

Direct synthesis Method – Based Controller Design for Cold Rolling Mill

S.Umamaheswari
Asst.Prof./EIE,
Mahenedra Engg.College,
Namakkal(DT), INDIA
umas.sundar@gmail.com

Dr.V.Palanisamy
Principal
Info Institute of Technology
Coimbatore, INDIA
vpsamy@gmail.com

Dr.M.Chidambaram
Director / NIT
Trichy.
chidam@nitt.edu

Abstract

The mathematical model (Interval Plant) of the web guide in cold rolling mill(CRM) is controlled using PID controller [1]. The given interval plant of the CRM is approximated to FOPTD +Integrator system using Sundaresan& Krishnamoorthy method.[2] The controllers are tuned using direct synthesis method proposed by Seshagirao et. al. Rao [5], Ziegler – Nichols technique(Z-N), internal model control(IMC) and the performances are compared by simulation. Using direct synthesis method, a PID controller in series with lead/lag compensator is designed for control of integrating plus first-order time delay(IFOPTD) process. Guidelines are provided for selection of the desired closed loop tuning parameter. The method gives significant load rejection performances. The direct synthesis method gives simple equations for the controller settings. The performance of the closed loop system is evaluated for both original and approximated modelThe abstract is to be in fully-justified italicized text as it is here, below the author information. Use the word “Abstract” as the title, in 12-point Times New Roman, boldface type, centered relative to the column, initially capitalized. The abstract is to be in 11-point, single-spaced type, and may be up to 3 in. (18 picas or 7.62 cm) long. Leave two blank lines after the abstract, then begin the main text. All manuscripts must be in English.

Keywords: Interval Plant, Cold rolling mill, Direct Synthesis Method

1. Introduction

There are many intermediate web guides in cold rolling mills process such as CRM (cold rolling mill), CGL (Continuous galvanizing line) and so on. The main functions of the web guide are to adjust the center line of the strip to the center line of the steel process. Rapid process speed cause large deviation between the center position of the strip and the process line should be compensated.

In general, the CPC of the web is obtained by hydraulic driver (or) electrical controller. The model of the web guide system is obtained from [1].

For the purpose of designing controllers, the dynamics of many processes can be described by first-order plus time delay (FOPTD) model. Methods for tuning PID controllers for such models are based on stability analysis Ziegler & Nichols [4]. To control the system, we compare the performances of the PID controller tuned by Ziegler- Nichols method, IMC method and direct synthesis method. an Internal model controller proposed by Rivera & Morari [3].

To control the system, we compare the performances of the PID controller tuned by Ziegler- Nichols method, IMC method and direct synthesis method.

2. Interval plant

The model of the web guide system by using geometrical relations of the guide ignoring the mass and stiffness of the web is given by [1]:

$$G(s) = \frac{a3s^3 + a2s^2 + a1s^1 + a0}{s^5 + b4s^4 + b3s^3 + b2s^2 + b1s^1 + b0}$$

Where the coefficients are of interval in nature, which is given by,

$$a3 = [4.5 \ 24] ; a2 = [5 \ 29] ;$$

$$a1 = [0.9 \ 5] ; a0 = [0.05 \ 0.3]$$

$$b4 = [4 \ 9] ; b3 = [4 \ 9] ; b2 = [0.7 \ 2]$$

$$b1 = [0.03 \ 0.08] ; b0 = [0 \ 0]$$

This is represented as model 1, model 2 and model 3 by considering only the minimum, maximum and average value of the interval.

