Artificial Neural Net Based Process Temperature Controller

Abstract

This paper demonstrates an easy and efficient way to implement *Artificial Neural Net (ANN)* as a process temperature controller. It contains a new method to construct training patterns. The paper also discuss a basic structure of ANN to incorporate in the system. It also shows the control action as graphs at different set points to validate controlling ability of the intelligent controller.

1. Introduction

Nowadays, the use of *Artificial Intelligence (AI)* in Control Applications is increasing significantly because of its easy implementation and human like approach.

ANN is computing tool having AI origin. ANN has basically mathematical structure, i.e. it is totally based on mathematical formula having multiplication and addition. There is no IF-THEN condition and no logical structure. So it is very easy to implement.

To Implement ANN as a controller, there are certain steps to follow.

1] Construction of a set of training patterns (by an expert).
2] Training of ANN with the set of patterns.
3] Simulation and verification of the ANN.
4] Implementation of the Trained ANN in actual control system.

Principle: One of the applications of ANN is ***Pattern Recognition***. A set of training patterns, having estimated inputs and desired outputs, is used to train the ANN. After training phase, whenever an input pattern is presented to ANN from the set, it will recognize the input pattern and produce output associated with it in the set of pattern. Now, consider that training patterns are rich in quantity. If ANN is presented an input pattern, which is not in the training set, it will interpolate its output between two adjacent patterns. Consider an example, ***10 : 5 : 0.5*** and ***1 : 5 : 0.2*** are two adjacent training patterns from the set, having first two inputs and one output. Now, If trained ANN is presented ***5 : 5*** as an input patterns, it will recognize the pattern and produce interpolated output between ***0.2*** and ***0.5***. So, when the ANN is presented an input pattern, it will recognize the pattern and accordingly generate output.

One of the advantages of ANN is that it mimics human behavior for controlling the process. In this case, ANN will mimic the approach of the expert, who defined the set of training patterns to control process temperature.

2. General System Description

Generally, a temperature controller is a close loop control system. The block diagram of a general control system is shown in figure 2. General Description of figure 2 is written below.

- Type of Temperature Sensing Element : *(1)Resistance Temperature Detector (RTD), (2) Thermocouple (TC),* etc.
- Type of Cooling : *(1) Air Cooling (Air Blower), (2) Oil cooling, (3)Water cooling,* etc.
- Type of Heating : *(1) Dielectric Heating (Mica Band Heater),* etc.
- Type of Output of controller : *(1) Solid State Relay (SSR), (2) Current-Loop,* etc.

From the figure 2, STe is the set temperature, ATe is process temperature at a given instant and Err is the error between STe and ATe. A temperature sensing element senses process temperature (ATe). The controller takes Err as an input and turns on/off Heater and Blower for the specific time according to Err. There are many controlling algorithms available such as PID, Auto-tune PID, Simple Auto-tune, On/Off type, etc. The controller drives Heater or Blower just by giving a triggering pulse to power switching device such as a Relay or a Thyristor. Power is supplied to Heater or Blower till a triggering pulse is applied to the switching device.

Operation Sequence: Temperature sensor senses the process temperature and feeds back to controller. The controller takes process temperature data. Then, it calculates error between actual process temperature and the set temperature. According to the input error, it adapts the output, i.e. it will turn on Blower or Heater for the specific time in order to manipulate process temperature either closer to set temperature or stick to set temperature.

3. Description Of ANN Based Control System

A block diagram of the close-loop control system based on ANN is shown in figure 3(a). Description of figure 3(a) is written below.

- Type of Temperature Sensing Element : Thermocouple (TC).
- Type of Cooling : Air Cooling (Air Blower).
- Type of Heating : Dielectric Heating (Heater).
- Type of Output of controller : Solid State Relay (SSR).
- The Single output of ANN is used to drive a Heater as well as a Blower.

Terms and Symbols used in figure 3(a) are discussed below.

Operation Band: The controller starts actual controlling action after the process temperature enters into fixed percentage error range. The range, from ***+40%*** to ***-10%*** error between Set temperature and Actual Temperature, is fixed for the controller. This range is called the Operation Band. If percentage error decreases below ***-10%,*** the controller will turn on Blower and turn off Heater until process temperature will be within the Operation Band.

Monitoring Time Period (tm) and Monitoring Cycle: Once, the controller updates its output, the effect of changing in output on Process temperature will be recorded after sometime. This effect is called Delay-effect. To accurately measure the effect of change of output on process temperature, a monitoring time period is introduced. The monitoring time period is divided into two equal time-span monitoring cycles. After updating output, the controller will be idle for two monitoring cycles. Thereafter, it will take a new sample of temperature and same way update output if necessary and wait for one monitoring time period or two monitoring cycles again.

Monitoring Time Period Adjustment: The monitoring time period depends on size & temperature of Heating Material, Heater & Blower efficiency and surrounding atmosphere, etc. It varies with Material, Heater and Blower type and Surrounding condition. To control process temperature efficiently & accurately, the monitoring time period must vary according to process environment and heating material. A test is performed every time before the controller enters into the Operation Band by an analyzing routine to calculate optimum monitoring time period. In the analysis, the controller will turn on Heater at a specific temperature, depends on the set temperature. The heater will be on until process temperature will be raised at a specific temperature. The controller will measure Heater On-time for fixed rise in degree temperature. Then, the controller will derive the Monitoring time Period from Heater On-time.

