Brain Emotional Learning Based Intelligent Controller for Temperature Control in Extrusion Process

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Abstract:

This paper deals with a Brain Emotional Based Intelligent Controller (BELBIC) for controlling the temperature in an extrusion. The quality of extrusion mainly depends on the temperature control. In general extrusion system is nonlinear and subjected to disturbances. To enhance the product quality, it is essential to improve temperature control. A Proportional Integral Derivative controller is widely used in industrial control which produces temperature oscillation during transient state and more time to settle. In this paper, Anti-windup PI controller is proposed to reduce oscillations in temperature. Artificial intelligent BELBIC is intended to overcome the problem associated with the PID controller and Anti-windup PI controller in extrusion. The entire system is analyzed with three different techniques using Matlab simulation. The performance of the conventional controller is compared with the AWPI and BELBIC controllers in terms of temperature oscillation and settling time.

***Keywords**:* Extrusion, temperature control, PID controller, Anti-windup PI controller, BELBIC.

1. Introduction:

Currently use of polymer materials has substantially improved over last few decades due to their various attractive properties such as ease of forming into complex shapes, light weight with high tensile/shock/tear strengths, high temperature and chemical resistance, high clarity, re-process ability 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, domestic, automotive, aerospace, marine, construction, engineering, and medical applications. Regardless of this success, it appears that efficient thermal monitoring and control remains an issue.

The temperature control in industry is a crucial process. Temperature control decides the nature and rigidity of the material. The temperature control is a tedious process which involves monitoring and quick response from the controller. Extrusion is a well established technique widely used in different industries like aluminium, sheet and plastic (Prabhat Kumar Mahto and Rajendra Mur (2015)).

The Proportional-Integral-Derivative (PID) controllers are very traditional controllers in industrial control systems because they can improve the steady-state error of the system (Kuo B C (1982)). Although significant endeavour has been dedicated to develop PID controllers, traditional PID controllers are not vigorous to the parameter deviations of the plants being controlled.

Even though many researchers analyzed the performance of extrusion using PI, PID and fuzzy logic controller, the overshoot and speed drop during load change are to be minimized (Astrom K and Hagglund T. (1995), Bohn C and Atherton D P (1995)). In the PID controller, the necessary action accumulates the error and causes a significant overshoot. It is called windup phenomenon (Youbin Peng D et al. (1996), Anirban Ghoshal and Vinod John (2010)). In this paper Anti windup PI controller is proposed to overcome this problem. PID controller in the first-order process provides a short term regulation, such as fuzzy PID controller (Berk

P et al. (2011)). Fuzzy Logic Controller (FLC) is developed to afford an intellectual control in mechanical systems (Tharwat O and Hanafy S. (2011), Rama Sarojinee et.al (2015)). Fuzzy logic efforts systematically and mathematically to simulate human reasoning and decision making. It also provides an intuitive way to execute control systems, decision making and diagnostic systems in various branches of modern industry (Truong Nguyen Luan Vu et al. (2007)). In many cases, an Artificial Neural Network (ANN) is an adaptive system that varies its structure which is based on internal or external information that flows through the network during the learning phase (Kalbande D R et al. (2011)). The design of a Neuro-Fuzzy Controller (NFC) is also considered because of their insensitivity to disturbance and uncertainty of model parameters (Nancy G Leveson et al. (1994)). The model of FLC and ANN for control problem are developed to control the inaccuracy of mathematical model of the plants usually, it disgrace the performance of the controller, especially for nonlinear and complex control problems (Nisha Jha et al. (2011), Jie Zhang. (2006)).

Therefore simple and efficient controller is necessary to control the temperature in extrusion. In this paper, BELBIC controller is proposed to control the temperature in extrusion.

