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Tuning of a PID Controller Using Soft Computing Methodologies Applied to Basis Weight Control in Paper Machine

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ABSTRACT

Proportional – Integral – Derivative control schemes continue to provide the simplest and effective solutions to most of the control engineering applications today. However PID controller is poorly tuned in practice with most of the tuning done manually which is difficult and time consuming. This research comes up with a soft computing approach involving Genetic Algorithm, Evolutionary Programming, and Particle Swarm Optimization and Ant colony optimization. The proposed algorithm is used to tune the PID parameters and its performance has been compared with the conventional methods like Ziegler Nichols and Lambda method. The results obtained reflect that use of heuristic algorithm based controller improves the performance of process in terms of time domain specifications, set point tracking, and regulatory changes and also provides an optimum stability. This research addresses comparison of tuning of the PID controller using soft computing techniques on Machine Direction of basics weight control in pulp and paper industry. Compared to other conventional PID tuning methods, the result shows that better performance can be achieved with the soft computing based tuning method. The ability of the designed controller, in terms of tracking set point, is also compared and simulation results are shown.

Keywords*: basis weight, soft computing, machine direction, PID controller*

1. INTRODUCTION

PID controller is a generic control loop feedback mechanism widely used in industrial control systems [1]. It calculates an error value as the difference between measured process variable and a desired set point [3]. The PID controller calculation involves three separate parameters proportional integral and derivative values. The goal of PID controller tuning is to determine parameters that meet closed loop system performance specifications, and the robust performance of the control loop over a wide range of operating conditions

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should also be ensured. Practically, it is often difficult to simultaneously achieve all of these desirable qualities [2]. The purpose of this paper is to investigate an optimal controller design for a Basis weight control process in Paper machine using the evolutionary Programming, Genetic Algorithm, Particle Swarm Optimization and Ant Colony Optimization. The function of a paper machine is to form the paper sheet and remove the water from the sheet. Paper machine controls try to keep quality variables at their target levels with minimum variability. Each paper grade has its specific targets and limits for many quality variables such as Basis weight, Moisture, Caliper, Ash content, smoothness, Gloss, Formation, strength properties and Fault distribution[24]. Quality parameters, such as basis weight, moisture, caliper, ash content, fiber orientation, color, and brightness are measured on-line in a paper machine [17]. The quality control system (QCS) is divided in two separate dimensions, the machine direction control (MD) and the cross direction control (CD). The conventional technique is to measure the MD and CD signals by scanning the sheet with a single sensor. The sensor is mounted in a scanner platform, where it moves back and forth in the cross direction, see Fig.1.In the paper making process, the

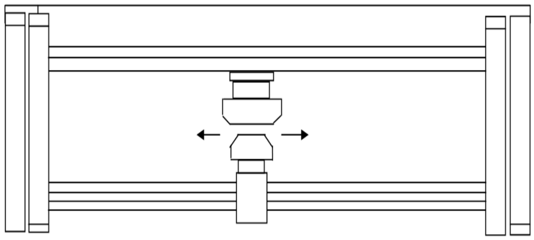

Fig. 1. Quality control scanner moves the sensor back and forth across the sheet.

paper sheet contains fiber, water and filler. The basis weight of the paper sheet is the total weight per unit area. The basis weight of the paper from a papermaking machine is measured by scanning the paper with a beta gauge. The beta gauge develops corresponding analog outputs which are given to Distributed Control System. A digital computer from these digital equivalent determines the difference between the measured basis weight and the desired the basis weight. The error signal is transmitted for valve opening for regulating the stock flow rate [6]. The block diagram of MD basis weight control system is shown in Fig. 2.

Objective of the research is to develop a soft computing based PID tuning methodology for optimizing the control of basis weight process loop in Paper machine.

