ARX-Model based Model Predictive Control of a pH Process using LabVIEW

V. Balaji, L. Rajaji

***Abstract*— ARX models, is a suitable model for linear control implementations. The parameter estimation problem is convex and easily handed for both SISO and MIMO system. This paper deals with a novel formulation of ARX Model –Predictive control for the pH Process in a Continuous Stirrer Tank Reactor(CSTR).An illustrative simulation is conducted to compare the proposed model based controller with the conventional Proportional – Integral –Derivative(PID) controller for the pH purification process. The simulation results confirm that MPC is one of the best possibilities for successful control for pH process.**

Keywords- pH Purification, Model Predictive Control, PID controller, CSTR, LabVIEW

I. INTRODUCTION

The pH process is mainly used in various areas such as the neutralization of industrial wastewater, biochemical and electrochemical processes, the paper and pulp industry, maintenance of the desired pH level at various chemical reactions, production of pharmaceuticals and biological processes, coagulation and precipitation processes and many other areas. A PID controller is mostly used to deal with this process however, it can only react to changes in a reference signal. On the other hand, a Model Predictive Control (MPC) approach is proactive and makes use of the information of the future reference signal which is usually known beforehand in a pH process. Although the MPC approach cannot follow a step function directly it can follow it much better than a PID Furthermore a MPC approach is more sophisticated than a PID in terms of handling input and output constraints, as well as dealing with difficult system behaviors like high nonlinearity and longtime delays. Model Predictive Control (MPC) is a multivariable control algorithm that uses (i) an internal dynamic model of the process (ii) a history of past control moves and an optimization cost function J over the receding prediction horizon to calculate the optimum control moves. The optimization cost function is given by:

$$J = \sum_{i=1}^{N} w_{x_i}(r_i - x_i)^2 + \sum_{i=1}^{N} w_{u_i}\Delta {u_i}^2$$

without violating constraints (low/high limits)

With:

xi = *i* -th control variable (e.g. measured temperature),
ri = *i* -th reference variable (e.g. required temperature)
ui = *i* -th manipulated variable (e.g. control valve)
W_{xi} = weighting coefficient reflecting the relative importance of *xi* Wui = weighting coefficient penalizing relative big changes in *ui*

An Auto Regressive Exogenous Model is used for the control of pH variations of impure Cephradine being prepared in the glass lined CSTR thereby obtaining purified Cephradine. The influent liquid (impure Cephradine), obtained from the previous stage, flows into the tank where it is mixed with the reagent (ammonia solution) to alter its pH. The effluent (pure Cephradine) is acidic with a desired pH of 4.8 the reagent (NH3 solution) is basic with a pH of 9. The pH is controlled in a glass lined continuous stirrer tank reactor. The reactor is glass lined in order to reduce corrosion of the tank and the tank is well stirred so that the pH is uniform throughout the tank. In the simulation study, LabVIEW Software is adopted for the control of pH in the glass lined Continuous stirrer tank reactor. Later sections of this paper provide a description of the work, experimental results, and a comparison with proportional integral derivative (PID) results. Conclusions are presented in the final section of this paper.

II. PROBLEM DESCRIPTION

This work concentrates on pH control during the purification stage of Cephradine. The final pH of 4.8 is obtained under carefully controlled conditions. In the purification stage, we get Cephradine from the previous stage, which has a pH of 1.8. The solution is clear with Cephradine of pH 1.8. Ammonia is then added which increases the pH slowly in the range of from 1.9 to 2.8. When the pH is 2.8, the color changes and the solution takes on a a slurry look. At this stage, ammonia addition and the rotation of the stirrer in the CSTR is stopped. The stirrer then starts to rotate after 20 min., the setup is stirred continuously, and the ammonia is again added and the pH increases slowly from pH 2.8 to pH 4.8. The condition is maintained until the set point 4.8 is reached. When the desired pH of 4.8 is obtained, the setup is left ideal for 20 min (timed). Cooling is applied to lower the temperature by 10 degrees. This 10 degree temperature decrease is attained within two and a half hours. Once the desired temperature is reached, the set up is left for 1 hour. Thus, the Cephradine is purified at pH 4.8. Table 1 shows the positions of stirrer and valve. At present, pH is controlled by PID in the plant. PID controller does not produce quality in its output and it can do only a single mode of operation. Hence, to overcome these problems, a new controller

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(MPC) was tried which can overcome the above drawbacks.

