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Intelligent PID controller Design for Extrusion Process

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Abstract

An injection module machine is a basic requirement of every plastic product. So, it is very intended to maintain the desired temperatures. Temperature control of plastic extrusion system suffers problems related to longer settling time, and undesirable overshoot. Conventionally, PID controller offers major constraint in the selection of controller gains but unable to control the temperature process due to its nonlinear behavior. Logic based intelligent concepts are used to control the temperature process. Fuzzy-PID gives satisfactory results only when there is no disturbance; however it is unable to stabilize the temperature at disturbances. In this paper ANN-PID controller is developed for temperature control in plastic extrusion system. The proposed ANN-PID controller was simulated using MATLAB software. Relatively the methodology and efficiency of the proposed ANN-PID methods are compared with that of traditional methods and results are provided. ANN-PID controller which offers best performance compared to prior traditional methods.

1. Introduction

Use of polymer materials has greatly increased over last few decades due to their many attractive properties such as ease of forming into complex shapes, lightweight with high tensile/impact/tear strengths, high temperature resistance, high chemical resistance, high clarity, reprocessibility and low cost. This has resulted in new industrial applications for polymer materials while enabling products to be more cost effective, flexible, and efficient. The extrusion process is used for the production of commodities in diverse industrial sectors such as packaging, household, automotive, aerospace, marine, construction, electrical and electronic, and medical applications. Despite of this success, it seems that effective thermal monitoring and control still remains a concern [2].

1.1 Polymer extrusion process

There are two basic types of polymer processing extruders [1] known as continuous and batch extruders (Rosato, 1998) [13]. Of these, single screw continuous extruders are the most commonly used in the plastics industry (Spalding and Hyun, 2003). The basic components of a single screw extruder are shown in Figure 1. The screw is the key component and has been divided into three main functional/geometrical zones (i.e. solids conveying, melting, and metering) based on their primary operations. The material fed into the machine through the hopper is conveyed along the screw while absorbing heat provided by the barrel heaters and through process mechanical work. Eventually, a molten flow of material is forced into the die which forms the material into the desired shape. More details of the mechanisms of polymer extrusion can be found in Rauwendaal (2001). Under poor thermal conditions, several processing problems can occur, e.g. thermal degradation, output surging, poor mechanical properties, dimensional instability, poor surface finish and poor optical clarity melt temperature homogeneity depends on the selection of processing conditions, machine geometry, and material properties. Moreover, it has been found that melt temperature non-homogeneity increases with screw speed. Therefore, it is a challenging task to run extruders at higher screw speeds although the process energy efficiency then increases.

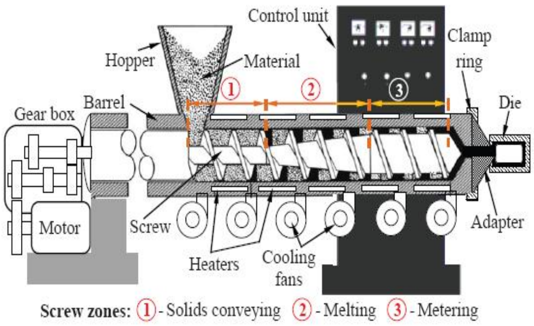

Figure.1 Basic components of Extruder plant

The temperature control in injection mould machine [3] is a key part of the machine. So, this controlling process is achieved by designing the controller for the response of the transfer function in accordance with the desired set point applied. Conventionally, PID (Proportional + Integral + Derivative) controller is used. PID controller is simple in algorithm, good in stability, high in reliability, easy in design, and wide in adaptation, it is the most extensive basic controller used in the application of process control. It can obtain satisfactory control effects in variety of linear time-invariant systems, particularly in systems whose parameters of controlled objects are fixed, non-linear is not very serious. However, the PID control is crisp control, the self-turning of the P, I, D parameters is a quite difficult job, and sometimes the PID control makes overshoot, and also with regard to the temperature control system the characteristics of which are distributed parameter, nonlinear, large time delay and large inertia, the conventional PID controller is very difficult to obtain satisfactory control results. In order to solve this problem, a control method which uses the fuzzy logic technology in temperature control for injection mould machine is used. Fuzzy controller can make full use of the successful operation experience of the operator which they get in real time non-linear adjustment. Also it can give full play to the fine control effect of the PID controller, makes the whole system to achieve the good control effect. So, the paper also proposes the method of fuzzy logic, for tuning the PID controller gain parameters. The temperature process of an injection mould machine is a kind of common controlled object in temperature control system. It can be described qualitatively by the model shown in equation (1).