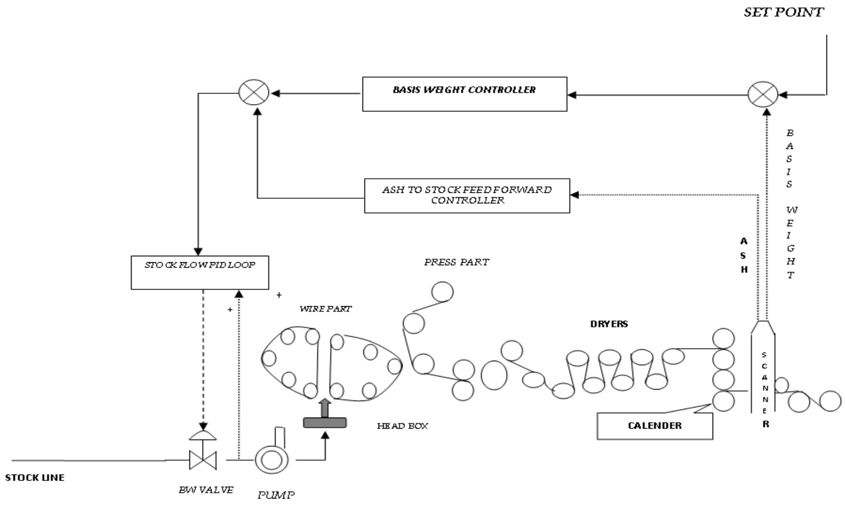

Fig. 2. MD basis weight control.

This research proposes the development of a tuning technique that would be best suitable for optimizing the MD control of processes operating in a single-input-single-output (SISO) process control loop. The SISO topology has been selected for this study because it is the most fundamental of control loops and the theory developed for this type of loop can be easily extended to more complex loops [22]. The efficacy of the proposed method has been proved to be the best by comparing the control performance of loops with the soft computing method to that of loops tuned using the conventional method of Ziegler-Nichols and Lambda methods.

In this approach the transfer function of the basis weight process was determined using system identification tool box in Matlab and utilized for the soft computing based tuning using simulation. The P and I tuning parameters determined from the soft computing methodology and best one was applied to a process plant that is in the Tamil Nadu Newsprint and Papers Limited at India.

2. IDENTIFICATION OF PROCESS PARAMETERS

The System Identification problem is to estimate a model of a system based on observed input-output data. Several ways to describe a system and to estimate such descriptions exist.This case study concerns data collected from a Honeywell Quality Control Scanner for Basis Weight Control.

The Process works as follows:

Thick stock is fed into the head box through main stock (BW) valve, after pressing and drying process, paper is formed

The Basis Weight sensors in the Quality Control Scanner use the Beta particles to measure the Basis Weight of paper (grams per square meter (GSM)).

Beta particles are emitted from the source. Since beta particles are electrons, they are collected by the receiver. This collection produces a low current flow, which is amplified to voltage typically from 4 volts DC to 8 volts DC.

The input (u) is the flow rate of thick stock (or) control valve opening position.

The output is the Basis Weight of paper (or the voltage from the sensor).

1000 input and output samples from this process are taken from the DCS and the measured data are used to identify the system transfer function (process model).

Technical Specification of the paper machine are tabulated in Table 1.

Table 1. Technical specifications of the paper machine

Part Name	Details
DCS System AC 450 Controller	Operate IT – HMI,ABB AI - 4 - 20 MA AO - 4 - 20MA AMPL – Programming
Quality Control Scanner	Basis weight – beta particle sensor Output- (4 - 8 VDC) Honey Well make
Main stock Control Valve	Size:12’’, Electric actuated
Dilution Head Box	115 Actuators, 125 mm Lip opening
Steam Pressure	3.5 Bar to 4.5 Bar
Steam Temperature	150^{o}C to 180^{o}C
Day Production	350 MT
Machine Speed	700 M

Process Transfer function

$$G(s) = e^{-5S}\,\frac{5.367e^{-015}S^3 + 1.676e^{-014}S^2 + 3.434e^{-014}S + 4.385e^{-014}}{S^3 + 1.1471S^2 + 4.132S - 0.0008674} \quad [1]$$

3. DESIGN OF PID CONTROLLER

The classical methods such as Ziegler Nichol's method and Lambda method are employed to find out the values of Kp, Ki and Kd. Although the classical methods cannot be able to provide the best solution [5], they give the initial values or boundary values needed to start the soft computing algorithms [10]. Due to the high potential of heuristic techniques such as EP, GA, PSO and ACO methods in finding the optimal solutions, the best values of Kp, Ki and Kd are obtained. The simulations are carried out using INTEL[R], Pentium [R] CPU 3 GHZ, 4GB RAM in MATLAB 7.10 environment. The Ziegler-Nichols tuning method using root locus and continuous cycling method were used to evaluate the PID gains for the system [4], using the "rlocfind" command in matlab, the cross over point and gain of the system were found respectively. Using the bump test Lambda tuning parameters were found respectively. After deriving the transfer function model the controller has to be designed for maintaining the system to the optimal set point. This can be achieved by properly selecting the tuning parameters Kp, Ki and Kd for a PID Controller. The initial values of PID gain are calculated using conventional Z－N method. Being hybrid approach, optimum value of gain are obtained using heuristic algorithm. The advantages of using heuristic techniques for PID are listed below,

1. Heuristic Techniques can be applied for higher order systems without model reduction [7].

2. These methods can also optimize the design criteria such as gain margin, Phase margin, Closed Loop Band Width (CLBW) when the system is subjected to step and load change [7].

