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A Model Reference PID Control System And Its Application To SISO Process

S.M. Jagdish , S.Sathishbabu
Department of Instrumentation Engineering, Annamalai University
Annamalai Nagar-608002, Tamilnadu, India

Abstract: In this paper an enhanced tuning methods of Model Reference PID (MRPID) control System is proposed to improve the control performance of the PID control systems. The proposed control scheme is combined with IMC and PD feedback where PD feedback is designed with Maclaurin series. Three different processes (Bio-reactor, Electrical and Mechanical) are taken and their transfer function is approximated to first order with time delay. Simulation runs for proposed scheme and conventional controller are carried out and their result demonstrates the effectiveness of MR-PID control scheme.
Keywords: MDPID, PID control, conventional PI.

1. Introduction

The modern day process needs robust control system. The controller has to be properly designed to give better closed loop performance and robustness to model uncertainty. The advantages of Model Reference Controllers are that it is simple and easy to understand the control system architecture, good tunability and robustness. However, these control systems have issues such as, a slow disturbance regulation and realization for unstable processes and oscillatory processes. In order to improve the control performance, a new PID control scheme based on the Model Reference Control concept, namely Model Reference PID (MR-PID) control is proposed, which is combined with PD feedback, IMC. The MR-PID control system using the PD feedback is capable of stabilizing with wide processes, regulating quickly for disturbance, and tracking quickly to the change of set point.

A Model Driven Control (MDC) concept is projected by K.Hidenori as an alternative control system [1]. MDC concept suggests using an ideal plant model as a block of a control system to compare the error of the actual plant against that of the ideal plant. A Model Driven PID control system developed by Masanori Yukitomo [2] combines a MDC control system with a PD feedback, an Internal-Model Control (IMC). In this paper each block is analyzed and the design method for the MR-PID control system is described. The MR-PID control is capable of stabilizing with unstable process by using PD feedback. The main controller consists of gain block, IMC block and the process model block. Some results are obtained by use of MR-PID control for the chemical process (temperature controlled process, drum level control loop of chemical process, Boiler and Turbine operation) [2, 3] are also described.

The paper is organized as follows: Section 2 summarizes the process description of three different processes namely Bio-reactor, D.C motor and conveyor belt. In Section 3 process description of MR-PID. In Section 4 describes the design approach of MR-PID. In Section 5 describes Results and Discussion. Summarized all work in section 6.

2. Modeling of Process

A model is a mathematical representation of a physical process, and it attempts to capture the relationship between the inputs and outputs for the system under study. The process of determining the equations that govern the model's dynamics is called mathematical modeling. This can be done off-line, for example, executing a series of measures from which to calculate an approximated mathematical model, typically its transfer function or matrix. Such identification from the output, however, cannot take account of unobservable dynamics. Sometimes the model is built directly starting from known physical equations.

2.1 Modeling of Bio-Reactor [4]

Biochemical reactors are cylindrical culture vessels used for the fermentation process in anaerobic breakdown of complex organic materials by the action of anaerobic microorganism or free enzymes takes place. Materials such as carbon, nitrogen, oxygen, which are called substrate, and other nutrias are brought with the cell into the culture vessel (bioreactor) and converted within the cell via hundreds of reactions to the various constituents of the cell as well as to biochemical product. Bioreactors provided a controlled environment that is necessary to bring the better growth of microbe, and also maintain constant temperature according to the need of microbes

During the breakdown process the microbes produce large number of intermediate and final products, including pharmaceuticals, food, and beverages. The reaction taking place inside the bioreactor is
Substrate +cell..............extracellular products + more cells

$$\sum S + X \ldots\ldots\ldots. © + nX \tag{1}$$

From the above equation the rate of growth is directly related to cell concentration and cellular reproduction. So it is necessary to maintain the cell concentration, i.e. the goal is to achieve the growth of these cells (biomass) in a bioreactor by manipulating the dilution rate, which is the flow rate per volume of the reactor. A typical control and instrumentation diagram of the bioreactor used in this paper for analysis, with biomass concentration as the measured output, is shown bellow

