Bulletin of Electrical Engineering and Informatics
ISSN: 2302-9285
Vol. 5, No. 1, March 2016, pp. 62~71, DOI: 10.11591/eei.v5i1.522

Basis Weight Gain Tuning Using Different Types of Conventional Controllers

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Abstract

Paper making is a vast, multidisciplinary technology that has expanded tremendously in recent years approaching to reach 20 million tons by 2020. As per demand implementation of necessary tools to optimize papermaking process and to increase the control precision, the precondition for stable operation and quality production is necessary. In the present work, an effort has been made to analyse gain tuning of Basis Weight output relative to the changing values of basis weight valve opening with step and variable input. The effects of the three constants K_P, K_D and K_I for different types of conventional controllers as P, PD and PID controller are examined by adding a disturbance to the control system. The effects of various scaling gains are studied on the output of the system and are tuned to get the optimum output both for the step input as well as the varying input. Simulation results show that P, PD and PID controllers provide automatic tuning to preserve good performance for various operating conditions. An analysis of practical performance indices is presented by comparing results of three different conventional controllers. The system developed can be used to serve as platform for Control engineering techniques used in industries.

Keywords: *K_P, K_D and K_I Conventional, P, PD and PID controller, scaling gain, automatic tuning*

1. Introduction

The Indian Paper Industry accounts for about 1.6% of the world's production of paper and paperboard. Paper Industry in India is moving up with a strong demand push and is in expansion mode to meet the projected demand. The main requirement for industries today is that, the companies must be more productive, flexible and produce high quality goods for customers and market requirements in the world market's conditions [1]. Therefore, every stage in organization and production systems can be used for continuous improvement. For this purpose, many tools, techniques, subsystems and systems can be used.

The papermaking process is a very complicated process with varying; heat and mass transfer steps at different stages. 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, Fault distribution etc. Out of these, Basis weight and moisture content are the two important parameters of quality which are measured and controlled on line [2], [3].

2. Basis Weight

The grammage per square meter (GSM) is considered as the target end product of paper. It not only reflects the quality of the end product, but also affects the economy. Therefore it must be controlled. The primary factor influencing the basis weight is the pulp flow that can be controlled by the basis weight valve opening at the head box. Thus the process as a whole has one controlled output i.e. Basis weight (B) and one manipulated input i.e. pulp flow (G) monitored by the basis weight valve opening (BWVO) at the head box. The input-output relationship is given by equation (1.1) that relates Transfer function between input function "G(s)" to output function "B(s)" [4]. It is given by:

Received September 23, 2015; Revised November 13, 2015; Accepted December 8, 2015

$$\frac{B(s)}{G(s)} = \exp(-144*s)\ \frac{5.12}{105\,s + 1} \qquad (1)$$

Where

G(s) = Pulp Flow at head box B(s) = Basis weight per square meter
Exp (-144*s) = Transportation Lag 105 = τ time constant of system in seconds
5.12= K constant representing the dimensional conversion factor based on equipments involved in the system.

The basis weight is continuously measured online on the reel and any variation required in its set point is accordingly adjusted by varying the basis weight valve opening at the head box. The data for basis weight has been collected from a middle density basis weight mill, where the speed of the paper machine is around 250 m/min and length of paper traveled from the head box to the reel is approximately 600 meters.

3. PID Controllers

PID controller is one of the earliest industrial controllers. A proportional-integral-derivative controller (PID controller) is a controlled closed loop feedback system that calculates an *error* value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the *error* by adjusting the process through use of a manipulated variable. It has many advantages of being robust, economic, simple and easy to be tuned. However, in spite of these advantages of the PID controller, there remain several drawbacks [5], [6]. It cannot cope well in cases of Non-linear time varying processes, compensation of rapid disturbances, and supervision in multivariable control.

The servo model for the nonlinear system using a conventional PID controller is developed and can be seen in Figure 1. The model shows a simple feedback loop which has a summing element to evaluate error; the evaluated error is given to a PID controller, the output of which is given as an input to the Process (Gp) through valve. The transfer function of the valve is assumed to be unity with no lag. The output of the process is given to the output block as well as feedback to the summing element to evaluate error by comparing it with the set point that comes through the input block.

