ON LINE MICROCOMPUTER CONTROL OF HEAT EXCHANGER

A DISSERTATION

submitted in partial fulfilment of the requirements for the award of the degree

of

MASTER OF ENGINEERING

in

ELECTRICAL ENGINEERING
(SYSTEMS ENGINEERING AND OPERATION RESEARCH)

By

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MARCH, 1989

DEDICATED TO
MY PARENTS

CANDIDATE'S DECLARATION

I hereby, Certify that, the work which is being presented in the dissertation entitled, ' ON LINE MICROCOMPUTER CONTROL OF HEAT EXCHANGER', in partial fulfilment of the requirements for the award of the degree of MASTER OF ENGINEERING in ELECTRICAL ENGINEERING with specialization in SYSTEMS ENGINEERING AND OPERATION RESEARCH, submitted in the ELECTRICAL ENGINEERING Department, University of Roorkee, Roorkee (INDIA), is an authentic record of my own work Carried out for a period of about 6 months from September, 1988 to March 1989, Under the Supervision of Sh. M.K. VASANTHA, Reader, ELECTRICAL Engineering Department, University of Roorkee and Dr. B. MOHANTY, Lecturer, Chemical Engineering Department, University of Roorkee, Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Dated 13/3/89

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This is to Certify that the above statement made by the Candidate is Correct to the best of our knowledge.

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A C K N O W L E D G E M E N T

I wish to express my deep sense of gratitude to Shri M.K. Vasantha, Reader, Electrical Engineering Department, University of Roorkee and Dr. B. Mohanty, Lecturer,Chemical Engineering Department, University of Roorkee, for their valuable guidance at all stages of this work. Inspite of their busy schedule they rendered very generous help and were meticulously careful in going through the manuscript and giving valuable suggestions.

I would fail in my duty if I don't thank Mr. A. Garg, Proprietor, M/s. Electrotech, Roorkee, for helping me in getting various units of my dissertation developed.

Sincere thanks are due to Dr. R.B. Saxena, Professor and Head, Electrical Engineering Department, University of Roorkee and to Dr. B.S. Varshney, Professor and Head, Chemical Engineering Department, University of Roorkee, for providing all the facilities required during the course of this work.

Also, I take this opportunity to express my sincere sense of obligation to my family members and friends who backed my interest and efforts by giving useful suggestions and possible help.

I should also thank the Typist for his patience while typing the thesis and having made a good job out of it.

PRAMOD V. BHAVE

ABSTRACT

The present work deals with the On-line Computer control of the exit temperature of a steam heated, fintube, double pipe, heat exchanger by manipulating coolent flow rate through the inner tube using a stepper motor controlled valve. For control, an IBM compatible PC/XT equipped with AD/DA and I/O timer card was used. For the control of stepper motor, a stepper motor driver card was developed. Temperature measurment at the inlet and exit of the inner tube and the steam was done by using IC transducer AD590.

The control algorithms used for the present study were basically those of J.Fuhrman, R.Mutharasan and D.Coughanowr with slight modifications. The inputs to the algorithm are inlet temperature of coolant,steam temperature and inlet coolant flowrate. The control parameter was flow rate of coolant. The different parameters in the control algorithm, which need tunning were tunned through simulation. For simulation an emperical model was fitted to the experimental transient response of exit temperature of the heat exchanger. It was observed that the experimental results closely follow the simulation profile, and the desired temperature was acheived in 18 sec, with a rise time of 3 seconds. On the other hand the exit temperature takes around 45 seconds to reach 97% of the desired temperature when no controller is used. From the simulated

results it was clear that the desired temperature can be acheived, even within shorter time interval of four second, provided the time constant of stepper motor control valve which is around 2.5 seconds at present is reduced to a value less than 1 second.

The software developed for the implementation of the control algorithm was developed in advanced version of BASIC (BASICA). The AD/DA conversion routines and the porthandling was also done in BASICA.

CONTENTS

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NOMENCLATURE

b	-	exponent of variation of overall heat transfer coefficient
k	-	integral number of sampling periods in residence time.
$m(\Theta)$	-	deviation from initial velocity, $\bar{v}/v_o$, dimensionless
S_t	-	sampling time in second
t	-	time
$\bar{v}$	-	deviation from steady state velocity, $v - v_o$
v	-	velocity of tube fluid
v_o	-	initial velocity of tube fluid
v_i	-	velocity at ith sampling instant.
Z	-	distance along the heat exchanger
A_c	-	area of cross section of flow in m^2
A_s	-	heat transfer surface of the heat exchanger
C_p	-	heat capacity of tube fluid. KCal/Kg ^oC
L	-	length of heat exchanger Cm
T	-	exit or Outlet temperature ^oC
T_i	-	inlet temperature of tube fluid, ^oC
T_s	-	steam temperature ^oC
U	-	overall heat transfer coefficient KCal/hr m^2 ^oC
U_o	-	overall heat transfer coefficient at reference velocity.
$V\rho$	-	valve position in degrees
V_{min}	-	dimensionless minimum expected velocity.

X - state variable, dimension less temperature, $(T_s-T)/(T_s-T_i)$

β - dimensionless heat transfer parameter $U_oA_s/A_cC_pv_o\rho$

η - dimensionless distance along heat exchanger

θ - time variable, dimensionless parameter, $t \cdot v_o/L$

θ_r - dimensionless residence time of exit element in the exchanger

θ_s - dimensionless sampling period

θ_{VD} - dimensionless valve delay

λ - fraction of sampling period required to yeald the residence time of the exit element in the exchanger, $\theta_r = K\theta_s + \lambda\theta_s$

ρ - density of tube fluid.

CHAPTER 1

SYSTEM DESCRIPTION

This chapter describes the experimental set up for the process to be controlled and the details of the hardware for control, which mainly consists of, IBM compatible PC/XT, equiped with AD/DA card and I/O Timer Card.

Experimental Set up:

The experimental set up is schematically depicted in the fig. 1.1; the photo-graphic view of the apparatus is shown in fig. 1.2. The experimental set up consists of:

1) An overhead tank (15) with a 4 inch overflow line (14) to maintain a constant water head.

2) ~~The Heat~~-Exchanger (1) with stepper motor controlled valve (2) connected at the inlet, coolant (water).

3) A steam generator (7) with cold water inlet (11) and a steam outlet (6) which is connected to the outer shell of the Heat exchanger (1).

4) Three temperature probes: Inlet temperature probe (3), Steam temperature probe (4) and an outlet temperature probe (5).

5) IBM compatible PC/XT (18) manufactured by M/S UNICOMP Ltd., equiped with AD/DA and I/O-timer cards.

The various components of the set up are discussed below:

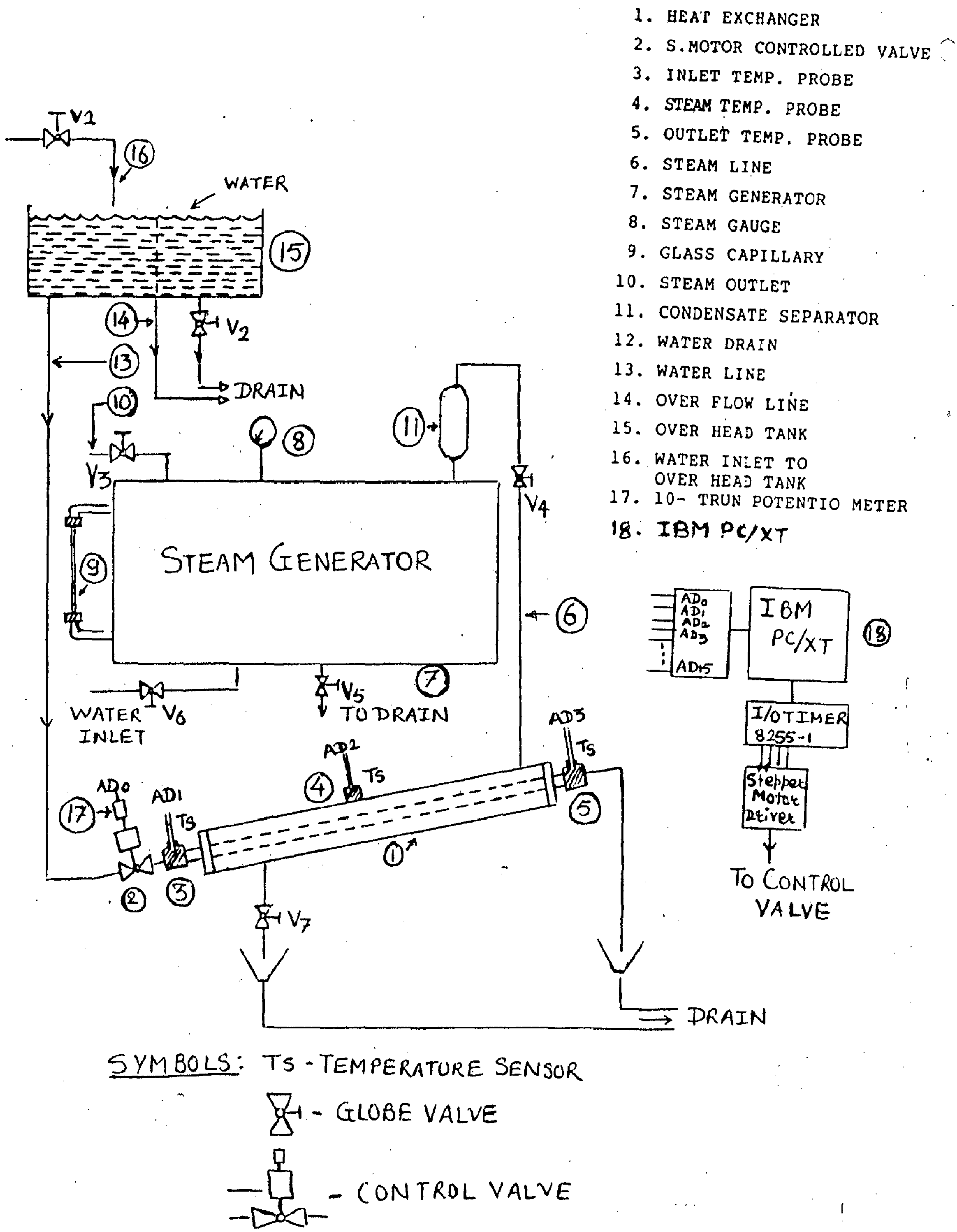


FIG. 1.1 SCHEMATIC DIAGRAM OF EXPERIMENTAL SETUP

Fig. 1.2 EXPERIMENTAL SETUP

(1) Over Head Tank (15)

It is a rectangular mild steel tank. It is provided with a 4 inch over flow line, which keeps the water head constant. Tank is painted with a coat of primer. This eliminates the possibility of the tank getting rusted and thereby eliminates the choaking of water line to Heat Exchanger.

(2) Heat Exchanger

The double pipe heat exchanger was fabricated in a Chemical Engineering Workshop. The dimensional details of the Heat Exchanger are described in the Fig. 1.3. 245 fins were cut along the length of the inner tube to increase the surface area effectively in contact with steam.

By using basic geometrical relations the total surface are at the base of fins can be evaluated as below.

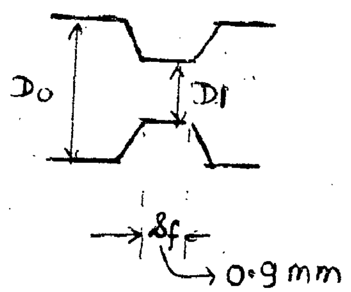
$$A = (N-1) \times s_f \times d_1 \times \pi = 244 \times 0.9 \times 17.38 \times \pi$$
$$= 0.0119 \text{ m}^2$$

Thus the total surface areain contact with steam

$$= 0.01199 \text{ m}^2$$

(3) Steam Generator

It is a cylindrical tank made of M.S. covered with a plaster of paris coating to reduce heat loss. The tank is provided with 4 electric heaters (immersion type) of 4 KW capacity each. The tank is provided with a glass



SINGLE FIN.

Dimensions

FINNED LENGTH = 438 mm
NO. OF FINS = 245
(DI), DIA. AT ROOT OF FIN = 17.38 mm
(Do), DIA AT TOP OF FIN = 19.1 mm

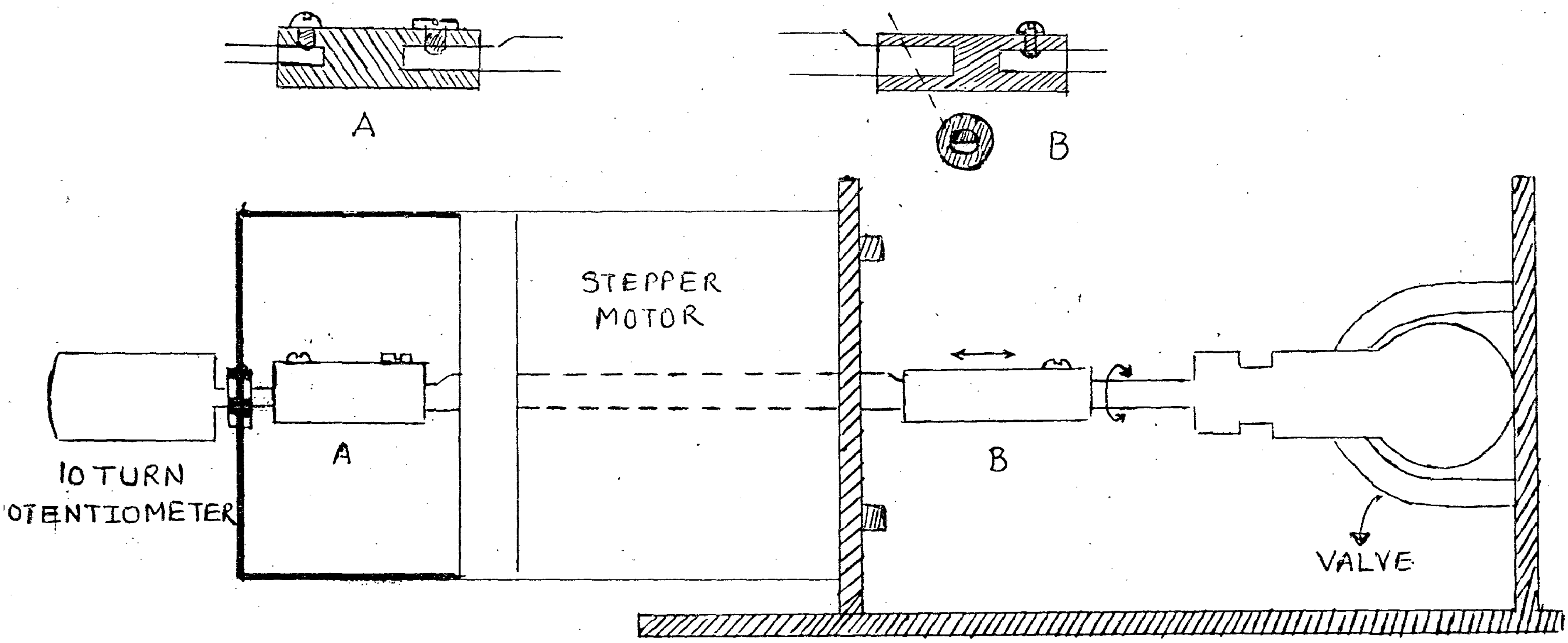
FIG 1.3 : DIMENSIONAL DETAILS OF HEAT EXCHANGER TUBE capillary to check the water level inside it. Tank is provided with cold water inlet as well as drainage valve at the bottom. Steam guage is also provided to note the pressure of steam generated. The main steam outlet is equiped with a manually operatable valve which is used to adjust the steam flow into the Heat Exchanger to a suitable value. Tank is provided with a second steam outlet equipped with a valve which can be operated manually in case of catestrophic conditions e.g. if the steam pressure increases beyond a certain limit.

4) Temperature Probes

For the temperature measurement of fluid at the inlet as well as outlet and for the measurement of steam temperature, three temperature probes are required. All these probes were fabricated in Heat Exchanger Research Lab. of Chemical Engineering Department. A semiconductor element AD590 (A two pin integrated Ckt.) is used for temperature sensing. The specific advantages of using AD590 over commonly used thermocouples is discussed in the Chapter 2, 'Transducers and Signal Conditioning'. The signal conditioning and the calibration of the probe is also discussed in above mentioned chapter.

5) Stepper Motor Controlled Valve

Fig.1.4 describes the details of the Control valve



A - S.MOTOR - 10-TURN POT COUPLING

B - S.MOTOR - VALVE SHAFT COUPLING.

FIG 1.4: SCHEMATIC DIAGRAM OF S.MOTOR COUPLINGS

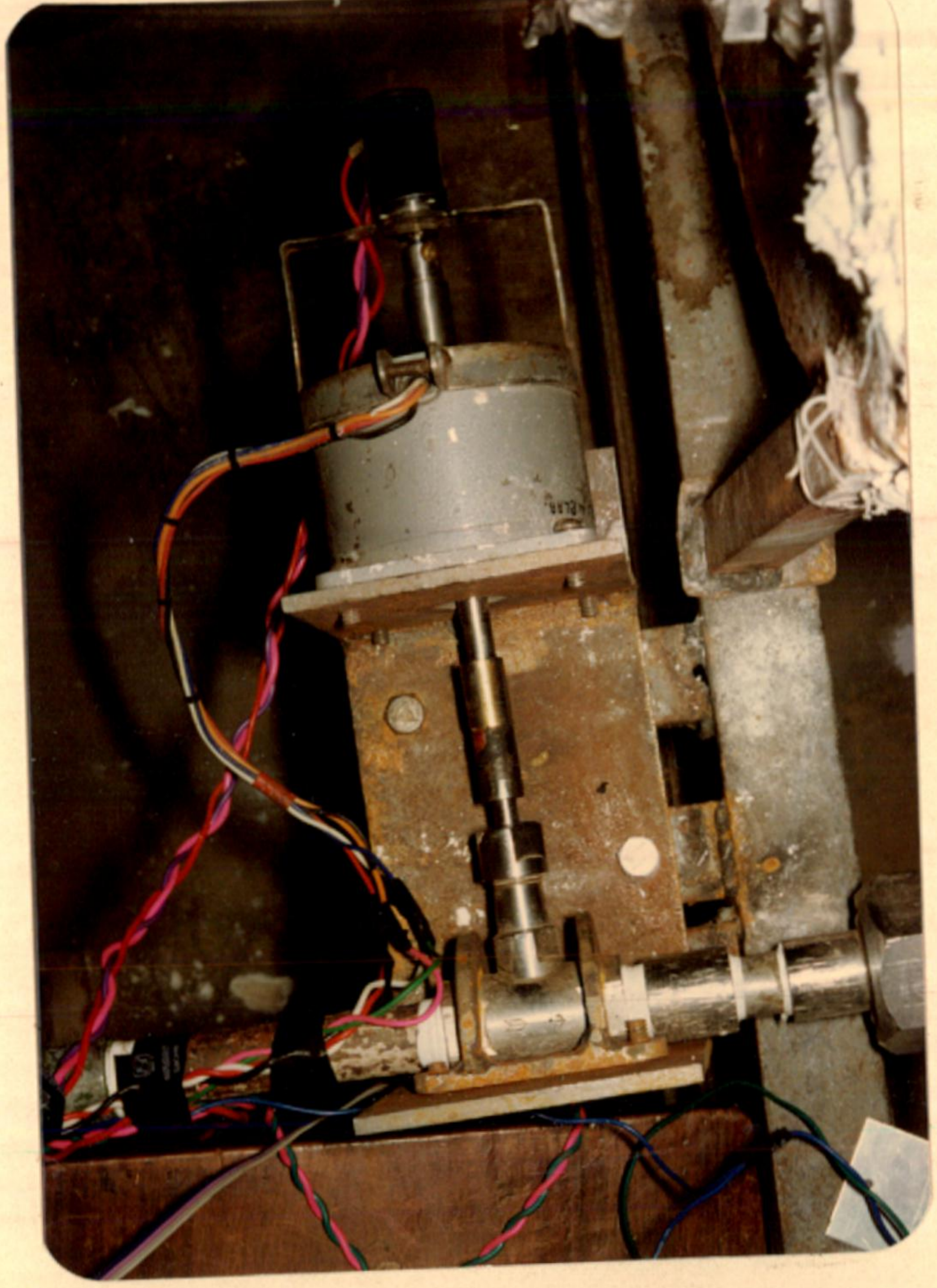


Fig. 1.4.1 STEPPER MOTOR COUPLING

coupling with stepper motor shaft. The valve and motor assembly was fabricated in the Chemical Engineering Workshop.

The control valve is operated with the help of a stepper motor which precisely controls the valve position. The stepper motor is activated by a pulse signal issued to it through 8255 of the I/O Timer Card of IBM Compatible PC/XT. The stepper motor when rotates in clockwise direction the valve opens and when it rotates in counter clockwise direction the valve gets closed. When the valve opens or gets closed the valve shaft undergoes a linear motion. This motion is taken care off by using a coupling which slides to and fro over the stepper motor shaft section of the coupling is shown in the Fig.1.4.

