. It has settling time of 6 seconds when the input is Fw and the output is Cf and also when the input is Fw for the same output. The system has settling time of 6.21 seconds when the input is Cs and the output is Cf and also when the input is Cw for the same output. It has settling time of 7.88 seconds when the input is Fs and the output is Cw. It is 14.9 seconds for input as Fw and the output as Cw. The settling time for input Cs and ouput Cw is 11.7 seconds.

3) MPC design for the selected Paper machine headbox model

Model Predictive controller is designed with the help of MPC toolbox available in MATLAB software. The tuning parameters selected were as Control interval of 2 minutes, Prediction horizon as 10 units and control horizon as 2 units. Constraints for both Fs and Fw are a minimum of -10, maximum of 10, max down rate as -2, Max up rate as 2. The important parameters are shown in the table. The servo response for unit step in headbox level setpoint is shown in the figure 12 and the Manipulated variable moves corresponding to figure 12 are shown in figure 13.

This output response has peak amplitude of 1 and peak time as 8 seconds for Lh. For Ch the corresponding values of peak amplitude are -1.68 and 2 seconds, whereas for Ch, the values are 0.172 and 2 seconds respectively.

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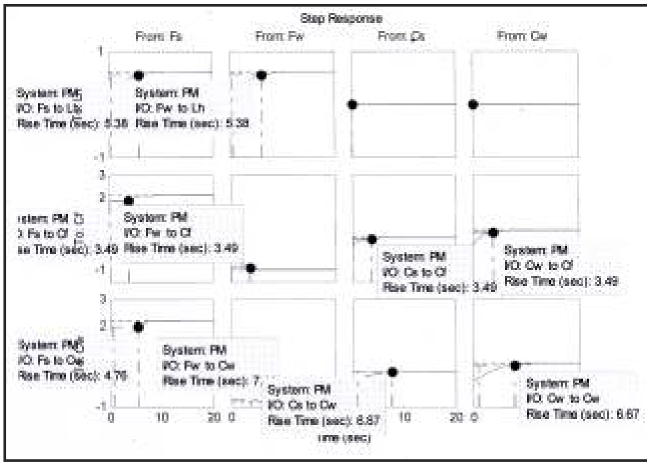

Figure 4 : Step response with rise time

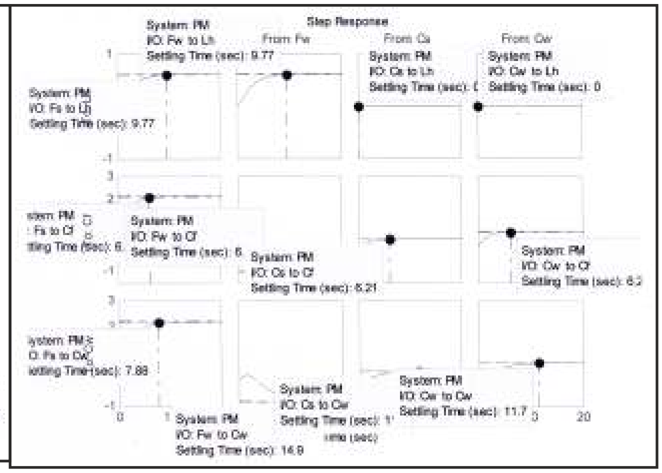

Figure 5 : Step response with settling time

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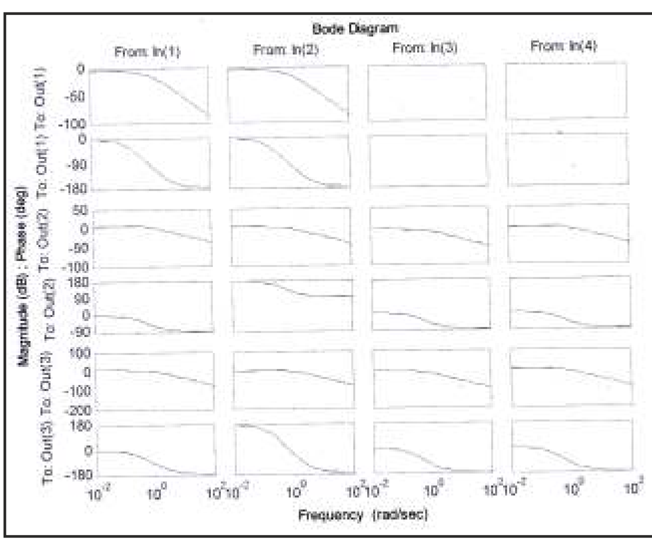

