

Design of Advanced Process Control Strategy for Industrial Pressure Process

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Abstract: In the process industry, pressure process control is important. Pressure process control systems have been refined and used in numerous implementations of in several process industries, pressure process plants are used, including chemical process industries, pharmaceuticals, wastewater treatment, and power plants. Pressure process management is essential in the process industry. Pressure process control systems have been refined and applied to a wide range of pressure process plant applications in a number of industries, including chemical manufacturing, pharmaceuticals, wastewater treatment, and power plants. The execution of such mechanism may result in remote and then the parameters can change over time.

Keywords: Pressure process, Traditional controller, Tyreus-Luyben, Internal Model Control, Direct synthesis method and CDM.

1. Introduction

During the pressure process, a control valve must be installed and a controller suitable in support of the framework must be selected. A three-term electronic or pneumatic controller (Proportional plus integral plus derivative or PID) is suitable in the majority of pressure management applications. There are hundreds of controllers of various brands and sizes to choose from, and the final decision will be based on the degree of performance and accuracy needed, as well as budgetary constraints. The output of the pressure transmitter is connected to the measurement input of the controller, while the controller's output is connected to the control valve [2]. The set point could be manual or remote, depending on how the process communicates with other parts of the plant. It's also vital to keep track of the controller's control actions. The action is said to be direct if the output increases as the measurement increases, while the action is said to be inverse if the output decreases as the measurement increases.

Pressure control is used to track pressures applied during mechanical ventilation in a wide variety of industrial and private-sector applications [8]. Commercial compressed air receivers and domestic hot water storage tanks are examples of what they can be found in these industries. Distillation towers, pressure reactors, mining vessels, Pressure management processes can be used in oil refineries and petrochemical facilities, as well as nuclear reactor vessels and submarines. Traditional controllers, Because of their simplicity, process industries typically employ PI or PID controllers. Every day, industrial processes require automatic control with high efficiency, simple design, and execution over a broad variety of operating conditions

2. Process Description

This paper demonstrates how effective the CDM is for nonlinear systems in the pressure process. Prof.shunjiManate created [11] and introduced CDM in 1991. It has the advantage of being easier to understand and accurate than the function of transfer and the expression of state space.It has the advantage of being easier to understand and accurate than the function of transfer and the expression of state space. This method requires the use of controller polynomials and simultaneous design of characteristics. All of the equations are based on polynomial expressions in the numerator and denominator that work better than pole zero

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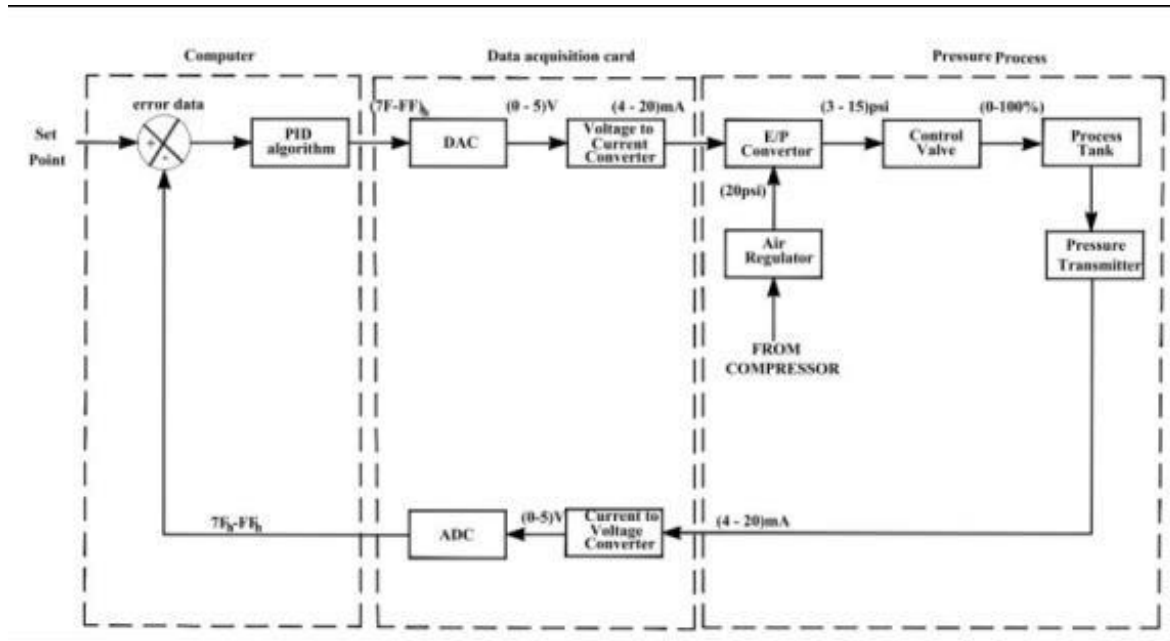