To rotate the stepper motor, the train of signal is sent till motor rotates through the predetermined angle. It is possible that the motor may not rotate always through the predetermined angle because of the coupling friction. To avoide the ambiguity about the valve position, a Ten turn potentiometer is connected to another end of motor shaft. A constant voltage is applied to fixed ends of the potentiometer. The analog voltage obtained at the variable end of the potentiometer is fed through A/D channel to PC. Thus exact valve position is always known.

6) Salient Features of the Special Purpose Cards used in IBM Compactible PC/XT:

Two special purpose cards are used in the project. They are (1) I-O/Timer Card
(2) A-D/D-A Card.

The photographs shown in Fig.1.5 show the basic structure of the cards while the photograph in Fig 1.6 shows how these card are connected to the outside world.

(1) I O/Timer CARD

The I-O/Timer card is a programmable input output interface card for IBM-PC/AT/XT or their compatibilities. The card contains 48 fully programmable I-O lines,3 independently programmable 16 bit counters, each with count rate upto 2 MHz. The hardware address is selectable between 01B0H & 01BFH and also between 01 F0H & 01FFH. The address can be so selected with the help of DIP switches provided on the card itself. The card has got system expansion slot connector, so that it can be inserted in any of the system expansion sockets provided on the mother board of PC. The required chip on the card is automatically selected depending upon the address on the common address bus.

A block diagram in the fig.1.7 shows the various important component used in the card. The card contains two Intel 8255 chips and one Timer Chip 8253. The decoder is used for chip selection. The counters of 8253 can be applied with the external or internal clock, as per the requirement by using appropriate DIP switch configuration. Port address selection

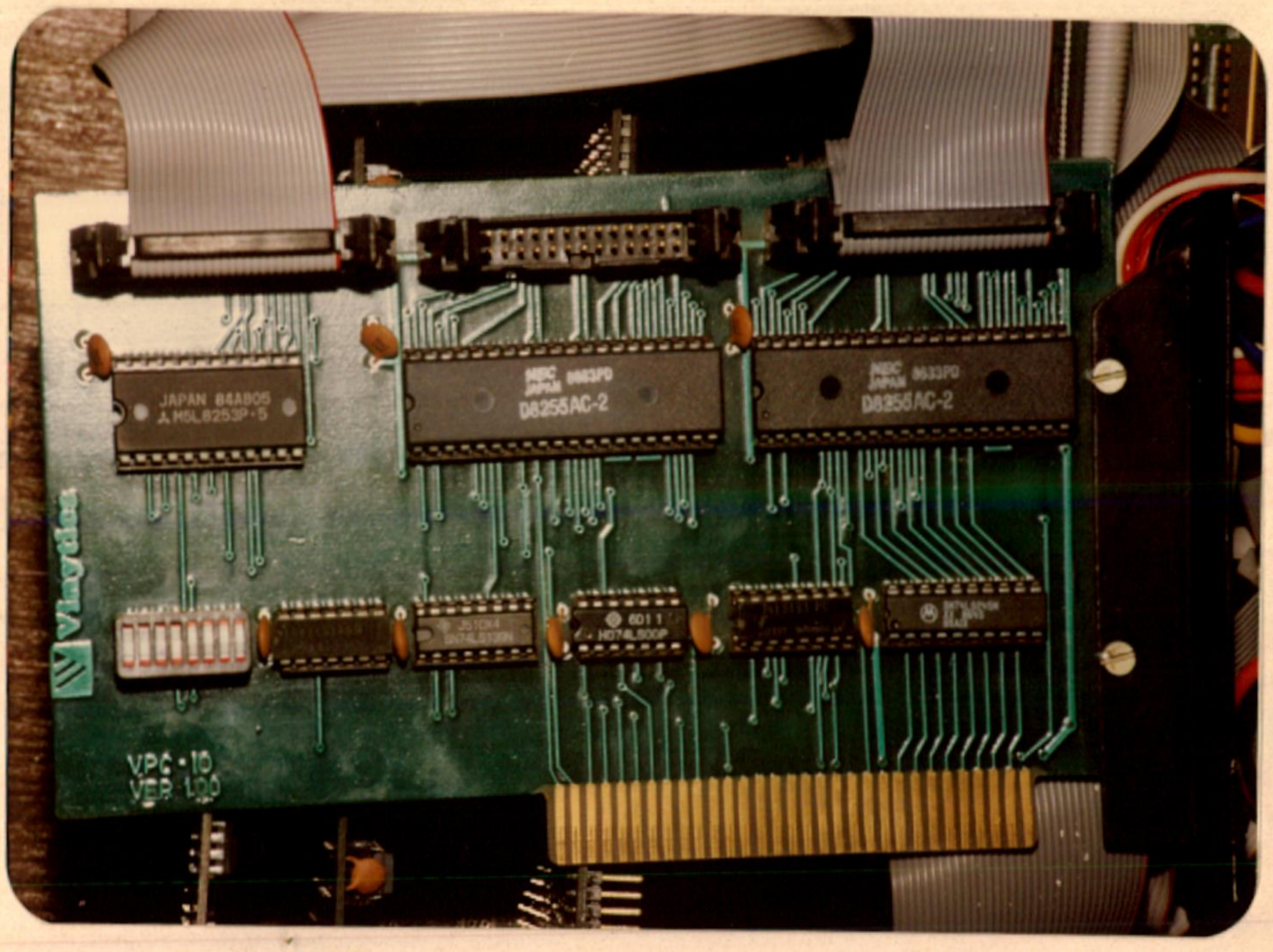


Fig. 1.5.1 I/O TIMER CARD

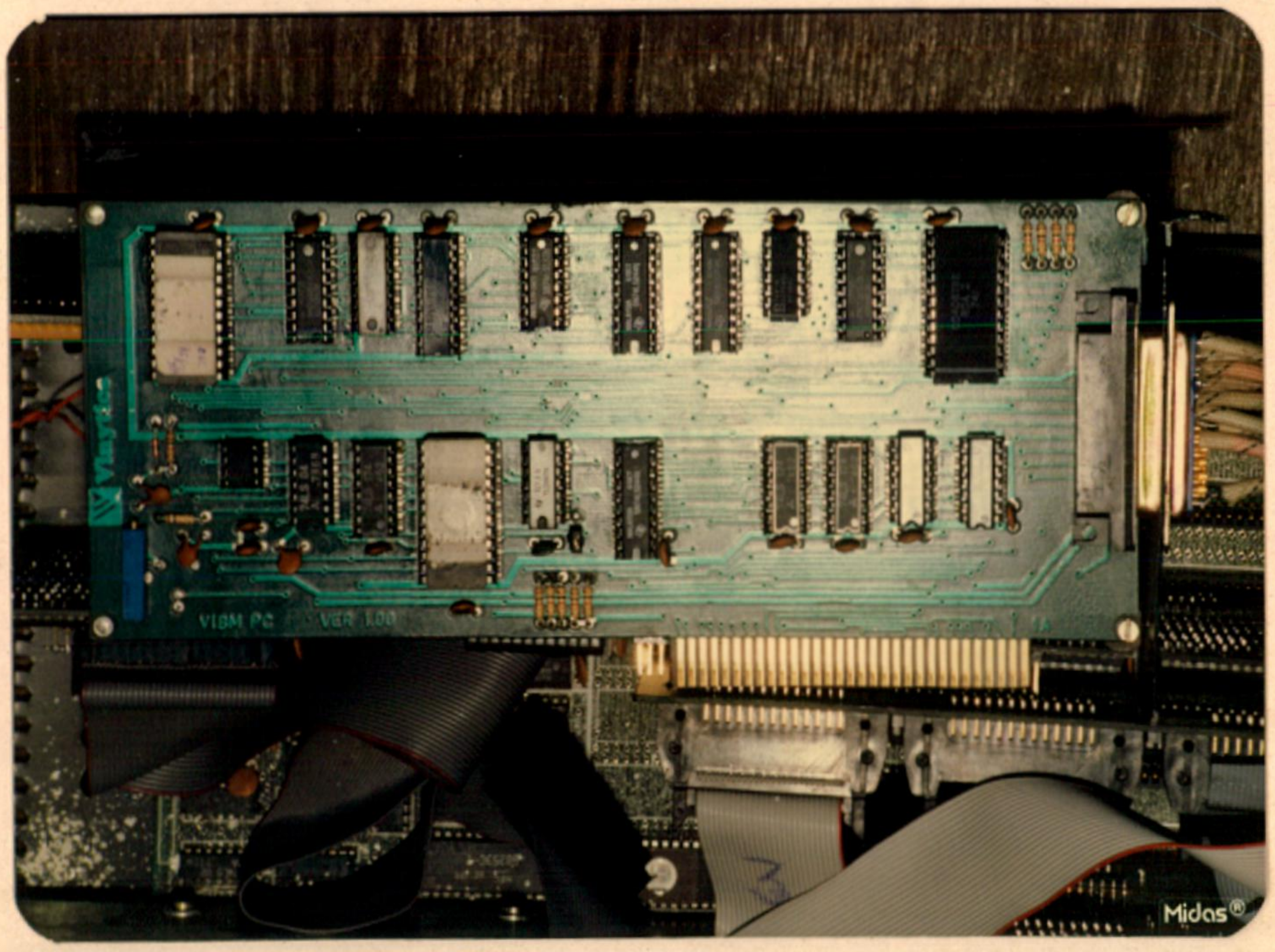


Fig. 1.5.2 AD/DA CARD

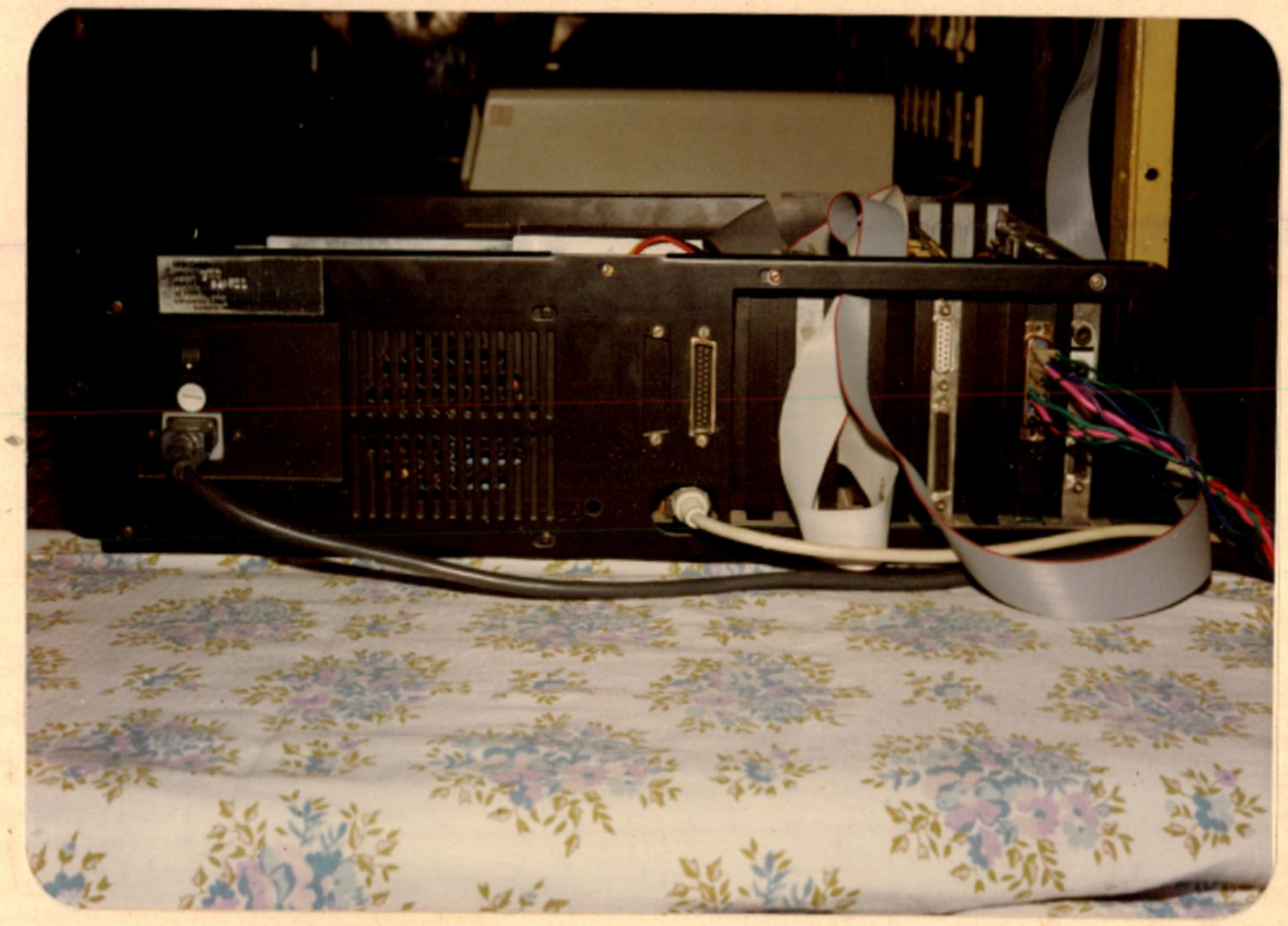


Fig. 1.6 CONNECTIONS OF SPECIAL PURPOSE CARDS TO OUTSIDE WORLD.

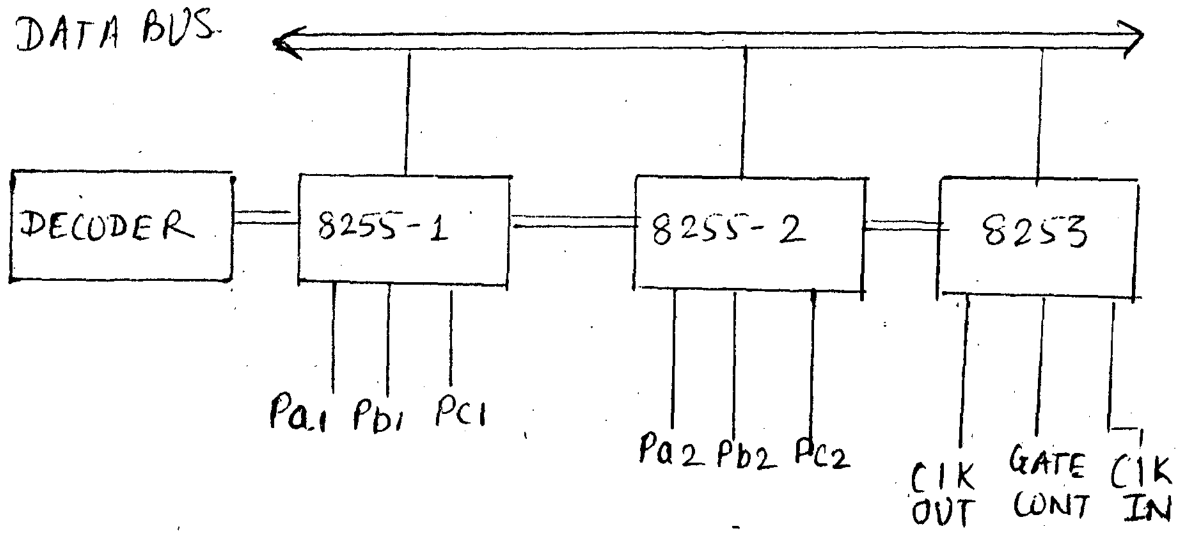


FIG:1.7 BLOCK DIAGRAM OF I/O TIMER CARD

and selection of clock option can be done by employing suitable options from the following.

(1) Port address selection -

i) SW4 = "OFF" and SW5 = "ON" for address 01B0H - 01BFH

ii) SW4 = "ON" and SW5 "OFF" for address 01F0H - 01FFH.

(2) Switch Selection -

For applying internal or external clock to timers of 8253 following switch configuration of DIP switches is used.

i) SW1 = "ON"; counter 'O' to use internal CLK of 1.19 MHz

ii) SW1 = "OFF"; Counter 'O' to use external clock.

iii) SW2 = "ON"; Counter '1' to use internal CLK of 1.19 MHz

iv) SW2 = "OFF"; Counter '1' to use external CLK.

v) SW3 = "ON"; Counter '2' to use internal clock of 2.38 MHz.

vi) SW3 = "OFF", Counter '2' to use external clock.

(3) Port Address -

<u>For 8255-1</u>

Port 1-A = 01F0H

Port 1-B = 01F1H

Port 1-C = 01F2H

Port 1 - CWR = 01F3H

FOR 8255-2

Port 2-A = 01F8H

Port 2-B = 01F9H

Port 2-C = 01FAH

Port 2-CWR= 01FBH

FOR 8253

COUNTER '0' = 01F4H

-do- '1' = 01F5H

-do- '2' = 01F6H

CWR = 01F7H

Input/Output Port Handling in BASICA -

Port operation in BASICA (Basic advanced) is done by two commonds INP'PORT' & OUT"PORT". Where 'PORT' specifies the Port address in hexadecimal equivallent which is to be read or written into.

The programming of PPI 8255 or timer 8253 can be understood by considering two program routins in BASICA.

(1)

```
10 PORT = & HIFO' PORT is the variable initialized.
20 OUT PORT + 0 + 3'& H80' Command word for all
30 OUT PORT + 0 + 8, & H80' ports of both 8255s
40 OUT PORT + 0, & H55'Out 55 to Port A-1
50 END.
```

(2)

```
10 PORT = & HIFO' Port is the variable intialized.
20 OUT PORT + 4 + 3, & H36' Intialize Counter 'O' in mode 3
30 OUT PORT + 4 + 0, 2' set valve 2 to counter 'O'
```

40 END.

In both the examples "PORT" variable is initialized to &H1FO where, &H denotes hexadecimal address in BASICA. While 1FO is the address of Port A-1.

For pin configuration of 26 pin connectors on I/O cards please refer to Appendix A, section A.1

(ii) 12-Bit AD/DA CARD

The 12-bit AD/DA Card is a high precision data conversion system. The card contains single channel of 12 bit Digital to Analog Convertor, (Unipolar or Bipolar, Jumper selectable) and 16 channels of 12-bit Analog to Digital Convertor (Unipolar only).

The card contains DAC 7521 which is a 12 bit high resolution digital to analog convertor A CMOS chip CD4007 used for selecting one out of 16 channels at any time. The channel no. is software selectable. Successive approximation method is used for conversion process. The card gives direct D to A output at the output connector.

Specifications:

D to A conversion - 12 bit, single channel.

- Output voltage range adjustable as 0-9 volt
- Unipolar or bipolar, selectable by J_2
- Nonlinearity 0.2%

A-D conversion - 12bit, 16 channels

- Input voltage range adjustable as 0-9 volt.
- Unipolar only
- successive approximation method
- conversion time 60 μs, each channel.

Power consumption - 2.2W

Weight - 170 gm

Card size - 23 x 10 cm

Port addresses:

The port address is between &H278 - &H27F i.e. between 632_{10}-639_{10}.

Thus if variable PORT is initialized to and H278 the various ports addresses can be given as

PORT + 0	=	Outdata 0-15 to select A/D channel
PORT + 1	=	Read A/D lower 8 bits.
PORT + 2	=	Read A/D higher 8-bits (D_8-D_{11})
PORT + 3	=	Out only, 00 to clear A/D register.
PORT + 4	=	loop back 7 times to select A/D, high 6 bit conversion
PORT + 5	=	loop back 7 times to select A/D, lower 8 bit conversion.
PORT + 6	=	Output D/A lower 8 bit Data.
PORT + 7	=	Output D/A higher 8 bit Data.

Conversion Process

The basic steps in A-D / D-A conversions are given below.

(a) A to D Conversion :

- Output channel no. to Port + 0
- Initialize the A/D register
- Start conversion by reading 7 times data from PORT+4 & PORT+5, individually
- Read data from PORT+1 (lower 8 bits) & PORT+2 (higher 8 bits)

(b) D to A Conversion :

- Output higher 4-bit data to PORT+7
- Output lower 8 bit data to PORT+6.

Basic subroutines for A/D & D/A Conversion

(1) A to D Conversion routine :

```
10 PORT = 632  Initialize variable port.
20 FOR J = 0 to 15
30 GO SUB 90
40 B = INP(PORT+2): C=INP(PORT+1)
50 D = (B-16*(INT(B/16)))*256+C
60 PRINT "Channel no",I,"DATA",D
70 NEXT I
80 GO TO 20
90 OUT PORT+3,0
100 OUT PORT+0,I
110 FOR J=1 TO 7!A=INP(PORT=4):NEXT
120 FOR J=1 to 7:A=INP(PORT+5):NEXT
```

The above routine monitors the 16 channels one by one and displays data monitored. The conversion is initialized in the lines 110 and 120.

(2) Program for D to A conversion :

```
10 PORT = 632
20 OUT PORT+6,0
30 FOR I10 to 15: OUT PORT+7,I= NEXT
40 GO TO 20
```

This routine sends train of pulses of different amplitudes at the analog output in of AD/DA card.

The pin configuration of D type connector of the AD/DA card is given in Appendix A, Section A-2.