BELBIC was introduced (Balkenius C and Moren J. (2001), Lucas C and Shahmirzadi D. (2004)) as a controller deals with the computational system of the limbic system of the mammalian brain. In recent years, this controller has been used in control devices (Lucas Caro et al. (2006)) and drives (Rouhani Hossein et al. (2007), Fatourechi M et al. (2001)) for several industrial applications. It is simple technique formed arithmetic equations (Fatourechi M et al. (2001)). The most benefit of this technique is less execution time in real-time implementation. So to limit the overshoot and to reduce the settling time in temperature with less processing time, Artificial Intelligence based BELBIC is proposed in extrusion. The performance of BELBIC based extrusion is compared with conventional PID and AWPI based extrusion control.

Materials and Methods

2. Polymer Extrusion Process:

Polymer processing extruders are classified into two types basically (Antonio Gaspar Lopes da Cunha. (1999)) known as continuous and batch extruders (Abeykoon et al. (2011)). Among the two types single screw continuous extruders are the most commonly used in the plastics industry. The essential components of a single screw extruder are shown in Figure 1. Based on their primary operations the screw is the key component and has been divided into three main functional/geometrical zones (i.e. solids conveying, melting, and metering) . 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. Many processing problems can occur under poor thermal conditions, e.g. output surging, thermal degradation,dimensional instability, poor mechanical properties, 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 nonhomogeneity increases with screw speed. Therefore, it is a challenging task to run extruders at higher screw speeds although the process energy efficiency then increases.

The temperature control in injection mould machine (Ven van de AAF Fons. (2003)) is an essential part of the machine. So, this controlling process is achieved by designing the controller for the response of the transfer function by the desired set point applied. Conventionally, Proportional Integral and Derivative (PID) controller is used. PID controller is simple in the algorithm, good stability, high in reliability, easy in design, and wide in adaptation, and it is the most extensive basic controller used in the application of process control. It can obtain satisfactory control effects in the 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. Regard to the temperature control system the characteristics of which are distributed parameter, nonlinear, large inertia and large time delay the conventional PID controller is tough to obtain satisfactory control results. To solve this problem, a control method which uses the fuzzy logic technology in temperature control for injection mould machine is used. The 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 attain 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 commonly controlled object in temperature control system. It can be described qualitatively by the model shown in equation (1).

$$G_s = (K/TS + 1)e^{-\tau s} \tag{1}$$

Hence, for the proposed system the transfer function (Hongfu Zhou (2008)) can be obtained as,

$$G_s = (0.92/144S + 1)e^{-}30s \tag{2}$$

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

3. Conventional PID Controller:

A PID controller is a feedback controller widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and the desired set point. This control involves three separate gain parameters, and is sometimes called three-term controller (Youbin Peng D et al. (1996)): proportional, integral and derivative values. By tuning the three parameters in the PID controller, the controller provides control action designed for specific process requirements (Bohn, C and Atherton D P. (1995)). The transfer function of a standard PID controller in an ideal form is

$$G(S) = K_p + K_i(1/S) + K_d S \tag{3}$$

Where,
K_P - proportional gain, K_i- integral gain, K_d-derivative gain.
In the PID controller,each parameter$_d$ have a different effect on the speed response and stability. The functionalities of each term are highlighted by the following:

i. K_p is to speed up the response and to improve the system accuracy.
ii. The Ki is reducing steady-state errors through low-frequency compensation by an integrator.
iii. Kd term is improving transient response through high-frequency compensation by a differentiator.

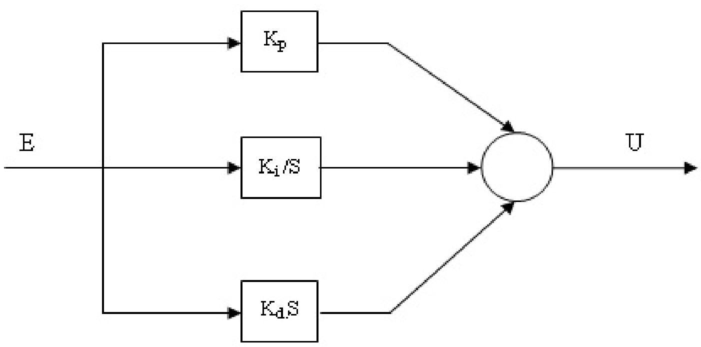

Figure 1. Block diagram of PID controller

Designing steps for a PID controller are

1. Determine the characteristics of the system which needs to be improved.
2. to decrease the rise time use KP.
3. to reduce the overshoot and settling time use Kd.
4. to eliminate the steady-state error use Ki.