The model1, model2 and model3 plant is given by,

$$\text{Model 1} = \frac{0.05 + 0.9s^1 + 5s^2 + 4.5s^3}{0.03s^1 + 0.7s^2 + 4s^3 + 4s^4 + s^5}$$

$$\text{Model 2} = \frac{0.3 + 5s^1 + 29s^2 + 24s^3}{0.08s^1 + 2s^2 + 9s^3 + 9s^4 + s^5}$$

$$\text{Model 3} = \frac{0.175 + 2.95s^1 + 17s^2 + 14.25s^3}{0.055s^1 + 1.35s^2 + 6.5s^3 + 6.5s^4 + s^5}$$

These models have been approximated to FOPTD with integrator system using the method of Sundaresan and Krishnamurthy method [2]. For the purpose of designing controller, the dynamics of many processes can be described by a FOPTD system. Here it has been approximated to FOPTD plus Integrator system. The approximated reduced model is given by,

$$\text{RModel1} = \frac{1.667}{s(0.5584s + 1)} e^{-0.3526s}$$

$$\text{RModel2} = \frac{3.75}{s(1.256s + 1)} e^{-0.793s}$$

$$\text{RModel3} = \frac{3.1818}{s(1.0659s + 1)} e^{-0.6731s}$$

In the present work, the method proposed by Seshagirirao et. al.[5] is used to design PID controllers for the FOPTD plus Integrator system and compared with corresponding original model and IMC and Ziegler-Nichols [4] method. The equations for the controller settings are simple in terms of the model parameters. Using direct synthesis method for set-point tracking, a simple controller design method with only one controller in a single feedback loop is used for (IFOPTD) integrator plus first order plus time delay system. However, with the conventional controllers, there may problem like large overshoot and settling time.

3. Direct Synthesis Method

Hence all the models are of the type

$$G_p = \frac{ke^{-\theta s}}{s(\tau s + 1)} \quad (1)$$

The desired closed loop transfer function is considered as,

$$\frac{y}{y_r} = \frac{(\eta_2 s^2 + \eta_1 s + 1)e^{-\theta s}}{(\lambda s + 1)^3}$$

For designing the controller G_c , the direct synthesis method [5] is considered here. This design method is chosen here because the desired output behavior of the closed loop can be specified as a trajectory model based on the process to design the required form of the controller Ogunnaike & Ray [7]. The closed loop relation for set point changes is given by,

$$\frac{y}{y_r} = \frac{G_c G_p}{1 + G_c G_p} \quad (2)$$

from eqn (2) the controller is given by,

$$G_c = \frac{1}{G_p} \frac{(y/y_r)}{1 - (y/y_r)} \quad (3)$$

According to the direct synthesis method, the closed loop trajectory model should be specified for designing the controller. The controller can be written as

$$G_c = \frac{1}{G_p} \frac{(y/y_r)_d}{1 - (y/y_r)_d} \quad (4)$$

where $(y/y_r)_d$ is the desired closed loop trajectory for set-point changes. Here the PID controller is designed in series with the lead/ lag compensator.

If the process is of $G_p = \frac{ke^{-\theta s}}{s(\tau s + 1)}$

the desired closed loop transfer function is considered as,
the desired closed loop transfer function is considered as,

$$\left(\frac{y}{y_r} \right)_d = \frac{(\eta_2 s^2 + \eta_1 s + 1)e^{-\theta s}}{(\lambda s + 1)^3}$$

using first-order Pade approximation for the time delay, after simplification the controller is obtained as

$$G_c = k_c \left(1 + \frac{1}{\tau_i s} + \tau_d s \right) \frac{(\alpha s + 1)}{(\beta s + 1)}$$

where

$$k_c = \frac{\eta_1}{k(3\lambda^2 + 1.5\theta\lambda + 0.5\theta\eta_1 - \eta_2)}$$

$$\tau_1 = \eta_1$$

$$\tau_d = \frac{\eta_2}{\eta_1}$$

$$\alpha = 0.5\theta, \beta = \frac{0.5\theta\lambda^3}{\tau(3\lambda^2 + 1.5\theta\lambda + 0.5\theta\eta_1 - \eta_2)}$$

in which $\eta_1 = 3\lambda + \theta$ and $\eta_2 = \frac{(0.5\theta - \tau)\lambda^3 + (3\tau^2 - 1.5\theta\tau)\lambda^2 + 3\theta\tau^2\lambda + 0.5\theta^2\tau^2}{\tau(0.5\theta + \tau)}$