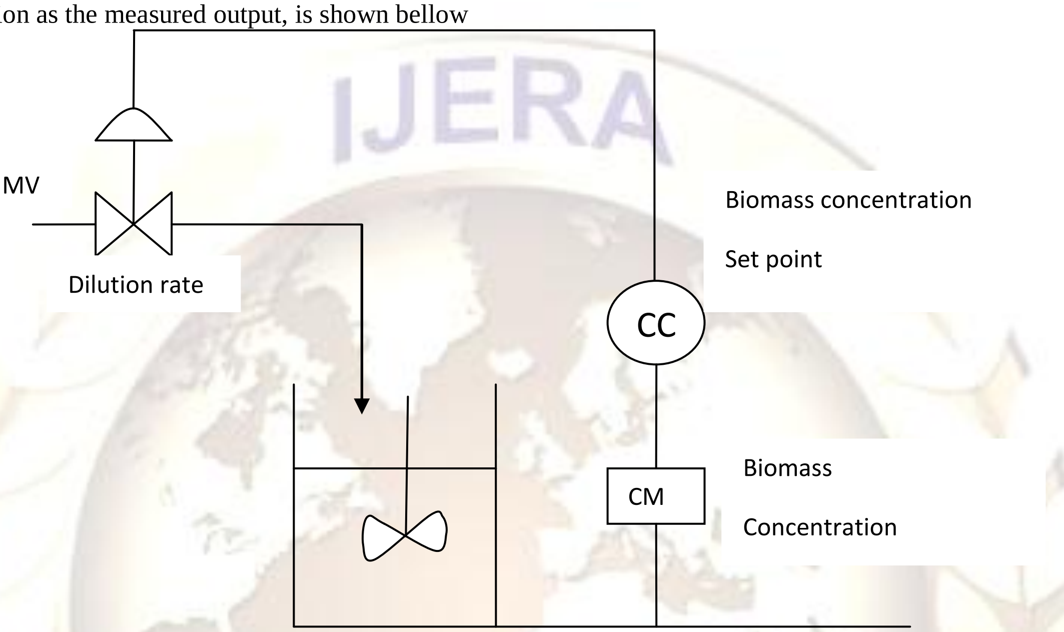

Figure 1. Simplified PI diagram for a biochemical reactor

The transfer function relating the dilution rate to the biomass concentration is,

$$G(s) = \frac{-0.6758\ e^{-1s}}{0.4417s+1} \tag{2}$$

2.2 Modeling Of DC Motor [5]

The principles of operation of a direct current (DC) motors are presented based on fundamental concepts from electricity and magnetism contained in any basic physics course. The D.C motor is used as a concrete example for reviewing the concepts of magnetic fields, magnetic force, Faraday's law, and induced electromotive forces (emf). The D.C. motor is the actuator at the heart of a position control servomechanism. It is the means by which electrical energy is converted to mechanical energy. There are many types of D.C. motor and their detailed construction is quite complex but it is possible to derive the equations for a satisfactory dynamic model from basic electromagnetic relationships.

Motors work on the basic principle that the magnetic fields produce force on wires carrying a current. In fact, this experimental phenomenon is what is used to define the magnetic fields. If one places a current carrying wire between the poles of a magnet, a force is exerted on the wire. Experimentally, the magnitude of this force is found to be proportional to both the amount of current in the wire and to the length of the wire that is between the poles of the magnet. That is, F magnetic is proportional to £i. The direction of the magnetic field B at any point is defined to be the direction that a small compass needle would point at that location.