The PID controller block diagram is shown in figure 1, where E is the error signal and U is the actuating signal.

4. Anti Windup PI Controller:

Integrator windup phenomenon in a PI controller produces a large overshoot. To reduce peak overshoot and settling time anti windup PI controller is proposed in this paper. It is similar to the PI controller except that the integral controller has feedback from the output (Bohn C and Atherton D P (1995), Youbin Peng D et al. (1996), Anirban Ghoshal and Vinod John (2010), Espina J et al. (2009), Murugananth G. and S Vijayan. (2012)). The main task of anti wind up method is to avoid over the value of inductance. It causes a reduction in overshoot. There are several methods in an anti wind up PI controller such as AWPI with a dead zone; AWPI conditioned, AWPI tracking and AWPI tracking with gain. In this study, AWPI tracking is proposed which has less overshoot and faster settling time (Murugananth G and S Vijayan (2012), Bohn C and Atherton D P (1995)) Feedback is a difference of output from before and after saturation. Feedback gain is referred as

$$F(s) = 1/K_p \quad (4)$$

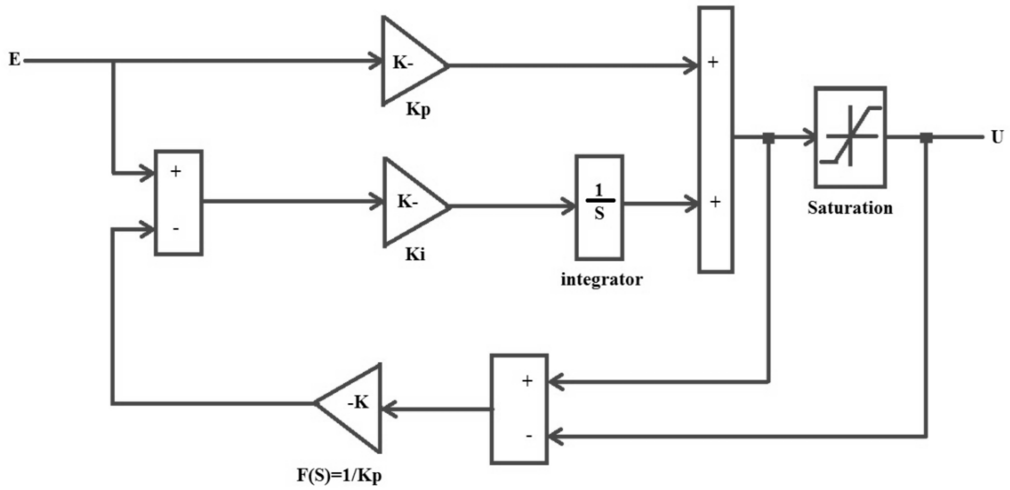

Figure 2. Simulation diagram of Anti Wind up PI controller

The simulation diagram of anti windup PI controller is shown in figure 2.

Anti windup PI controller with the effect of saturation improves the system performance by allowing it to work in the linear region most of the time and settleback quickly from nonlinearity. Fixed values of control gains *Kp* and *Ki* produces more drop in speed during the load change.

5. BELBIC Controller:

To enhance the speed performance a controller withs less processing time, easy and effective control BELBIC is proposed in this paper. It is proposed to reduce the overshoot, settling time and drop in speed during the change. It can be achieved by proposing BELBIC because it is a dual feedback controller. PID and Anti windup PI are single feedback controllers. BELBIC receives temperature error of machine as one of the feedback and the controller output as another feedback. It results in accurate tuning of the controller based on the present state.