CHAPTER - 2

TRANSDUCERS AND SIGNAL CONDITIONING

A transducer is a device which converts the process variable to be monitored into the form in which the monitoring device can read it. In the present dissertation work the monitoring device is IBM compatible PC/XT. The input range of AD channels of AD/DA card used is 0 to 9V DC. So any quantity to be monitored should be first converted into the equivalent voltage in the range of 0 to 9V, before it can be read.

For the present work two types of transducers are necessary, one which converts the temperature into d.c. voltage and the other which converts the valve position into d.c. voltage.

2.1 TEMPERATURE TRANSDUCERS :

Temperature transducers which are usually employed are of thermocouple type. But there are severe disadvantages which have to be tackled if they are used viz.

(1) Nonlinearity : Thermocouple output is nonlinear one. For finding the temperature, one has to refer to standard table for particular transducer type. So for their

use one has to store these standard tables in the P.C. memory or split these tables suitably, so as to get different proportional constants for different ranges. This procedure is very humdrum.

(2) Necessity of perfect cold junction : The most severe disadvantage in case of thermocouples is that their operation requires maintenance of constant temperature junction (reference junction). The potential produced is proportional to the temperature difference between the junction under study, and cold or the reference junction. Thus the accuracy in reading the temperature is hampered if temperature of reference junction itself changes.

(3) Very small voltage gain : The gain of thermocouples is of the order of μV per degree centigrade. Hence it has to be amplified by almost 1000 times to get the compatible output. Hence the error if present also gets amplified.

To avoid all these difficulties and to get the more efficient operation, in the present work, solid state sensors (AD590) have been used.

2.2 IC TRANSDUCER AD590 :

AD590 is an integrated circuit temperature transducer which produces an output current proportional to absolute temperature. The device acts as a high impedance constant current regulator, passing 1 $\mu A/^{o}K$ for supply voltage between +4V and +30V. Schematic diagram and other specifications are given in the Appendix A.

The different advantages of AD590 over normal thermocouples can be described as below.

(1) AD590 gives excellently linear output throughout the wide range of temperature. This can be easily appreciated when one gives glance at the characteristics of the probes used for the project work.

(2) No reference junction as such is required for probes using AD590. AD590 probes are readily available for monitoring just after their calibration. Also there is practically no drift of its characteristics due to aging or temperature surges.

(3) AD590 gives about 10 $mV/^{o}K$ without any amplification at 12 V power supply. By using single stage of analog amplifiers its output can be amplified to about 100 $mV/^{o}K$. Thus by using these probes one can get greater voltage change along same temperature range as compared to thermocouple probes. So the temperature can be read at very very high accuracy.

(4) The ineherent feature of AD590 is very small time constant. So practically temperature is read instantly.

2.3 SIGNAL CONDITIONING OF AD590 TEMPERATURE PROBES :

2.3.1 Purpose of Signal Conditioning :

For a variable to be monitored by a particular device two conditions should be satisfied :

(1) The variable should be available in the form which can be understood by the device.

(2) The monitoring device should not load the transducer output; while reading.

First condition is readily satisfied by AD590, when one connects the suitable resistance in series with it. The temperature dependent voltage is available at the resistance. To satisfy the second condition i.e. to avoid the loading of the probe output by AD channel some sort of buffering is necessary. The required buffering has been provided by using unity gain opamp stage between tranducer output and AD channel. The circuit using AD590 with the signal conditioning stage is as shown in the Fig. 2.1. By this circuit the gain of 10 mV/^{o}K is achievable. Thus at the ambient temperature of 25^{o}C the probe output is approximately 2.98V while at 100^{o}C the output is 3.73 V. This range is very well compatible with AD channel.

2.3.2 Manufacturing of Temperature Probes :

The probes were developed in the Heat Transfer research Lab. of Chemical Engg. Department by the author. For the reliable operation of AD590 probe, one must see that there is no water leakage into the probe which will damage AD590 and secondly AD590 top must be in firm contact with the probe cylinder.

In the present work the copper tube of suitable diameter was cut into pieces of suitable length. One end of each of the pieces was arc welded. Then all the probe tubes were checked for leakage by applying pressure of 2 Kg/cm^2 with the help of air compressor. Leads were carefully soldered to the emitter and collector of AD590. The heat conducting material was then applied to the tip of AD590 and was inserted into the probe cylinder. With AD590 tip in firm contact with cylinder, the open end of probe was sealed by thick layer of Areldyte (water proof adhesive). The cap with two holes (to enable the leads to come out) was then fixed on the probe's mouth. Photograph in Fig. 2.2 shows relative size of AD590 and probe compared with inch scale.

2.3.3 Converting AD590 into a Constant Voltage Source :

As previously stated AD590 is a constant current device, current being proportional to temperature. To achieve compatibility with AD channel one has to convert it into a voltage source.

The circuit for this is as shown in the Fig. 2.1. Trimming resistance of 100 Ohms is used in series with 10K ohms resistance. This is used to adjust the output of the transducer to proper value when probe temperature is at the

Fig.2.2 TEMPERATURE PROBE

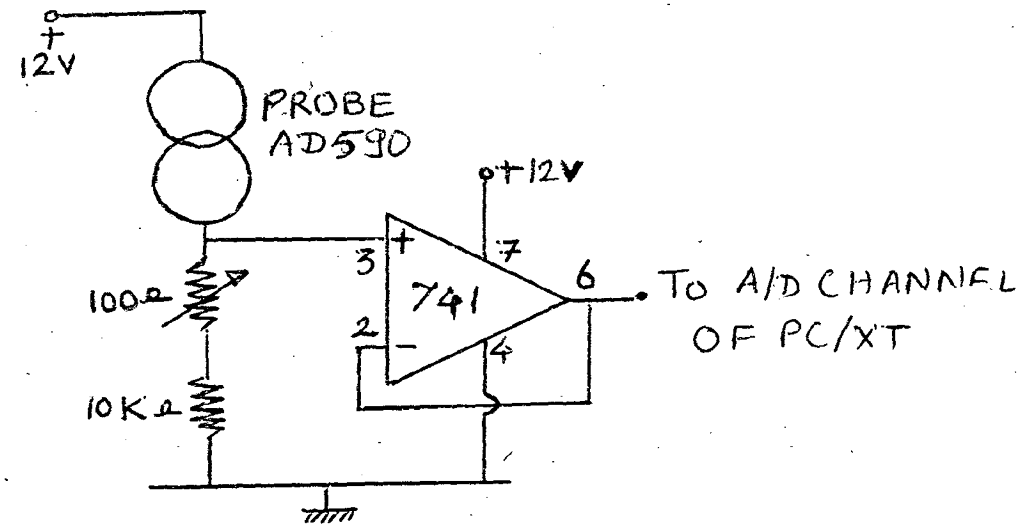


FIG. 2.1. SIGNAL CONDITIIONING OF AD590

average level of the range in which it has to be used. Thus the voltage proportional to temperature is available across the series combination of 10K ohms and 100 ohms resistances.

Now in order to avoid the loading by AD channels the buffer stage has been used as shown in the Fig. 2.1. The buffer stage is nothing but the unity gain noninverting operational amplifier. Op-amp used is IC741. Thus the output of 741 can be directly wired to AD channel of the AD/DA card. Analog to Digital conversion thus makes the digital voltage dependent on the temperature at the probe-tip .
Now this voltage will not have any significance unless the probe has been calibrated. Next section discusses the calibration procedure of the probes.

2.4 CALIBRATION OF TEMPERATURE PROBE :

This is an another important part in development of probes as the inaccuracy in calibration will directly reflect on the efficiency of the on-line control scheme.

Calibration means defining the relation between transducer input and transducer output. The probes were calibrated by using water bath (Mfd.by THERMOSTAT U10)
This bath is equiped with very accurate thermometer (Manufactured by THERMOSTAT U10) with resolution of 0.05°C
It is also equiped with the magnetic thermostat by which temperature can be adjusted to the resolution of 0.2° celcius.

Water in the bath can be continuously stirred to get uniform temperature which can be set with the help of thermostat. This water bath resides in a porcelain vessel which acts as a perfect insulation to heat.

For calibration -

(1) Temperature probe is dipped into a water bath along with the thermometer.

(2) Temperature of the bath is set to an average value of the temp. range for which probe is to be used, e.g., for inlet temperature probe the temperature was set at 20^{o}C, for steam temperature probe, the temperature was set at 99^{o}C and for outlet temperature probe, the temperature was set at 35^{o}C.

(3) The trimming resistance is then adjusted to give the voltage at the probe output to be equal to that for the assumed gain of 10 mV/^{o}K.

(4) Then the temperature is varied above and below the average value for each probe and sufficient number of readings corresponding to different temperature values are noted.

The characteristics of probe output Vs. temperature are then plotted for all the three probes. Fig.2.5, Fig.2.6, and Fig.2.7 show the characteristics of inlet, steam and outlet temperature probes respectively. It is seen that the relation between voltage and temperature is almost linear and slope values for all the three probes is

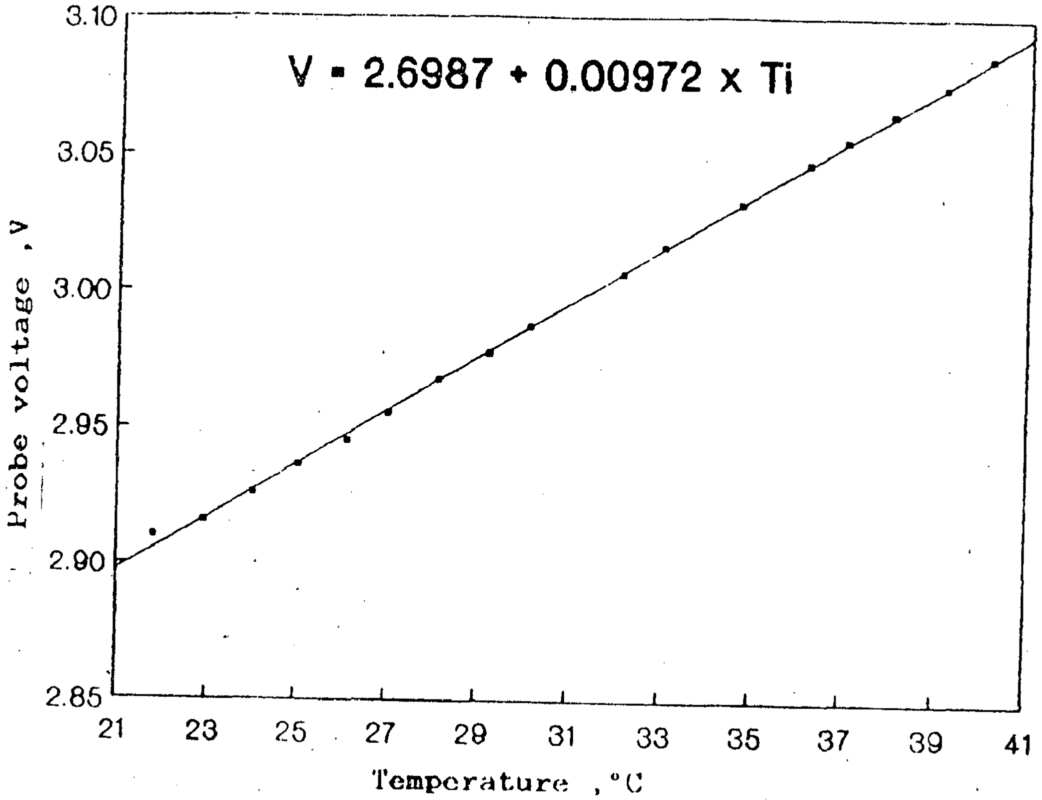


Fig.2.4 Calibration curve for probe (AD590) No. 1 when supply to the probe was +12 V dc

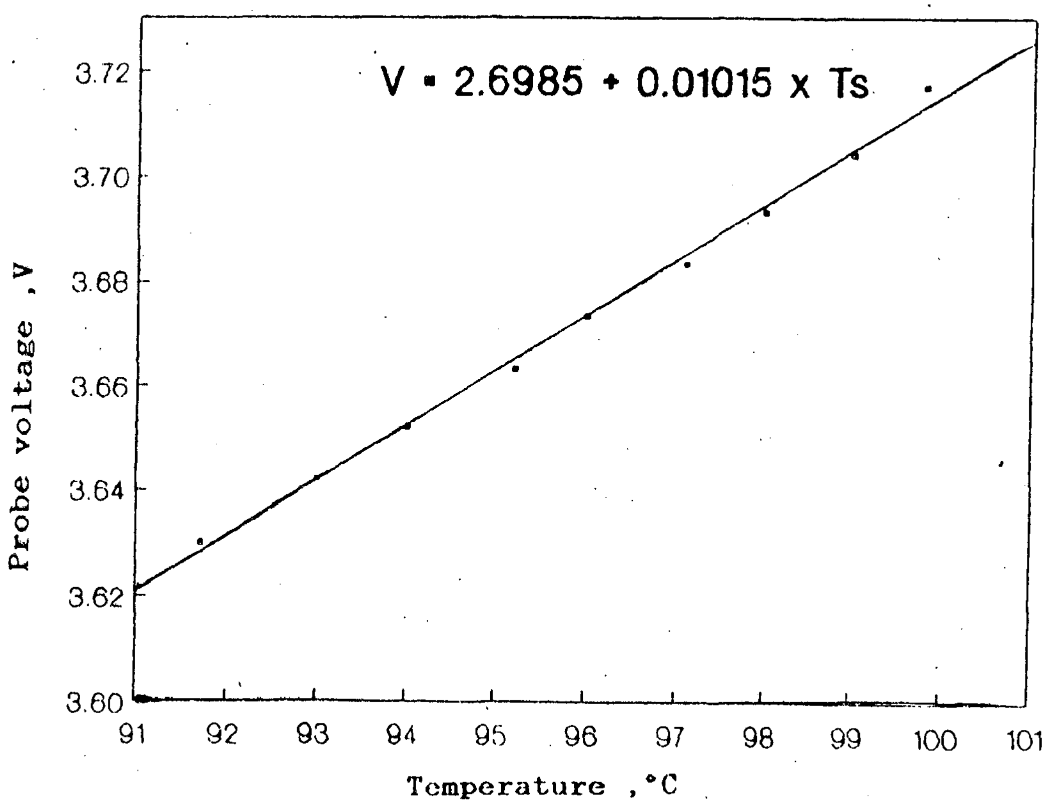


Fig.2.5 Calibration curve for probe (AD590) No. 2 when supply to the probe was at +12 V dc

almost equal to 10 mV/^{o}K as per signal conditioning circuit design. Being linear the characteristics can be fitted in y = mx + C form. The characteristics for inlet temperature probe given by $y = 2.698 + 9.72 \times 10^{-3} x$, those for steam temperature probe is given by y = 2.6958 + 0.0105X x and lastly the characteristic eqn. for outlet temperature probe is given by y = 2.725 + 0.01x.

Thus by directly using this characteristic equation in the software, PC/XT can be made to monitor the Inlet temperature, the steam temperature and an outlet temperature.

2.5 INLET VALVE POSITION TRANSDUCER :

In order to avoid the ambiguity about the valve position this transducer has been used. Simplest form of the rotary transducer is 10 turn potentiometer. (The valve opens through 5 rotations). If one applies the suitable voltage across its fixed ends the variable voltage can be obtained at its output terminal as the potentiometer shaft rotates.

In the present work 2KΩ ± 3% value 10 turn helical potentiometer is used. The voltage of 5 Volts is applied across the fixed terminals of the potentiometer. The varying terminal is connected directly to the input AD channel '0' of the AD/DA card. In this case there is no need for signal conditioning as output signal available is compatible with AD channel.

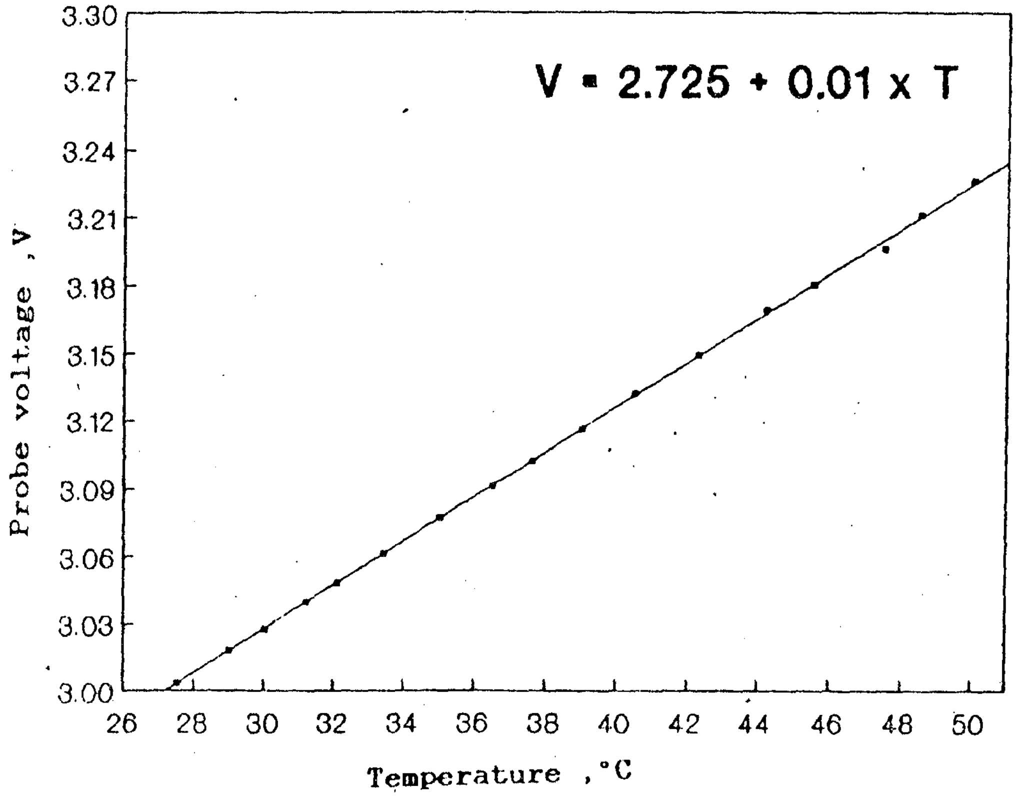


Fig.2.6 Calibration curve for probe (AD590) No. 3 when supply to the probe was at +12 Vdc

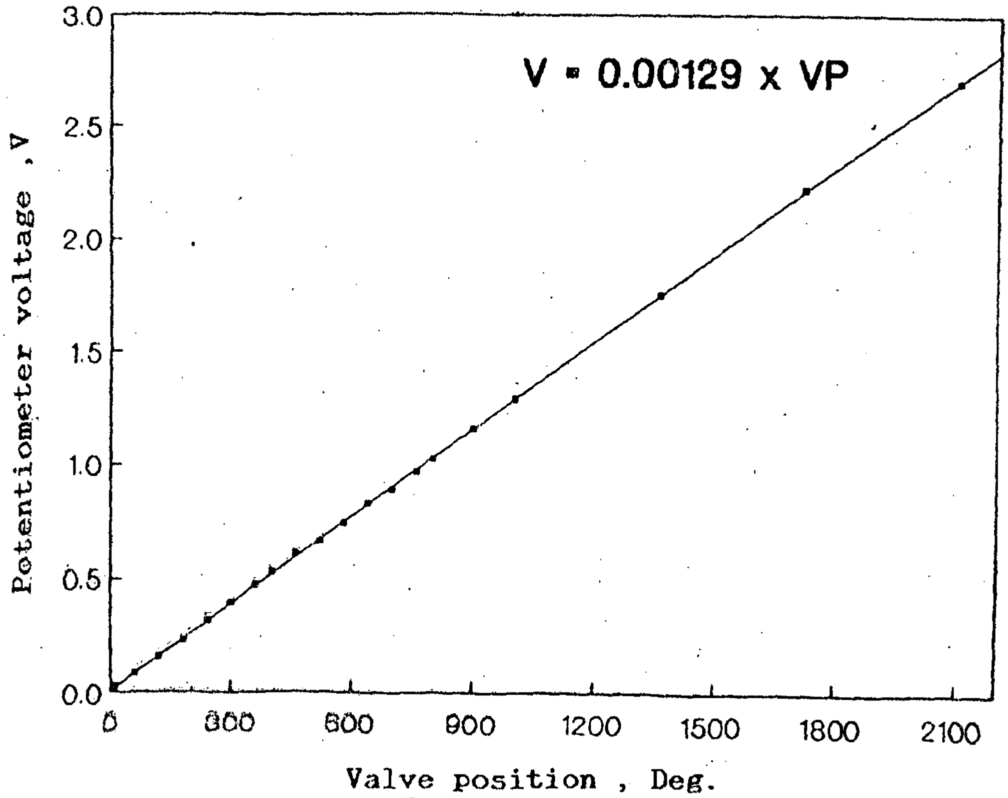


Fig.2.7 Variation of 10-turn helical potentiometer voltage with valve position

The ten turn potentiometer is coupled with stepper motor shaft. While coupling,the care was taken as to assure that the potentiometer rotation is not blocked when valve opens or get closed. The variable voltage available is thus dependent on valve position. The different voltage values for different angle positions of the valve are noted and the characteristics of voltage Vs. angle were then plotted. The plot is as in the Fig. 2.8 . It is seen that the relation is perfectly linear with the slope of 0.00129 Volts/degree. The relation in form of characteristic can Y = 0.00129x is used in the software. Thus PC/XT is able to locate the exact position of the valve at any time.