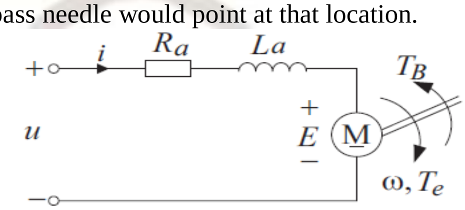

Figure 2. DC motor equivalent circuit

The voltage balance equation of the DC motor is

$$u = R_a.i + L_a.\frac{di}{dt} + K_e \quad (3)$$

Where, I is armature current (A); is equivalent inductance of armature circuit (H); is equivalent resistance of armature circuit (); is terminal voltage of armature circuit (V); $K_e$is voltage coefficient of DC motor (V.s/rad). The torque balance equation of DC motor is expressed as

$$K_i.i - B.\omega = J.\frac{d\omega}{dt} \quad (4)$$

where, *J*is the inertia moment of the rotor (Kg.m^2); $K_t$is the torque coefficient of DC motor (N.m/A). B is viscous friction coefficient of DC motor (N.m.s/rad). The linear DC motor model is obtained as

$$J\omega = -B\omega + K_t i \quad (5)$$

$$L_a i = -K_e\omega - R_a i + u \quad (6)$$

$$y = \omega \quad (7)$$

The transfer function of the D.C motor is given as follows

$$G(s) = \frac{2}{0.5s+2} \quad (8)$$

2.3 Modeling of Mechanical Process [5]

A mechanical process (or conveyor belt) consists of two or more pulleys, with a continuous loop of material - the conveyor belt - that rotates about them. One or both of the pulleys are powered, moving the belt and the material on the belt forward. The powered pulley is called the drive pulley while the unpowered pulley is called the idler. There are two main industrial classes of belt conveyors; those in general material handling such as those moving boxes along inside a factory and bulk material handling such as those used to transport industrial and agricultural materials, such as grain, coal, ores, etc. generally in outdoor locations.

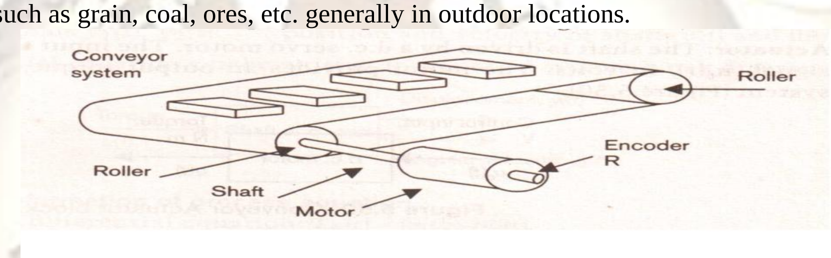

Figure 3. Mechanical Process

The transfer function of the conveyor belt is given as follows

$$G(s) = \frac{1}{0.1s+0.5} \quad (9)$$

3. Process Description of MR-PID

In order to improve the control performance, a new PID control scheme based on the Model Reference Controller concept, namely Model Reference PID (MR-PID) control, which is combined with Main controller, Process model and PD feedback compensation. Here the main controller consists IMC Gain, IMC block and Process Model block. The first order delay with dead time model is used in the process model block. Moreover λ, τ_c tuning parameter and closed loop time constant are also referred. The MR-PID control system using the PD feedback is capable of stabilizing with wide process, regulating quickly for disturbance and tracking quickly to the change of set point. The schematic diagram of Model Driven PID control system is given below