Heuristic techniques like Genetic Algorithm, Evolutionary Programming, Particle Swarm Optimization and Ant Colony Optimization methods have proved their excellence in giving better results by improving the steady state characteristics and performance indices [22. 25].

3.1 GA Based Tuning of the Controller

The optimal value of the PID controller parameters K_p, K_i, K_d is to be found using GA[25]. All possible sets of controller parameters values are particles whose values are adjusted to minimize the objective function, which in this case is the error criterion.

$$\text{ISE} = \int_0^{\infty} e^2(t)dt \quad [2]$$

The chromosome is assigned an overall fitness value according to the magnitude of the error, smaller the error larger the fitness value [25]. Initializing the values of the parameters is as per table II. The flowchart of the GA control system is shown in Fig. 3.

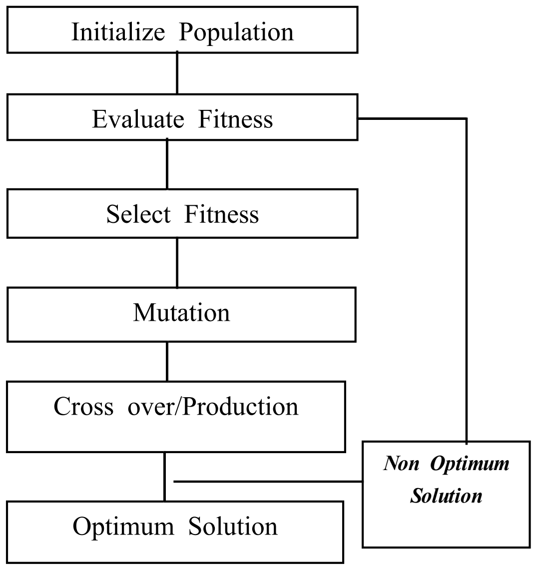

Fig. 3. Flowchart of GA.

3.2 EP Based Tuning of the Controller

There are two important ways in which EP differs from GAs.First, there is no constraint on the representation. The typical GA approach involves encoding the problem solutions as a string of representative tokens, the genome. In EP, the representation follows from the problem [9].

Second, the mutation operation simply changes aspects of the solution according to a statistical distribution which weights minor variations in the behavior of the offspring as highly probable and substantial variations as increasingly unlikely[7]. The steps involved in creating and implementing evolutionary programming are as follows:

Generate an initial, random population of individuals for a fixed size (according to conventional methods Kp, Ki, Kd ranges declared).

Evaluate their fitness (to minimize integral square error). ISE= $\int_0^\infty e^2(t)dt$

Select the fittest members of the population.

Execute mutation operation with low probability.

Select the best chromosome using competition and selection.

If the termination criteria reached (fitness function) then the process ends. If the termination criteria not reached search for another best chromosome. The EP parameters chosen are given in table II. The flowchart of the EP control system is shown in Fig.4.

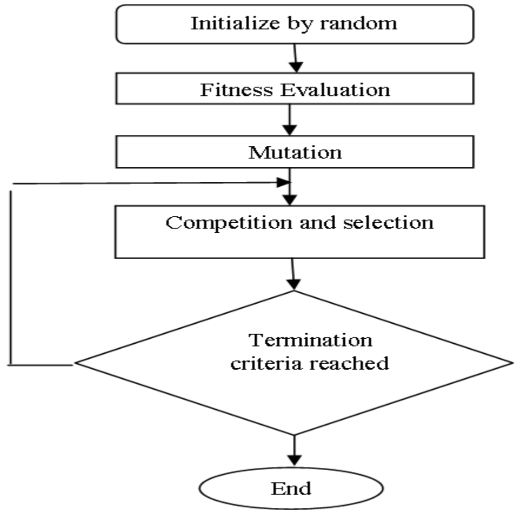

Fig. 4. Flowchart of EP.