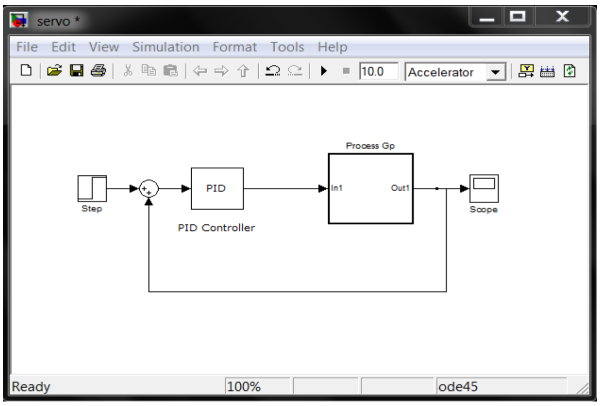

Figure 1. Conventional PID Controller for Servo problem

The input will be the step input as well as the varying input. The model is simulated for different values of K_P, K_D and K_I and has been discussed accordingly in following sections.

4. Servo Model for Step Input
(a) P Type Controller

In this case, only the Proportional gain constant i.e. K_P is given some specified value and the other two gains i.e. the differential (K_D) and integral (K_I) gains are kept at zero. Different values are assigned to K_P while K_D and K_I were kept zero. It was found that for a step input, on increasing the value of K_P, the system response became more and more oscillatory and hence the system became unstable. Simulation results for test done for K_P = 0.1, 0.2, 0.3 and 0.5 can be seen in the Figure 2. It is clear that the system becomes unstable at K_P = 0.5. It is also observed that though the oscillatory behavior increases with the increase in K_P but the offset is also reduced to some extent.

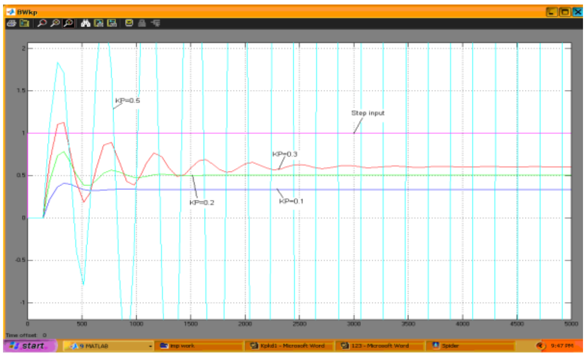

Figure 2. Output for step input servo model for the basis weight for varying values of K_P

Again tests were performed for some more values of K_P, to find the out optimum value of K_P for the step input of the system. Now the test values were taken as K_P = 0.3, 0.32, 0.34, 0.38. The simulation results for the same are plotted in Figure 3.

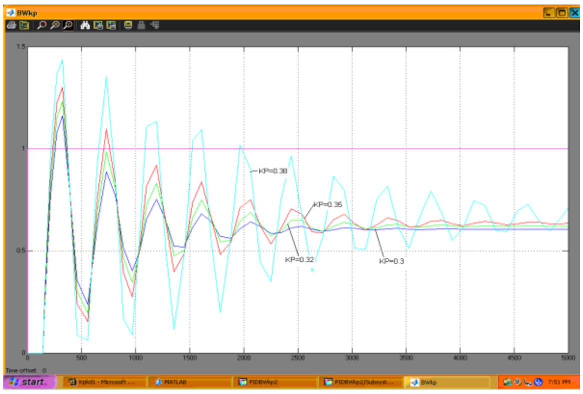

Figure 3. Output for step input servo model for the basis weight for varying values of K_P

It is observed from Figure 3 that for values of K_P equal to and below 0.38, the system gives the bounded output and hence it is stable though very oscillatory. But as can be seen in the next simulation result (Figure 4) that as the value of K_P increases beyond 0.4 the system suddenly becomes unstable. The simulation results for different values of K_P = 0.35, 0.38, 0.4, 0.42 are shown in Figure 4.