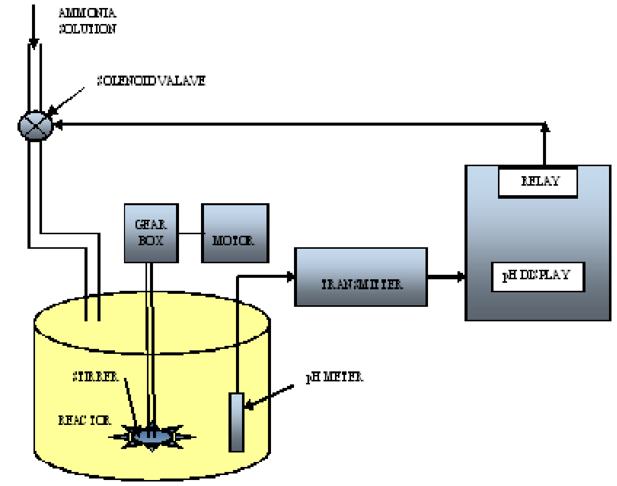

Fig. 1. pH Control Setup

pH	Stirrer	SOLENOID VALVE
1.8-2.8	Rotates	Open
2.8-4.7	Rotates	Open
4.8	Rotates	Closed

Table 1: status of stirrer and solenoid valve

III. ARX MODEL ESTIMATION

The general form is

$$y(k) = -a_1 y(k-1) - a_2 y(k-2)\cdots - a_n y(k-n) + b_0 u(k) + b_1 u(k-1)\cdots + b_m u(k-m) \quad (1)$$

Z transform

$$y(z) = Z[y(k)] \quad (2)$$

backward shift operator (z^{-1})

$$Z[y(k-1)] = z^{-1} y(z) \quad (3)$$

$$Z[y(k-2)] = z^{-2} y(z) \quad (4)$$

$$(1 + a_1 z^{-1} + \cdots + a_{n-1} z^{-n+1} + a_n z^{-n}) y(z) = (b_0 + b_1 z^{-1} + \cdots + b_m z^{-m}) u(z) \quad (5)$$

$$y(z) = \frac{(b_0 + b_1 z^{-1} + \cdots + b_m z^{-m}) u(z)}{(1 + a_1 z^{-1} + \cdots + a_{n-1} z^{-n+1} + a_n z^{-n})}$$

$$\therefore g(z) = \frac{b_0 + b_1 z^{-1} + \cdots + b_m z^{-m}}{1 + a_1 z^{-1} + \cdots + a_{n-1} z^{-n+1} + a_n z^{-n}} \quad (6)$$

for most process systems there is not an immediate effect of the input on the output so b_0 =0; for four parameter

$$y(k) = -a_1 y(k-1) - a_2 y(k-2) + b_1 u(k-1) + b_2 u(k-2) \text{ for } k = 1\cdots N \quad (7)$$

$$y(1) = -a_1 y(0) - a_2 y(-1) + b_1 u(0) + b_2 u(-1)$$

$$y(2) = -a_1 y(1) - a_2 y(0) + b_1 u(1) + b_2 u(0)$$

$$y(N) = -a_1 y(N-1) - a_2 y(N-2) + b_1 u(N-1) + b_2 u(N-2) \quad (8)$$

IV. EXPERIMENTAL RESULTS

The pH control using MPC is modeled and simulated using Lab VIEW Software as shown in figure below. The block diagram contains this graphical source code. Front panel objects appear as terminals on the block diagram. Additionally, the block diagram contains functions and structures from built-in LabVIEW VI libraries. Wires connect each of the nodes on the block diagram, including control and indicator terminals, functions, and structures. For each of the components created in the front panel, there appears an indicator automatically in the block diagram

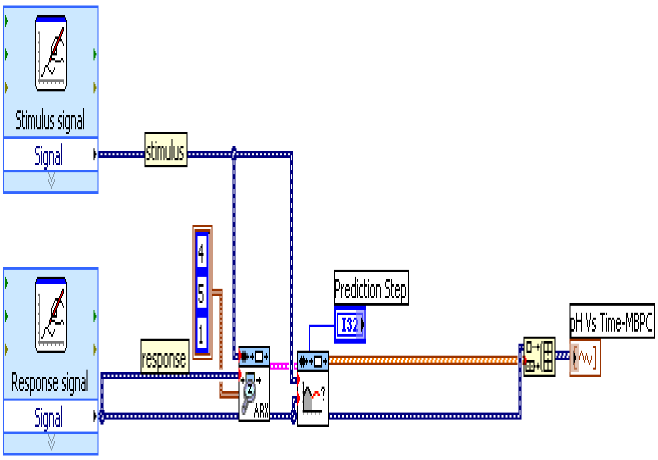

Fig. 2. Block Diagram of ARX Model in LabVIEW Environment

For the variation of process value, selecting it from the structures icon in the function palette creates a flat sequence. The flat sequence is created in order to integrate the various stages of the program. Next a while loop is created from the numeric data type of the functions palette, obtain the addition block. A shift register with initial value set to 1.8 is given as one of the inputs to the addition block while the other input is 0.1. The other end of the shift register is given to the output of the addition block. The output of the addition block is given to the less than or equal to block obtained from the comparison option in the functions palette. The other input to this block is the constant 2.8For the stirrer operation, a divide block is created from the numeric option in the functions palette. The iteration is given as one of the input to this block and the other input is a constant 2 since there are 2 LEDs in the stirrer.