3.1 Tuning parameter selection

The tuning parameter λ should be selected in such a way that the resulting controller gains should be positive for positive values of k. hence, as per the method given by Seshagirirao et. al. [5] to get positive values of controller gain(kc), the constraint to be followed is,

$$\eta < 3\lambda^2 + 1.5\theta\lambda - \eta_2 + 0.5\theta\eta_1$$

Also, λ should be selected in such a way that the resulting controller gives good robust control performances. The initial value of the tuning parameter can be taken as equal to half of the time delay of the process to get good control performances. If not then, the tuning parameter can be increased from this value till good nominal and robust control performances are achieved.

For suitable value of λ and β , the controller designed on DS method gives good control performances. However for high value of β , the phase lag imposed by the term $(\beta s + 1)$ in the controller is more and thus the designed controller with this value of β is not able to give robust control performances which results in low gain and phase margins of the open loop system than the required values (gain margin should be >1.7 and phase margin should be $>35^\circ$ for robust control of a process [6].

Based on many simulation studies, it is observed that taking '0.1 β ' instead of β gives good compromise between nominal performances and robust control performances. Thus, in the present work, the value of β obtained is modified as '0.1 β ' for simulation studies. The performances of the closed loop system are evaluated by giving a unit step in the set point and a negative step input of 0.1 in the load at $t=25s$. Fig.1-3 shows the comparison of original model 1, 2 & 3 with the controller tuned using DS method.

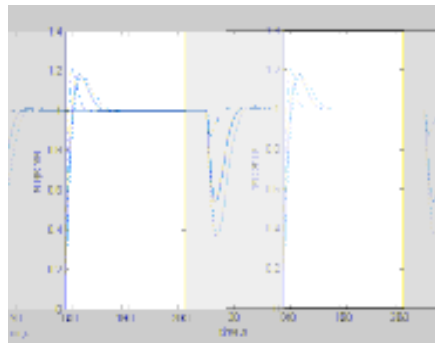


Figure 1. Comparison of model 1, 2 & 3. Controller designed on each model. Dash-dot \rightarrow DS; Dashes \rightarrow IMC; Solid \rightarrow Z-N

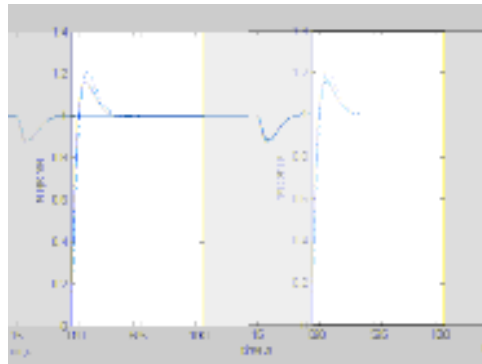


Figure 2. Closed loop response on model 1, 2 & 3 Controller designed on model

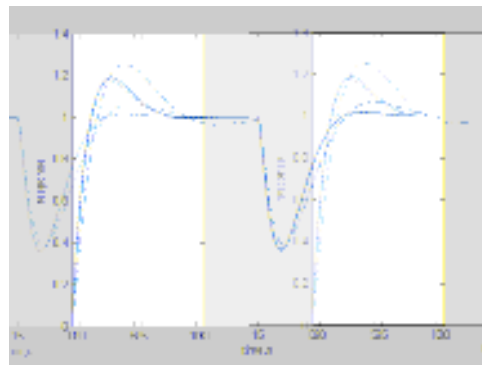


Figure 3. Closed loop response on model 1, 2 & 3. Controller designed on model 2.