BELBIC is based on the architecture of the "Limbic System" of the human brain (Balkenius C and Moren J. (2001)). The limbic system is responsible for the emotional learning in human beings (Lucas C and Shahmirzadi D. (2004)). Figure 3 shows the block diagram of BELBIC controller.

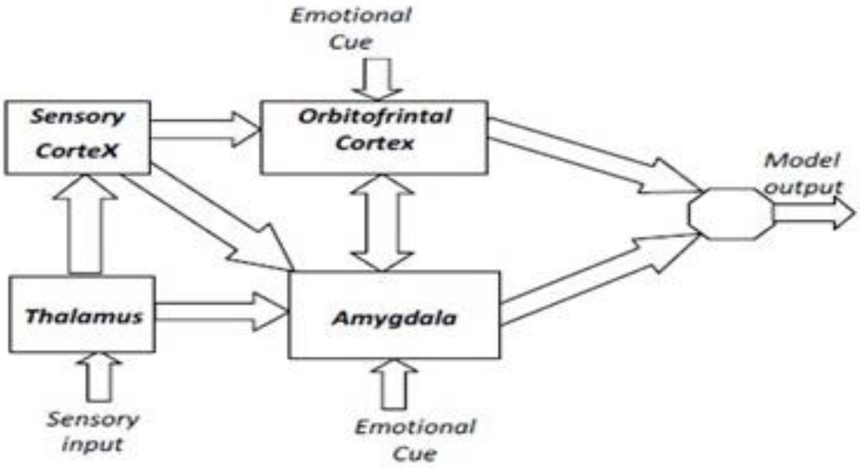

Figure 3. Block Diagram of BELBIC

BELBIC is a simple composition of the Amygdala and Orbitofrontal cortex in the brain. A simple limbic system of the brain is shown in figure 4.

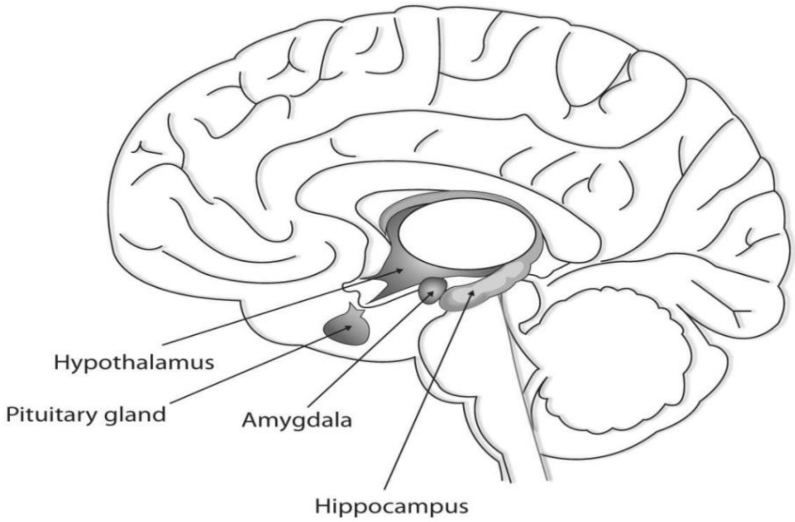

Figure 4. Limbic System of Brain

Thalamus does the Pre-processing on sensory input signals such as noise reduction or filtering . The emotional evaluation of stimulus signal is carrying out through the Amygdala, which is a small part of the medial temporal lobe in the brain. As a result, this emotional mechanism is utilized as a basis for emotional states and reactions.