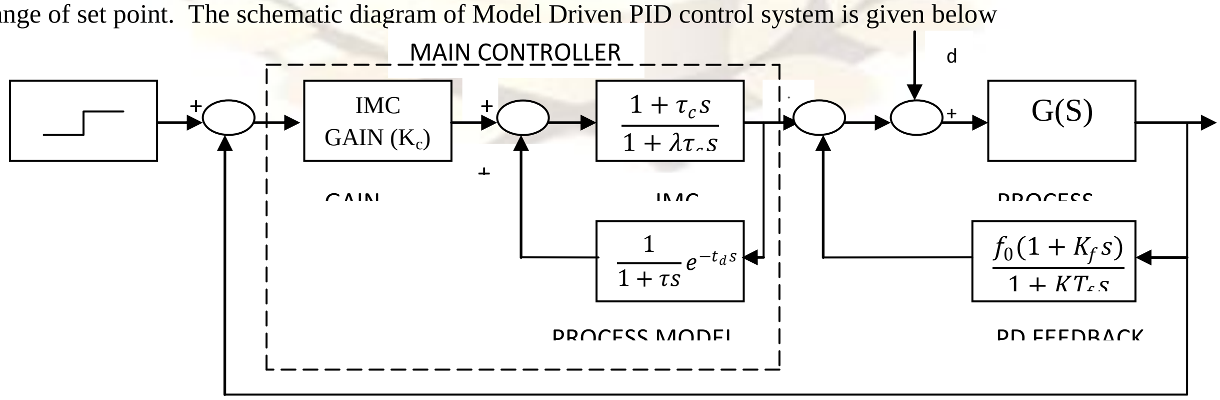

Figure 4 Model Reference PID Control System

4. Design Approach

The MR-PID control system can be designed with the following steps. Many processes are expressed by the first order with dead-time model or the integral with dead-time model. The denominator polynomial form can be expressed by using the Maclaurin series expansion of dead time.

G(s) is the given function

By using Maclaurin series expansion

$$G(s) = \frac{1}{g_0+g_1 s+g_2 s^2+\cdots} \tag{10}$$

g_i (i=1, 2, 3…) are the i^{th} order parameter of denominator polynomial.

4.1. PD Feedback Compensation

The polynomial series representation (i.e. Maclaurin series) of any infinitely differentiable function P(s) whose value, and the values of all of its derivative at s=0is given by

$$G(s) = G(0) + G^{'}(0)s + \frac{G^{''}(0)}{2!}s^2 + \frac{G^{'''}(0)}{3!}s^3 + \cdots \tag{11}$$

Where

$$G(0) = g_0 \tag{12}$$

$$G^{'}(0) = g_1 \tag{13}$$

$$G^{''}(0) = g_2 \tag{14}$$

$$G^{'''}(0) = g_3 \tag{15}$$

and for PD feedback compensation

$$\sigma = \frac{\beta_2 g_3}{\beta_3 g_2} \tag{16}$$

$$f_0 = \frac{g_2}{\beta_2 \sigma^2} - g_0 \tag{17}$$

$$f_1 = (g_0 + f_0)\sigma - g_1 \tag{18}$$

Where

σ =Response time of the loop

β_2 *and* β_3 are response shape factor

Now the values of the K_f *and* T_f can be easily derived from the above values as

$$K_f = \frac{f_1}{f_0} \tag{19}$$

Now from the f_0 *and* K_f values the PD feedback compensation block can be designed as

$$PD\ feedback = \frac{f_0(1+K_f s)}{1+KK_f s} \tag{20}$$

Where the value of K is usually from the value 0.01

5. Results and Discussion

The diagram of the MR-PID is shown in figure 4. For designing fast and overshoot response, the response shaping factor β_2 and β_3 values are chosen accordingly. The response time σ, f_0, K_f is obtained using the PD feedback compensation based on Maclaurin series compensation as discussed in section 4. Simulation runs are carried out for the three processes with MR-PID control loop and conventional PID control loop. Their output responses are recorded in figure 5 to 10. In all the cases the normal operating point is 30% of the total output is maintained. Performance analysis is done for both servo and regulatory responses based on ISE and settling time and their values are tabulated in the table 1 to 3. From the table it is clear that the MR-PID controller gives good performance than the conventional PID controller.