Figure 1: Typical pressure process unit setup

Here, the PC serves as a detector and controller for errors. According to the error signal, a control signal is generated by the computer and provided to the I/P converter that operates the control valve. The control valve functions as the final control feature within the process tank that controls the pressure by adjusting the opening of its plug according to the output of the controller (17). The output of the process is provided by the data acquisition system to the personal computer and the personal computer compares the signal from the output of the process and the set point and gives the data acquisition system the required signal.

3. Experimental model and control design

This chapter describes the system identification by using open loop experimental data with the help of the MATLAB environment system identification toolbox.

3.1 Model Identification from experimental data

The toolbox for device identification allows models to be generated from calculated input-output data. It assists in the analysis and processing of data. The required model structure is then calculated and the parameters of the model are estimated.

- The open loop programme in MATLAB Simulink is connected to the pressure process system, and data can be saved in the MATLAB workspace.
- Open the MATLAB device identification toolbox by typing identification in the command window.
- Import the input and output data from the response of the open loop method
- Pick the process model for the imported data and provide an estimation to see the role of the process transfer.
- The transfer function for the pressure phase and the equation(1) for the process are obtained from this process.

$$G(s) = \frac{k_p}{\tau s + 1} e^{-t_d s} = \frac{4.4593 \cdot e^{-0.679}}{0.1298s + 1} \quad (1)$$

K_p - Proportional gain ; τ - Integral time ; t_d - delay time

4. Traditional controller

Compared with advanced controllers, the general standard controllers are developed and implemented in real time processes.

4.1 PI Controller

A typical industrial controller, the PI controller. It will eliminate forced oscillations, which cause on-off controller operation, and steady state error, which causes proportional controller operation. Setting the I (integral) and D (derivative) gains to zero accomplishes this. After that, the "P" (proportional) gain, K_p , is increased (from zero) until the ultimate K_u gain is reached, at which point the control loop output has stable and consistent K_u oscillations, and the T_u oscillation period is used to set the gains of P, I, and D, depending on the type of controller used(15).

Table 1.Nicholas Ziegler's tuning parameters for closed loop oscillation systems

Controller	k_c	τ_i	τ_d
P	$0.5k_p$	-	-
PI	$0.45k_p$	$\frac{\tau}{1.2}$	-
PID	$0.6k_p$	$\frac{\tau}{2}$	$\frac{\tau}{8}$

The obtained PI Controller values are based on Ziegler Nichols tuning

$$k_c = 1.08372 \text{ sec}; \tau_i = 0.0649 \text{ sec}$$

4.2 .PID Controller

Table 2.Conventional PID controller tuning parameters

Close Loop Response	Rise Time	Overshoot	Settling Time	Steady State Error
K_p	Decrease	Increase	Small change	Decrease
K_i	Decrease	Increase	Increase	Eliminate
K_d	Small change	Decrease	Decrease	Small change

The obtained PID Controller values are based on Ziegler Nichols tuning

$$K_c = 2.0155 \text{ sec}; \tau_i = 0.01081666 \text{ sec}; \tau_d = 0.016225 \text{ sec}$$

5.CONTROLLER TUNING

5.1. Tyreus-Lyuben

Since it is more efficient with minimal values for dead time, this is a more controlled than ZN method. When dead time is critical, however, it results in a slow development. When tuning the controller, it concede ultimate gain K_u and frequency P_u .