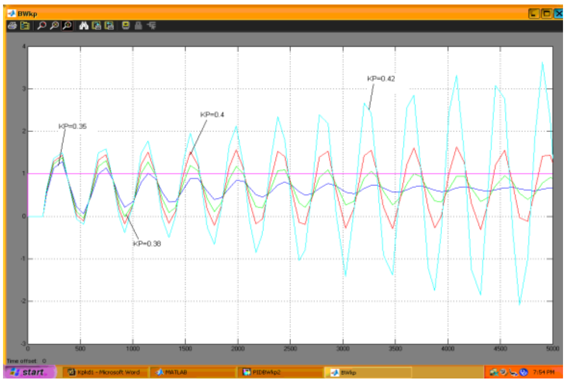

Figure 4. Output for step input servo model for the basis weight for varying values of K_P

Out of all these test values, K_P = 0.1 was selected as the optimum value as it had the minimum oscillatory behavior.

(b) PD Type Controller

Once the value of K_P has been selected, now the system is tuned for optimum value of K_D. As it is a PD type of controller, therefore K_I is kept zero. Thus the simulation is performed for K_P as 0.1 and K_I as zero and different values of K_D are taken as 0.1, 1, 10, and 20, the results for the same can be seen in the Figure 5.

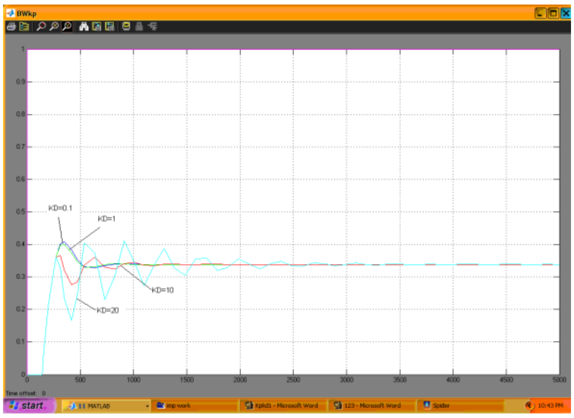

Figure 5. Output for step input servo model for the basis weight for varying values of K_D

It can be clearly seen from Figure 5 that as the value of K_D increases the overshoot is decreased i.e. the derivative action dampens the system and tries to improve the stability of the system, though for higher values of K_D the response is oscillatory but yet stable. Tests are also performed for K_D = 0.001, 0.01, 0.1 and the results for all the three values were almost coinciding. Thus out of all these values K_D = 0.1 gives the best results; hence it is taken as the optimum value. It can be said here that the value of K_D if increased to a large extent affects the system output, for smaller values of K_D the output has minor affect on its dynamics.

(c) PID Type Controller

Now the effect of integral part is analyzed by introducing the K_I part in the system. The optimum values of K_P and K_D are taken from the above results. K_P = 0.1 and K_D = 0.1 is taken and Different values of K_I are taken as K_I = 0.001, 0.0005, 0.0001, 0.00001. The results for the same can be seen in Figure 6.

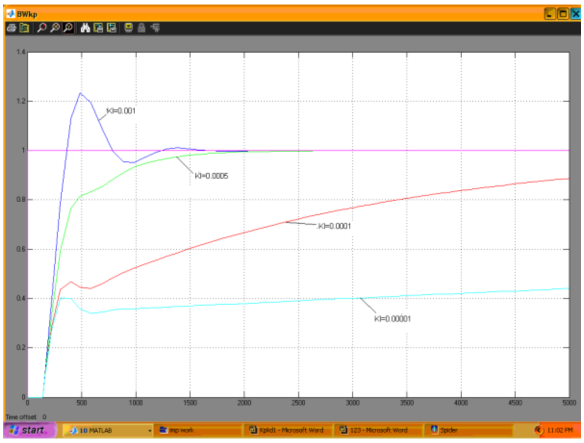

Figure 6. Output for step input servo model for the basis weight for different values of K_I

It can be seen from Figure that as the value of K_I increases, the offset is decreased. For K_I = 0.001, the offset is zero, even for K_I = 0.0005 the offset is zero. But for the values of K_I above this, the offset appears. Tuning of the system becomes difficult; hence the tests are again performed for values of K_I between 0.0005 and 0.001. The simulation results are shown in Figure 7 for other values i.e. for K_I = 0.0006, 0.0007, 0.0008 and 0.0009, K_P = 0.1and K_D = 0.1.