CHAPTER - 3

DESCRIPTION OF HARDWARE INTERFACE

Hardware developed consists of

1) Stepper Motor Driver Card
2) Triac Controlled Supply
3) Circuit for signal cinditioning of temperature transducers.

Besides these,following cards have been interfaced through expansion slots provided in IBM/PC/XT. The photographs in Fig 3.1 & Fig.3.2 show the close view of these cards. The pin configuration of the important chips used in these cards is given in the Appendix A.

3.1 Stepper Motor Driver Card:

Stepper motor is used to control flow rate of the water passing through inner tube of Heat exchanger.

Stepper motor is one of the most suitable devices to convert digital pulses into a precise increamental rotory motion & can be effectively used to control valve position which in turn defines the flow rate.

The specifications of the stepper motor used are

*Type: permanent magnet, D.C. motor

*Supply voltage: 12 V/phase

*No of phases (P): 4

*Rotor teeth (Nr): 50

*Step angle (θ_s) : 1.8 Deg/step $\theta_s = \left[\frac{360}{N_r x P}\right]$

*Steps/revolution: 200

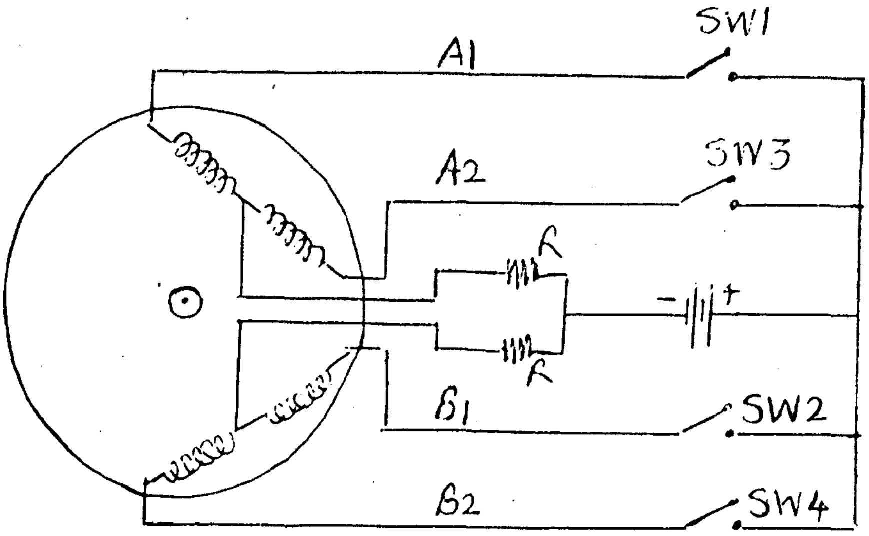
3.1.1 Working of Stepper Motor

Fig 3.3 shows schematic of stepper motor. In the Ckt. if the Coils are energized with Sw1 & Sw2 'on', then changing to Sw1 and Sw4 'On' causes the motor shaft to rotate through 1.8^o, clockwise. A change to Sw3 and Sw4 on causes motor to rotate by another 1.8^o in clockwise. A change to switches 2 and 3 'on' gives another 1.8^o turn and switching back to switches 1 and 2 'on' gives 1.8^o rotation in clockwise. This sequence can be repeated to produce as many steps as desired in clockwise direction. If motor is to be rotated in counter clockwise direction the sequence is simply reversed. If all the switches are turned off the motor shaft is held in its last position by permanent magnet in the motor.

There are three different modes in which permanent magnet stepper motor can be operated. They are

1) Single Phase Mode - In this mode, only one phase of the motor windings is excited at a time. There are 4 steps in excitation sequence.

2) Two Phase Mode - In this mode, two windings are excited at a time. There are 4 steps in excitation sequence.



SCHEMATIC OF STEPPER MOTOR

FIG. 3.3

SWITCHING SEQUENCE							
4 STEP				8 STEP			
B1	B2	A1	A2	B1	B2	A1	A2
1	0	1	0	1	0	1	0
0	1	1	0	0	0	1	0
0	1	0	1	0	1	1	0
1	0	0	1	0	1	0	0
				0	1	0	1
				0	0	0	1
				1	0	0	1
				1	0	0	0

CC-WISE ↑

C-WISE ↓

SWITCHING SEQUENCE

FIG: 3.4

2) Two Phase Mode -

In this mode, two windings are excited at a time. There are 4 steps in excitation sequence.

In both these modes step angle is same but in second case rotor position is 45^o away from that in the first case.

3) Hybrid Mode -

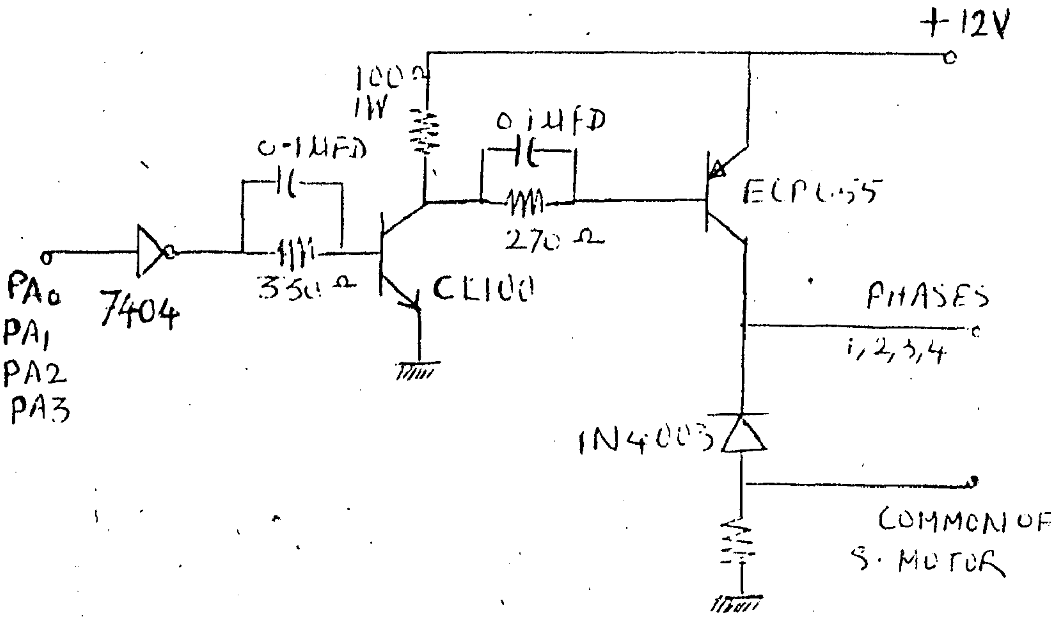
In this mode alternately one and two phases are excited. The step angle in this case is halved as compared to step angle in case1& Case 2. There is 8 step excitation sequence in this case.

The switching sequence for 4 and 8 steps input sequence is given in the Fig 3.4. The upward direction is used for counter clockwise rotation as seen from valve coupling end. The downward sequence is used for reverse rotation. For stepper motor rotation 4 step sequence in two phase mode is employed here.

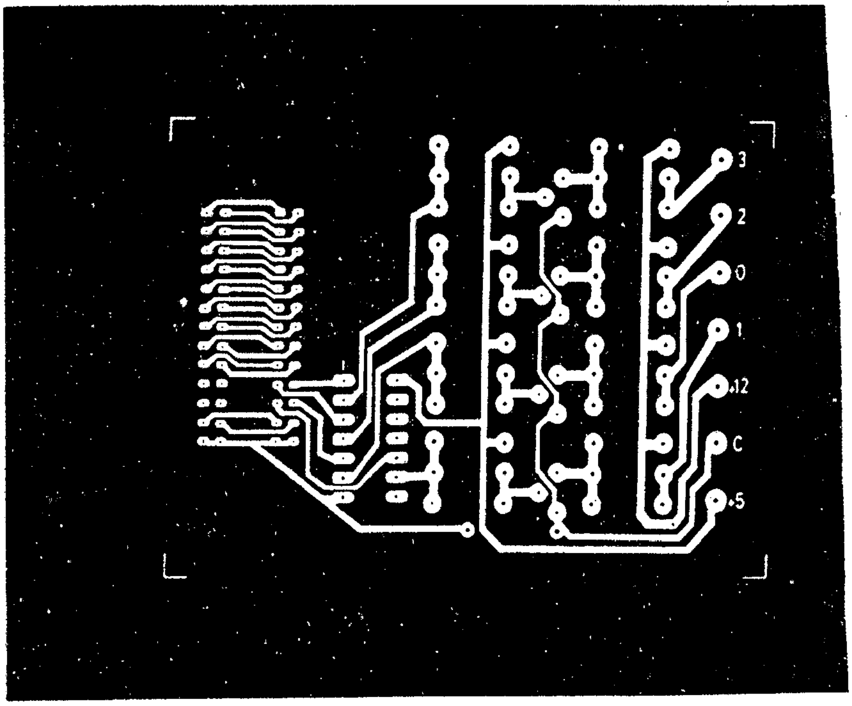
3.1.2 Stepper Motor Driver Card Circuit -

The circuit developed for stepper motor driver card is as in the Fig 3.5.

The step sequence required for stepper motor rotation is obtained from port-A (PA_0 - PA_3) of 8255-1 of I-O/TIMER Card of the PC/XT. In order that the driving card does not load 8255 PPI, IC 7404, which is a HEX 'NOT' gate, is used.



STEPPER MOTOR DRIVER CARD CKt.
(SINGLE PHASE) FIG. 3.5



-VE OF S·MOTOR DRIVER CARD

FIG· 3·6.

To provide necessary current to stepper motor windings PNP transistor ECPO55 is used. These power transistors are activated by transistors CL100.

The circuit functioning is explained below. When PA_o is logic 'zero' input to the base of CL100 is high which turns it on. Ine resistance values are so adjusted that CL100 goes into saturation. Thus its collector voltage drops to low value. This causes ECP055 to conduct. The collector gets diverted through the corresponding winding of stepper motor, because of reversed biased diode present in collector circuit of ECP055. The diode is used to provide free wheeling action (i.e. it provides the inductive current of stepper motor windings to flow when ECP055 has just turned off).

Reverse action occurs when PA_o is at logic 'one'. The Ckt shown is for single phase. Same Ckt is used for each phase of stepper motor. Four 8255 pins are used for stepper motor operation they are PA_o, PA_1, PA_2, & PA_3. Thus by controlling the status of these four pins by software necessary sequence can be produced to rotate the stepper motor in clockwise as well as anticlock wise direction. The voltage supply of +5V & +12V D.C. is also developed as an integral part of the module. The module thus developed is as in the photograph, in Fig.3.5. The -ve of printed circuit board developed is in Fig 3.6.

3.2 TRIAC COUNTROLLED SUPPLY

The circuit developed for triac controlled supply is as in the Fig 3.7. The circuit can be devided into three section.

1) Zero crosing detector
2) Integrator
3) Oscillator

1) Zero Crossing Detector -

In this section of the circuit, Op-amp is used in the comparator configuration. The input AC of 9v is fed to input P. The zener diode limits the input to the Op-amps to 3.3 V. When input to noninverting terminal goes above zero the voltage at point A shoots to logic 'high' while if the input P goes below zero, output A of the Op-amp drops to logic 'zero'.

The output A is fed to the combination of resistance and capacitances which act as differentiators. The pulse output is obtained at the points B1 & B2 at each zero crossing point of input wave. Pulses at B_1 & B_2 are logically nanded by using CMOS Nand gate CD4011, so that at each zero crossing instant +ve going spikes are obtained at output B as in the fig.3.8 . The signal at B is fed to an Integrator.

2) Integrator: Integrator uses single op-amp stage as in the circuit diagram. At each zero crossing instant B6147 conducts, hence momentarily voltage at point C drops to zero. The capacitor action of C_3 produces saw tooth

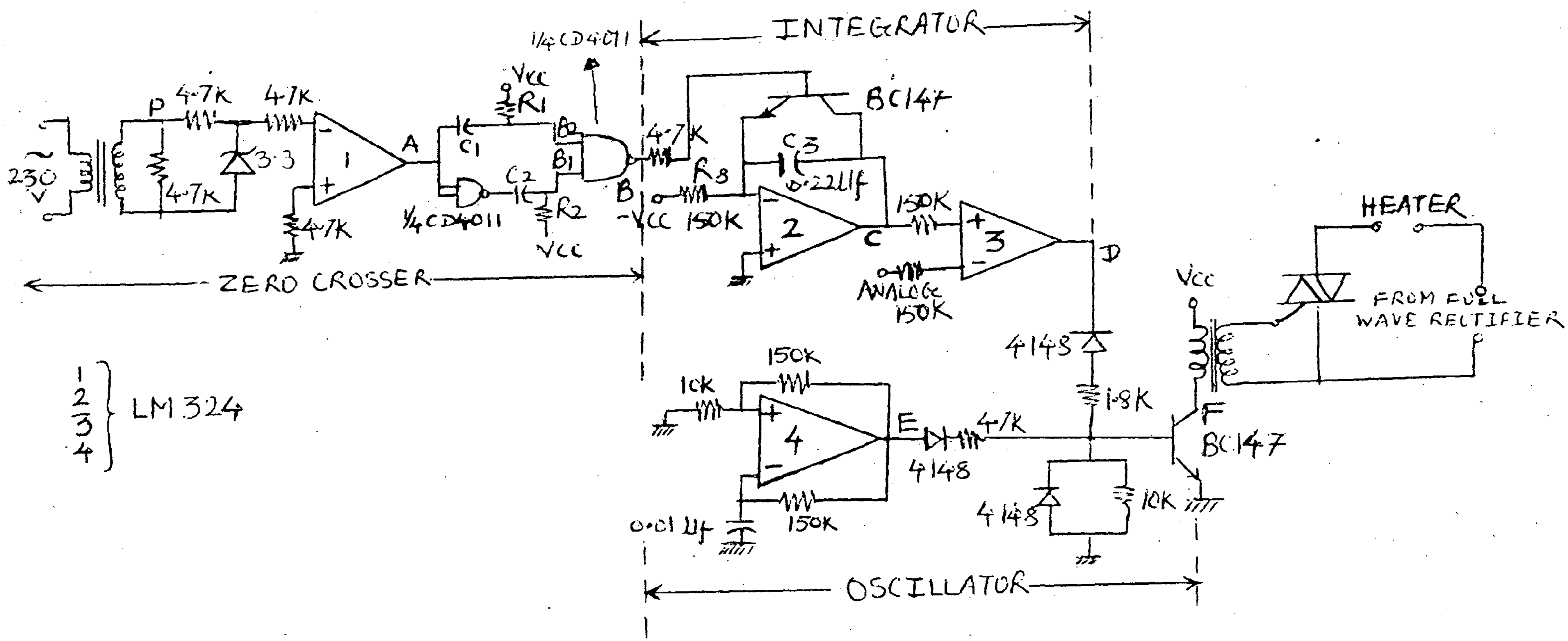
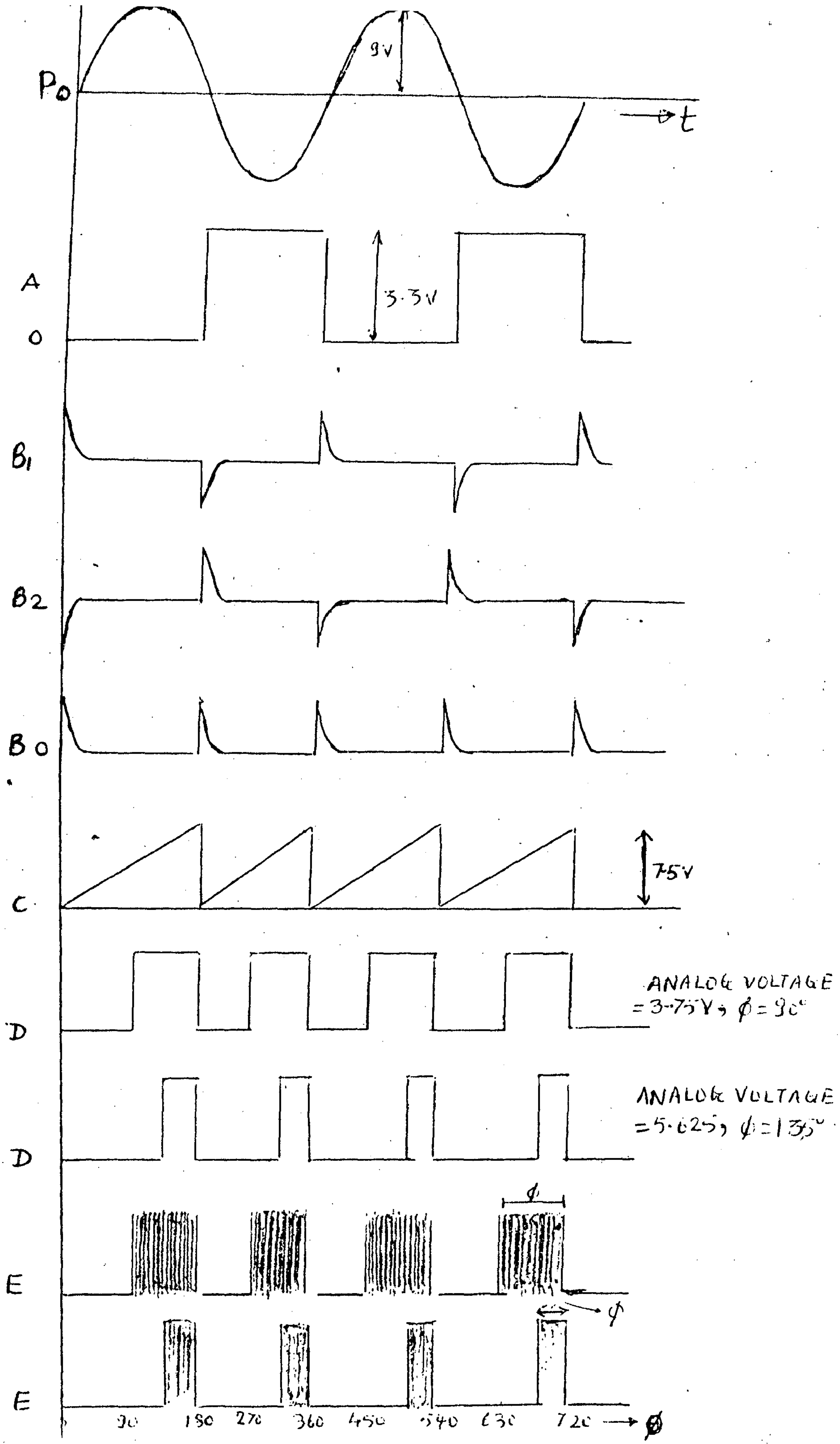


FIG. 3·7 TRIAC CONTROLLED POWER SUPPLY



Po
9V
t
A
O
3.3V
B1
B2
BO
C
7.5V
D
ANALOG VOLTAGE
=3.75V, ϕ=90°
D
ANALOG VOLTAGE
=5.625, ϕ=135°
E
ϕ
E
90
180
270
360
450
540
630
720
ϕ

FIG: 3.8

signal at point C, which is also seen from fig3.8 . This signal is fed to the comparator stage. The analog signal from D to A channel of AD/DA card of PC/XT is applied to the inverting terminal of comparator. The train of pulses are obtained at the comparator output, the pulse width being inversly proportional to the analog signal applied. This signal is then fed to the oscillator section.

3) <u>Oscillator</u>: Oscillator consists of Op-amp stage and with resistance and capacitance combination connected at its inverting terminal. This combination is so adjusted that the pulse signal period at oscillator output is sufficient to turn on the trial.

It is seen from circuit that as long as the signal at D is high, oscillator signal directly get passed to the base of BC 147. Thus if analog voltage is higher, the oscillator pulses will get transferred to base of BC147 for shorter period, starting from 180° backwards, and vice versa. The fig.3.8 shows the wave form for two different values of Analog voltage.

At analog voltage 3.75V the Triac gets fired at 90° in each half cycle or firing angle is 90° while at analog voltage of 5.62 the triac gets fired at 135° in each half cycle. Thus firing angle becomes 135°. As the analog voltage is increased from 0 to 7.5° the firing angle increases from 0 to 180°.