Table 3. Parameter tuning for Tyreus-Luyben

Controller modes	K_c	τ_i	τ_d
PI	$\frac{K_p}{3.2}$	2.2τ	-
PID	$\frac{K_p}{2.2}$	2.2τ	$\frac{\tau}{6.3}$

Tuning parameter of Tyreus-Luyben based PID tuning

$$K_c = 1.2526 \text{ sec}; \tau_i = 0.028556 \text{ sec}; \tau_d = 0.00206031 \text{ sec}$$



Figure 2. TyreusLuyben's Simulink model for PID controller
IMC based PID

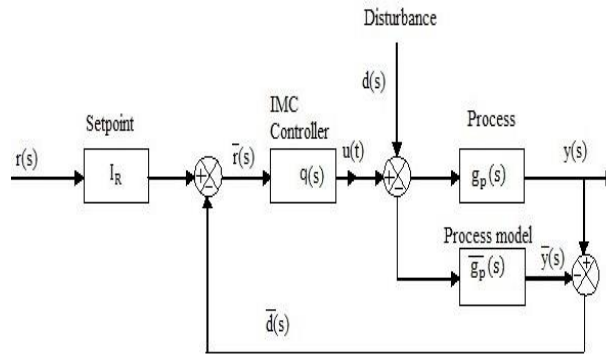
The internal model theory underpins Internal Model Control (IMC). Regulation can only be achieved, according to the internal model principle, if the control system encapsulates some representation of the mechanism to be controlled, either implicitly or explicitly. The model-based control system is primarily used to achieve the desired setpoint while also excluding minor external intervention.

The controller with normal feedback, which is similar to IMC, is demonstrated in this Equation. [8]. (2)

$$g_c(s) = \frac{q(s)}{1 - \bar{g}_p(s)q(s)} \quad (2)$$

To obtain the PID Equivalent form for time-delay processes, where the dead time is approximated using the first-order Pade approximation as shown in Equation (3) - (5)

$$g_p(s) = \frac{k_p}{\tau s + 1} e^{-t_d s} \quad (3)$$


Figure 3. IMC structure

$$e^{-t_d s} = \frac{1 - \frac{t_d s}{2}}{1 + \frac{t_d s}{2}} \quad (4)$$

$$g_p(s) = \frac{k_p(1 - 0.5t_d s)}{\tau s + 1(1 + 0.5t_d s)} \quad (5)$$

The IMC controller transfer function is shown as $q(s)$ in Equations (6)-(8).

$$q(s) = \bar{q}(s) f(s)$$

$$q(s) = \frac{\tau s + 1(1 + 0.5t_d s)}{k_p} \frac{1}{\lambda s + 1} \quad (6)$$

$$\text{Where } \bar{q}(s) = \frac{\tau s + 1(1 + 0.5t_d s)}{k_p} \quad (7)$$

$$f(s) = \frac{1}{\lambda s + 1} \quad (8)$$

λ = Parameter for Filter Tuning

Equation shows how to make an analogous standard feedback controller [8] by applying the transformation (9)

$$g_c(s) = \frac{\bar{q}(s)f(s)}{1 - \bar{g}_p(s)f(s)} \quad (9)$$

$$g_c(s) = \frac{1}{k_p} \left[\frac{(\tau s + 1)(1 + 0.5\tau_d s)}{(\lambda + 0.5\tau_d)s} \right] \quad (10)$$