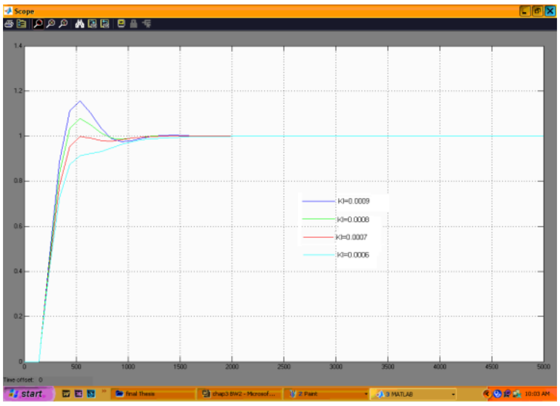

Figure 7. Output for step input servo model for the basis weight for varying values of K_I

It is clear from Figure 7 that the value of K_I between 0.0007 and 0.0008 would give the optimum value. Tests were done and the value of K_I = 0.00073 which gave a minimum overshoot and zero offset was taken as the optimum value. Also it is observed that the integral part is responsible for the offset and also the overshoot for servo model with step input. Thus a conventional controller with an optimum output for the step input-servo model has been developed with values for different gains as: K_P =0. 1, K_I = 0.00073, K_D = 0.1.

The model of Figure 1 using a PID controller is simulated for variable inputs i.e. the data for the reference inputs is collected from the mill where online sensors are incorporated and the value of the inputs. Thus the basis weight continuously changes according to the demand. This data has been saved in the m-file of Matlab and is collected from the workspace from where it is given as the input to model of Figure 1. First a P-Type controller is made to run and then further PD and then PID models are simulated.

5. Servo Model for Varying Input

(a) P Type Controller

Different values are assigned to K_P, the Proportional gain and the other two gains i.e. the integral (K_I) and the differential (K_D) gains are kept at zero. Thus the different values assigned to the gains are K_D=0, K_I=0 and different values of K_P are K_P = 0.1, 0.2, 0.3, and 0.4 as in Figure 8.

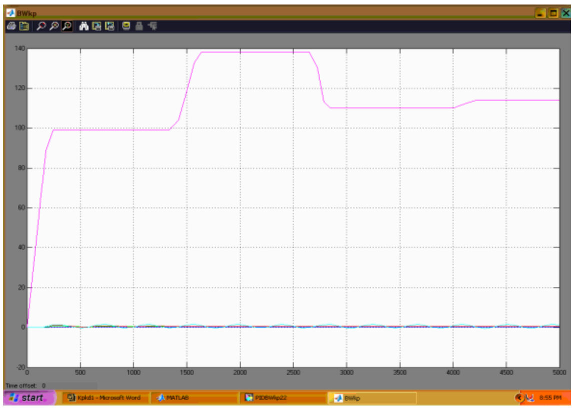

Figure 8. Output for varying input servo model for basis weight for varying values of K_P

It can be seen from Figure 8 that as the value of K_P increases the response of the system becomes more and more oscillatory, but it is also clear from the response that the effect of change in the values of the reference input on the output response is almost nil for different values of K_P. Thus the system response is very poor. Moreover it is also seen that as the value of K_P is increased beyond 0.4 the system becomes highly unstable. For K_P = 1 the Y- axis becomes 1×10^{10}. So from the above results the optimum value of K_P is selected as 0.1 for further work.