Heater and Blower percentage Duty Cycle: The controller output is in terms of percentage Duty Cycle. Consider that the duty cycle of Heater is ***50%.*** As early mentioned that the controller will be idle for two monitoring cycles. So, in the first monitoring cycle the heater will be on for half ***(50%)*** of cycle time and off for remaining half cycle. The same will repeat for the second monitoring cycle.

A Diagram, shown in figure 3(b), will elaborately explain terms discussed above in the section.

Input of the controller:

1] $\% Err = \dfrac{\text{(Set Temperature - Actual Temperature)}}{\text{Set Temperature}} \times 100 = \dfrac{(STe - ATe)}{STe} \times 100$

2] Rate of Change of Temperature $= dT/dt = (ATe - ATe\_old) \times (K / Nc)$.

Where, K = Scaling factor, depend on Monitoring time period(tm).
Nc = Number of Monitoring Cycles in the period.
ATe = Current Process Temperature.
ATe_old = Process Temperature before One Monitoring time Period.

Output of the controller:

1] Heater or Blower percentage Duty Cycle.

Operation Sequence: Thermocouple (TC) is used to sense process temperature. The control system takes a sample of process temperature (ATe) and calculates percentage Err as the first input. The controller calculates dT/dt, the second input to ANN, using above formula. These two inputs are fed to ANN. It will recognize the input pattern and supply appropriate percentage duty cycle to Heater and Blower Driver. Then, the controller will be in idle state. It will remain in the state until a next sample will be taken after one monitoring time period or two monitoring cycles time.

4. ANN Topology & Training Patterns Construction

Topology: A 3-layer feedforward type ANN, shown in figure 4(a), is implemented as a process temperature controller. The ANN has two input neurons, three hidden neurons and one output neuron. Two input neurons have linear threshold activation function shown in figure 4(b) and 4(c). The output neuron and three hidden layer neurons have sigmoid activation function.

$$f(y)=1/(1+e^{-SX}).$$

Where, SX is weighted sum of inputs to neuron.

Training Patterns Construction: For constructing a set of control patterns to train ANN, there are two methods mentioned below.

1] Make a fuzzy set and defuzzified it and gets control patterns and train ANN.

2] The second method is describe below.

In this paper, the second method is used to construct training patterns for the process temperature controller. In the method, percentage Error range is divided into various zones. Each zone is associated with different duty cycle for Heater or Blower at a given rate of change of temperature. A table is created using center value of each percentage error zone (input), rate of change of temperature (input) and associated percentage duty cycle of heater or blower (desired output). A set of training patterns at a given rate of change of temperature is shown below as an example.

%Err	% Duty Cycle		Heater On/Off	Blower On/Off	Condition
	Heater	Blower			
Less than -10%	0%	100%	OFF	ON	Above The Operation Band
-10% to -4%	0%	50%	OFF	ON	"
-4% to -2%	0%	50%	OFF	ON	"
-2% to -1%	10%	0%	ON	OFF	The Operation Band
-1% to 1%	20%	0%	ON	OFF	"
1% to 2%	30%	0%	ON	OFF	"
2% to 5%	40%	0%	ON	OFF	"
5% to 10%	50%	0%	ON	OFF	"
10% to 15%	60%	0%	ON	OFF	"
15% to 25%	70%	0%	ON	OFF	"
25% to 35%	80%	0%	ON	OFF	"
35% to 55%	90%	0%	ON	OFF	"
Greater than 55%	100%	0%	ON	OFF	Below The Operation Band

The 3-D surface graph of Training Patterns used to train the ANN is shown in figure 4(d). From 3-D surface graph, it is clear that the Blower is used when the temperature overshoots over ***-2%*** error (***2%*** higher than the Set Temperature). The controller uses Blower just to bring down process temperature into the Operation Band at a specific condition (overshoot) and, at that time, Heater will be turned off (***0%*** Duty Cycle). The Heater is used when process temperature is in the operation band and, at this time, Blower will be turned off (***0%*** Duty Cycle). Whenever Heater is on, Blower is off and vice versa. So, only one output is used to drive Heater as well as Blower Driver at different input conditions.

The efficiency of the training set is tested by simulating the process using trained ANN. According to response of the controller, the training set is adjusted by trail and error to achieve reasonably good result.

5. ANN Training Session

Learning is the actual process of adjusting weight factors based on trial and error. There are two different approaches to training ANN.

1] Supervised Learning : An external teacher controls the learning.

2] Unsupervised Learning : No external teacher is used. The ANN develops its own models without additional input information.

In supervised training or learning phase, a set of Input-Output patterns is repeatedly presented to the ANN. The weights of all the interconnections between nodes(neurons) are adjusted until the specified input yields the desired output. Through these activities, the ANN learns the correct input-output response behavior.

The Supervised Learning is the most common type of learning used in ANNs today. Error-Correction Learning is a form of Supervised Learning, where weights are adjusted in proportion to the error between actual output and desired output for the particular input pattern.