The PID tuning parameters are

$$k_p = \frac{\tau + 0.5\tau_d}{k_p(\lambda + 0.5\tau_d)} = 0.083459 \text{ sec}$$

$$\tau_i = \tau + 0.5\tau_d = 0.35248 \text{ sec}$$

$$\tau_d = \frac{\tau \tau_d}{2\tau + \tau_d} = 0.0125214 \text{ sec}$$

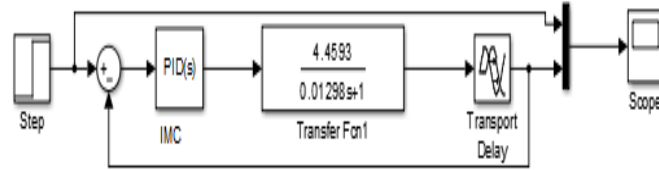


Figure 4. IMC-based PID Simulink model

5.3 Direct Synthesis Method

PID controller direct synthesis methods are usually based on a performance criteria in the time-domain or frequency-domain. The controller is based on the closed-loop transfer mechanism that is needed. The response of the closed-set-point loop is then measured analytically to ensure that it matches the desired response.

$$\frac{Y}{Y_{sp}} = \frac{K_m G_c G_v G_p}{1 + G_c G_v G_p G_m} \quad (11)$$

Let's call $G \triangleq G_v G_p G_m$ and assume $G_m = G_k$ for the sake of simplicity.

$$\frac{Y}{Y_{sp}} = \frac{G_c G}{1 + G_c G} \quad (12)$$

The feedback controller can be expressed as follows after rearranging and solving for:

$$G_c = \frac{1}{G} \left(\frac{\frac{Y}{Y_{sp}}}{1 - \frac{Y}{Y_{sp}}} \right) \quad (13)$$

Since a priori, the closed-loop transfer function is not established. Equation above cannot be used to design a controller. It's used to differentiate between the real process G and the model \bar{G} that approximates the process's behaviour. By substituting G for \bar{G} and $\frac{Y}{Y_{sp}}$ for a desired closed loop transfer function $\left(\frac{Y}{Y_{sp}} \right)_d$, a practical design equation can be obtained.

$$G_c = \frac{1}{\bar{G}} \left(\frac{\left(\frac{Y}{Y_{sp}} \right)_d}{1 - \left(\frac{Y}{Y_{sp}} \right)_d} \right) \quad (14)$$

The specification of $\left(\frac{Y}{Y_{sp}} \right)_d$ is the most critical design decision.

The opposite of the process model is found in the controller transfer function in Equation (14) because of the term $\frac{1}{G}$. The first-order model in Equations (13) is a logical choice for processes that do not have a time delay.

$$\left(\frac{Y}{Y_{sp}}\right)_d = \frac{1}{\tau_c s + 1} \quad (15)$$

The controller design Equation is replaced by Equation (15) in Equation (14) and solved by G_c

$$G_c = \frac{1}{G} \frac{1}{\tau_c s} \quad (16)$$

The $\frac{1}{\tau_c s}$ term defines a control operation that is integral rather than offset.

The configuration parameter τ_c provides a continuous tuning parameter for the controller, allowing it to be rendered more aggressive (small τ_c) or less aggressive (large τ_c). If the process transfer function has a known time delay t_d , a rational option for the desired closed-loop transfer function is

$$\left(\frac{Y}{Y_{sp}}\right)_d = \frac{e^{-t_d s}}{\tau_c s + 1} \quad (17)$$

Since it is physically impossible for the governed variable to react to a change in set-point $t=0$ before $t=t_d$, the time-delay term in Equation (15) is critical. If the length of the delay is unclear,

Equations (17) and (14) when combined have

$$G_c = \frac{1}{G} \frac{e^{-t_d s}}{\tau_c s + 1 - e^{-t_d s}} \quad (18)$$

PID controllers for basic process models can be estimated using Equations (18). The time delay term is approximated in the denominator of Equation using a truncated Taylor series expansion (18).