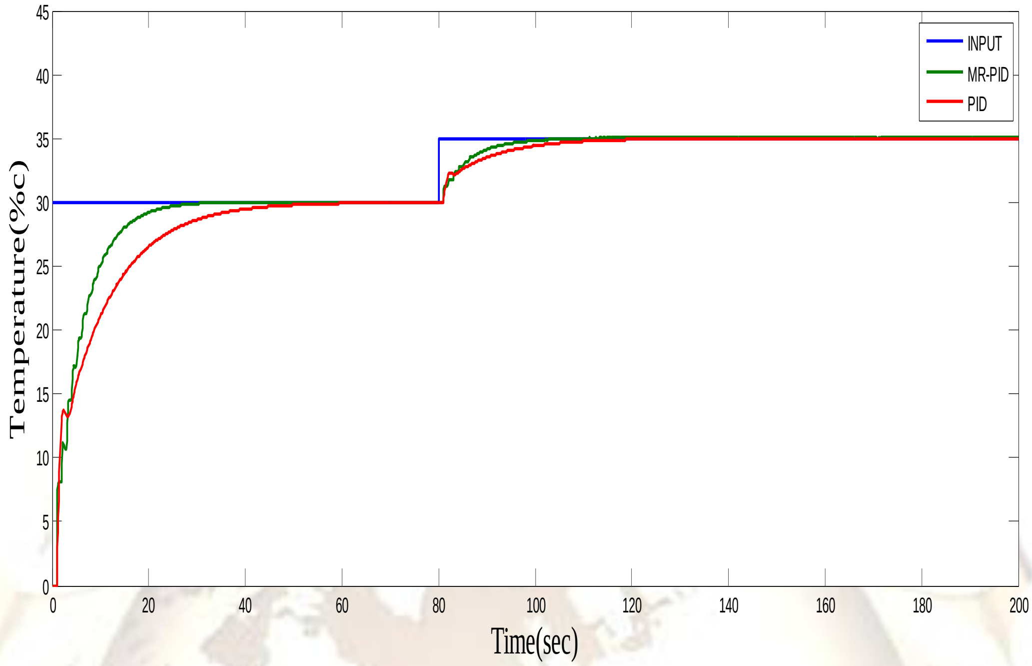

Figure 5. Closed loop Servo response of Bio-Reactor

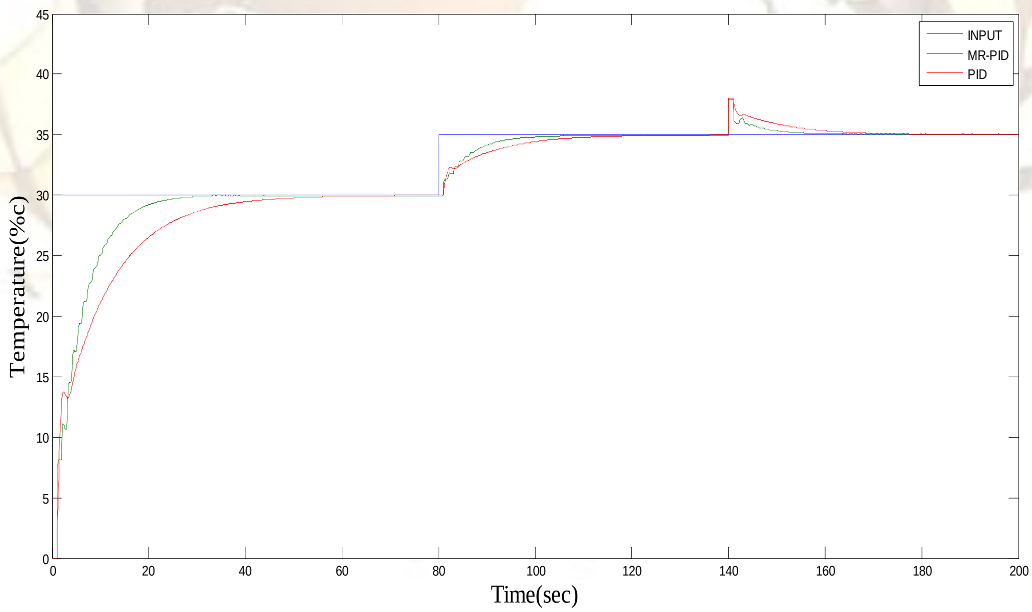

Figure 6. Closed loop Regulatory response of Bio-Reactor

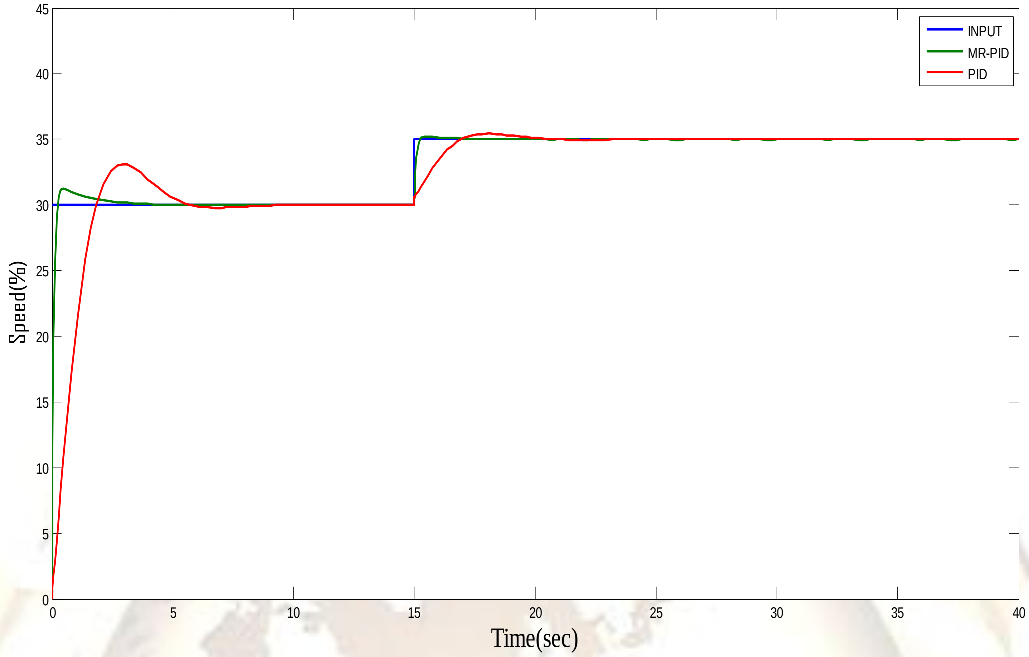

Figure 7. Closed loop Servo response of DC-Motor

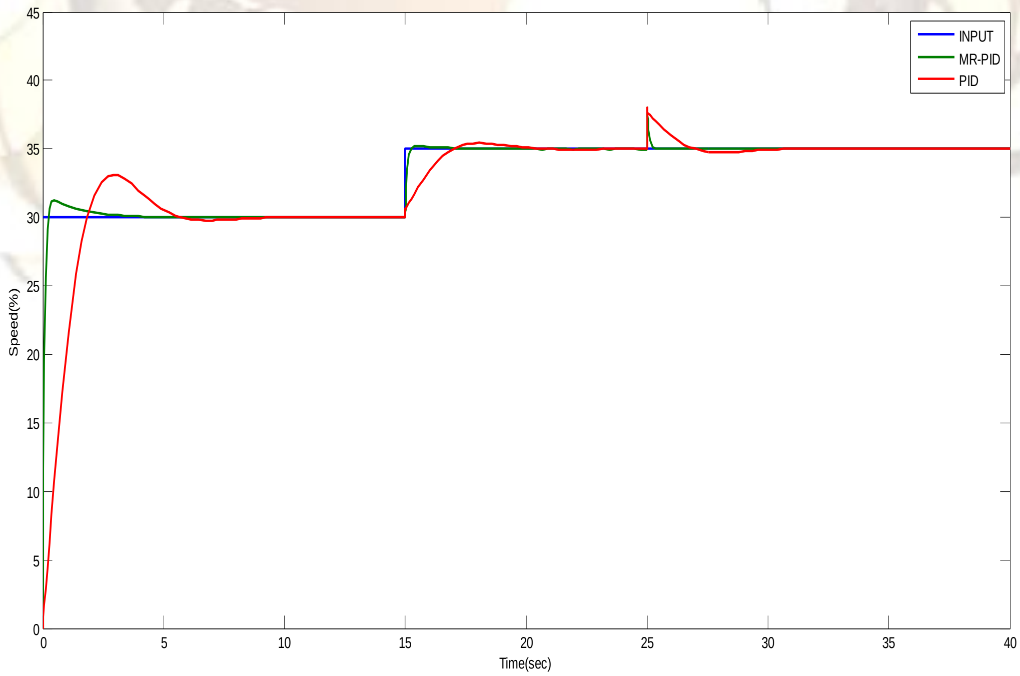

Figure 8. Closed loop Regulatory response of DC-Motor

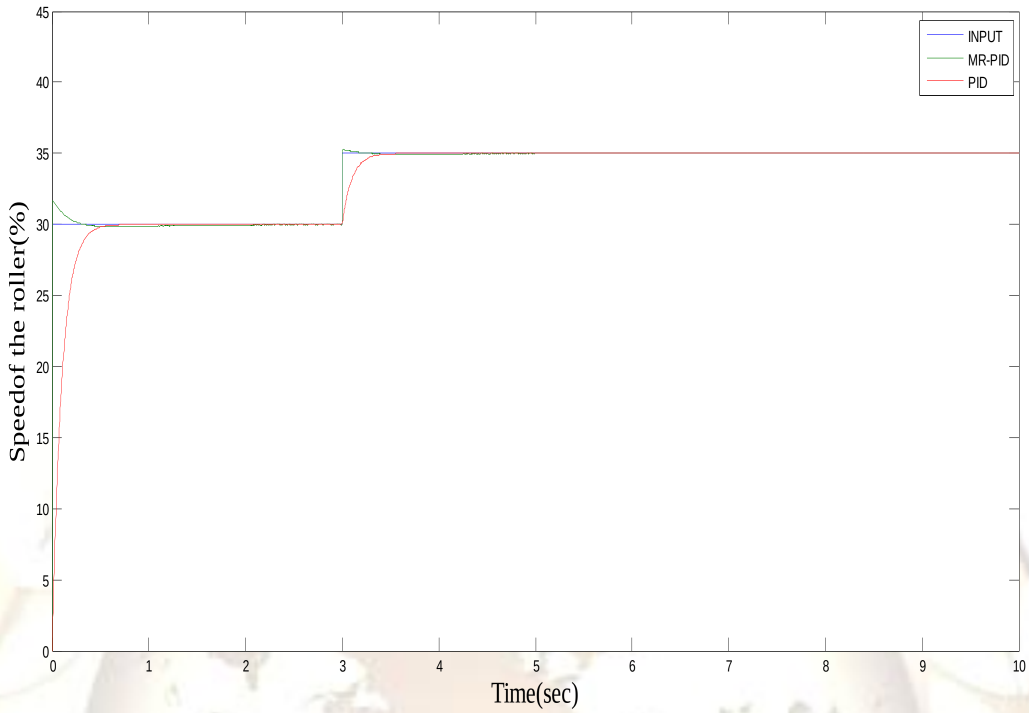

Figure 9. Closed loop Servo response of Mechanical system

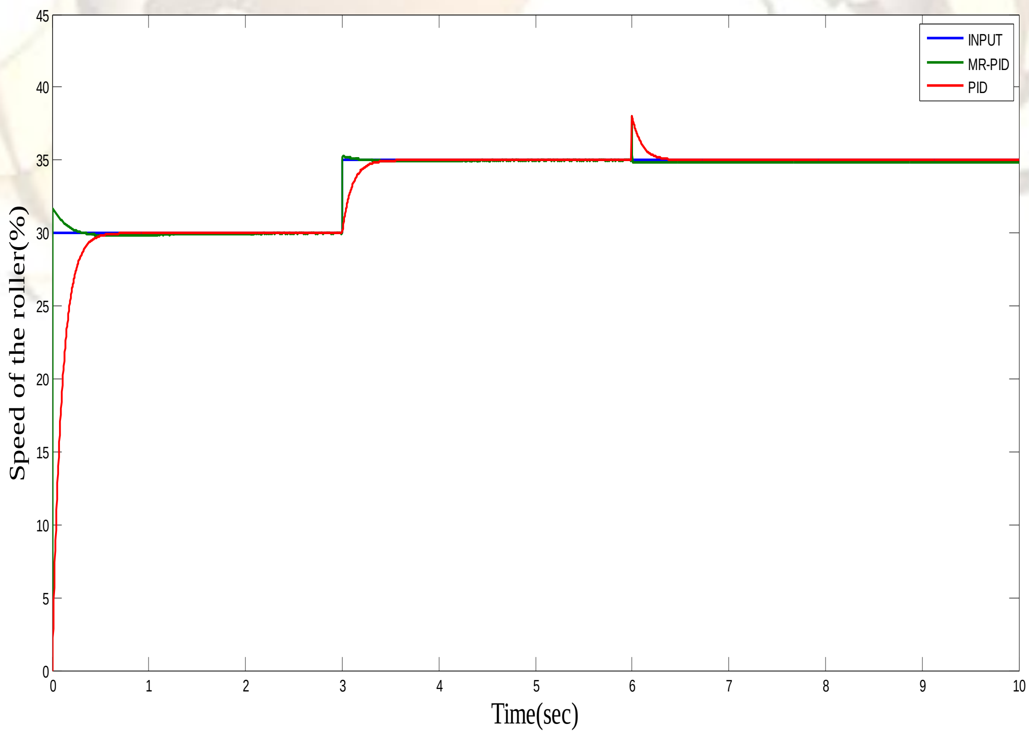

Figure 10. Closed loop Regulatory response of Mechanical system

5.2 Performance Analysis

The performance analysis of the three processes based on the ISE and settling time is shown below:-