In this paper, the Error-Correction supervised learning is used to train the ANN. Weights of Network are initialized with random numbers ranging from ***-10.0*** to ***+10.0.*** Training began with a set of 30 input-output patterns. A set of training pattern is applied to ANN and, for each pattern, weights are updated by *Generalized Delta-Rule (GDR)* with *Back Propagation* of the error between desired output and actual output of the ANN. Initially, learning parameter ETA set to ***0.3***. During the process of training, the learning parameter may be changed to avoid local minima and to achieve absolute error within acceptable range. The set of training patterns is repeatedly presented to the ANN until the absolute error is within the range of ***0.1*** to ***0.2***.

6. Experimental Results

Entire Controller is incorporated in a commercially available Single Board Computer (SBC). The board also contains 8-bits A/D converter for converting analog process temperature into digital format. The controlling task is carried out by a routine written in BASIC language, running in interpreter mode on the SBC. A 486-PC is used as a dummy terminal for recording the experimental results. The PC and SBC are communicate through RS-232C Serial Communication Channel. Under this environment program can easily debug.

The controller is tested at different set temperature values. Results at two different set values, ***100'C*** and ***200'C***, are shown in terms of temperature v/s time graph along with heater and blower percentage duty cycle v/s time graphs. The results are shown in Figure 6(a) and 6(b). Figure 6(a) shows the experimental results at set temperature 100'C. Figure 6(b) shows the experimental results at set temperature ***200'C***. Scales of temperature, heater and blower % duty cycle graphs are *20'C per div., 10% per div. & 10% per div.* respectively.

For both Set temperature values in the experimental results, the process parameters are shown below.

- The Operation Band is from ***40%*** to ***-10%*** Error.
- Number of Monitoring Cycles during Monitoring Time Period is fixed at two.
- Monitoring Time period was set by the analyzing routine before the controlling action had started.

7. Conclusion

An ANN base process temperature controller is implemented successfully. The experimental results show control system efficiency and controlling ability. A simple training patterns contrusction method is introduced to reduce training time of the net. The controller used a Heater to control process temperature in operation band. A Blower is used when the temperature overshoots above the operation band limit. From the experimental results, there is an overshoot above the set temperature because it is a strategy to achieve the set temperature early in the process like Thermoplastic. Thereafter, the control system is stable. To improve the system performance, a analyzing routine is introduced, which adjust the monitoring time period. Though the controller is a single point (a single output), the response of controller is good. The controller can be used in plastic processing industries.

8. Appendix

The experiment is performed on a *45 mm* Thermoplastic Extrusion Machine barrel as heating material, having length of *300 mm*, *106 mm* outer diameter and *45 mm* inner diameter. A *1/6 H.P.* single phase, *2800 rpm*, *230 Volt*, *50 Hz* supply motor is used in Air Blower as a cooling device. Mica Band Heater, having *1500 Watt* output, *230 Volt*, *50 Hz* supply is used as a heating element. A Fe/Con Bayonet type thermocouple is used as a temperature sensing element.

References

1] R. P. Lippmann, "An Introduction to Computing with Neural Nets", IEEE ASSP Magazine, April 1987.

2] Don R. Hush and Bill G. Home, "Progress in Supervised Neural Networks", IEEE Signal Processing Magazine, pp. 08-38, Jan. 1993.

Figure No.	Figure Description
2.	General Temperature Control System Block Diagram.
3(a)	Block Diagram of The Process Temperature Controller using ANN.
3(b)	Heater & Blower Duty Cycle related with Monitoring Cycles.
4(a)	A 3-Layer Feedforward Neural Net Used as the controller.
4(b)	Linear Threshold Activation function of Input Neuron - 1.
4(c)	Linear Threshold Activation function of Input Neuron - 2.
4(d)	3D Surface Graph of Training Patterns, used to train ANN.
6(a)	Experimental Results at 100'C Set Temperature.
6(b)	Experimental Results at 200'C Set Temperature.

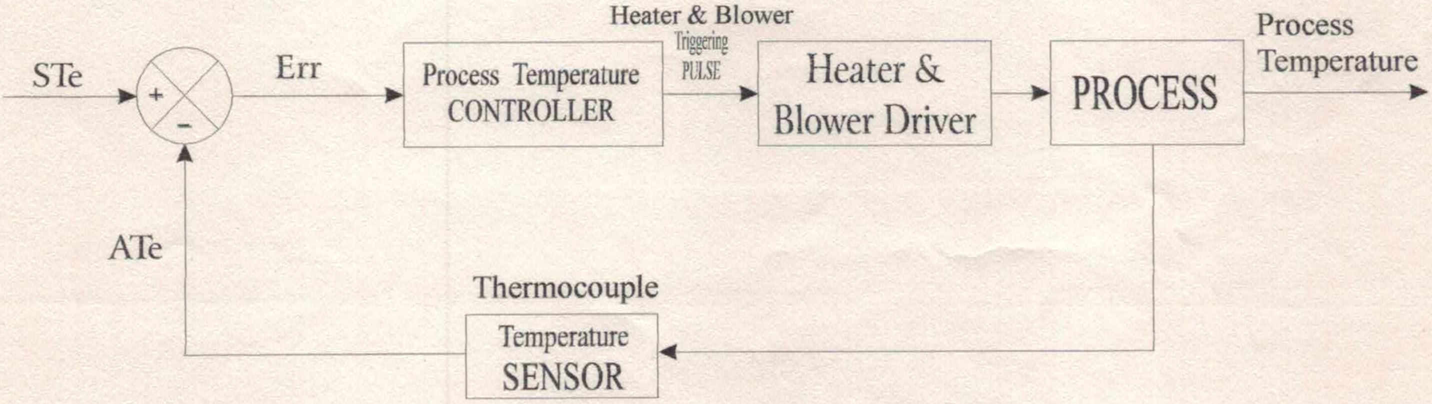


Fig 2 General Temperature Control System Block Diagram.