3.3 PSO Based Tuning of the Controller

The algorithm proposed by Eberhart and Kennedy (1995) uses a 1-D approach for searching within the solution space. For this study the PSO algorithm will be applied to a 2-D or 3-D solution space in search of optimal tuning parameters for PI, PD and PID control [8].The flowchart of the PSO－PID control system [21] is shown in Fig.5. In PSO method each particle contains three members P, I and D. It means that the search space has three dimension and particles must

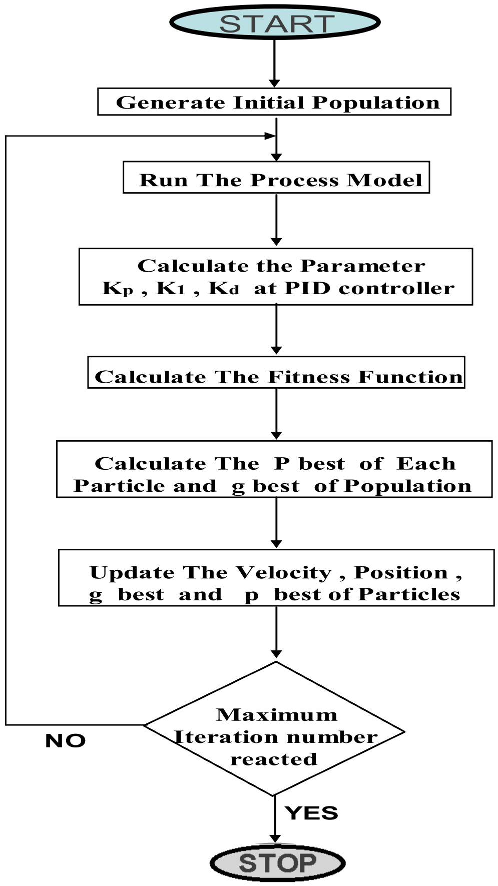

Fig. 5. Flowchart of PSO.

'fly' in a three dimensional space [18]. Initializing the values of the parameters is as per Table 2.

3.4 ACO Based Tuning of the Controller

ACO's are especially suited for finding solutions to different optimization problems[13]. A colony of artificial ants cooperates to find good solutions, which are an emergent property of the ant's co-operative interaction .Based on their similarities with ant colonies in nature, ant algorithms are adaptive and robust and can be applied to different versions of the same problem as well as to different optimization problems [23].

3.5 Implementation Algorithm

Step 1 Initialize randomly a potential solutions of the parameters (K_p, K_i, K_d) by using uniform distribution [16]. Initialize the pheromone trail and the heuristic value

Step 2 Place the ATh ant on the node. Compute the heuristic value associated in the objective function (minimize the error).

Step 3 Use pheromone updation function to avoid unlimited increase of pheromone trails and allow the forgetfulness of bad choices.

Step 4 Evaluate the obtained solutions according to the objectives.

Step 5 Display the optimum values of the optimization parameters.

Step 6 Globally update the pheromone, according to the optimum solutions calculated at step 5. Iterate from step 2 until the maximum of iterations is reached.

Initializing the values of the parameters is as per table II. The flowchart of the ACO – PID control system is shown in Fig. 6.

4. RESULTS AND DISCUSSION

The Process is modeled for designing basis weight control loop by using DCS available in the paper plant. A transfer function to validate the basis weight control process is obtained with the real time data using Matlab system identification toolbox in Eq. 1.

The tuned values through the traditional, as well as the proposed techniques, are analyzed for their

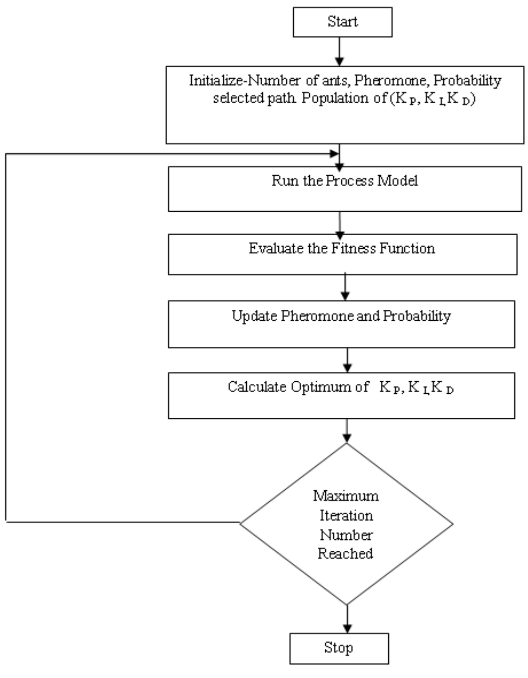

Fig. 6. Flowchart of ACO.