$$G(s) = \frac{K}{TS+1}e^{-\tau s} \qquad (1)$$

And hence, for the given system the transfer function [5] can be obtained as,

$$G(s) = \frac{0.92}{144S+1}e^{-30s} \qquad (2)$$

Where,
Static gain (K) = 0.92
Time constant (T) = 144sec
Lag delay time (τ) = 30 sec

2. SYSTEM DESIGN WITH PID CONTROLLER

A simple strategy widely used in industrial control is PID controller. But the parameter selection for the K_P, K_I, K_D gains is always a challenge. Many tuning algorithms were developed, but still it is a major pain to select particular algorithm for designing PID gain values for the particular system for a particular process control. Figure.2 shows the system architecture with PID controller. Equation (3) shows the mathematical description of a general PID controller [4].

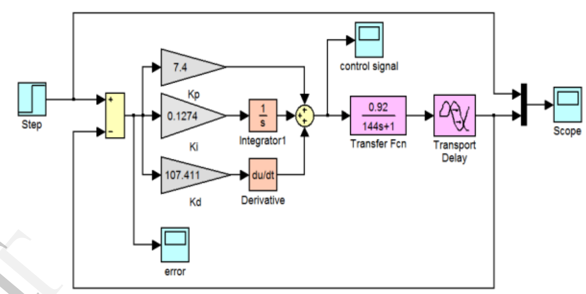

Figure.2. System Design with PID controller

$$U(t) = Kp\, e(t) + \frac{Kp}{Ti}\int_0^t e(t)dt + Kp\, Td\, \frac{de(t)}{dt} \quad \ldots.(3)$$

Where,
U (t) = Control signal applied to plant
K_P = Proportional Gain
K_I = $\frac{K_P}{T_I}$ = Integral Gain
K_D = $K_P \times T_D$ = Derivative Gain

The selection of these K_P, K_I, and K_D values will cause for the variations in the observed response with respect to the desired response. In general, the dependency will be as per the Table.1.

Table 1. Effect of increasing parameter values independently on the response

Parameter	Rise time (Tr)	Overshoot (Mp)	Settling time (Ts)	Error (Ess)
K_P	Decrease	Increase	Small change	Decrease
K_I	Decrease	Increase	Increase	Decrease notably
K_D	Minor Decrease	Decrease	Decrease	No effect

Open Loop Transient Response Tuning method used for setting up the values of
$K_P = 7.4$, $K_I = 0.1274$, and $K_D = 107.411$.

3. SYSTEM DESIGN WITH FUZZY LOGIC CONTROLLER

FLC is relatively easy to implement, as it usually needs no mathematical model of the control system. Fuzzy logic has rapidly become one of the most successful of today's technologies for developing sophisticated control systems. Fuzzy logic addresses such applications perfectly as it resembles human decision making with an ability to generate precise solutions from certain or approximate information

De-Fuzzification is the process of producing a quantifiable result in fuzzy logic, given fuzzy sets and corresponding membership degrees. Figure 4, shows the system architecture with fuzzy logic controller. Fuzzy logic controller [6] takes two inputs namely, error and error change and produces control signal according to the Fuzzy Inference Structure (FIS) designed with assumed fuzzy rules. Each of the input and output quantity is described with its corresponding membership function. Table 2 indicates If-then Fuzzy Rules [11] for Developing FIS.

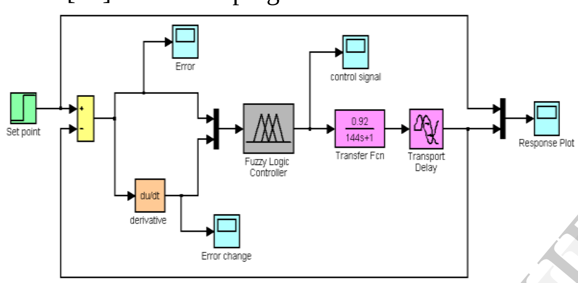

Figure.3 System Design with Fuzzy Logic controller

Table 2. Fuzzy rules for developing Fuzzy Inference Structure (FIS) for Fuzzy Logic Controller

EC \ EU	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PB	PB	PM	PS	ZO
NM	PB	PB	PM	PM	PS	ZO	NS
NS	PB	PB	PM	PS	ZO	NM	NM
ZO	PB	PM	PS	ZO	NS	NM	NB
PS	PM	PM	ZO	NS	NM	NB	NB
PM	PS	ZO	NS	NM	NM	NB	NB
PB	ZO	NS	NM	NB	NB	NB	NB

Where, NB – Negative Big; NM – Negative Medium; NS – Negative Small; PB – Positive Big; PM – Positive Medium, PS – Positive Small, ZO- Zero value.