ANN BASED PROCESS TEMPERATURE CONTROLLER

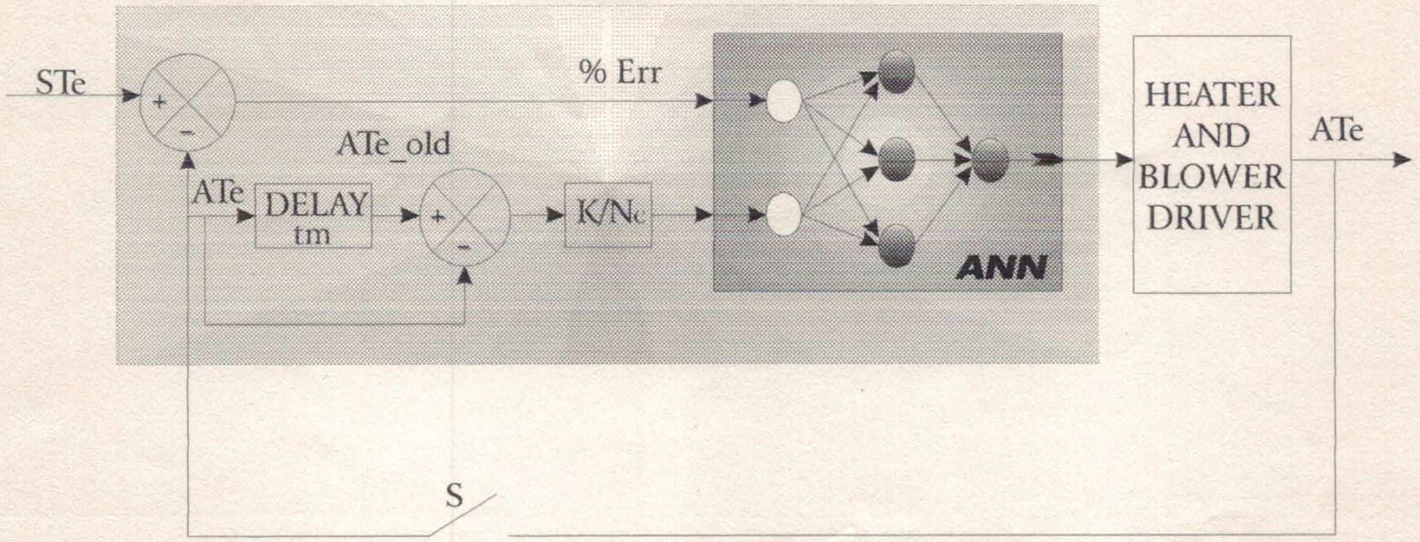


FIG.3(a) The Process Temperature Control System Using ANN

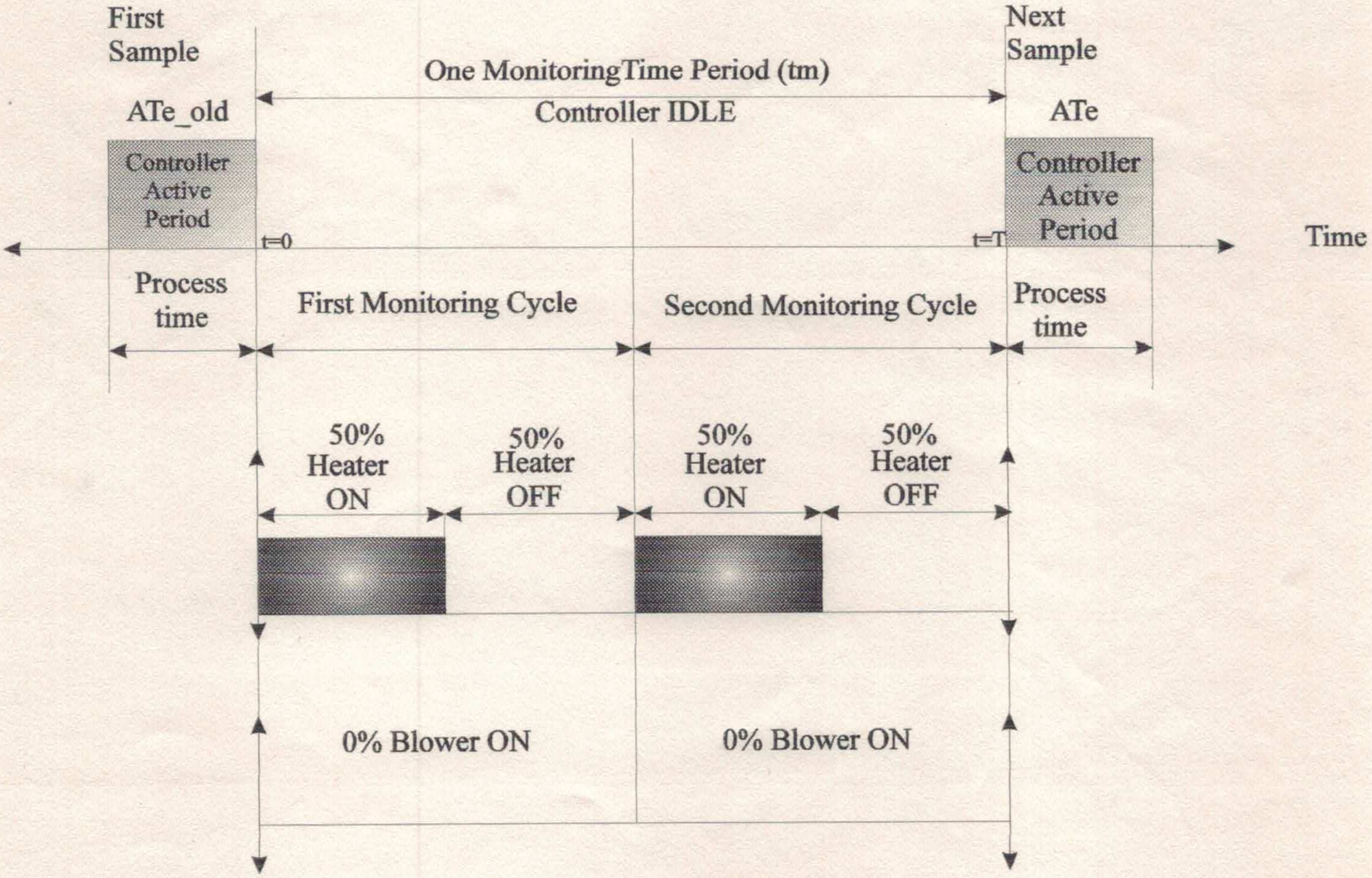


Fig. 3(b) 50% Heater Duty Cycle and 0% Blower Duty Cycle related