The DA card has the resolution of 0.22V thus the firing angle resolution is equal to

$$\frac{0.22 \times 180}{7.5} \simeq 5.3 \text{ DEG}$$

The equation for average voltage supplied to the load at firing angle ϕ can be obtained as below

Consider the Fig. 3.9 given below

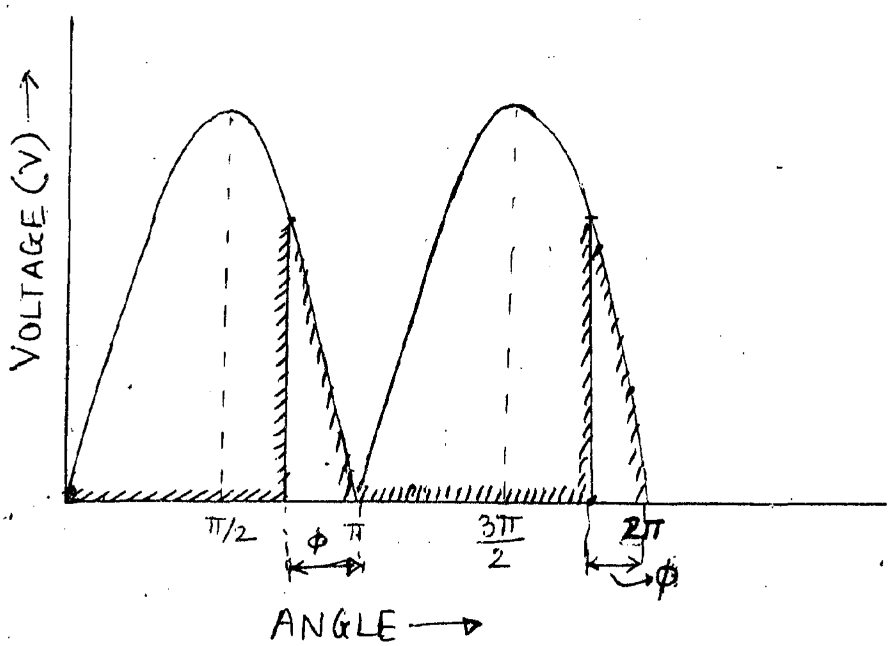


FIG: 3.9

∴ The average voltage at angle ϕ is

$$E_{av} = \frac{1}{\pi} \int_{\phi}^{\pi} V_m \sin\theta \, d\theta$$

$$= \frac{V_m}{\pi} \Big[-\cos\theta \Big]_{\phi}^{\pi}$$

$$= \frac{V_m}{\pi} \Big[\cos\phi - (-1) \Big]$$

$$E_{av} = \frac{V_m}{\pi} (1 + \cos\phi) \qquad .. (I)$$

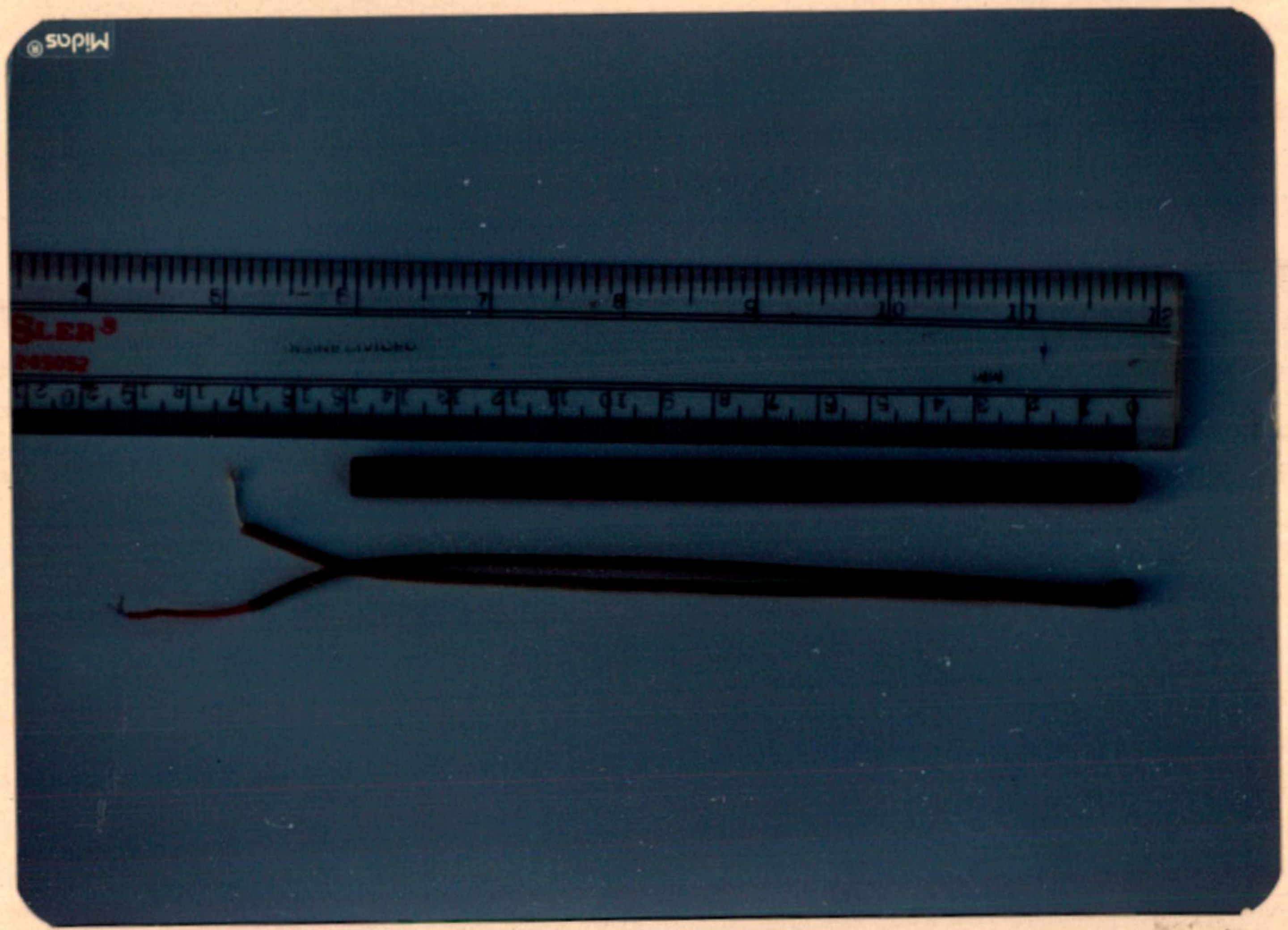


Fig.2.2 TEMPERATURE PROBE

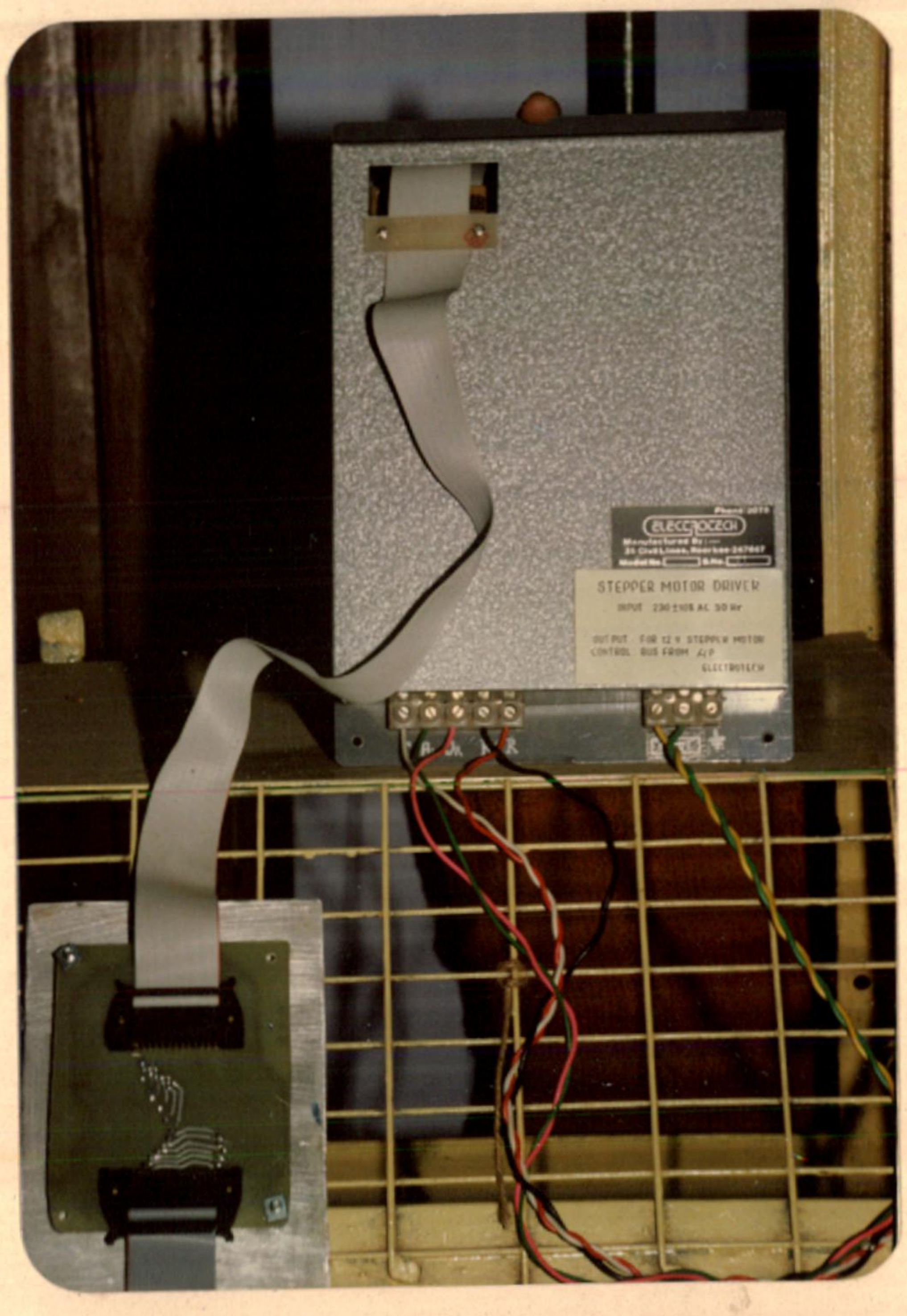


Fig.3.5.1 S.MOTOR DRIVER CARD

Fig.3.10 TRIAC CONTROLLED SUPPLY

Now firing angle of 1 radian is equivallent to $\frac{7.5}{\pi}$ V of analog signal.

Firing angle (1 rad) = 2.387 V

or Firing angle = 2.387 x V_A

∴ Where V_A is analog voltage applied.

Average voltage across the load (heater) in terms of analog voltage can be expressed as

$$E_{av} = \frac{V_m}{\pi} \left(1 + \cos (2.387 \times V_A) \right) \quad .. \text{(II)}$$

This equation can be used in software to control load voltage.

(3) <u>Signal Conditioning Circuit for Transducer</u>:

This has been already discussed in signal conditioning section of Chapter 2.

CHAPTER - 4

DESIGNING OF CONTROL ALGORITHM FOR ON LINE CONTROL OF HEAT EXCHANGER

4.1 DESIGNING OF CONTROL ALGORITHM

4.1.1 General Computer Controlled System :

One of the main features of computer process control, is that the computer is shared by all the control loops. Fig. 4.1 gives the block diagram of a general computer controlled system. Personal computer is provided with a software developed by using an appropriate algorithm. The algorithm compares an output variable with a set point value. If the discrepancy exists, the controlled variable is computed. The variable so computed is sent to the final control element. Again the new output value is read after a predetermined sampling time. This procedure continues till the required set point has been achieved. The basic feature of the algorithm is that the algorithm stores the loop's parameter and its past history (i.e. past manipulated variable values, past error value etc.).

Since the controller is a personal computer, the processes output is measured (and hence available) only at sampling instants which are separated by a sampling period θ_s.

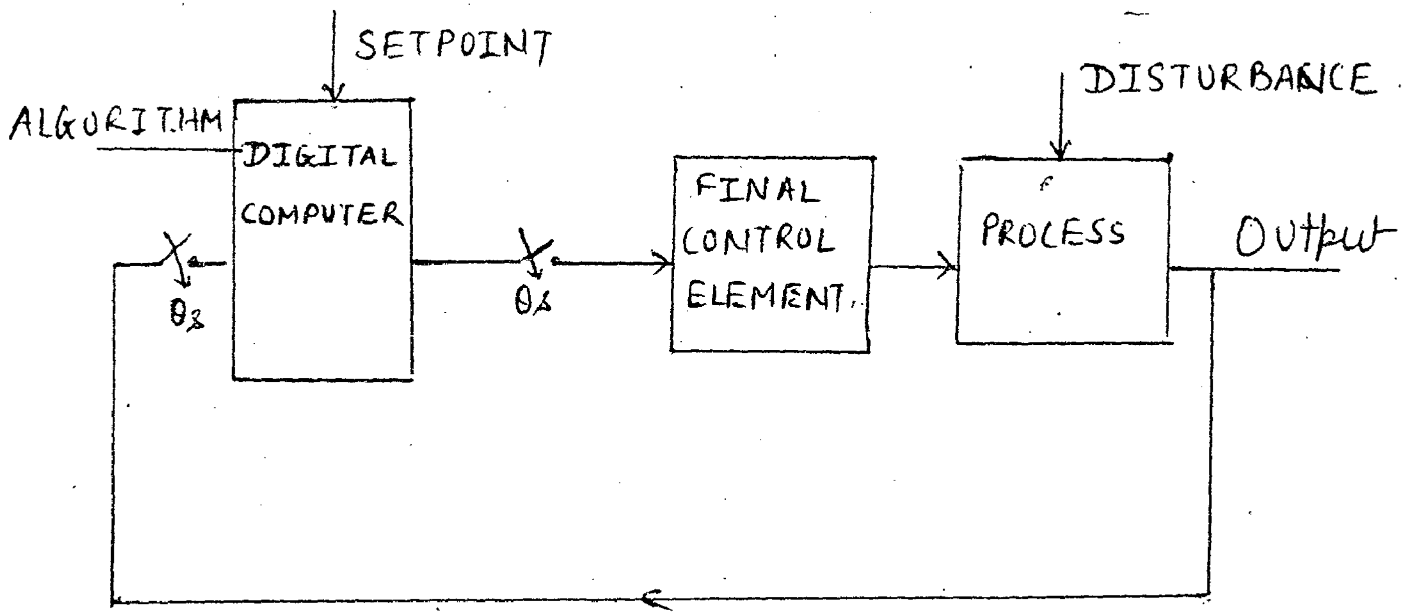


FIG 4.1 BLOCK DIAGRAM OF GENERAL COMPUTER CONTROLLED SYSTEM

4.1.2 Process Model and Control Algorithm :

The dynamic behaviour of a shell and tube exchanger (steam condensing on the shell side) is described by

$$\frac{\partial X}{\partial \theta} + (1+m(\theta))\frac{\partial X}{\partial \eta} = -\beta(1+m(\theta))^{b} X \quad \text{-----} \quad (I)$$

where X denotes dimensionless temperature and the parameter is given by $\frac{U_o A_s}{A_c C_p V_o \rho}$

here U_o overall heat transfer coefficient at

A_s surface area of tube in contact with steam

A_c area of cross section of tube

V_o velocity (initial) of fluid

ρ density of fluid through tube.

For the development of the hyperbolic partial differential eqn (I) refer to Appendix B.

In a direct digital control structure, the velocity is manipulated by the computer to the desired value, at each sampling instant, based on the outlet temperature. It is assumed that the velocity remains constant between the sampling instances and is given by $V_i = 1 + m_i$. Here m_i is dimensionless deviation in the velocity computed between ith & $(i+1)^{th}$ sampling instances.

Fig. 4.2 shows the motion of a particle of fluid in a position-time diagram. The characteristics consist of line segments of constant slope and the particular characteristic path shown in figure is for fluid element which leaves the exchanger at the ith sampling instant.

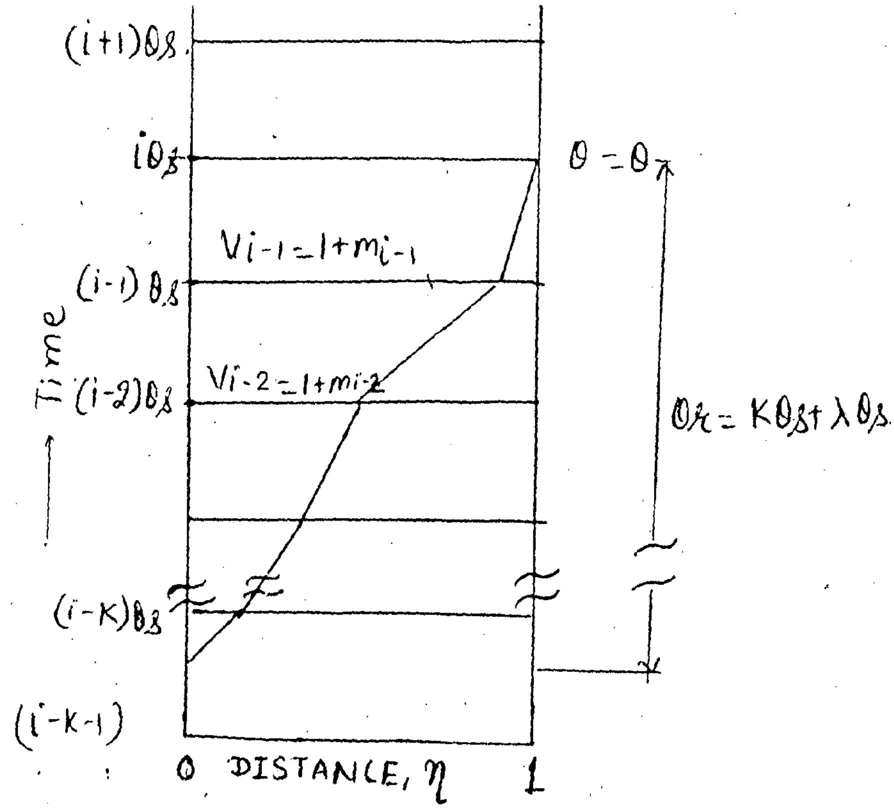


FIG. 4.2. CHARACTERISTIC PATH OF FLUID ELEMENT (NEGLECTING VALVE DELAY)

The slope of the time segment between consecutive sampling instants is inversely proportional to the velocity computed at the beginning of the sampling interval. The residence time is the time spent by the fluid in the heat exchanger and is denoted by θ_r. In terms of dimensionless variables the residence time for the fluid element leaving the exchanger at time $i\theta_s$ may be calculated from the following equation in which the integration of velocity with respect to time, must be equal to the length of Heat exchanger (Unity for dimensionless variables)

$$\int_{i\theta_s-\theta_r}^{i\theta_s} (1+m(\theta))d\theta = 1 \qquad .. (1)$$

Since the residence time is equivalent to an integral number (K) of sample periods plus a fraction (λ) of a sample period i.e. $\theta_r = K\theta_s + \theta_s$; hence the integral equation (1) can be written in descrete form as

$$\sum_{j=1}^{k} (1 + m_{i-j})\theta_s + (1 + m_{i-k-1})\lambda\theta_s = 1 \qquad .. (2)$$

where the index K is such that

$$\sum_{j=1}^{k+1} (1 + m_{i-j}) \theta_s > 1 \qquad .. (3)$$

$$\sum_{j=1}^{k} (1 + m_{i-j})\theta_s \leqslant 1 \qquad .. (4)$$

Equation (2) can be rearranged to obtain λ as

$$\lambda = [1- \sum_{j=1}^{k} (1+m_{i-j})\theta_s]/[(1+m_{i-k-1})\theta_s]$$

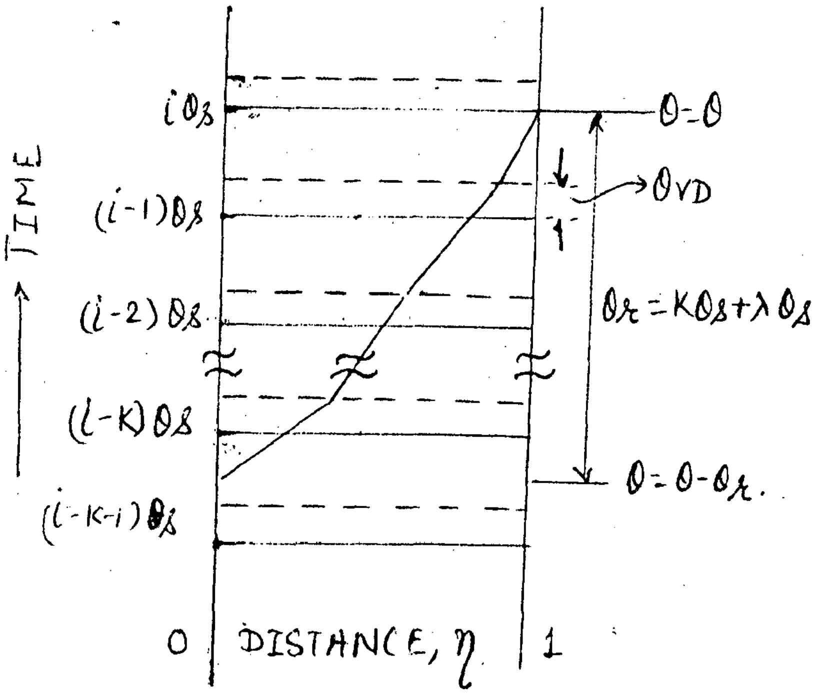


FIG. 4.3. CHARACTERISTIC PATH OF FLUID ELMENT WHEN VALVE DELAY IS PRESENT

The manipulated dimensionless velocity needed to cause the outlet temperature to reach the set point in one residence time as given by

$$m_i = \left\{ \frac{1}{\beta} \left[\frac{X_2(i\theta_s)\exp(B\sigma)}{X_s} \right] \right\}^{1/(b-1)} - 1 \quad .. (5)$$

where $\sigma = \sum_{j=1}^{k} (1+m_{i-j})^b \theta_s + (1 + m_{i-k-1})^b \ \theta \quad .. (6)$

X_2 = state variable at exist, dimensionless outlet parameter

X_s = outlet temperature set point dimensionless.