IV. SYSTEM DESIGN WITH FUZZY-PID CONTROLLER

Fuzzy machines, which always tend to mimic the behavior of man, work the same way. However, the decision and the means of choosing that decision are replaced by fuzzy sets and the rules are replaced by fuzzy rules. Fuzzy rules also operate using a series of if-then statements. Table 3, shows the fuzzy rules for developing FIS. The fuzzy control rule is based on fuzzy decision-making, which satisfies some input conditions and has an output result. Figure 4, shows the design of the system with Fuzzy-PID controller [7] where the gain values of PID controller are tuned by Fuzzy controller.

Table 3. Fuzzy rules for developing Fuzzy Inference Structure (FIS) for Fuzzy - PID Controller

EC \ E (K_P, K_I, K_D)	NB	NM	NS	ZO	PS	PM	PB
NB	PB NB PS	PB NB NS	PM NM NB	PM NM NB	PS NS NB	ZO ZO NM	ZO ZO PS
NM	PB NB PS	PB NB NS	PM NM NB	PS NS NM	PS NS NM	ZO ZO NS	NS ZO ZO
NS	PM NB ZO	PM NM NS	PM NS NM	PS NS NM	ZO ZO NS	NS PS NS	NS PS ZO
ZO	PM NM ZO	PM NM NS	PS NS NS	ZO ZO NS	NS PS NS	NM PM NS	NM PM ZO
PS	PS NM ZO	PS NS ZO	ZO ZO ZO	NS PS ZO	NS PS ZO	NM PM ZO	NM PB ZO
PM	PS ZO PB	ZO ZO NS	NS PS PS	NM PS PS	NM PM PS	NM PB PS	NB PB PB
PB	ZO ZO PB	ZO ZO NM	NM PS PM	NM PM PM	NM PM PS	NB PB PS	NB PB PB

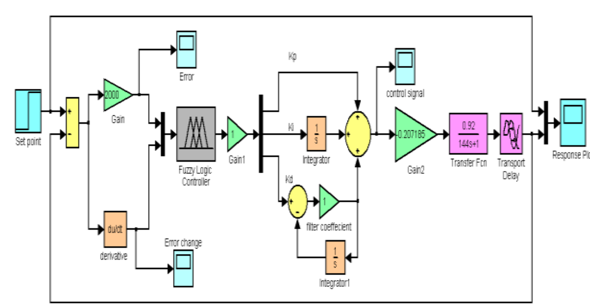

Figure.4 System Design with Fuzzy - PID Controller

Fuzzy-PID performs well as per the requirement to the plant. But when problem rises means if any disturbance arises it is unable to handle. Disturbances are commonly took place in industries occurs either from internal source or external basis. In Injection Mould machine the disturbances caused to poor quality in product, disorder in shapes leads to great loss. In order to rectify these losses disturbance has to overcome. In this paper Artificial Neural Networks with

PID was proposed to overcome the losses occurred due to disturbances. Figure.5 shows the system designed with different disturbances. Table 4. Shows the Fuzzy rules for Fuzzy-PID with Disturbances.

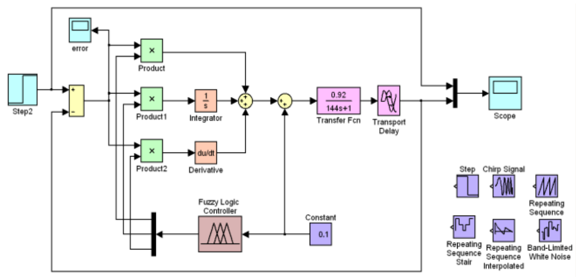

Figure.5 System design with Fuzzy-PID with Disturbances.

Table 4. Fuzzy rules for developing Fuzzy Inference Structure (FIS) for Fuzzy - PID with Disturbances

PID / Disturb	K_P	K_I	K_D
NB	AA	BA	CA
NS	AB	BB	CB
ZO	AC	BC	CC
PS	AD	BD	CD
PB	AE	BE	CE

V. ARTIFICIAL NEURAL NETWORKS

Artificial Neural networks [9] are motivated by human way of learning and the network structure is motivated by human nervous system in the characteristics like learning from examples, fault tolerant, learns from experience, distributed in nature and etc. Neural networks has been successfully applies in the fields of load forecasting, pattern recognition, image processing, optimization and where the input output data is available. If spikes or transients are sufficiently involved in the trained data, then no doubt about that the neural networks will give accurate solutions.