$$e^{-t_d s} = 1 - t_d s \quad (19)$$

Rearranging the equation (19) and substituting it into the denominator (18) yields

$$G_c = \frac{1}{G} \frac{e^{-t_d s}}{(\tau_c + t_d)s} \quad (20)$$

For Direct Synthesis, the (FOPTD) method is used.(14)

$$\bar{G}(s) = \frac{k e^{-t_d s}}{\tau_c s + 1} \quad (21)$$

Rearrangement is achieved by substituting Equations (20) into Equation (19) and using a PID controller.

$$G_c = \frac{\tau s + 1}{k(\tau_c + t_d)s} \quad (22)$$

The gain values obtained from the tuning PID controller optimization using the direct synthesis method are as follows:

$$\begin{aligned} k_c &= \frac{\tau}{k_p(\tau_c + t_d)} = 1.039496 \text{ sec;} \\ \tau_i &= \tau = 0.01298 \text{ sec;} \\ \tau_d &= \frac{t_d}{2} = 0.2395 \text{ sec} \end{aligned}$$

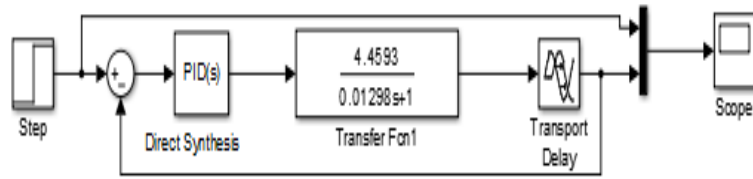


Figure 5. Based on Direct Synthesis, Simulink model for PID controller

5.4 Coefficient Diagram Method

The coefficient diagram process is among the most common sophisticated and efficient methods of style of controls. It is very reliable and durable in the control system, and the system responds without overshooting and with there isn't much time to settle. The CDM solves the classic control problem by automatically determining a goal characteristic polynomial for the closed-loop method based on a few meaningful design parameters. The implementation of CDM and PID will be applied to a nonlinear uncertain system represented by two differential equations with partial solutions around a real-world operating point, and the modified controllers will then be implemented to the nonlinear system. The outcomes of the simulation indicate that the CDM-based controller has a quick response time, no overload, and the best perturbation elimination conditions to use in conjunction with PID.

This procedure is an algebraic method to the polynomial loop's parameter space, where a special diagram known as a coefficient diagram will provide the appropriate design information. The importance of CDM for any plant under practical constraints is its simplicity and robust capacity. Because of its simplicity, the controller design has proved to be useful for systems of varying degrees of uncertainty. CDM has been used to effectively develop a range of control systems. When compared to other design methods, CDM was already found to provide a stable and robust controller design as well as the optimal device response speed. As a consequence, parameter changes cause less disruptions and small uncertainties in CDM. As a result, CDM is an essential control process design.

6. CDM CONTROLLER DESIGN

The CDM control scheme is depicted in Figure (7) as a block diagram, with $N(s)$ representing numerator polynomials and $D(s)$ representing plant transition mechanism denominator polynomials. In the CDM controller, The forward denominator polynomial is $A(s)$. As a result, the transfer function of the controller has two numerators, suggesting input structures that are two-dimensional. Here r represents the computer reference input, u represents the control signal, d represents the signal of external disturbance, and y represents the control device output.