Figure 6 : Bode diagram

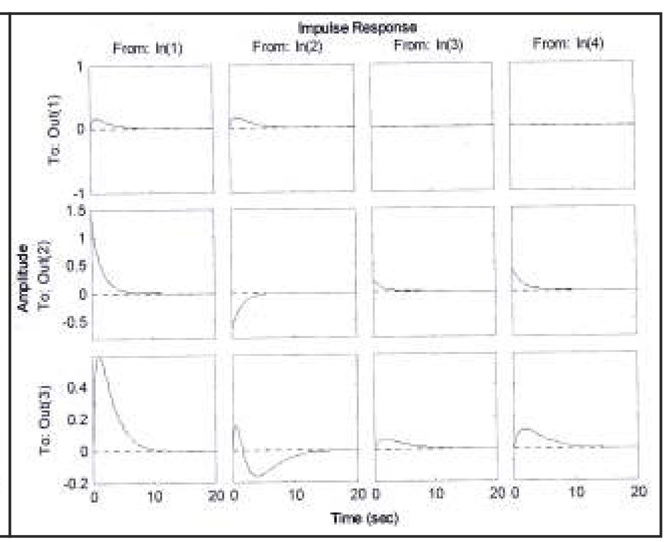

Figure 7 : Impulse response

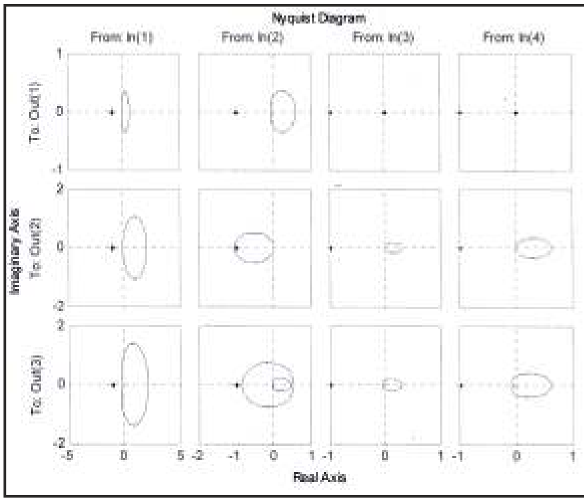

Figure 8 : Nyquist diagram

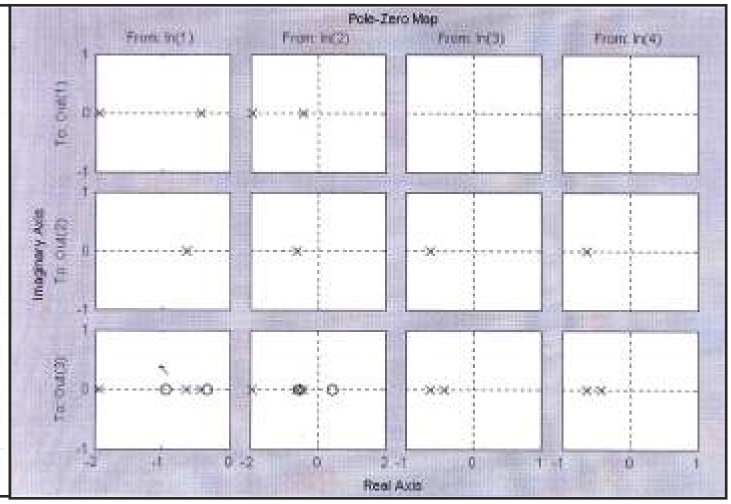

Figure 9 : pole zero plot

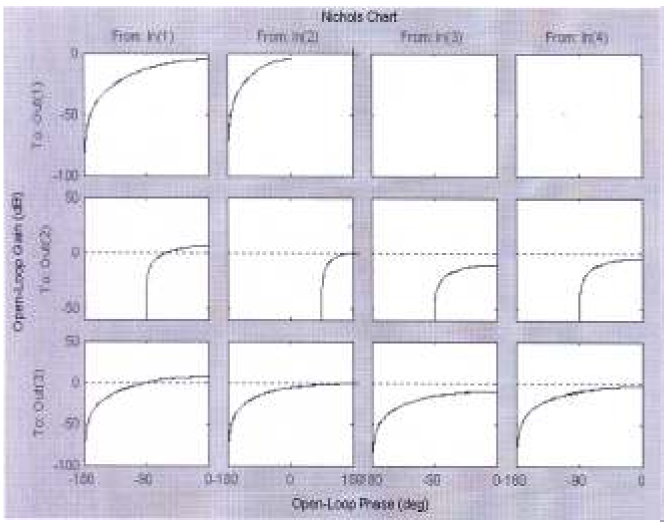

Figure 10 : Nichols chart