NOTE: No mathematical calculations are required to train NN and to about results from trained Neural Network.

Figure.6 shows the mathematical model of the neuron. $x_1, x_2 .... x_n$ are the scalar inputs and those are multiplied with synaptic weights $w_1, w_2 .... w_n$ respectively and they are summed with bias (W_0). A bias is also like a synaptic weight with input signal one. The total sum is given as input to the activation function. *Y* is the output of the neuron. This is given by equation 1

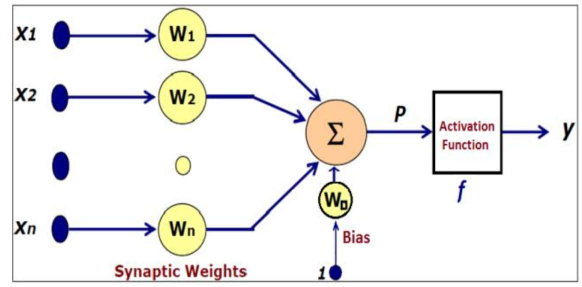

Figure.6 Mathematical model of a neuron

$$y = f(p) = f\left[w_0 + \sum_{i=1}^{n} w_i x_i \right] \qquad (4)$$

There are many activation functions used for the neurons. Of them, commonly used are linear, tan-sigmoidal and log-sigmoidal activation functions. Multi-layer feed forward neural network architecture which is used in this paper due to is flexible characteristics.

At this juncture training the Neural Networks plays a key role. There are several learning algorithms [10] such as Hebbian, Competitive, Gradient descent, and Back Propagation. Among the learning method Back Propagation is the best. In the proposed method tan-sigmoidal used as activation function and back propagation used as learning method. In multi-layer feed forward network appropriate input output and hidden layer neurons were used.

Figure.7 shows the design of system with Artificial Neural Networks PID [8] with different types of disturbances. Of them, used in this paper are repeated sequence interpolated, constant disturbance, chirp, white-band noise, repeated sequence, step, repeated sequence stair. For all these applied disturbances proposed method was able to overcome the disturbance with appreciable results.

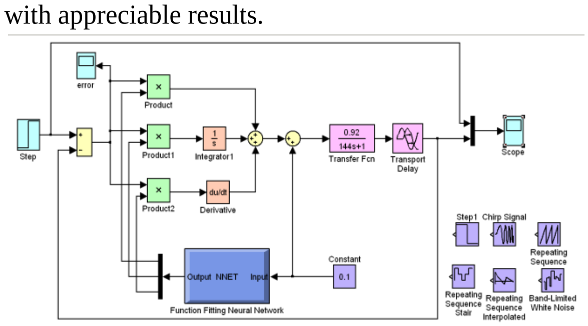

Figure.7 System design with ANN_PID with disturbances.

VI. SIMULATION RESULTS

The dynamic performance of the system can be analyzed based on the time response plot. Those performance parameters are called as time domain specifications, can evaluate the effectiveness of various control schemes proposed in this paper.

MATLAB is used to simulate the simulink models. Figure 8 gives result for PID controller, for Fuzzy controller then Fuzzy-PID controller. Now Figure. 9 shows the result for 10% disturbance to Fuzzy-PID controller. Drawbacks were rectified in figure 10 which is response of ANN-PID controller.

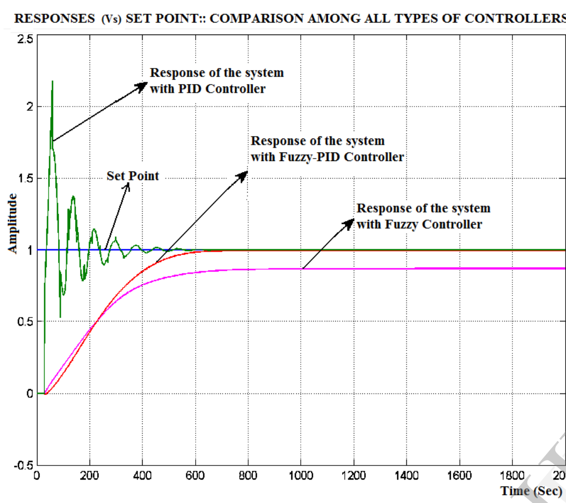

Figure.8 System response with conventional PID, Fuzzy, and Fuzzy-PID controller.