Initially Sensory Input signals are going into Thalamus for pre-processing on them. In this paper temperature error is considered as Sensory input. Then Amygdala and Sensory Cortex receive their processed form, and their outputs will be computed by Amygdala and Orbitofrontal based on the Emotional Signal received from the environment. The final output is the subtraction of the Amygdala and Orbitofrontal Cortex. One of the Amygdala's inputs is called Thalamic connection and calculated as the maximum overall Sensory Input S as equation (5). This specific input is not projected into the Orbitofrontal part and cannot by itself be inhibited and therefore it varies from other Amygdalas' inputs.

$$A_{th} = i_{max} S_i \quad (5)$$

Every input is multiplied by a soft weight V in each A node in Amygdala to give the output of the node. The O nodes behaviors produce their output signal by applying a weight W to the input signals as well as A nodes. To adjust the Vi difference between the reinforcement signal rew and the activation of the A nodes has been made use. To tune the learning rate the parameter is used, and it is set to a constant value. As shown in equation (6) Amygdala learning rule is an example of the simple associative learning system, although this weight adjusting rule is almost monotonic. For instance, Vi can just be increased.

$$\Delta_{vi} = \alpha \left(S_i \max \left(o, rew - \sum A_j \right) \right) \quad (6)$$

α Is the learning step in the Amygdala. to attain the result of this training to be permanent, after training of emotional reaction limitation is adjusted, and it is handled through of the Orbitofrontal part when it is inappropriate (Miller T. J. E. (1989)). Subtraction of reinforcing signal from past output E makes the signal of reinforcement for O nodes. Comparison of set and actual reinforcement signals in nodes O inhibits the model output. The Orbitofrontal Cortex learning equation is drawn in Eq. (7).

$$\Delta w_i = \beta \left(s_i \sum (o_j - rew) \right) \quad (7)$$

The amygdala and Orbit frontal learning rules are much alike, but the Orbitofrontal weight W can be changed in both ways to increase and decrease as needed to track the proper inhibition. And the rule of β in this formula is similar to the α ones.

Mathematics, the Linear Model of BEL Controller, is represented by Following Simplified Equations

$$A = G_A.SI \quad (8)$$

$$O = G_{OC}.SI \quad (9)$$

$$\frac{dG_A}{d\tau} = \alpha SI(ES - A) \quad (10)$$

$$\frac{dG_{OC}}{d\tau} = \beta.SI(A - OC - ES) \quad (11)$$

$$MO = A - OC \quad (12)$$

Where MO is Model Output, SI is Sensory Input, ES is Emotional Sensor, A is Amygdala Output, O is Orbitofrontal Cortex, α is Learning rate of Amygdala, P is Learning rate of Orbitofrontal cortex, G_A is Gain for Amygdala, G_{OC} is Gain for Orbitofrontal Cortex. Based on the above equations mathematical model of BELBIC is formed. Since BELBIC is purely formed by the arithmetic equations, it is ease to implement and consumes less processing time.

6. Simulation Results and Analysis:

Transfer function based extrusion model is developed in Matlab/Simulink. An initially system is analysed with PID controller. Then the system performance is analysed using AWPI and BELBIC.

A temperature reference is set as 100C. Figure 5 shows the actual temperature of PID controlled extrusion system.