Table 2. PSO, GA, EP and ACO Parameters

PSO PARAMETERS	GA PARAMETERS	EP PARAMETERS	ACO PARAMETERS
Population size:100	Population size:100	Population size:100	Population size:100
Wmax=0.6	Mutation rate:0.1	Normal distribution	No. of Ants=10
Wmin=0.1	Arithmetic Crossover	Mutation rate:0.01	No. of Path=15
Iteration:100	Iteration:100	Iteration:100	Iteration:100
Fitnessfunction:ISE	Fitnessfunction:ISE	Fitnessfunction:ISE	Fitnessfunction:ISE

responses to a unit step input, with the help of Matlab simulation and, then, the real time application for the basis weight control in paper machine is presented. A tabulation of the time domain specifications comparison and the performance index comparison for the obtained models with the designed controllers is presented.

Conventional methods of controller tuning lead to a large settling time, overshoot, rise time and steady state error of the controlled system. Hence Soft computing techniques is introduces into the control loop. GA, EP, PSO and ACO based tuning methods have proved their performance in giving better results by improving the steady state characteristics and performance indices. Performance characteristics of process were indicated and compared with the intelligent tuning methods as shown in the Fig.7 and values are tabulated in Table 3.

4.1 Real Time Response of The Basis Weight Control Process

Fig.7 illustrates that PSO has proved its excellence by producing high quality of the solution when compared to GA, EP and ACO. With these optimized values of K_p, K_i and K_d obtained as a result of PSO, the system settles down within 0.0103 seconds with no peak overshoot.

The most important aspect of the paper is presented

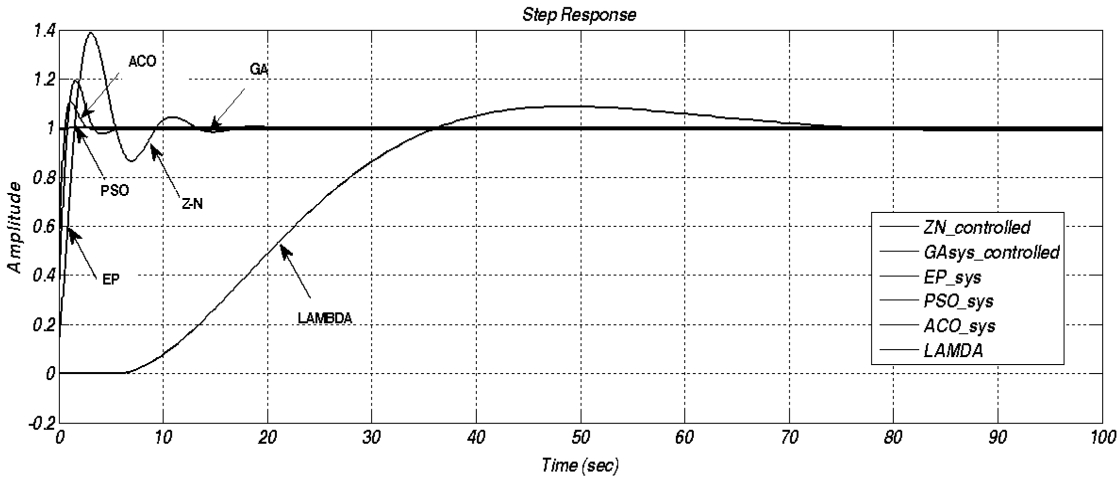

Fig.7. Comparison result of Z-N, Lambda tuning and soft computing methods.