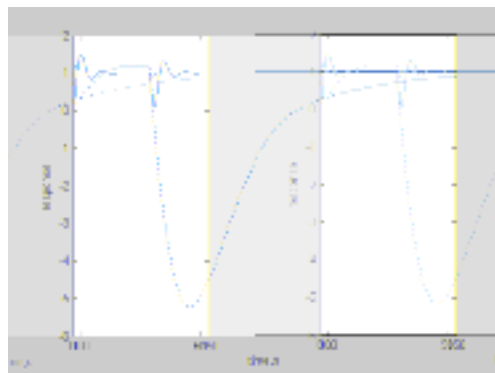


Figure 4. Closed loop response on model 1; Dash-dot→ DS; Dashes→IMC;
Solid→Z-N

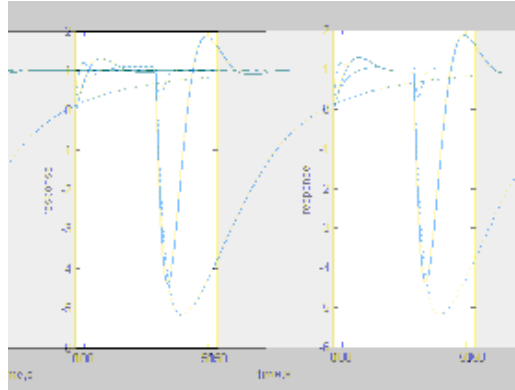


Figure 5. Closed loop performance on model 2, legend as in Fig.4

TABLE 1. COMPARISON OF ISE AND IAE VALUES FOR SERVO RESPONSE

Process	Controller	ISE	IAE
Model 1	DS	0.177	33.2
	IMC	190.3	480.0
	Z-N	0.83	143.9
Model 2	DS	0.73	143.9
	IMC	245.0	629.0
	Z-N	57.61	174.0
Model 2	DS	0.396	87.29
	IMC	176.8	456.0
	Z-N	20.51	874.8

It can be observed that, DS method gives the best performances and Z-N is better than IMC. From the ISE values it is evident that the DS method gives the lowest ISE values. The regulatory response of model, 2& 3 are shown in Figs 7-9. Here the IMC and ZN show overshoot.

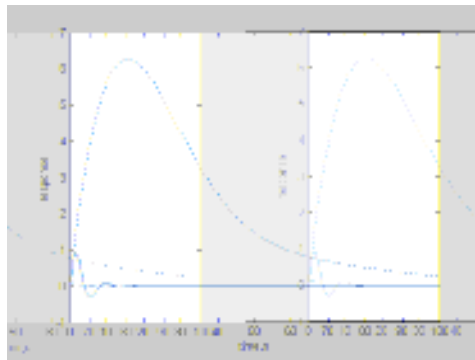


Figure 6. Regulatory response of model1 legend as in fig.4

The table 2 shows the ISE, IAE values for regulatory response. From the ISE and IAE values , it is observed that DS method is better than IMC and Z-N method is more or less similar to DS.