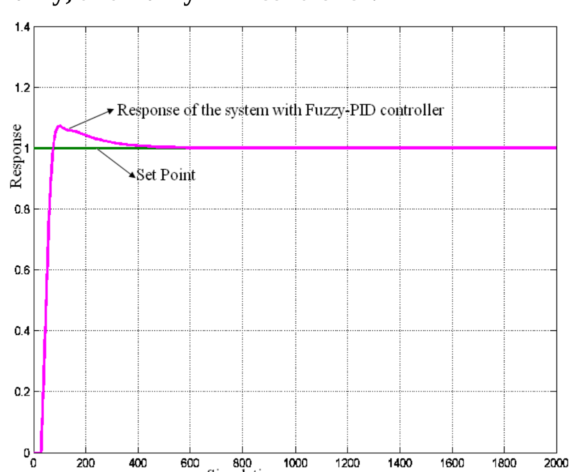

Figure. 9 System response with Fuzzy-PID controller for 10% disturbance.

When a 10% constant disturbance was applied to Fuzzy-PID system gives the result of peak overshoot which is undesirable to the plant causes a great loss to industry. When the same 10% constant disturbance was applied to ANN-PID system gives the result peak overshoot was eliminatedand and settling time also minimized shown in Figure. 10.

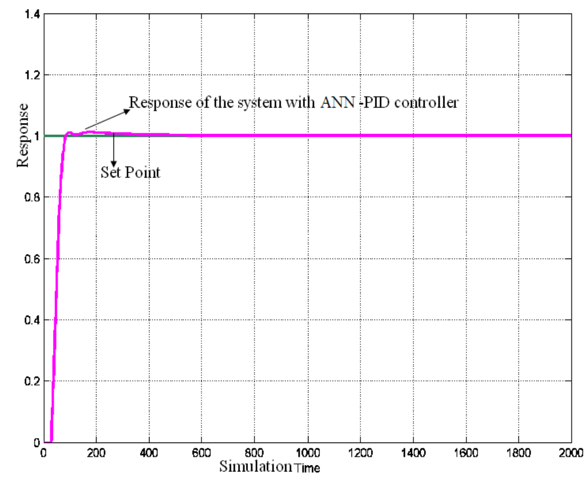

Figure.10 System response with ANN-PID controller for 10% disturbance.

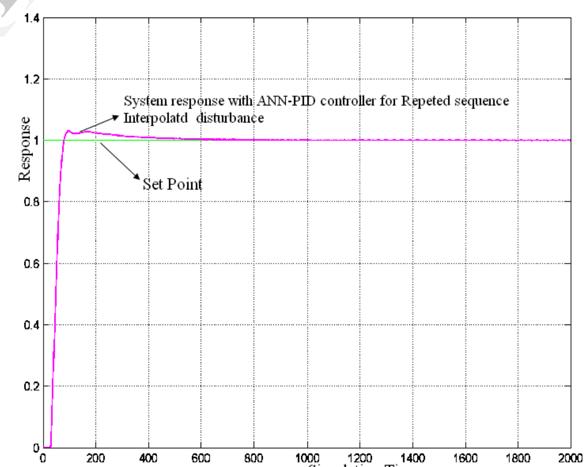

Figure.11 System response with ANN-PID controller for Repeated Sequence Interpolated disturbance.

Different types of disturbances were applied to system with ANN-PID controller[12] such as step, Repeating Sequence Stair, Chirp Disturbance, Repeating Sequence Interpolated Disturbance, Band Limited White Noise, Repeating Sequence, and the results are tabulated in Table 4, shown below.

Table 4. Comparision table of PID, Fuzzy-PID & ANN-PID control system for different disturbances