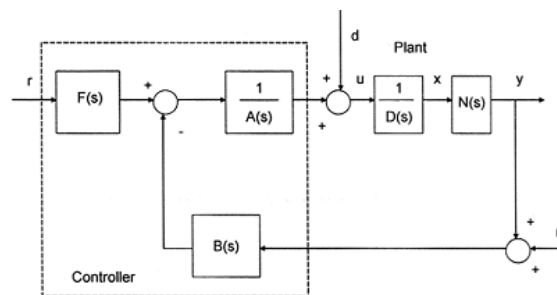


Figure6. CDM's Block Diagram

$$y = \frac{N(s)F(s)}{p(s)} r + \frac{A(s)N(s)}{P(s)} d \quad (23)$$

Here $P(s)$ denotes closed loop system characteristics polynomial [11] and is described by

$$p(s) = A(s)D(s) + B(s)N(s) \quad (24)$$

The control polynomials are defined as A(s) & B(s), respectively.

$$A(s) = \sum_{i=0}^p (I_i s^i), B(s) = \sum_{i=0}^q (K_i s^i) \quad (25)$$

For functional recognition, the constraint $p \geq q$ should be met. F(s) becomes the polynomial chosen as follows:

$$F(s) = \frac{p(s)}{N(s)} = S(0) \quad (26)$$

In the Coefficient Diagram Method architecture, the equal time constant (τ) and stability indices (γ_i) were two essential parameters. The equivalent time constant is chosen as $\tau = \frac{t_s}{2.5 \approx 3}$ to provide the reaction time of a closed loop [11], Stability indices γ_i where t_s is the user-defined settling time. Values will decide the stability, shape of the reaction time. The γ_i values are chosen in standard form as $\{2.5, 2, 2 \dots 2\}$. The designer will alter the above γ_i values to suit his or her needs. The important factors (τ and γ_i) can be used to frame the target characteristic polynomial, P target (s).

$$P_{target}(s) = a_0 \left[\left\{ \sum_{i=2}^n \left(\prod_{j=1}^{i-1} \left(\frac{1}{\gamma_{i-j}} \right) \right) ((\tau s)^i) \right\} + \tau s + 1 \right] \quad (27)$$

The closed loop characteristic polynomial P is obtained by replacing the control polynomials in Equation (25) in to the Equation (24). The coefficients of the CDM controller polynomials l_i , K_i and a_i must be calculated.

Use the formula below.

The CDM responses for the process function as follows

$$\begin{aligned} \frac{F(s)}{B(s)} &= \frac{1.78266}{0.172295s^2 + 1.235129s + 1.78266} \\ \frac{B(s)}{A(s)} &= \frac{0.172295s^2 + 1.235129s + 1.78266}{0.009793s^2 + 0.363639s} \\ \frac{N(s)}{D(s)} &= \frac{-0.09825568s + 0.24811}{0.06115608s^2 + 0.45921s + 1} \end{aligned}$$

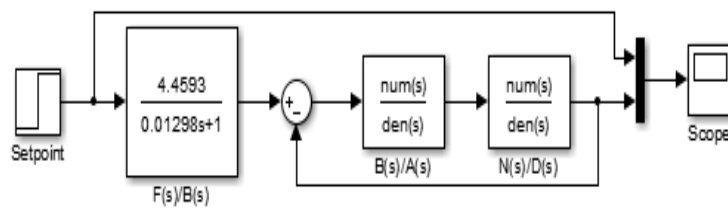


Figure 7. Simulink model for CDM controller

7. RESULTS

Various controller tunings and their simulation findings are discussed in this chapter. Simulation is used to determine the optimum functioning of the mechanism, protection and environmental constraints. It is used to evaluate, test and optimize operating conditions while the process is in operation. It guarantees the operator's protection as well as the hardware device. Thus, it is necessary to simulate the obtained model before implementing the controller design in real time. PI, PID, Tyreus-Luyben, IMC (Internal Model Control), Direct Method of Synthesis and CDM are the various controllers used in the pressure operation (Coefficient Diagram Method)(13).