The division operation is performed and the remainder so obtained is compared with the value1.The output of the equal to block is given to 2 Boolean indicators, to one directly and to the other through a not gate so that both the LEDs can glow alternately. For increasing the level of the tank gradually, a case structure block is created from the structures option in the functions palette. Next the fill colour of the tank can be obtained by expanding the property node of the tank for fill colour and to change the level of the ammonia solution in the tank, expand the property node by value. All these are placed inside the case structure and the connections for the true and false conditions are given. The solenoid valve and the pipe indicators are given to the true condition while the relay is given to the false condition through the NOT gate. The V/I converter is given to a true condition through the Boolean data type. The waveforms of the PID and MPC is obtained through the waveform charts given to the pH indicator through the PID block from the control design and simulation tool kit and the ARX and model prediction block respectively. In the next flat sequence when the setup is ideal, the waveform after the value 2.8 is obtained from the waveform chart by using for loop. In the next flat sequence, above steps are followed for the variation of pH from 2.8 to 4.8. In the next flat sequence, the condition for fluctuation of pH and finally the stabilizing of pH is obtained.

V. PERFORMANCE OF PROPOSED MODEL

The Performance of the designed predictive controller for pH control for Cephradine purification process was simulated using LabVIEW and the GUI front panel is Shown in Figure

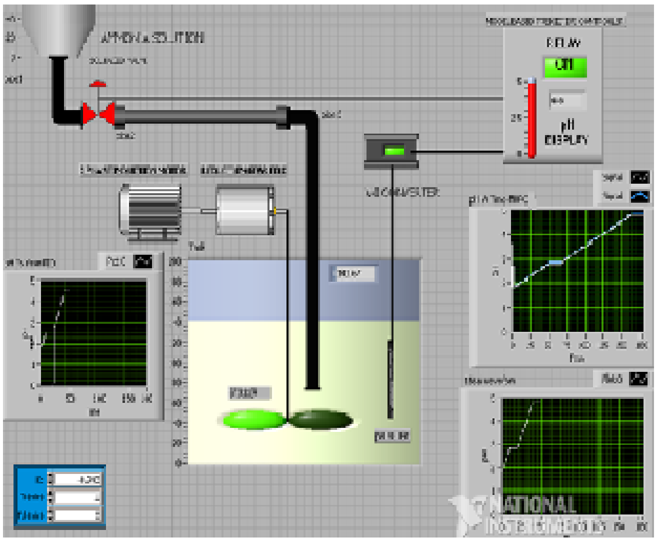

Fig. 3. Front panel Diagram at 4.8 pH

Front Panel is used to interact with the user when the program is running. Users can control the program, change inputs, and sees data updated in real time. The controls are used for inputs. Indicators are used as outputs. When the program is run, the relay inside the MPC closes, the solenoid valve is opened and the ammonia solution flows into the tank and the level of the solution inside the tank gradually increases. Simultaneously the two-waveform charts show the variation of pH with respect to the time for PID and MPC. The display of the pH is shown inside the MPC. Initially the value of pH increases linearly from 1.8 to 2.8. After reaching 2.8 the pH is maintained constant for a particular time and then again increases gradually from 2.8 to 4.8. At 4.8, the waveform chart shows some fluctuations for certain time and then settles to the value of 4.8. When comparing the waveform of the PID with MBPC, it is seen that the waveform of PID shows greater deviations

VI. RESULTS AND DISCUSSIONS

The figure shows the pH responses for our application. In the ideal response pH initially varies from 1.8 to 2.8 linearly and remains constant at 2.8 for some time and again varies from 2.8 to 4.8 linearly and maintained constant at 4.