In the algorithm discussed above dynamics for the valve and the sensor have been neglected. However in the experimental system it may be possible that valve and measurement dynamics become a significant fraction of a time constant of the process. Such dynamics can be incorporated to modify the algorithm developed previously.

Consider the Fig 4.3 which shows the characteristics path of a fluid element when valve delay is present. A pure delay in the control valve affects the characteristic by shifting the path line upward by θ_{VD} time units. Hence the equation (2) gets modified as below.

$$(1 + m_{i-1})(\theta_s - \theta_{vD}) + (1+m_{i-k-1})\ \theta_s + \sum_{j=2}^{k} (1+m_{i-j})\theta_s = 1 \quad .. (7)$$

The index K can be computed such that

$$(1+m_{i-1})(\theta_s - \theta_{vD}) + \sum_{j=2}^{k+1} (1 + m_{i-j})\ \theta_s > 1 \quad .. (8)$$

$$(1+m_{i-1})(\theta_s-\theta_{vD})+\sum_{j=2}^{k}(1+m_{i-j})\theta_s \leqslant 1 \qquad ..\ (9)$$

and the parameter λ is obtained as

$$= \left[1-(1+m_{i-1})(\theta_s-\theta_{vD}) - \sum_{j=2}^{k}(1+m_{i-j})\theta_s\right]/\left[(1+m_{i-k-1})\theta_s\right] \qquad ..\ (10)$$

The manipulated dimensionless velocity needed to cause the outlet temperature to reach the set point in one residence time is still given by eq.(5). The σ in present algorithm is given by

$$\sigma = (\theta_s-\theta_{vD})(1 + m_{i-1})^b + \sum_{j=2}^{k}(1+m_{i-j})^b\theta_s+(1+m_{i-k-1})^b\,\theta_s \qquad ..\ (11)$$

Thus equation (7) enables the calculation of the residence time of the fluid element leaving at $i\theta_s$ when the dynamics of the control value are significant compared to the exchanger dynamics.

The more accurate model of the control value is represented by a straight line approximation of the flow velocity from the past velocity to the new desired velocity in the period, θ_{vD}. The characteristic will be curved in the interval $i\theta_s \leqslant \theta < i\theta_s + \theta_{vD}$. The average velocity is used in the calculation of the length of the exchanger travelled during the time period, θ_{vD}. For $\theta_{vD} < \theta_s$ eqn. (2) becomes.

$$\sum_{j=1}^{k}(1+m_{i-1})(\theta_s-\theta_{vD})+\sum_{j=1}^{k}\left[\frac{(1+m_i-j)+(1+m_{i-j-1})}{2}\right]\theta_{vD} + (1+m_{i-k-1})\lambda\theta_s = 1 \qquad ..\ (12)$$

Throughout this report, the algorithm which makes use of equations 2,3,4 and 6 will be referred to as ALG-1 while, the algorithm which makes use of equations 8 to 11 will be referred to as ALG-2. In the experimental work reported here, the value dynamics were approximated as time delay, hence equations 8 to 11 are used in actual algorithm i.e. ALG-2 has been employed.

4.2 ALGORITHM IMPLEMENTATION

The implementation of the algorithm by the Computer required that the memory storage requirements of the past velocities be estimated. The relationship between the maximum number of stored velocities and the expected minimum dimensionless velocity, V_{min} is maximum no. of stored values $= \frac{1}{V_{min}\,\Theta s}$. In the present application, the velocity array of 6 elements is used, to store the past values of dimensionless velocity, V starting with most recent value in position number one progressing to the oldest sample value in position number 6. The array is initialized to values of 1, indicating no previous deviation in the velocity. The computer calculation used to implement the control algorithm can be summerized as below,

1) Sample outlet temperature and convert it into dimensionless form.

2) Compute residence time by the following procedure - (a) set R=0, i=1, (b) calculate $R=R+Vi\theta_s$ where past dimensionless velocities are stored in an array of length N.(C). If R>1 go to step e, (d) Increment i, If i>N, print error message. Return to step b (e) Calculate K=i-1 (f) Calculate λ by equation 10.

3) Calculate velocity required to reach set print in one residence time by equation 5.

4) Update the velocity array and store the newest velocity data.

5) Send signal to valve after necessary conversion of units.

The flow chart for the above algorithm is given in the Chapter 5.

CHAPTER - 5

SOFTWARE DEVELOPMENT

The philosophy behind the control scheme using a distributed parameter approach for on line control of the heat exchanger is discussed in the preceeding Chapters. In order that the actual goal is achieved, the necessary software to implement the control scheme has to be developed.

The complete software is developed in advanced version of BASIC (BASICA) developed by Microsoft.

5.1 The software developed is devided into two main parts.

(I) Software for Experimentation -

This contains different programs developed for evaluation of various parameters and relations between them as well as a software for simulation.

(II) Software for Online Heat Exchanger Control (Main Program) -

This contains the program for actual control algorithm discussed in the previous chapter.

Software programs in both sections make use of various subroutines in common. The software tree for each program is discussed first. It gives the subroutines called in the perticular program. The actual subroutines called are discussed at a later stage.

5.1.1 I) <u>Software for Experimentation</u> -

This mainly consists of

(i) ANVL: Program for finding a relation between angle position of the valve and the voltage obtained at 10 turn helical potentiometer output.

(ii) FLTM: Programme for finding a relation between outlet temperature and flow rate.

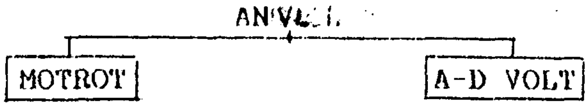
(iii) STEPRES: Program to store the outlet temperature values after step change in velocity of water is given at the inlet of inner tube.

(iv) Simulation: This is the program for semi-theoretical simulation of Heat Exchanger system;& uses a model discussed in Chapter 6.

5.1.1.1

(i) ANVL: Software tree for this program and its flowchart are given in Fig. 5.1.

The program first reads angle position through keyboard, in degrees (0 degree position corresponds to completely closed position of the valve). It then issues the necessary pulses to 8255 port, for rotating valve to desired angle position, through subroutine 'MOTROT'. After desired valve position is reached, the program reads the voltage at 10 turn potentiometer output & displays it on the screen. The voltage against the current angle position is then stored in a file 'ANGVOL.DAT'. The program then loops back and waits for new angle position to be supplied through key board. The program can be terminated



SOFTWARE TREE FOR ANGVOL

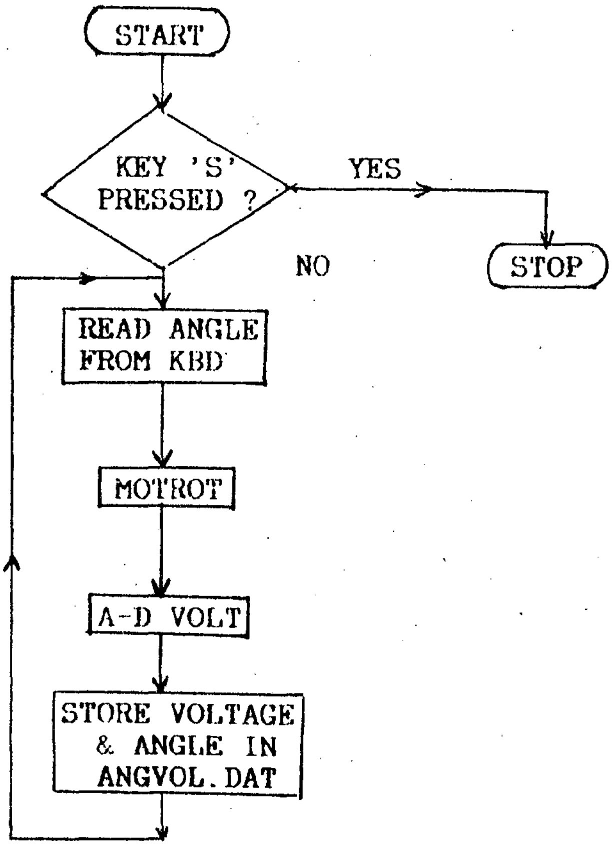


FIG.5.1. FLOWCHART FOR ANV

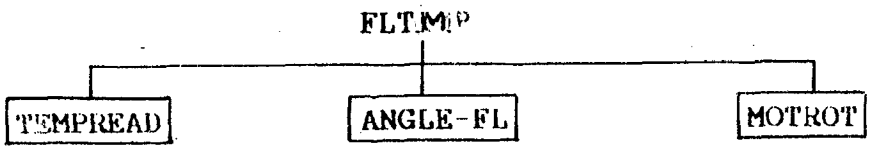


FIG.5.2 (A) SOFTWARE TREE FOR FLTMP

by pressing key 'S' at this instant if required.

5.1.1.2

(ii) FLTM: Software tree for this program & its flow-chart are given in the Fig 5.2.

The program first reads & displays the inlet, outlet & the steam temperature using a subroutine 'TEMPREAD'. It then waits for valve position in degree to be fed through key board. When angle position is fed it computes the corresponding flowrate in ℓpm using 'ANGLE-FL' subroutine. It then issues the pulse signals to 8255 so as to achieve new desired position using 'MOTROT' subroutine. When desired position is reached, it continuously reads the outlet temperature till any key is pressed. It is imperative that the key is pressed only after stabilised temperature is reached. Outlet temperature in degrees, °C is stored against the flowrate in lpm in a file 'FTEMP-DAT'. The program then loops back and new angle position of valve to be fed. If one wants the program can be terminated by using key 'S' at this stage.

5.1.1.3

(iii) STEPRES - Software tree and flow chart for this program are as in Fig. 5.3.

The program reads and displays inlet and outlet temperature of water & temperature of steam, using a subroutine 'TEMPERED'. It then reads the voltage at 10 turn potentiometer and calculates the current flow rate in ℓpm

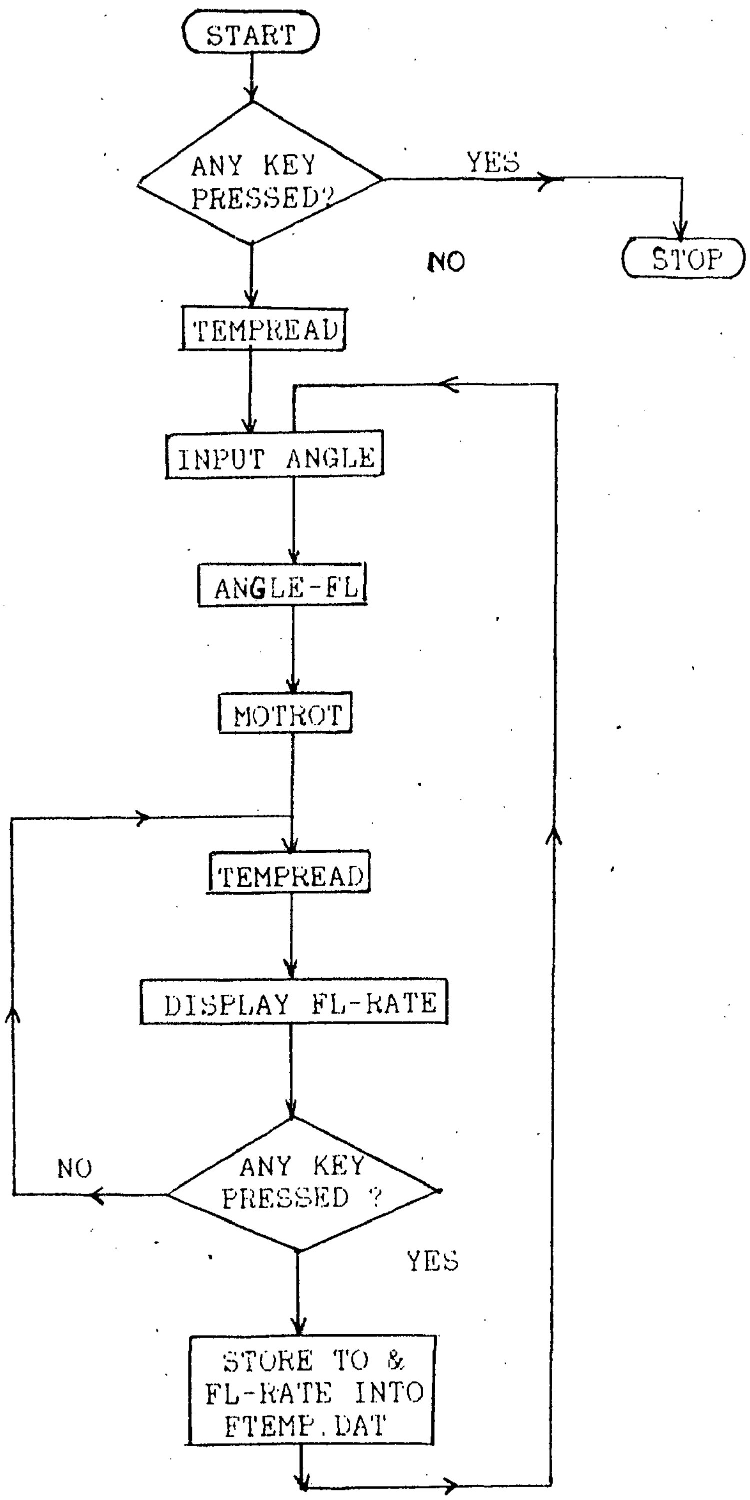
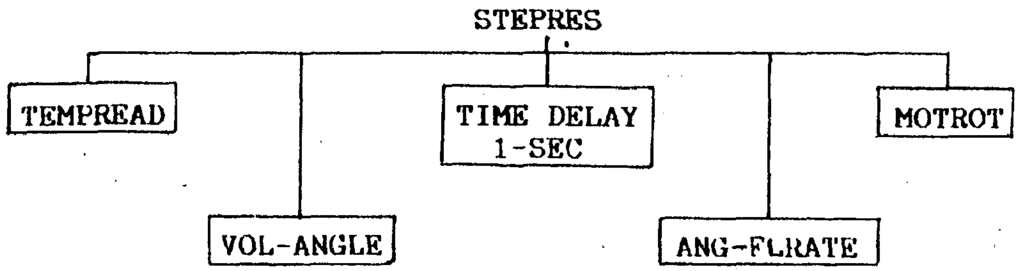


Fig. 5-2 (B) FLOW CHART FOR FLTM



SOFTWARE TREE FOR STEPRES

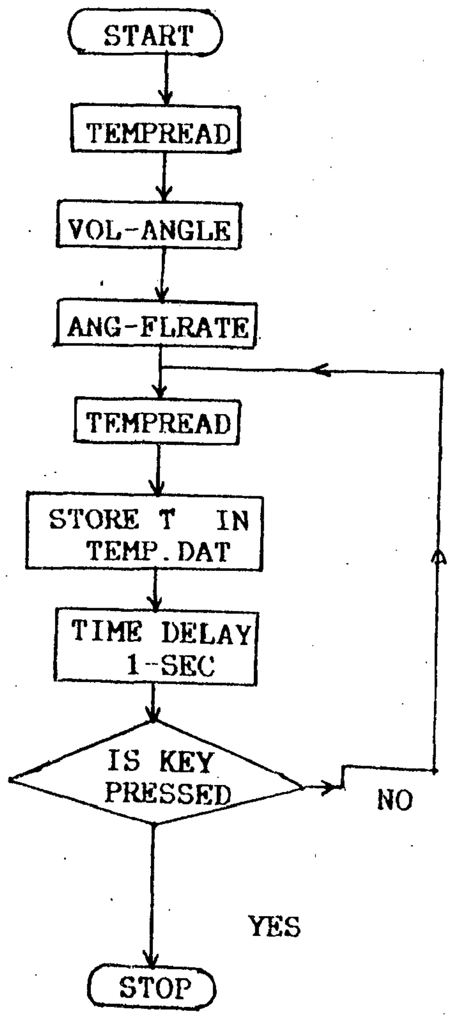


FIG. 5.3. FLOWCHART FOR STEPRES

using a subroutine the 'VOL-ANGLE' and'ANGLE-FL'. The program then waits for new angle position to be entered through a key board. The pulse sequence required to rotate the motor is issued through 8255 ports to stepper motor driver card using subroutine 'MOTROT'. The program then starts reading the outlet temperature with a sampling period of 1 sec. The temperature is stored into file 'Temp. Dat' just after it is read. The temperature is sampled similarly till one presses any key. It is imperative that the key is pressed only after steady state temperature value has been reached.

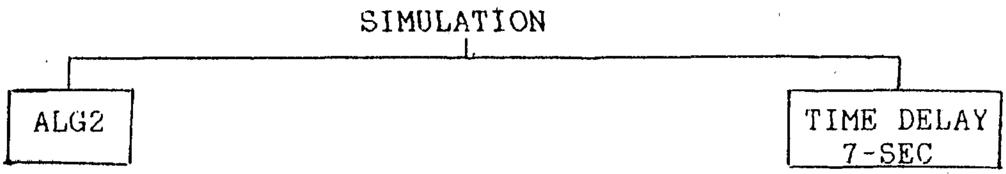
5.1.1.4.

(ii) SIMULATION:

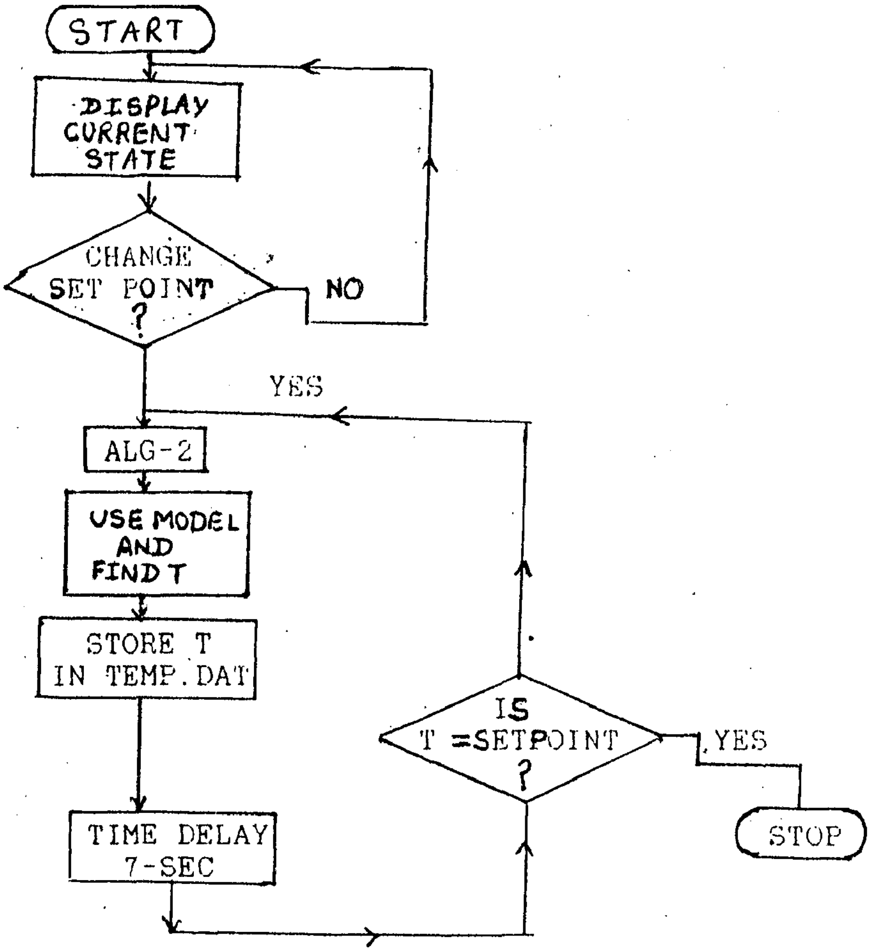
Software tree & a flowchart for this program are given in Fig. 5.4.

The program continuously displays the current state of the system while waiting for new set point to be entered from key board in °C . Upon reading the new set point, ALG-2 subroutine decides the new flow rate for the system. From the flowrate step, the temperature variation at the outlet with time is determined using the model developed for this program are given in the Fig. 5.4.

The program continuously displays the current state of the system while waiting for new set point to be entered from key board in °C. (Upon reading the new, set point, AlG-2 subroutine decides the new flow rate



SOFTWARE TREE FOR SIMULATION



FLOWCHART FOR SIMULATION

FIG:5.4.

for the system. From the flowrate step, the temperature variation at the outlet with time is determined using the model developed for heat exchanger. (The model is described in Chapter 6). Thus the exit temperature at the end of sampling period is known. This state is compared with the set point specified. If discripancy is found then the program loops back to calculate next better flow rate to achieve the set point by using the past data of flow-rates stored. This procedure is continued till the set point is achieved with the deviation of ± 0.3 degrees °C.