(b) PD Type Controller

To behave like a PD-Type of Controller, the term K_D is assigned some value in servo model instead of zero. Now K_P = 0.1, and K_I = 0 and different values of K_D are taken as: K_D=1, 0.1, 0.01 and 0.001. As seen from the simulation result shown in Figure 9 that the output of all the values of K_D almost coincide. A minor difference is seen in the overshoot but rest curves are almost the same for all values.

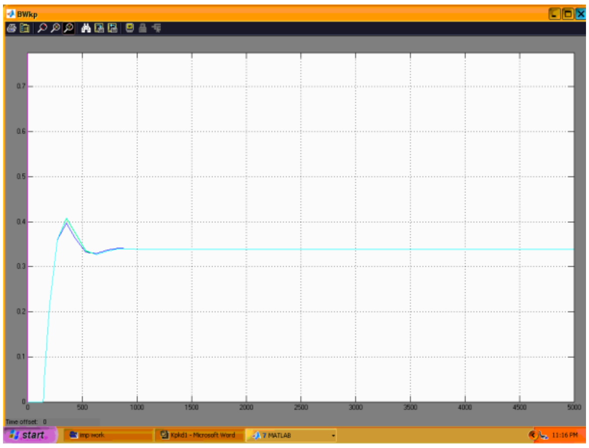

Figure 9. Output for varying input servo model for basis weight at different values of K_D

Simulation is again performed for more values of K_D such as K_D = 1, 10, 15 and 20 keeping K_P = 0.1, and K_I = 0, and it was observed that as the value of K_D is increased, the oscillatory behavior increases as can be seen in Figure 10 but there is no effect of changing input on any of these values. The system output does not vary according to the Basis weight and set point changes. Thus from the above results the value of K_D =1 is taken as the optimum value.

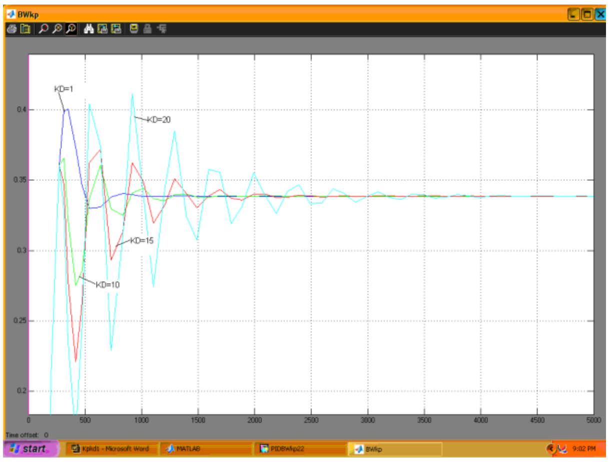

Figure 10 Output for varying input servo model for basis weight for varying values of K_D

(c) PID Type Controller

The integral term K_I term is introduced to the servo model. The simulation was performed for various values of K_I as in Figures 11, 12 and 13. The different values of K_I in Figure 11 are 0.00005, 0.00001, 0.000005, and 0.000001 while the values of K_P and K_D are taken as 0.1 and 1 respectively. It is clear that the response for all the values does not vary with the changing input. Also it is observed that as the value of K_I increases, the offset is reduced to some extent.

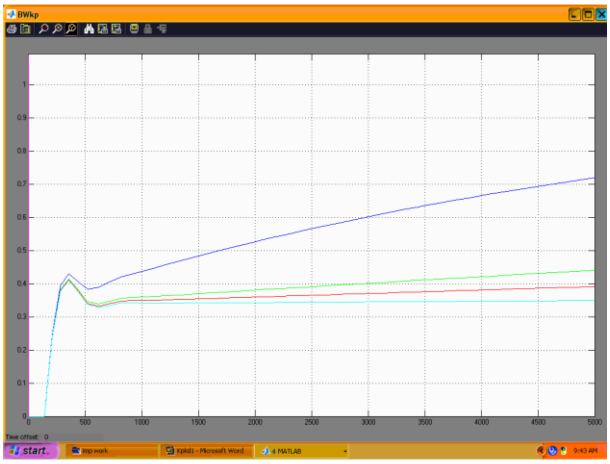

Figure 11. Output for varying input servo model for basis weight for varying values of K_I

The simulation is performed for more values of K_I as 0.0005, 0.0001, 0.00007, and 0.00001 while K_P and K_D are taken as 0.1 and 1 respectively. For these values in Figure 12 same observations are made as above i.e. as the value of K_I increases, the offset is reduced.