Table 1: Performance Analysis of Bio-Reactor

CONTROLLERS	ISE		SETTLING TIME	
	SERVO	REGULATORY	SERVO	REGULATORY
MR-PID	2701	2717	110	160
PID	3333	3365	120	180

Table 2: Performance Analysis of D.C. Motor

CONTROLLERS	ISE		SETTLING TIME	
	SERVO	REGULATORY	SERVO	REGULATORY
MR-PID	33.33	33.67	18	27
PID	40.5	44.2	21	30

Table 3: Performance Analysis of Mechanical System

CONTROLLERS	ISE		SETTLING TIME	
	SERVO	REGULATORY	SERVO	REGULATORY
MR-PID	0.6387	0.7555	3.1	6.01
PID	1.5	5.45	3.5	6.5

6. Conclusion

In this paper an improved tuning methods of Model Reference PID (MRPID) control System is proposed. This scheme is combined with IMC and PD feedback where PD feedback is designed with Maclaurin series. Three different processes (Bio-reactor, Electrical and Mechanical) are taken and their transfer function is approximated to first order process with time delay. Simulations are done for the three processes with conventional PID controller and MR-PID controller. Performance analysis are also done and tabulated. From the results it is proved that the MR-PID controller is a fast controller than PID controller.

Reference

[1]. Y.M. Zhao: "Improved Parameters Tuning Method of Model Driven PID Control Systems" Natural Science and Engineering Research Council of Canada(NSERC) Discovery Grant, IEEE 978-1-4244-8756-1/11 2011

[2]. Takashi Shigemasa, Masanori Yukitomo: "A Model-Driven PID Control System and Its Case Studies"Proceeding of the 2002 IEEE International Conference on Control Applications, Glasgow, Scotland, U.K, September 18-20, 2002.

[3]. Masanori Yukitomo , Yasushi Baba, Takashi Shigemasa, Morimasa Ogawa, Koji Akamatsu, Souichi Amano: "A Model Driven PID Control System and Its Application To Chemical Process", Toshiba Corporation, Toshiba-Cho, Fuchu City, Tokyo, Japan, Mitsubishi Chemical Corporation,3-10, Ushiodori, Kurashiki, Okayama, Japan, SICE(2002)

[4]. S.M. Giriraj Kumar, etal, "Genetic Algorithm Based PID Controller Tuning For A Model Bio-Reactor", Indian Chemical Engineer, Indian Institute of Chemical Engineers, vol.50 n o.3, pp 214-226,2008.

[5]. Jacqueline wilkie, Michael Johnson, Reza Katebi, "Control Engineering, An Introducing Course", www.palgrave.com, pg-105-150.