with Monitoring Time Period and Monitoring Cycles.

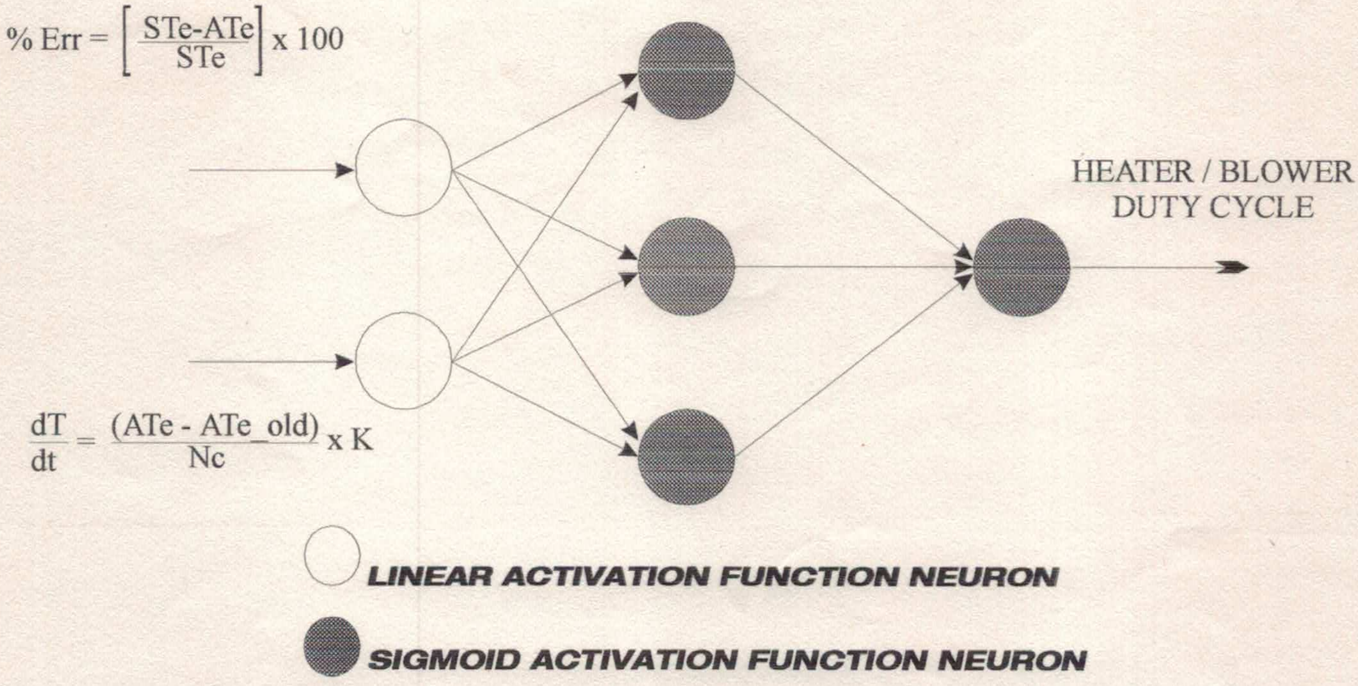


FIG 4(a) A 3- LAYER FEEDFORWARD NEURAL NET

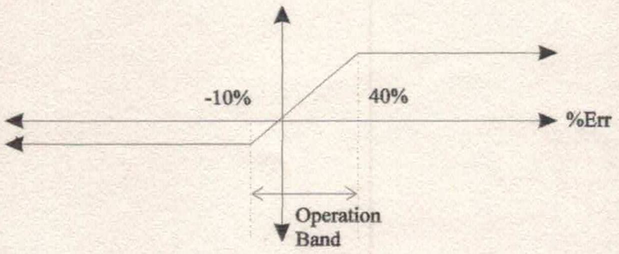


Fig. 4 (b) Linear Threshold Activation Function of Input Neuron-1.