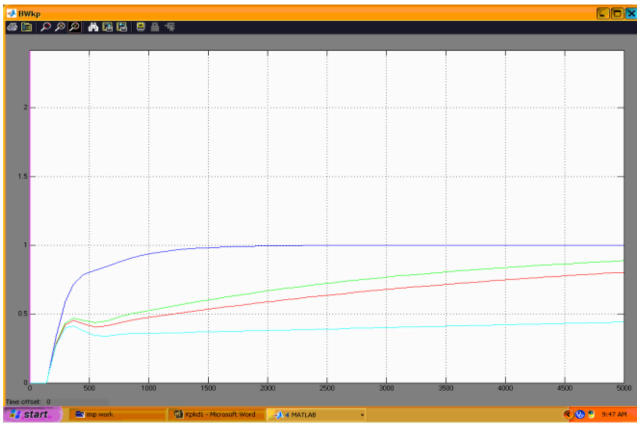

Figure 12. Output for varying input servo model for the basis weight for varying values of K_I

It has been observed from the simulation results that for none of the values of K_I, the system is giving a good output. The system is giving a bounded output for some values but as the value of K_I is increased beyond 0.001, the output becomes quite unstable. The same can be seen in the scope window of Figure 13. where different values of K_I are taken as K_I = 0.005, 0.001, 0.0007 and 0.0001, keeping the value of K_D and K_P same as for the above cases. Moreover for none of the cases the output is changing along with the input hence the system response is very poor.

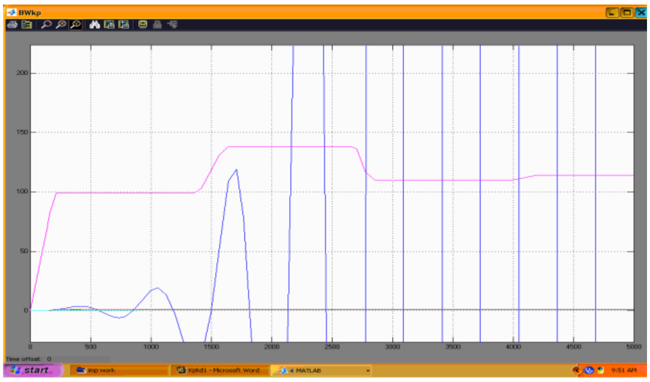

Figure 13. Output for varying input- servo model for the basis weight when the value of K_I is 0.001

It is worth mentioning here that as the value of K_I increases beyond 0.001, the system becomes unstable, as it gives the unbounded output for the bounded input.

6. Results and Analysis

An ideal proportional controller, with increase in value of K_P decreases rise time but does not eliminate the steady state error. An integral control K_i eliminates steady state error but makes response slower. A derivative control K_d increases stability, reduces over shoot, and improves response. Table 1 [11] highlights the effect of different parameters on ideal proportional controller. Table 2 gives the outputs relative to basis weight step and variable input experiments.

Table 1. Ideal Proportional Controller Time, Overshoot and Error

CONSTANT	RISE TIME	OVER SHOOT	SETTLING TIME	STEADY STATE ERROR
Kp	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small change	Decrease	Decrease	No Change

Table 2. Basis weight Closed loop Time, Overshoot and Error

CONSTANT	RISE TIME	OVER SHOOT	SETTLING TIME	STEADY STATE ERROR
Kp	Decrease	Increase	Small Change	Decrease
Ki	Increase	Decrease	Increase	eliminate
Kd	Small change	Decrease	Decrease	No Change

It is clear that increase in Ki produces opposite effect when compared to conventional controllers. Similarly for both step input and variable input, the value of K_P responsible for offset as well as the oscillatory behavior is tabulated in Tables 3 and 4.