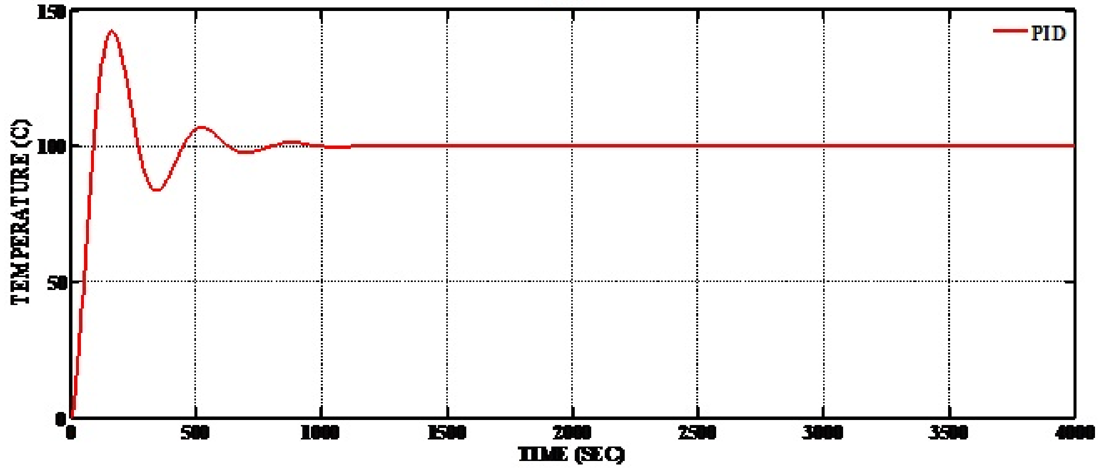

Figure 5. Temperature of PID controlled extrusion system

The figure 5 shows that the PID controller settles the temperature in its reference value after some oscillations. Figure 6 and 7 show the performance of AWPI and BELBIC controlled extrusion system.

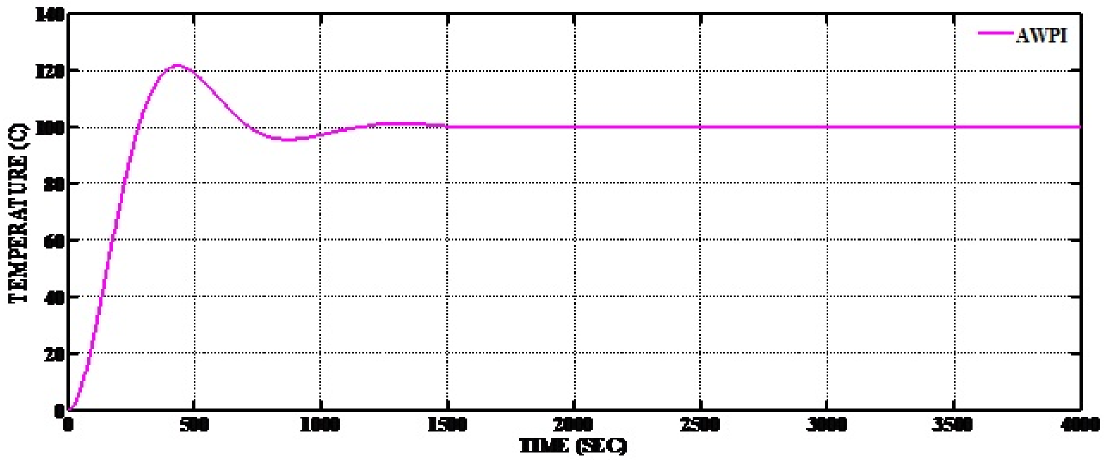

Figure 6. Temperature of AWPI controlled extrusion system

From the figure 6, it is evident that in AWPI controlled extrusion temperature swing is less compare to the PID controlled extrusion.