Table 3. Comparison result of Z N, Lambda tuning and soft computing methods

Tuning Method	PID Parameters			Dynamic performance specifications			Performance Index
	Kp (Proportional gain)	Ki (Integral gain)	Kd (Derivative Gain)	T r (Rise time)	Ts (Settling time)	M p (%) (Peak overshoot)	ISE (Integral square error)
ZN	2.5	2.5	0.0813	0.1	11.3	72.6	6.8514
LAMBDA	0.5	5	0	6	70	10	1.8
EP	10	50	0.2	0. 0012	0.3	5	0.0044
GA	20	3	3	0. 001	0.0505	0. 0	0.0054
PSO	50	80	16	0. 001	0.0103	0. 0	4.2849e-006
ACO	90	12.8	45	0. 001	0.0175	0. 193	2.2236e-005

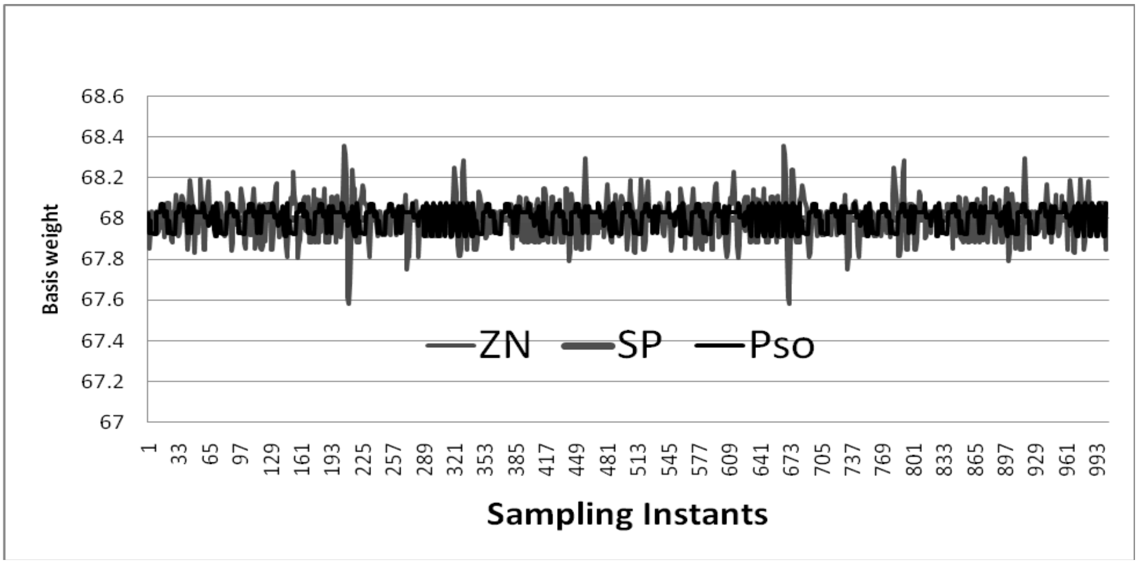

Fig. 8. Comparison result of Z-N, Lambda tuning and PSO methods for Real time Process.

in this section. Further to prove to the potential of soft computing methods in solving the real-time problems, the experimentation is done in ABB DCS of TNPL plant for basis weight control loop. The designed settings for the process were implemented for one set point. The ABB DCS is fed with these optimized values (PSO)(K_p, K_i and K_d) for that basis weight control process .The real time response of the system was observed by giving a set point of 68GSM, and the corresponding variation of basis weight from a set point was recorded. The response of the basis weight process for a set point are presented in Fig.8. It is clear, from the responses, that the PSO based controller has the advantage of a better closed loop time constant, which enables the controller to act faster with a balanced overshoot and settling time. The response of the conventional controller is more sluggish than the PSO based controller.

5. CONCLUSIONS

Research work has been carried out to get an optimal PID tuning by using GA, EP, PSO and ACO for a basis weight control process in machine direction (MD). The Soft computing technique is applied to a real time control of a basis weight (MD) system using ABB AC450 DCS. The performance of the soft computing based controller is compared with conventional PID controller tuning settings. The performance is compared for set point 68GSM. For the conventional controller set point tracking performance is characterized by lack of smooth transition as well it has more oscillations. Also it takes much time to reach set point. The Soft computing based controller tracks the set point faster and maintains steady state. It was found for a basis weight control process for 68 GSM set point and load changes, the performance of the Soft computing based controller was much superior to the conventional control. Soft computing techniques are often criticized for two reasons: algorithms are computationally heavy. PID controller tuning is a small-scale problem and thus computational complexity is not really an issue here. It took only a couple of seconds to solve the problem. Compared to conventionally tuned system, PSO tuned system has good steady state response and performance indices.

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