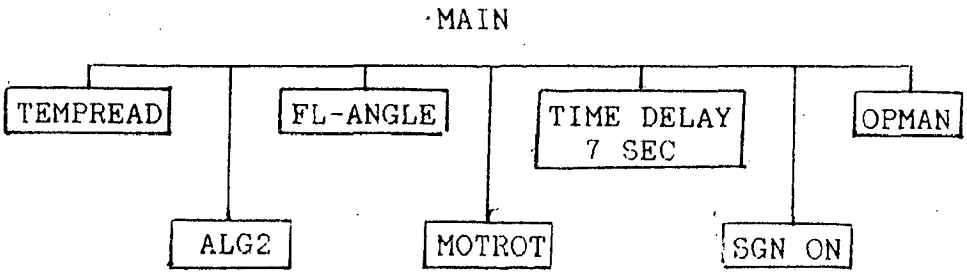
5.1.2

(II) Main Program Software free for Main program for on line control is given in the Fig 5.5(a) while its flowchart is as in the Fig 5.5(b). The program first displays the Initial message

"HEAT EXCHANGER READY"
Press H for Operation Manual
Press C to continue when READY
Press A to Abort

Upon detection of Key 'H' if diverts to display operation Manual which contains various manual operations to be done before the algorithm can function successfuly. The display is

* "BEFORE CONTROL ALGORITHM IS RUN PLEASE ENSURE ABOUT FOLLOWING.



SOFTWARE TREE FOR PROGRAM MAIN

FIG: 5.5(a)

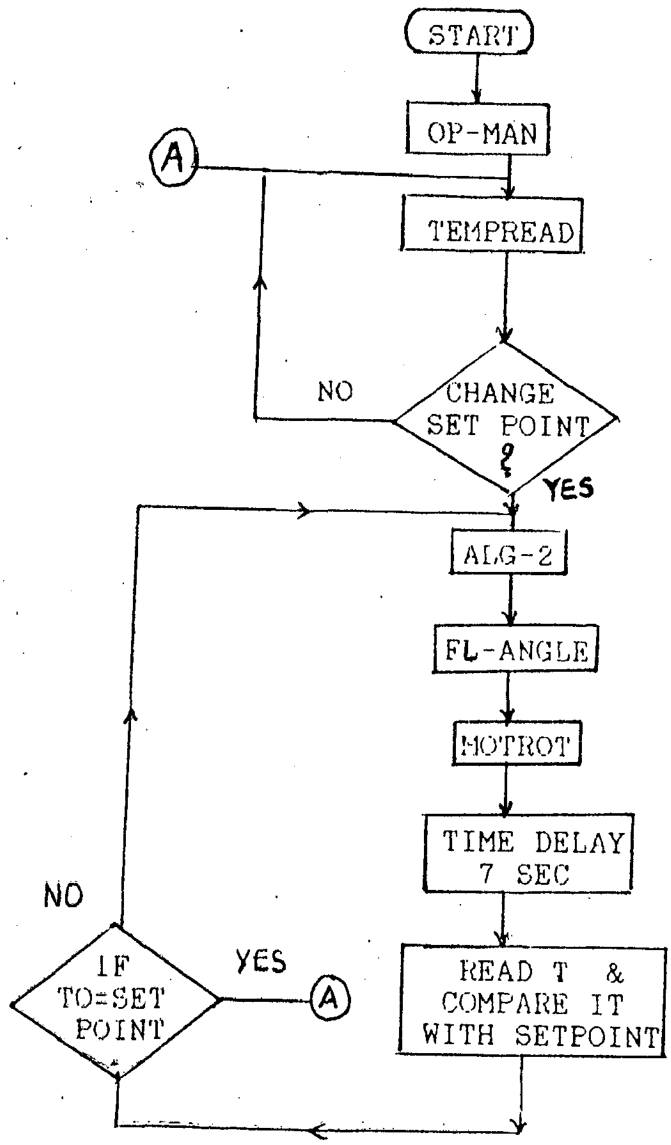


FIG: 5.5(b) FLOWCHART FOR PROGRAM MAIN

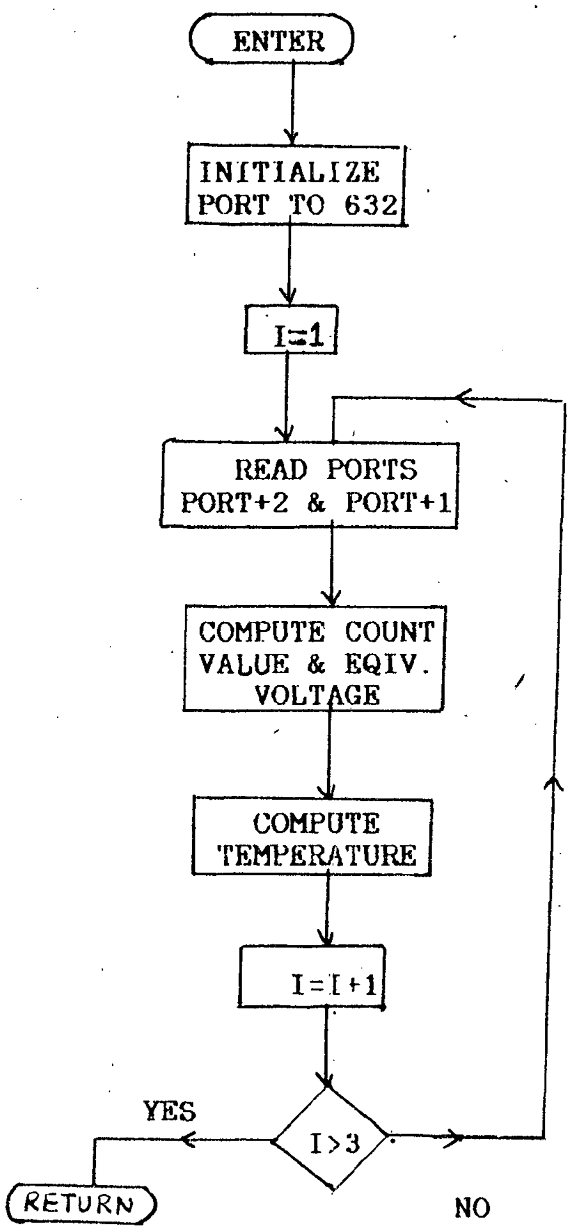


FIG:5.6 FLOWCHART FOR TEMPREAD

* STEAM GENERATOR Contains enough water
* STEAM GENERATOR heater supply is ON
* Water is continuously flowing into overhead tank and overflow line is functioning.
* STEAM TEMPERATURE has reached a minimum of 100°C (BE PATIENT)

PRESS "B" to GOBACK to MAIN DISPLAY, when B is pressed initial display is again displayed. At this stage one can choose any of the options depending upon the requirement. When A is pressed program stops the excecution. While if C is pressed program proceeds to control. Inlet, outlet and steam temperatures are read and displayed using subroutine "TEMPREAD". It continuously displays the current state while waiting for new set point to be fed. When new set point in degree C is read using ALG-2 the new flow rate is decided. Using "MOTROT" new valve position is acheived. The programe waits for predetermined time (sampling time) and reads the Outlet temperature. The outlet temperature is then compared with the set point specified. Upon finding no match the program loops back to decide next better flowrate using ALG-2. The procedure continues till the set point is reached with the deviation of ± 0.3 deg. °C.

5.2 The different subroutines used in the programs discussed above are explained as below -

(1) TEMPREAD

Input to subroutine - nil

Output from subroutine - T, Ts and Ti, degree °C.

This subroutine reads the steam temperature, inlet temperature and outlet temperature and returns back. The flow chart for this subroutine is as in the Fig 5.6.

(2) ANGLE-FL :

Output from subroutine	:	Angle in degrees
Input to subroutine	:	Flow rate in ℓpm

This Subroutine computes the Angle in degrees (Valve position) when the flow rate in ℓpm is specified, using the equations 6.1, 6.2, 6.3 and 6.4. The flowchart for this subroutine is given in the Fig 5.7.

(3) MOT ROT:

Input to Subroutine:	Angle in degrees
Output to Subroutine:	Nil

This subroutine calculates the voltage of 10 turn helical potentiometer corresponding to the new angle position. Then it issues the pulse sequence for the rotation desired through 8255 ports to stepper motor driver card till the 10 turn potentiometer voltage reaches to the precalculated value. When new angle position is reached the subroutine returns control to main program.

The flowchart for this subroutine is as in the Fig 5.8.

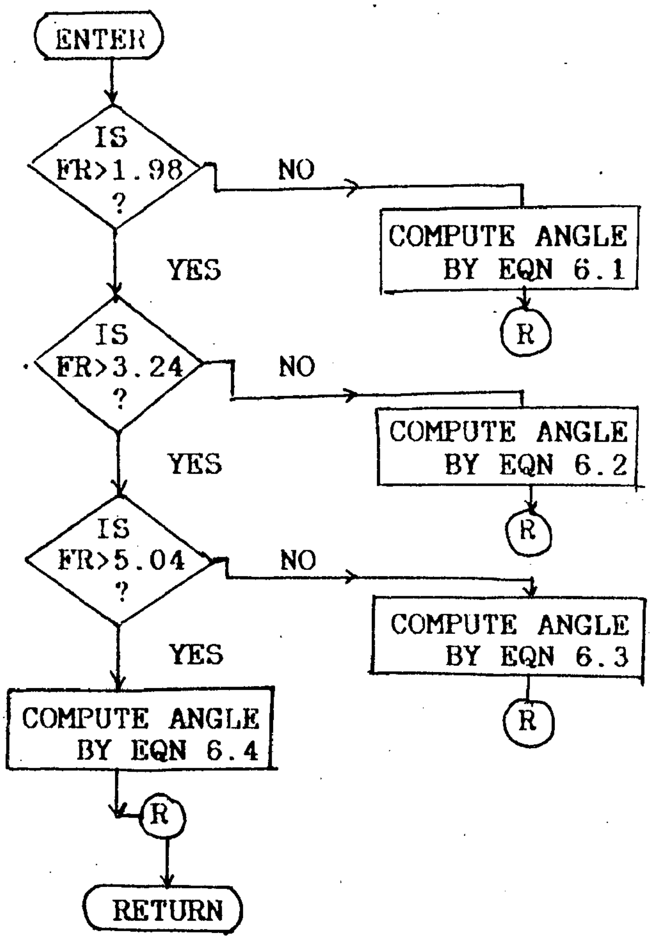
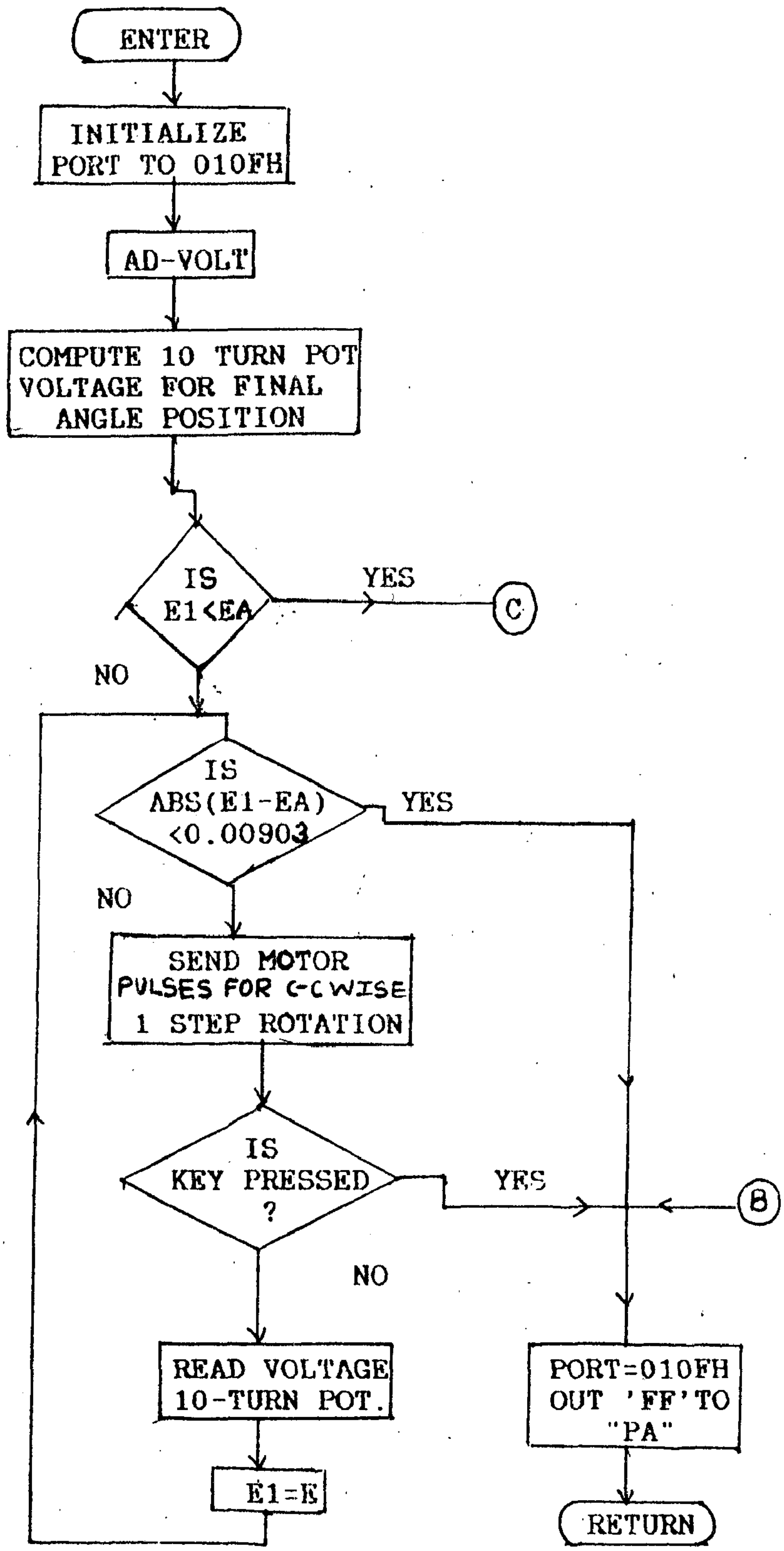


Fig.5.7 FLOW CHART FOR ANGLE-FL



ENTER
INITIALIZE PORT TO 010FH
AD-VOLT
COMPUTE 10 TURN POT VOLTAGE FOR FINAL ANGLE POSITION
IS E1<EA
YES
C
NO
IS ABS(E1-EA) <0.00903
YES
NO
SEND MOTOR PULSES FOR C-C WISE 1 STEP ROTATION
IS KEY PRESSED ?
YES
B
NO
READ VOLTAGE 10-TURN POT.
E1=E
PORT=010FH OUT 'FF' TO "PA"
RETURN

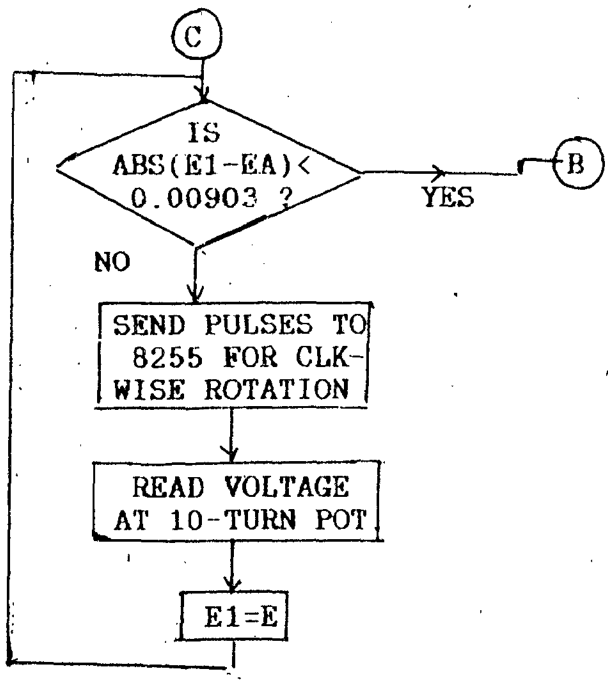


FIG.5.8 FLOWCHART FOR MOTROT

4) <u>A-D Volt Subroutine</u> -

Input to Subroutine : Nil

Output from Subroutine : Voltage in Volts

Sensed at A-D channel 'O' of AD/DA Card. This subroutine converts the Analog Voltage at AD channel into the equivallent counts. These counts then are multiplied with a factor so as to obtain the equivallent voltage in volts. For this conversion equation V = Count/450 is used. (It is found for the AD/DA card that the maximum count when 9V are applied to A-D channel is 4050 instead of 4095 which is actual 12 bit count value. Hence the factor used is 1/450). The flow chart for this subroutine is as in Fig. 5.9.

5) <u>Vol.Angle</u> -

Input to Subroutine : Voltage at 10 turn helical potentiometer in volts.

Output to Subroutine : Angle position in degrees.

This subroutine calculates the current angle position of valve in degrees, when voltage sensed at 10 turn helical potentiometer output is specified. This computation is done using the equation V = 0.00129 X VP, which defines the relation between angle position and 10 turn potentiometer output. The flowchart for this subroutine is as in the Fig. 5.10.

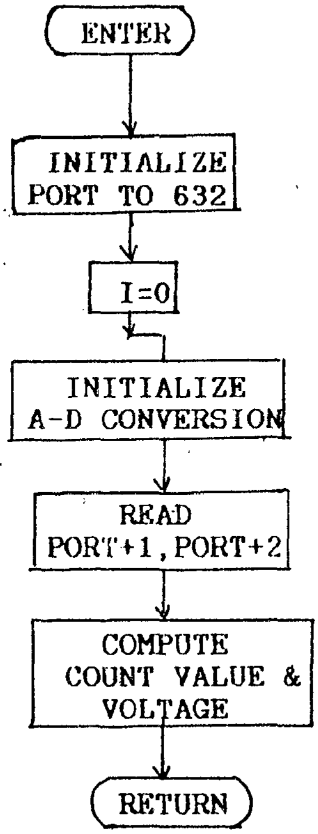


FIG.5.9 FLOWCHART FOR AD-VOLT

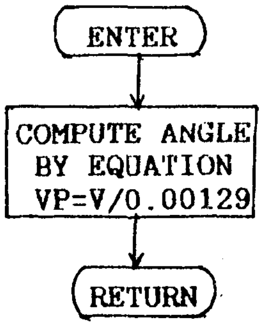


FIG.5.10 FLOWCHART FOR VOL-ANGLE

6) Time delay 1 Sec:

Input to Subroutine : Nil

Output from Subroutine : Nil

This subroutine uses the Real Time Clock of P.C. using 'TIME \$' Command in BASICA. The subroutine first sets 'TIME \$' to zero and then reads 'TIME \$' continuously till sec value reaches 01_{10}. This generates the delay of 1 sec. After sec reaches 10_{10} subroutine returns control to Main program. The flowchart of this subroutine is as in the fig 5.11.

7) FL-temp. Subroutine:

Input to Subroutine : Flow rate in ℓpm.

Output from Subroutine : Outlet temperature in deg.C.

This subroutine Computes the Outlet temperature in deg. C., by using the equations 6.5, 6.6 and 6.7 which describe the relation, flowrate and outlet temperature, when flowrate is specified in ℓpm. The flowchart for this subroutine is in the Fig 5.12.

8) Time Delay.7 Sec. :

Input to Subroutine : None

Output from Subroutine : None

This subroutine works exactly as Time delay - 1 sec. subroutine, only difference being this return control to main program after 7 sec are elapsed after its calling. The

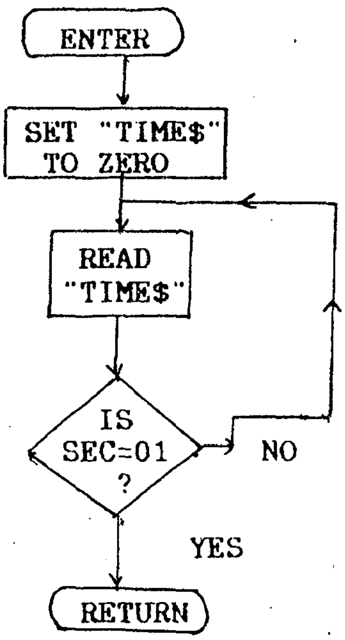


FIG.5.11 FLOWCHART FOR TIME DELAY 1-SEC

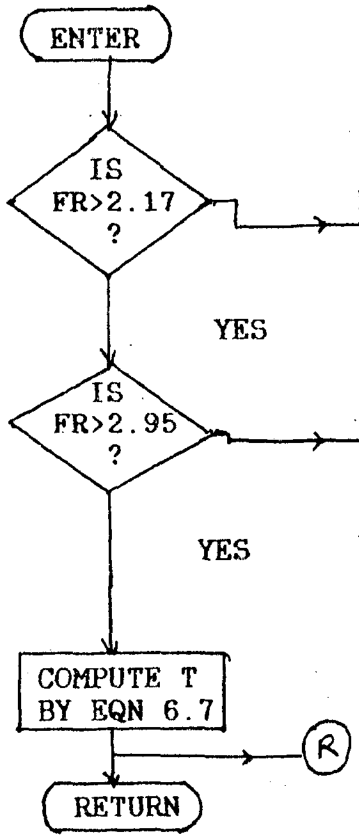


Fig.5.12 FLOWCHART FOR FLTEMP

flowchart of this subroutine is in Fig. 5.13.