Table 3. Ideal Closed loop Stability, Accuracy and Response

CONSTANT	STABLITY	ACCURACY	RESPONSE TIME
Kp	Deteriorate	Improve	Increases
Ki	Deteriorate	Improve	Decrease
Kd	Improve	No impact	Increases

Table 4. Basis weight Closed loop Stability, Accuracy and Response

CONSTANT	STABLITY	ACCURACY	RESPONSE TIME
Kp	Improve	Improve	Increases
Ki	Deteriorate	Improve	Decrease
Kd	Improve	No impact	Increases

If offset has to be reduced the value of K_P has to be increased but it results in increase of oscillations in the system. While relating distinction of step input and variable input oscillatory effect was higher for variable values of basis weight as compared to step input. Talking about value of K_D, an increase in its value decreases the overshoot i.e. the derivative action dampens the system and tries to improve the stability of the system. Though, for higher values of K_D response is oscillatory, yet stable. It can be indicated from the results that decreasing K_I causes offset to appear in the system and vice versa.

Based on different Controllers, it is described that Proportional controller accelerates response, but has a non-zero offset making system unstable. PD controller causes damped oscillations leaving offset but results increase in stability. In PID controller, integral action eliminates offset oscillations.

7. Conclusion and Future Scope

Servo control responds to change in set point. There could be improved model design consideration as regulatory control. It responds to a change in some input value, bringing system in steady state. FLC based systems can be designed in the process industries for such case studies.

References

[1] Bihani BL. The bleaching of pine pulp. 1968; 5(1): T27-T32.
[2] Keswani. SL. Indigenous capability for electronic process control in pulp and paper industry. IPPTA annual general meeting & international seminar, Hotel Hyatt regency, New Delhi, March 8th.1984.
[3] Bergeron M, Boulay R, Drouin B, Gagnon R. Simulataneous Moisture and Basis Weight Measurement. *Pulp and Paper Canada*. 1988; 89(12): 173-176.

[4] Shen Y, Zhang JQ, Wang Y and Xinmin Z. A New Sensor for Paper Basis-Weight and Ash-Content Measurements. *IEEE Transactions on Instrumentation and Measurement*. 1997; 46(4): 937.
[5] Astrom KJ & Hagglund H. PID controllers: Theory, design and tuning (2nd Ed.). Research Triangle Park, NC: Instrument Society of America. 1995.
[6] Jantzen J. *Tuning of Fuzzy PID Controllers*. Technical University of Denmark, Department of Automation, Bldg 326, DK-2800 Lyngby, DENMARK. Tech. reports no 98-H 871 (FPID). 30 Sep 1998.
[7] Dotoli M, Turchiano B. *Fuzzy Gain Scheduling of Coupled PID Controllers for Stabilization of the Inverted Pendulum*. Proceedings of EUNITE2003 – the 3rd European Symposium on Intelligent Technologies, Hybrid Systems and their Implementation on Smart Adaptive Systems, Oulu, Finland, 2003:136-144.
[8] KJ Astrom, T Hagglund. Revisiting the Ziegler–Nichols step response method for PID control, Department of Automatic Control. *Journal of Process Control*, Sweden. 2004.
[9] Markku Ohenoja, Ari Isokangas & Kauko Leiviska. Simulation studies of paper machine basis weight control. Tutorials on Control Engineering Laboratory, University of Oulu. 2010.
[10] Hiroshi Fukumine, Fumiharu Miura. Control Parameter Optimization Service for Paper Machine Quality Control Systems. QCS Tune-up Engineering, for Ideal Paper Manufacturing Plant, Yokogawa Technical Report English Edition. 2011; 54(1).
[11] Control Tutorials on Matlab Simulink Introduction Design to PID Controllers.