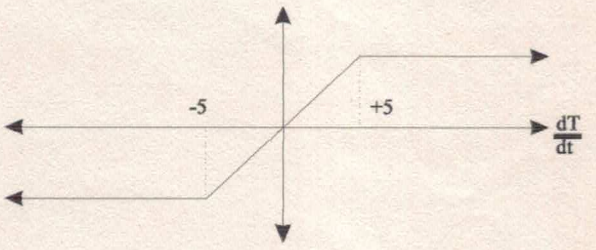
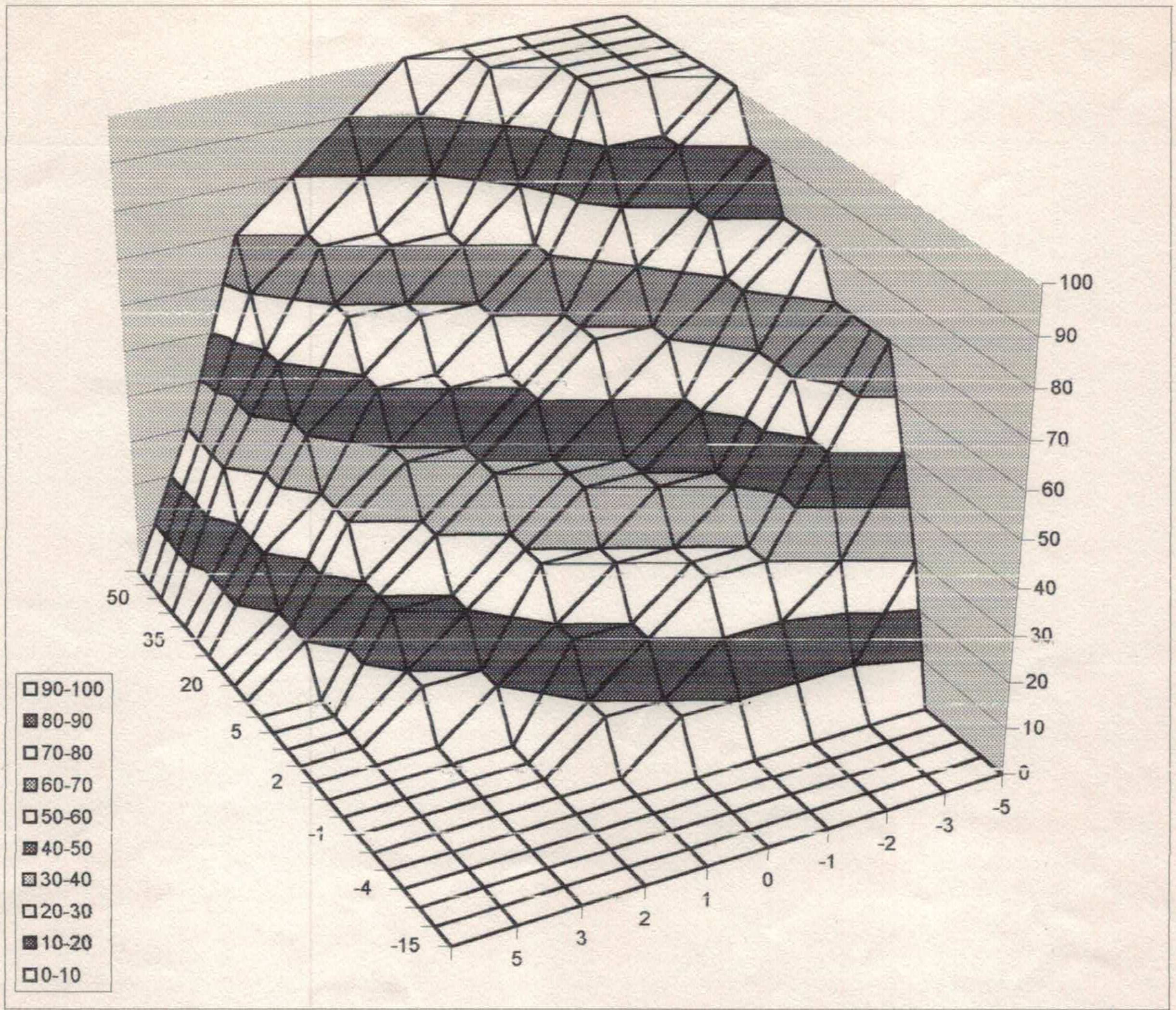


Fig. 4 (c) Linear Threshold Activation Function of Input Neuron-2.