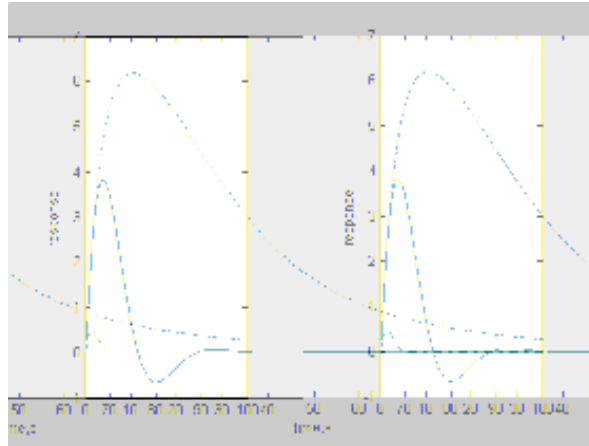


Figure 7.Regulatory response of model1 legend as in fig.4

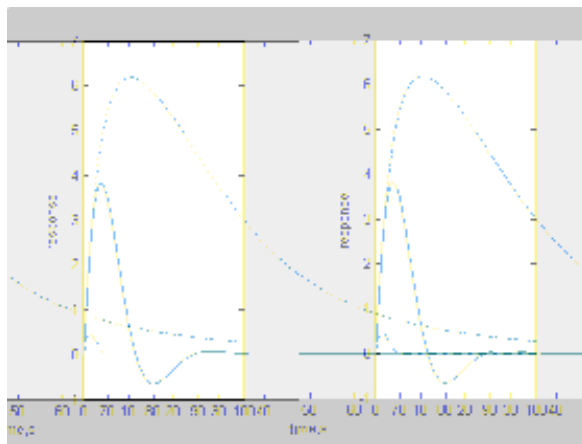


Figure.8 Regulatory response of model3.legend as in fig.4

TABLE 2. COMPARISON OF ISE AND IAE VALUES FOR SERVO RESPONSE

Process	Controller	ISE	IAE
Model 1	DS	19.94	1990
	IMC	120.34	3470
	Z-N	20.3	2040
Model 2	DS	52.54	5390
	IMC	297.5	8900
	Z-N	53.74	5260
Model 2	DS	17.9	1870
	IMC	113.41	3290
	Z-N	27.71	2114

The main advantage of the DS method is that it is simple with conventional feedback structure. Also there is only one tuning parameter to be selected, viz. the desired closed loop time constant (λ).

4. Conclusion

The mathematical model of the web guide of the CRM (Interval Plant) system was tuned using PID controller by DS method and compared with IMC and ZN. Good robust control performance is achieved with direct synthesis method. The controller designed on reduced model (Rmodel) using DS method works well for all original systems and gives robust performance

5. References

- [1] Sang Min Kim, Byoung Joon Ahn etc., "The modeling and control of web guide process in cold rolling mill," IEEE Industrial Electronics Society, 2004, Korea.
- [2] Sundaresan, K.R.&P.R. Krishnamoorthy., "Estimation of time delay, time constant parameters in time and frequency domain," Canadian JI Chem Engg, 56, 257-262 (1978).
- [3] Rivera,D.E.,Morari,M.& Skogestad.S, "IMC-PID controller design. Industrial Engineering and Chemical Process, Design and Development", 25, 252 (1986).
- [4] Zielgler,J.G., & Nicholds,N.B," Optimum settings for automatic controllers," ASME Transactions, 64, 759, 1942.
- [5] Seshagirirao, A., V.S.R Rao, and M.Chidambaram, "Direct synthesis – based controller design for integrating processes with time delay," Journal of the Franklin Institute, 2008.
- [6] M.A.Johnson, M.H.Moradi, "PID control: New Identification and Design Methods," Springer, London, 2005

Authors

S.Umamaheswari has completed her B.E (Electronics & Instrumentaition) from Tamilnadu college of Engineering, Coimbatore in the year 1996. she has pursued her M.E from Coimbatore Institute of Technology, Coimbatore in 2003. she is being in the field of teaching for the past 10 years. Presently she is doing her Ph.D from Anna University, Chennai. Currently she is working as Asst.Professor in Mahendra Engineering College, Namakkal, Tamilnadu, INDIA



Dr.V. Palanisamy received his B.E. degree in Electronics and Communication Engineering, from PSG College of Technology, Coimbatore in 1972, M.E. in Communication systems in 1974 from Anna University, Chennai and Ph.D. in Antenna Theory in 1987 from IIT Karagpur, India. Since 1974 he has been working in various capacities of Technical Education in Tamilnadu and as a Principal for Government Institution, Coimbatore, India. His interest includes Microwave communication ,Bio-Medical, Robotics, Dsp, Networking, Modeling and Simulation and Neural Networks etc., He has published number of Technical papers in National and International Journals and Conferences. He is a member of various professional bodies.

Dr.M.Chidambaram has completed his B.E in chemical engineering in the year 1975 from Annamalai university, Chidambaram. He attained his M.E (Chemical Engg) and Ph.D from Indian Institute of Science, Bangalore in the year 1977 and 1984 respectively. He worked as faculty in Indian Institute of technology, Bombay from 1984 to 1991 and in IIT, Chennai from 1991 to 2003. From 2004 , he is being as Director in National Institute of Technology, Trichy till now. His interested research areas are process modeling and control, controller tuning etc. He has authored number of Books and published more International Journals.