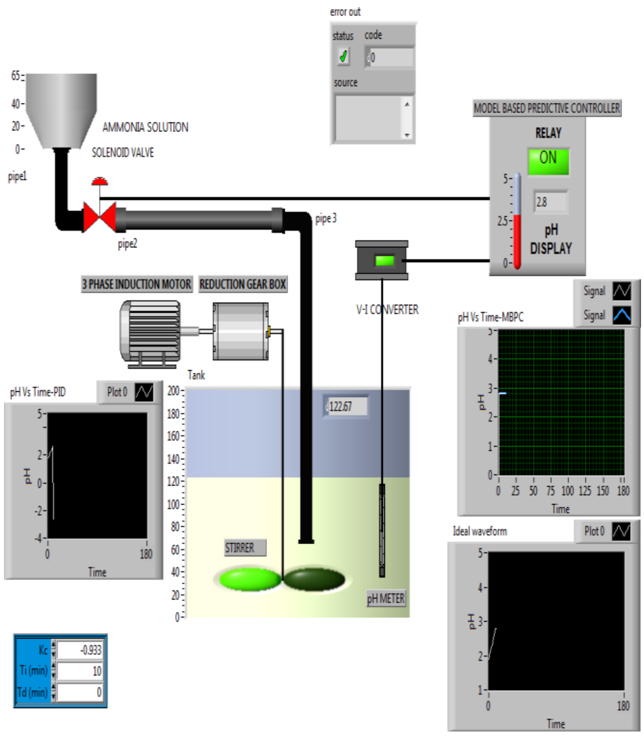

Fig. 4. Front panel Diagram for 2.8

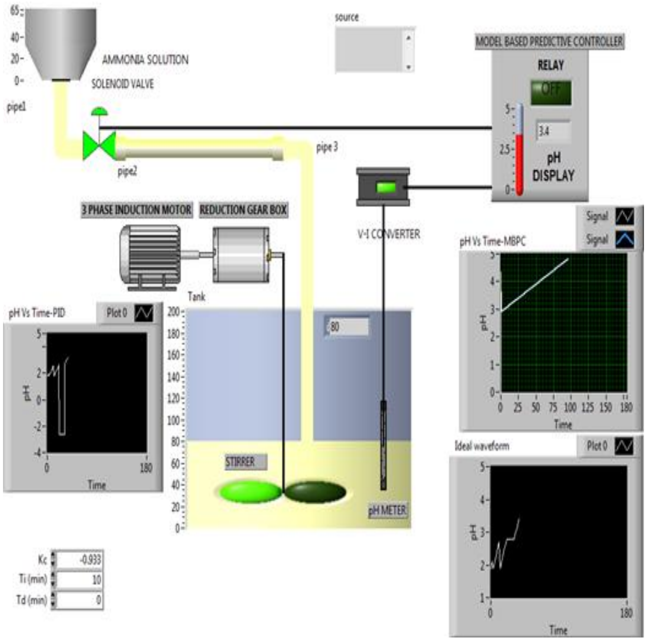

Fig. 5. Front panel Diagram at 3.4 pH

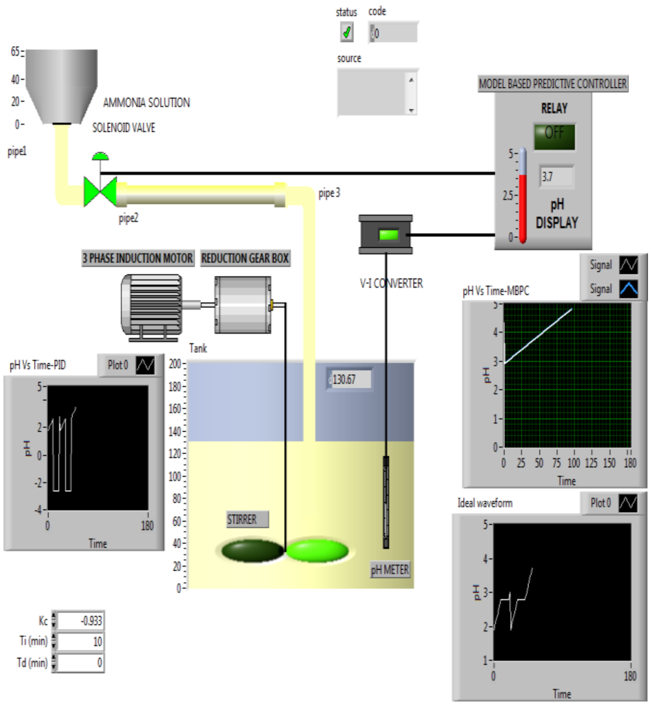

Fig. 6. Front panel Diagram at 3.4 pH

Fig 4, Fig 5, Fig 6 shows the responses of pH Vs time for MPC and PID. The response of MPC coincides with the idea response, which can be well observed in the above figure. This is the main advantage of MPC since the delay periods are well shown without any disturbance. In the response of PID, the graph shows a large deviation for the time at which 2.8 is constant and small amount of deviations for the rest of the part of the graph. Hence, the obtained response of MPC is better than that of PID.

VII. CONCLUSION

A control strategy is applied for the process of pH control in CSTR using Model Predictive Control technique in order to improve the control performance on the reactor that could not be controlled satisfactorily using PID controls. The MPC technique not only controls the status of the valve but is also used to control the stirrer whereas PID could be used only to control the status of the valve. The automatic control of the pH now enables the plant to reduce the batch cycle time, to increase the plant productivity. Using LabVIEW software the output response of our application with MPC and PID controller was compared. From this, the result shows that the response of MPC is accurate and nearer to the ideal response, When compared to PID.

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AUTHOR PROFILE

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