S. No	Type of Disturbance	Dynamic Performance Specification	For the Conventional PID Control System	For the FUZZY-PID Control System	For the Proposed ANN-PID Control System	Improvement from PID to ANN-PID in %
1	No Disturbance	Delay Time (T_D) in Sec	11.623	19.513	20.401	-43.02
		Rise Time (T_R) in Sec	18.546	33.768	38.632	-51.96
		Settling Time (T_S) in Sec	295.210	265.541	56.720	80.78
		Peak Overshoot (M_P) in %	38.07	7.33	0	100
		% Steady state Error (ESS)	0	0	0	0
		Nature of Oscillations	Oscillatory	Smooth	No	100
2	A Step Disturbance of '-0.1R'	Delay Time (T_D) in Sec	12.502	20.00	21.120	-40.80
		Rise Time (T_R) in Sec	19.310	35.356	41.500	-53.46
		Settling Time (T_S) in Sec	293.320	233.538	120.421	58.94
		Peak Overshoot (M_P) in %	34.20	5.35	0	100
		% Steady state Error (ESS)	0	0	0	0
		Nature of Oscillations	Oscillatory	Smooth	No	100
3	A Step Disturbance of '+0.1R'	Delay Time (T_D) in Sec	11.043	19.052	19.013	-41.91
		Rise Time (T_R) in Sec	18.512	32.645	37.510	-50.64
		Settling Time (T_S) in Sec	297.311	288.368	51.301	82.74
		Peak Overshoot (M_P) in %	39.50	9.32	0	100
		% Steady state Error (ESS)	0	0	0	0
		Nature of Oscillations	Oscillatory	Smooth	No	100
4	Repeating Sequence Stair Disturbance	Delay Time (T_D) in Sec	11.323	18..571	18.303	-38.13
		Rise Time (T_R) in Sec	17.534	32.465	31.346	-44.03
		Settling Time (T_S) in Sec	368.051	361.843	350.00	4.90
		Peak Overshoot (M_P) in %	43.50	15.50	8	81.60
		% Steady state Error (ESS)	0	0	0	0
		Nature of Oscillations	Oscillatory	Smooth	No	100
5	Repeating Sequence Interpolated Disturbance	Delay Time (T_D) in Sec	11.531	18.625	19.453	-40.72
		Rise Time (T_R) in Sec	18.413	31.651	35.326	-76.18
		Settling Time (T_S) in Sec	362.00	310.176	210.00	41.90
		Peak Overshoot (M_P) in %	39.50	11.5	3	92.40
		% Steady state Error (ESS)	0	0	0	0
		Nature of Oscillations	Oscillatory	Smooth	No	100
6	Repeating Sequence Disturbance	Delay Time (T_D) in Sec	11.864	20.158	19.651	-39.62
		Rise Time (T_R) in Sec	18.100	36.974	40.097	-54.85
		Settling Time (T_S) in Sec	297.105	245.879	148.750	49.93
		Peak Overshoot (M_P) in %	38.30	9.83	1.80	95.53
		% Steady state Error (ESS)	0	0	0	0
		Nature of Oscillations	Oscillatory	Smooth	N0	100
7	Chirp Disturbance	Delay Time (T_D) in Sec	11.903	21.927	20.573	-42.14
		Rise Time (T_R) in Sec	18.756	39.756	38.852	-51.72
		Settling Time (T_S) in Sec	295.571	280.694	56.00	81.05
		Peak Overshoot (M_P) in %	35.80	13.62	0	100
		% Steady state Error (ESS)	0	0	0	0
		Nature of Oscillations	Oscillatory	Smooth	No	100
8	Band Limited White Noise Disturbance	Delay Time (T_D) in Sec	12.090	19.534	20.122	-39.91
		Rise Time (T_R) in Sec	18.572	34.476	39.471	-52.94
		Settling Time (T_S) in Sec	352.651	293.650	61.534	82.26
		Peak Overshoot (M_P) in %	35.50	7.10	1	97.18
		% Steady state Error (ESS)	0	0	0	0
		Nature of Oscillations	Oscillatory	Smooth	No	100

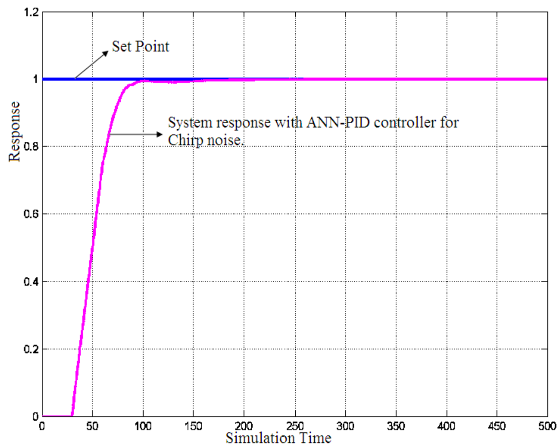

Figure.12 System response with ANN-PID controller for Chirp Noise.

VI. CONCLUSION

Various PID controllers including Fuzzy-PID and ANN-PID for the extrusion plant with several types of disturbances are tabulated above and results are shown. Results exhibited from proposed method provides less settling time and peak overshoot. Finally, ANN- PID was succeded in overcoming the adverse effects of disturbances. Risetime and delay time were not improved but detereorated.

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