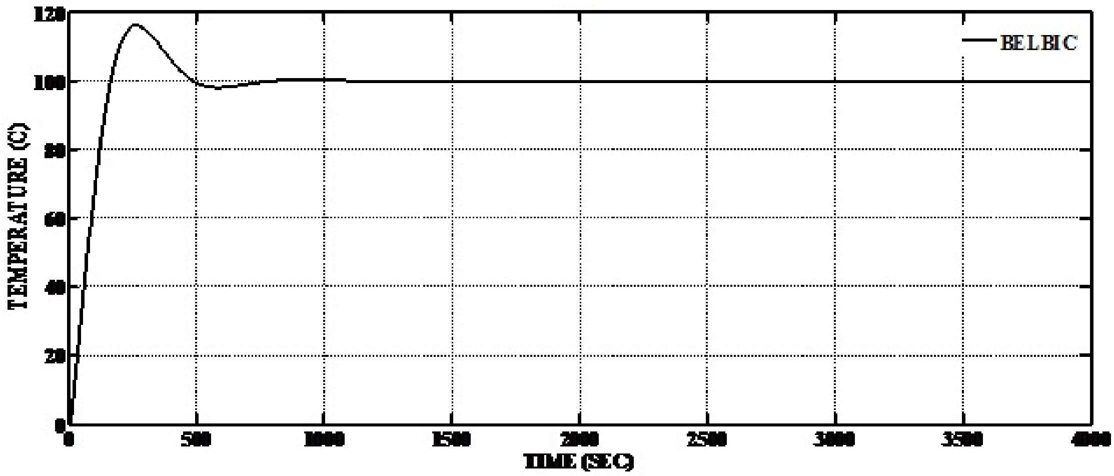

Figure 7. Temperature of BELBIC controlled extrusion system

From the figure 5-7, it is obvious that in all controllers temperature reaches reference value. In a PID controller settling time and peak overshoot are high compared to AWPI and BELBIC controller. AWPI controller reduces peak overshoot compare to PID controller, but settling time is not reduced. A performance of all controllers is compared and shown in figure 8 and tabulated in Table 1.

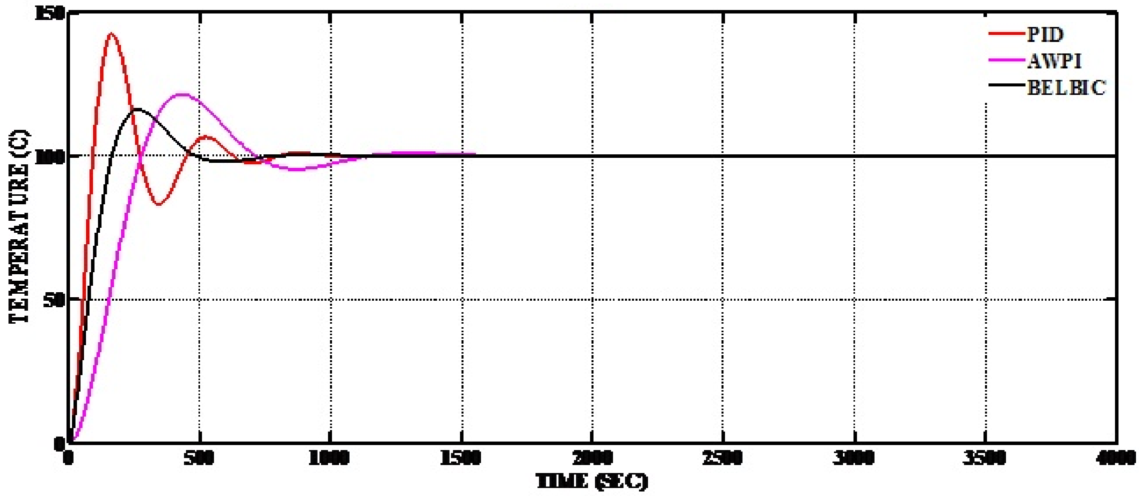

Figure 8. Comparison of PID, AWPI and BELBIC in extrusion control

Table 1. Performance comparison of various controllers in extrusion

Controller	Peak overshoot (%)	Settling time (s)
PID	43	1000
AWPI	22	1300
BELBIC	16	800

Figure 8 shows the performance comparison of three controllers in extrusion.PID controller produces high overshoot and long settling time. The AWPI controller reduces overshoot compare to the PID controller, but it increases settling time. Settling time is also the primary parameter in temperature control. From the figure 8 and table 1 it is evident that BELBIC controller produces reduced overshoot and minimum settling time compare to all other controllers.

7. Conclusion:

Temperature control is the crucial part in an extrusion. Controller performance decides the quality of the product. The performance of the most used PID controller is analyzed in this paper. The result showed the oscillation in temperature at a time of starting and took more time to settle. Overshoot is the temperature oscillation at the time of transient, and it is reduced by the proposed AWPI controller. Proposed BELBIC controller is an intelligent controller formed by pure arithmetic function, which consumes less processing time. It reduces settling time as well as peak overshoot. Therefore BELBIC is an optimum controller for real time implementations in extrusion application.

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