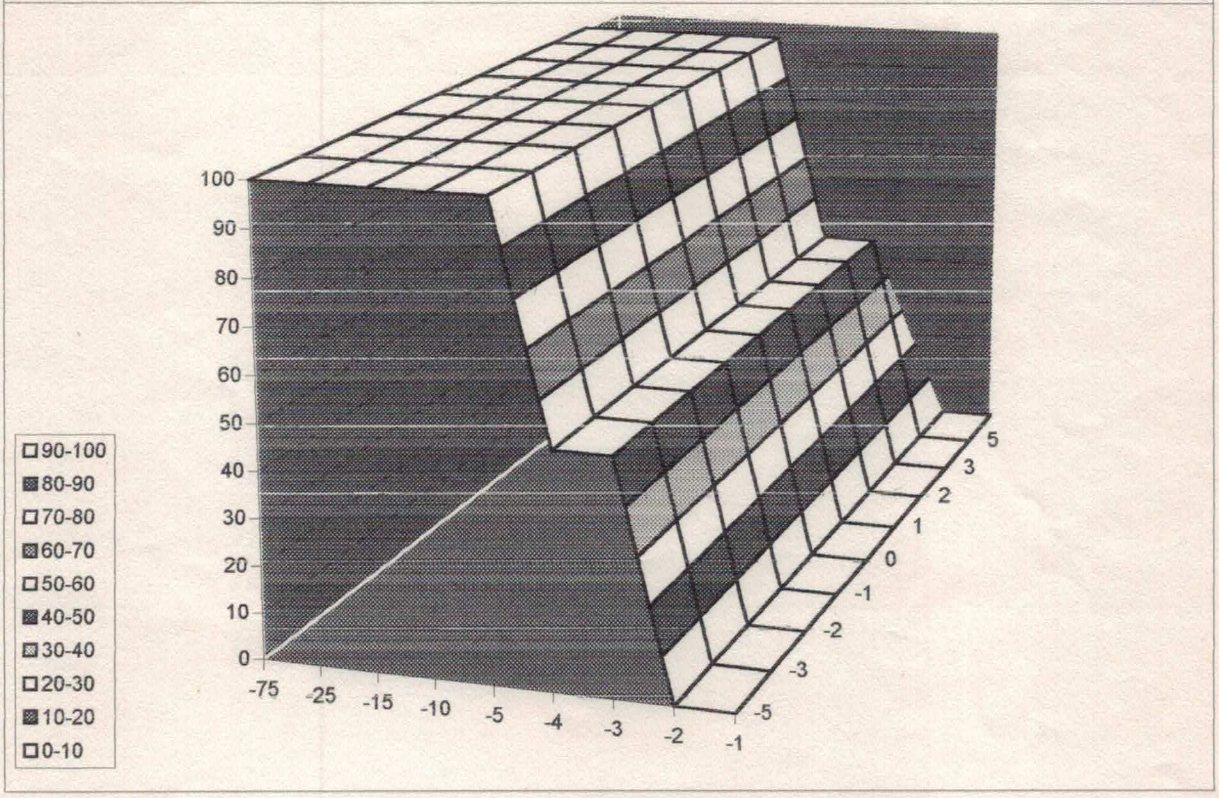


Fig 4(d) 3D Surface Graph of Training Patterns, used to train ANN.