7.1 Open Loop Response

With no feedback loop, the open loop response is taken in real time and the process model is identified by this method and the response is given in the figure (8)

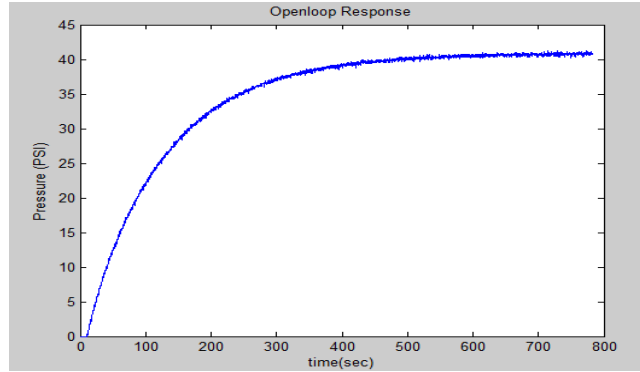


Figure 8. Open loop response

The comparative analysis of controller performance is described and reported in Table 4 based on delay time, rise time, set time, and peak time, and the error indices are reported in Table 4.

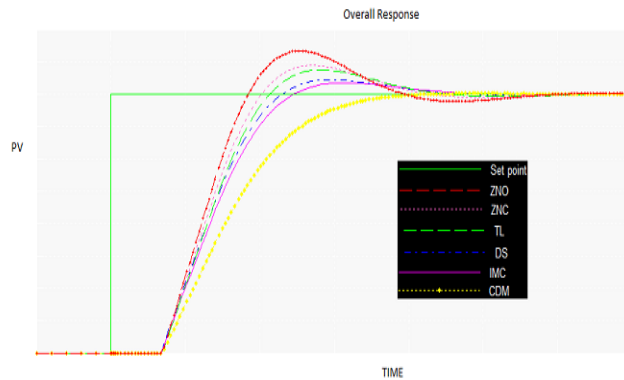


Figure 9. Simulated response of PI,PID,TL,IMC,DS,CDM Controllers

Table 4. Conventional PI, PID, TyreusLuyben, IMC based PID, Direct Synthesis process, and CDM performance metrics are

	Delay time(sec)	Rise time(sec)	Peak Overshoot (%)	Settling time(sec)
PI Controller	2.53	2.25	5.63	5.4
PID Controller	2.35	2.17	5.40	4.65
TyreusLuyben	2.31	2.30	4.25	6.12
Internal Model Control	2.33	2.05	5.36	4.3
Direct synthesis	2.35	2.03	4.23	5.12
Coefficient Diagram Method	1.68	1.17	0.286	3.48

CONCLUSION

Nonlinear machine management is a very difficult job to accomplish. Using different control systems such as PI, PID, TyreusLuyben, IMC based PID, direct synthesis method and Coefficient Diagram Method, the pressure value is controlled in simulation. The effectiveness of the CDM for nonlinear systems for the pressure phase is demonstrated in this work. In CDM, the polynomial and the controller features are built with the aid of the coefficient diagram at the same time. Stability and answer are defined by the characteristic polynomial. Robustness is ensured by the control structure. A simple controller that meets the requirements for stability, response and robustness can therefore be built. The design of the CDM shown here is for the SISO system. This approach also refers to SIMO, MISO, and so on. For future research, the extension to the MIMO issue is left to.