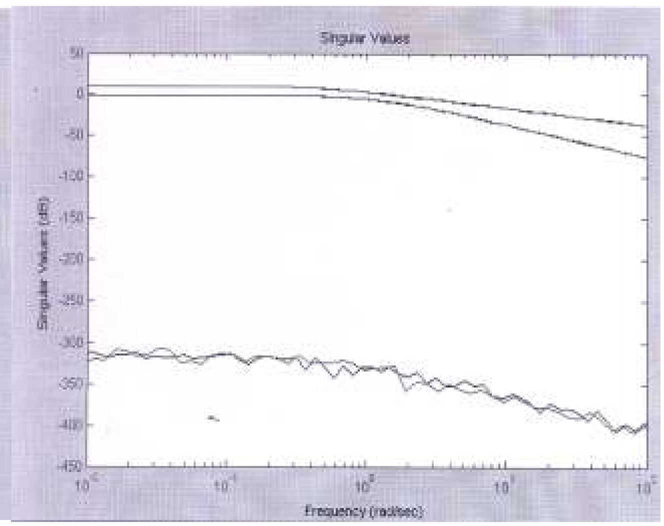

Figure 11 : Singular Values

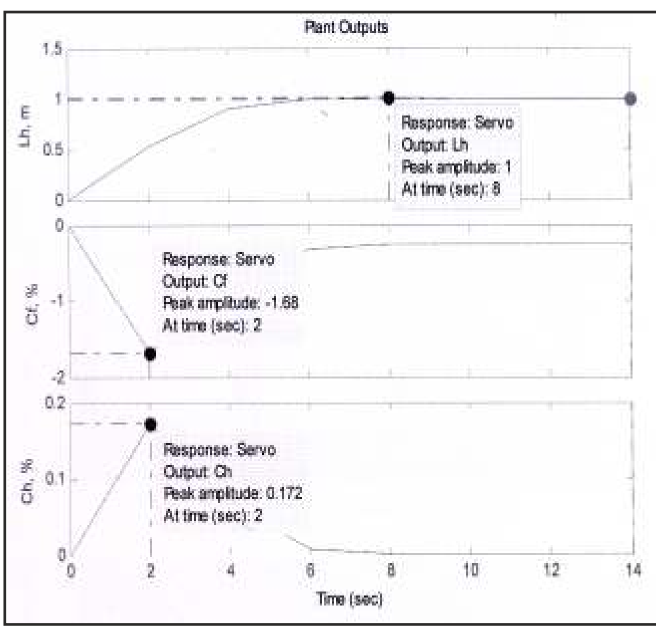

Figure 12 : Plant outputs for servo response for unit Step in Headbox level setpoint

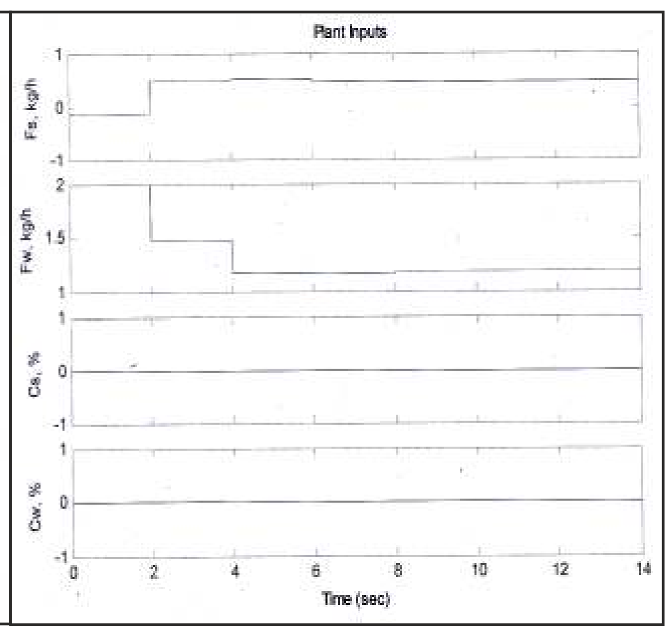

Figure 13 : Mainipulated variable moves corresponding to above figure 12