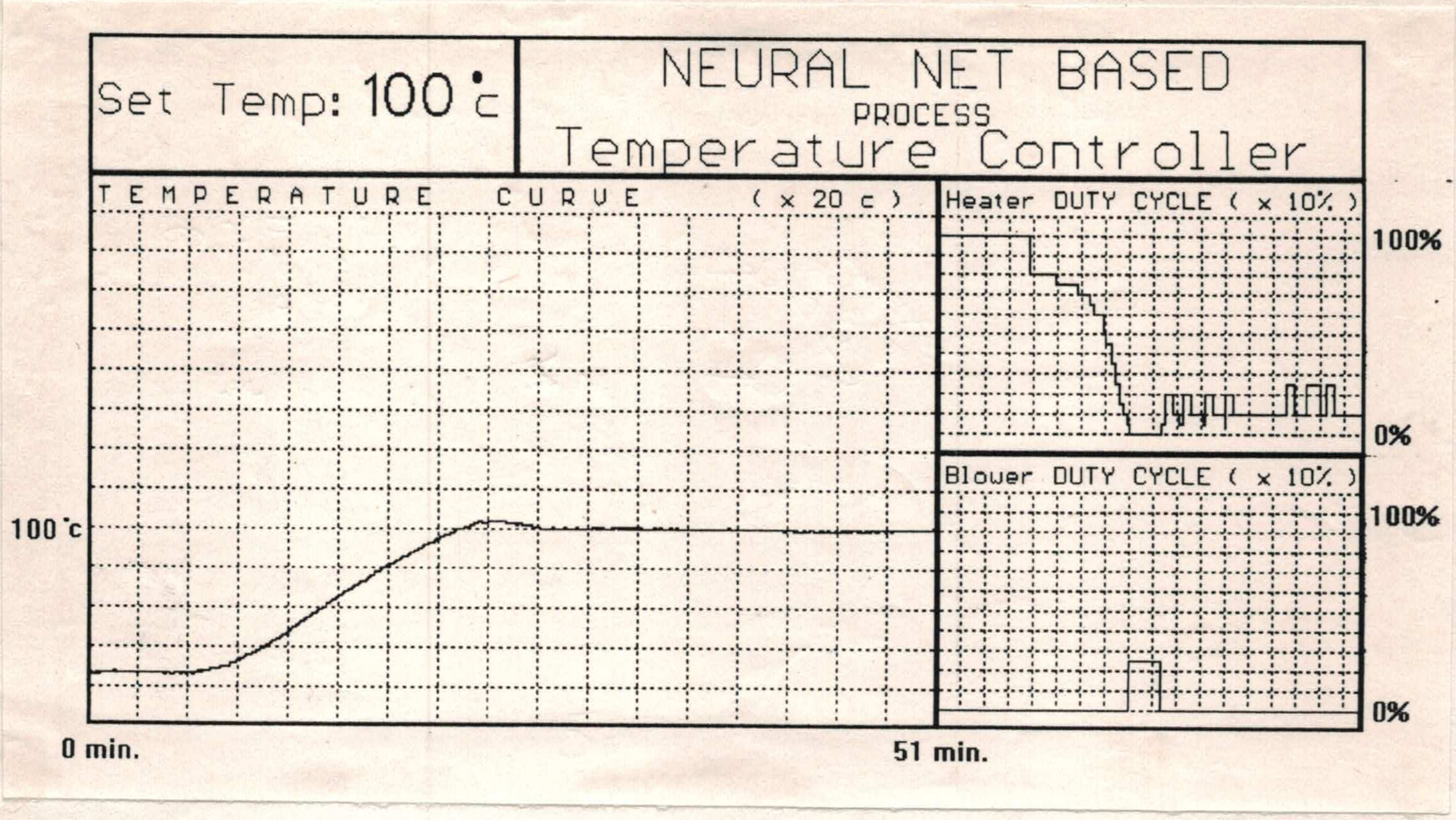


Fig 6(a) Experimental Result at 100'C Set Temperature.

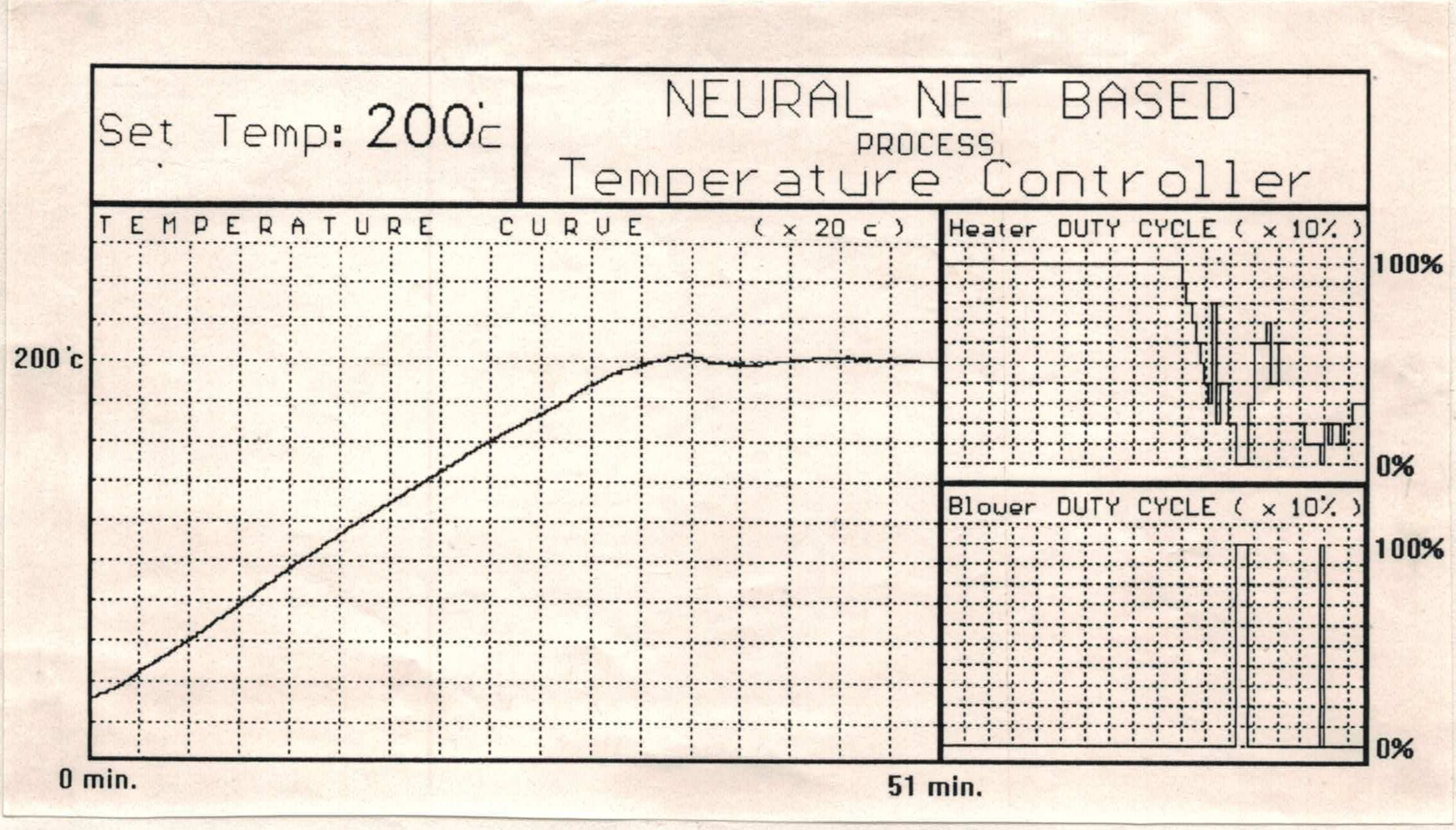


Fig 6(b) Experimental Result at 200'C Set Temperature.