REFERENCES

- Ali Khaki-Sedigh, PeymanBagheri and TaherehGholaminejad (2016), 'Adaptive Tuning of Model Predictive Control', IEEE 4th International Conference on Control, Instrumentation and Automation, pp.169-182
- Al Shehhi .H and Boiko.I (2014), 'MRFT-Based Robust and Adaptive Controller Design for Gas Loop of Liquid-Gas Separator', IEEE 13th Workshop on Variable Structure System, pp.351-356.
- Anitha, T., Gopu, G., Nagarajapandian, M., &Devan, P. A. M. (2019, October). Hybrid Fuzzy PID Controller for Pressure Process Control Application. In 2019 IEEE Student Conference on Research and Development (SCOREd) (pp. 129-133). IEEE
- Ashraf A. Zaher and MounibKhanafar (2017), 'A Systematic Approach to Model and Simulate Controlling Industrial Processes with Uncertainties', IEEE International System Conference, pp.247-252
- Bingi, K., Ibrahim, R., Karsiti, M. N., Hassan, S. M., &Harindran, V. R. (2018, April). Fractional-order PI controllers for real-time control of pressure plant. In 2018 5th International Conference on Control, Decision and Information Technologies (CoDIT) (pp. 972-977). IEEE.
- Bingi, K., Ibrahim, R., Karsiti, M. N., Hassan, S. M., &Harindran, V. R. (2019). Real-time control of pressure plant using 2DOF fractional-order PID controller. *Arabian Journal for Science and Engineering*, 44(3), 2091-2102.
- David Banjerdpongchai and Tat Angwattanapanich (2014), 'Design and Implementation of Wiener Nonlinear Model Predictive Control for Pressure Control Loop', IEEE System International Annual Conference, pp.143-149
- Devan, P. A. M., Hussin, F. A., Ibrahim, R., Bingi, K., &Abdulrab, H. (2020, December). Fractional-order Predictive PI Controller for Process Plants with Deadtime. In 2020 IEEE 8th R10 Humanitarian Technology Conference (R10-HTC) (pp. 1-6). IEEE
- Devan, P. A. M., Hussin, F. A. B., Ibrahim, R., Bingi, K., &Abdulrab, H. Q. (2020). Fractional-Order Predictive PI Controller for Dead-Time Processes With Set-Point and Noise Filtering. *IEEE Access*, 8, 183759-183773.
- Fangzhou Liu , Jialu Fan , JianbinQiu , Lin Zhao and Minyou Chai,(2013) 'Integrated Network-Based Model Predictive Control for Setpoints Compensation in Industrial Processes', *IEEE Transaction On Industrial Informatics*, Vol.9, No.2, pp.1246-1249.
- Feng Yu chang and Shi Dong lin (2012), 'Model Free Adaptive Predictive Control for Main Stream Pressure System of Power Plant' ,ELSEVIER, International Conference on Future Electrical Power and Energy Systems , pp.1682-1688.
- HOU ZhongShengJIN, LI Xiao and Shang Tai(2012), 'Model-free Adaptive Control for Magnetic Levitation Ball System', IEEE 31stchinese control conference, pp.524-529.
- Prabakaran M and Naveen kumar P (2016), 'Design of Model Predictive Controller for Industrial Pressure Process', *International Journal of Engineering Sciences and Computing*, Vol.6, No.5, pp.5724-5727.
- Rajeev Kumar, Sunil K Singla and Vikram (2013), 'A Comparative Analysis of different Methods for the tuning of PID Controller', *International Journal of Electronics Communications and Electrical Engineering*, Vol. 3, No. 2, pp. 73-78.
- Shangtai Jin and ZhongshengHou (2011),'Data-Driven Model-Free Adaptive Control for a Class of MIMO Nonlinear Discrete-Time Systems, *IEEE Transaction on neural networks*, Vol.22, No.12, pp. 2173-2188.
- Senthilkumar K and Angeline Vijula D (2015),'Implementation of two-degree-of-freedom (2DOF) controller using coefficient diagram method (CDM) techniques for three tank interacting system', *International Research Journal of Engineering and Technology*, Vol.2, No.9, pp.90-96
- TaotaoTian and ZhongshengHou (2016),'Lazy-Learning-Based Data-Driven Model-Free Adaptive Predictive Control for a Class of Discrete-Time Nonlinear Systems', *IEEE Transaction on neural networks* ,Vol.12, No.08, pp. 1196-1199.

Nagarajapandian.M, Kanthalakshmi S,Anitha .T and Devan P.A.M (2019). 'Linear Matrix Inequality Based Controller used in Multivariable Systems', IEEE Student conference on research and Development, SCORed, pp. 134-139.