9) ALG-2:

Input to Subroutine:	: i)	Ti, T, Ts in Deg. C.
	ii)	Set point desired Xs in Deg.°C.
Output from Subroutine	: i)	V_{NEW} in dimensionless form.
	ii)	Stores T in Deg°C in TEMP.DAT.
	iii)	Stores Velocity Values in SAMP.DAT. in dimensionless form.

This subroutine computes the new dimensionless Velocity using passed values stores in an array. For this computation the subroutine uses the current values of steam temperature and the inlet temperature of water. The flowchart of this subroutine is as in the Fig 5.14.

10) SGN ON:

Input to Subroutine : None

Output to Subroutine : None

This subroutine displays the message

"HEAT EXCHANGER READY
PRESS C TO CONTINUE
PRESS H FOR HELP
PRESS A TO ABORT."

and waits till certain key is detected. If 'H' is detected the program diverts to display the operations Manual. If 'A' is detected program stops executing while, if key 'C' is detected then program proceed to on line control algorithm. The flowchart for this subroutine is as in the Fig. 5.15.

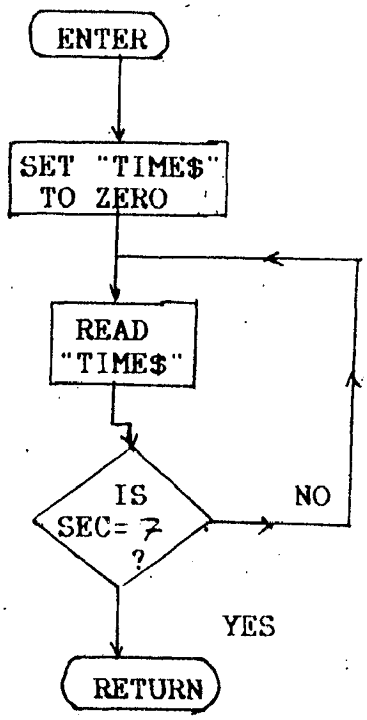


FIG.5.13 FLOWCHART FOR TIME DELAY 7 SEC

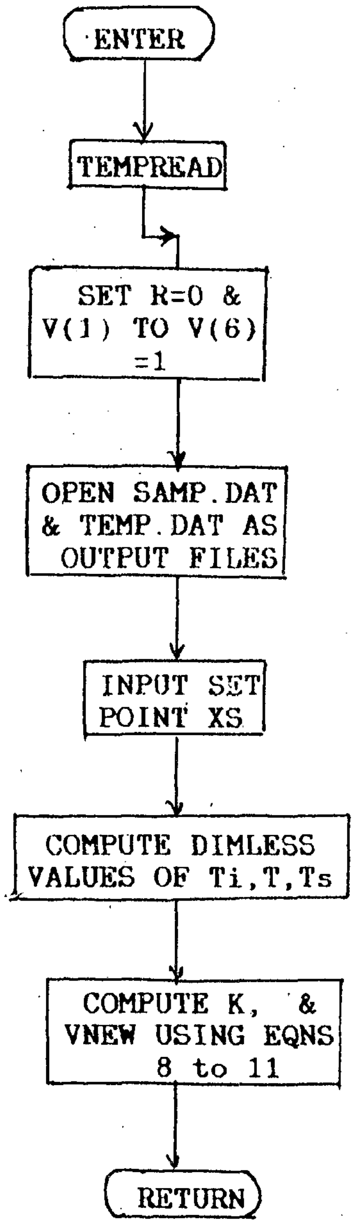


FIG.5.14 FLOWCHART FOR ALG-2

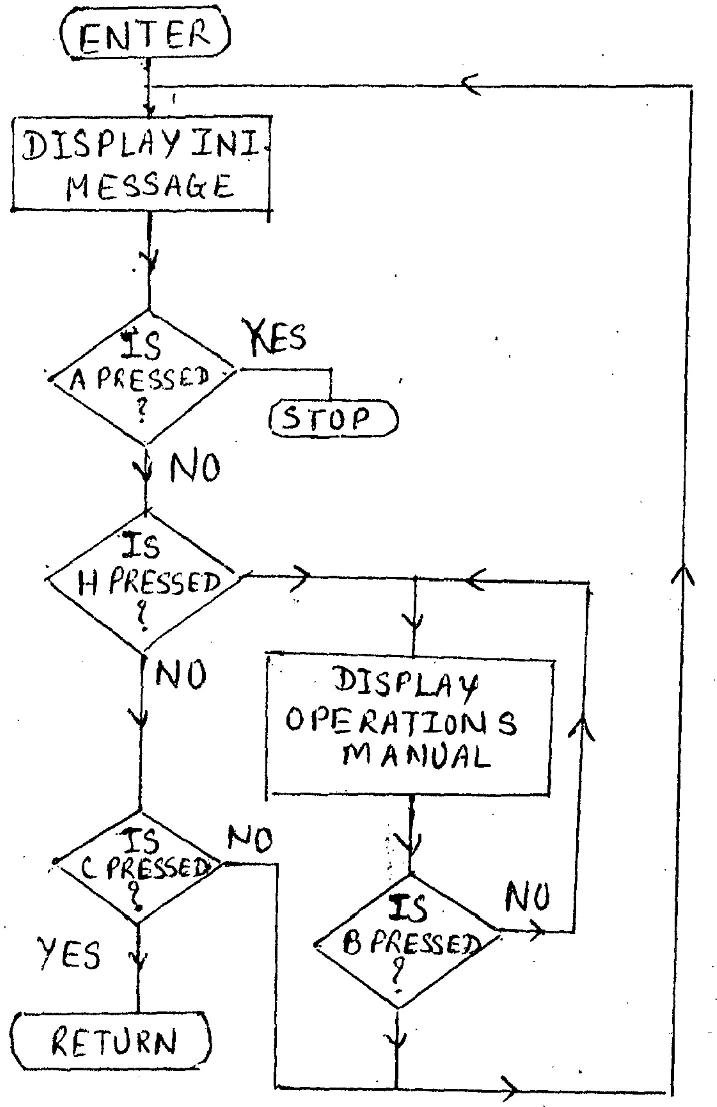


FIG. 5.15. FLOWCHART FOR SGN ON

CHAPTER - 6

EXPERIMENTATION AND RESULTS

The experimental setup as shown in the Fig. 1.1, was assembled and tested for satisfactory performance. Experiments were then carried out to evaluate a few pertinent parameters like, β , U , θs etc. necessary for temperature control and simulation. Subsequently the parameters were directly used in the control algorithm, for temperature control of heat exchanger. Besides these, calibration data for temperature transducers, motorised valve etc. were also generated from experiments for the controller. The details of the experiments are listed below :

6.1.1. Variation of Flow Rate of Water with Valve Position:

It was necessary to generate reliable data relating to the valve position and flow rate of water to the heat exchanger for the controller. To generate the data following steps were taken :

(i) Water inlet to the overhead tank (15) was opened. Flow rate into the tank was maintained in such a way that the overflow line (14)start functioning, thus keeping the constant head of liquid in the tank.

(ii) Valve (2) was then opened from its fully closed position (valve position at 0 degrees) to the angle at which a series of droplets start dripping from the outlet of inner tube of heat exchanger.

(iii) Time to fill a one litre flask with water from exit of heat exchanger was then noted with the help of a stop watch to determine the flow rate of water.

(iv) The valve was then further opened to a suitable angle by feeding required angle value through console, so that there was a sufficient rise in the flow rate. The flow rate was then determined as in step (iii).

(v) Then procedure in the step (iv) was reported till the stepper motor controlled valve was completely opened.

It was found that flow rate - valve position trend of the motorised valve was different when data were taken in increasing and decreasing flow conditions. In other words it showed hysteresis in flow rate. To account for this change in flow rate, flow rate - valve position data were taken for increasing order as well as for decreasing flow rate conditions.

The variation in the flow rate for various valve position is plotted in the Fig. 6.1 for both increasing and decreasing orders. It is seen that the hysteresis is observed in the range of 0 to 800^o. The hysteresis region was incorporated in the control algorithm through two sets of equation. These equations were fitted out by using least square curve fitting technique. The equations obtained are given below alongwith their range of operations :

(FR denotes the flow rate in ℓpm)

For decreasing flow rate conditions the equations are :

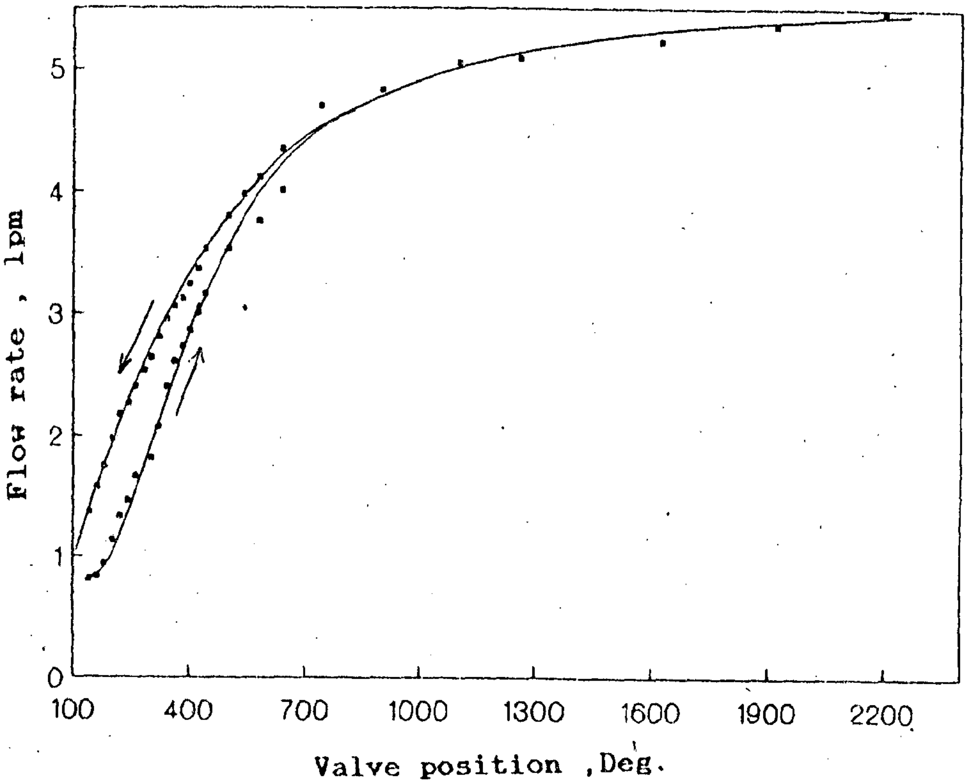


Fig.6.1(a) Variation of flow rate of water in heat exchanger with valve position

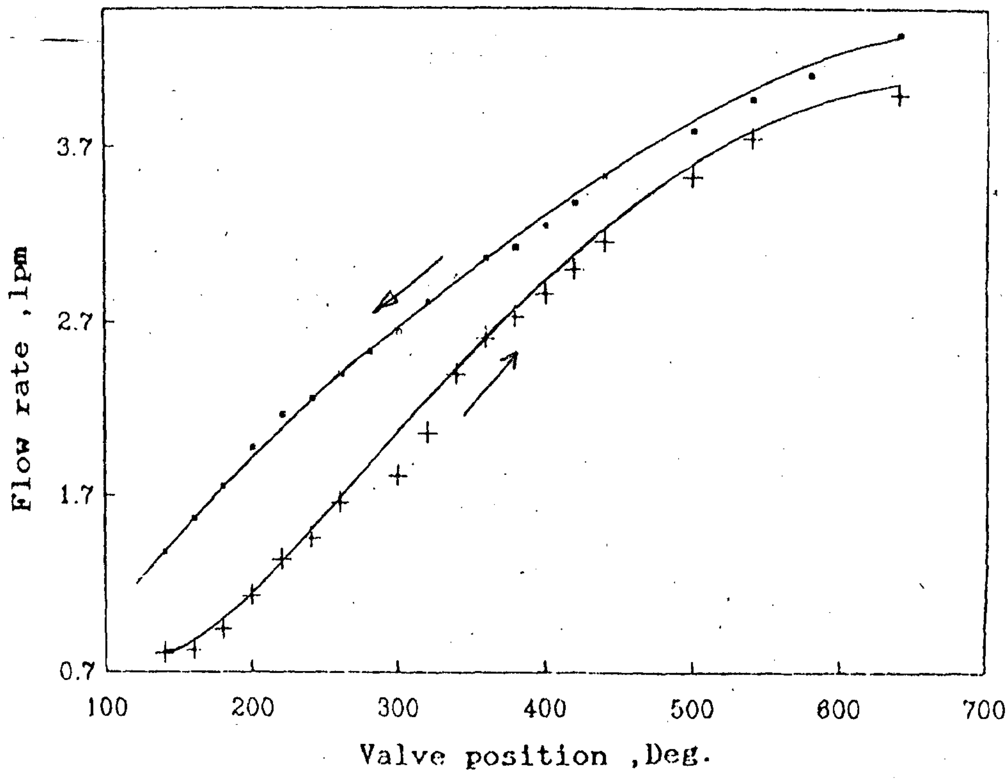


Fig.6.1(b) Hysteresis in flowrate observed during the operation of motorised valve

```
FOR FR < 1.9802
ANGLE=-1279.681475#+5865.234912#*FR-8090.9431691#*FR^2+2755.4579589#*FR^3+2157.6   6.1
940811#*FR^4-932.61604119#*FR^5-714.38636772#*FR^6+271.50887141#*FR^7+112.610723
#*FR^8-43.897917779#*FR^9
FOR  1.9802< FR < 3.2432
ANGLE=123.713875#+5118.4392341#*FR-6682.6290921#*FR^2+2388.7543607#*FR^3+54.1918   6.2
85833#*FR^4-29.765926261#*FR^5-55.103950857#*FR^6-4.2545462927#*FR^7+8.950778662
5#*FR^8-1.3152774788#*FR^9
FOR   3.2432< FR < 5.042
ANGLE=310053.46373#-344908.47712#*FR+118635.33154#*FR^2+342.95851787#*FR^3-7826.   6.3
34595616#*FR^4+750.35697#*FR^5+325.73137139#*FR^6-78.563273591#*FR^7+5.304887468
6#*FR^8-.036180891963#*FR^9
FOR FR > 5.042
ANGLE = 3198.315#+21175.2244#*FR+3847.46336#*FR^2+225.4254064#*FR^3+51.5855   6.4
*FR^4-16.40983602#*FR^5-4.9264009#*FR^6-.5453093511#*FR^7+.087953759711#*FR^8+.
0144066789#*FR^9
```

For increasing flow rate conditions the equations are :

```
FOR FR<1.132
ANGLE=64781.649269#-276161.57248#*FR+406034.61166#*FR^2-202023.81816#*FR^3-
31649.03713#*FR^4+39138.2349#*FR^5
FOR  1.132<FR<2.609
ANGLE=1873.2049789#-5513.9416901#*FR+6753.7039071#*FR^2-3910.5820515#*FR^3+
1096.8161968#*FR^4-119.69922997#*FR^5
FOR FR > 2.609
ANGLE=-7852.4152801#+8835.4227887#*FR-3329.0757181#*FR^2+439.6368991#*FR^3+
1873.205 6#*FR^4-5.1120397335#*FR^5
```

6.1.2 Variation of Heat Exchanger Outlet Temperature with Water Flow Rate :

This was obtained by performing following steps :

(i) The program FLTM discussed in the Chapter 5 was executed for various valve positions and steady state exit temperature of water from heat exchanger was noted. Suitable increments in valve position were given in each loop of execution and corresponding steady state exit temperature was noted. The program was executed several times. The results obtained are plotted in Fig. 6.2.

(ii) The equations governing the relation between the steady state exit temperature and flow rate was obtained by using a least square curve fitting technique. The equations and their range of operation are given below.

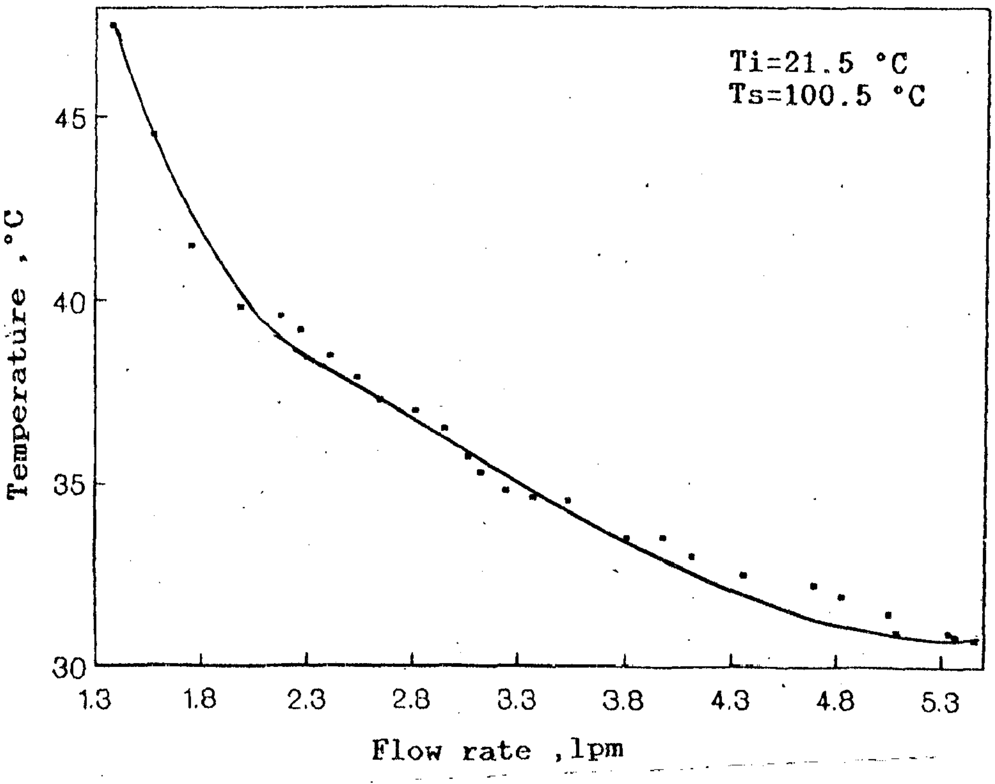


Fig.6.2 Steady state exit temperature of Heat Exchanger for different flow rates

```
FOR  0 <FR < 2.1739
T=2.171571709#+.46953136589#*FR+2.9003357218#*FR^2-3.7974670733#*FR^3+1.68599161   6.5
25#*FR^4-.25605531035#*FR^5
FOR  2.1739< FR < 2.9556
T=-11.735932136#+18.454499007#*FR-6.3834571357#*FR^2-.52147508531#*FR^3+.6578402   6.6
2647#*FR^4-.091795500123#*FR^5
FOR 2.9556< FR <= 3.797
T=28.579578259#-21.047367553#*FR+3.0314597362#*FR^2+1.75007713257#*FR^3-.6289992   6.7
891#*FR^4+.057763132548#*FR^5
FOR FR > 3.397
T=-14.142764237#+10.851342453#*FR-.97006388416#*FR^2-.67372842251#*FR^3+.1764931   6.8
8518#*FR^4-.012452606842#*FR^5
```

6.1.3 Overall Heat Transfer Coefficient U at Various Flow Rates :

To find U following steps were performed :

(1) The flow rate into the overhead tank was so adjusted, that the overflow line started functioning, thus keeping the water head constant throught out the experiment.

(2) Heaters of steam generator were put ON and steam temperature was allowed to rise above 100°C.

(3) Range of control of exit temperature was selected and flowrate was adjusted so as to obtain minimum value of the selected range with the help of program FLTM discussed in Chapter 5.

(4) Steam temperature, inlet temperature and exit temperature of water from heat exchanger were noted for a particular flow rate values.

(5) Flow rate was then decreased so that there is a rise of about 1.5 to 2^{o}C in the outlet temperature was obtained.

(6) Steps 4 & 5 are then repeated. This procedure is continued till the exit temperature reaches the maximum value of the range selected. The sample calculation for the estimation of U is given in Appendix-C, Section C.1.

6.1.4 Dimensionless Parameter b :

The dimensionless coefficient b relates the overall heat transfer coefficient at any velocity value to that at reference velocity Vo. The relation can be expressed as

$$U = U_o(1+m(\theta)^b.$$

Determination of parameter b is discussed in Appendix-C, Section C.2.

6.2 SEMITHEORETICAL SIMULATION

This was done for estimation of sampling period (st) β & b for the implementation of above parameters in the actual control algorithm.

In the semitheoretical simulation the heat exchanger assembly is replaced by a mathematical model developed.

The development of model is discussed below. The response of exit temperature for a step change in flow rate was plotted in the Fig. 6.3.(a) The response is similar to that of a reaction curve. To the reaction curve, a tangent was drawn

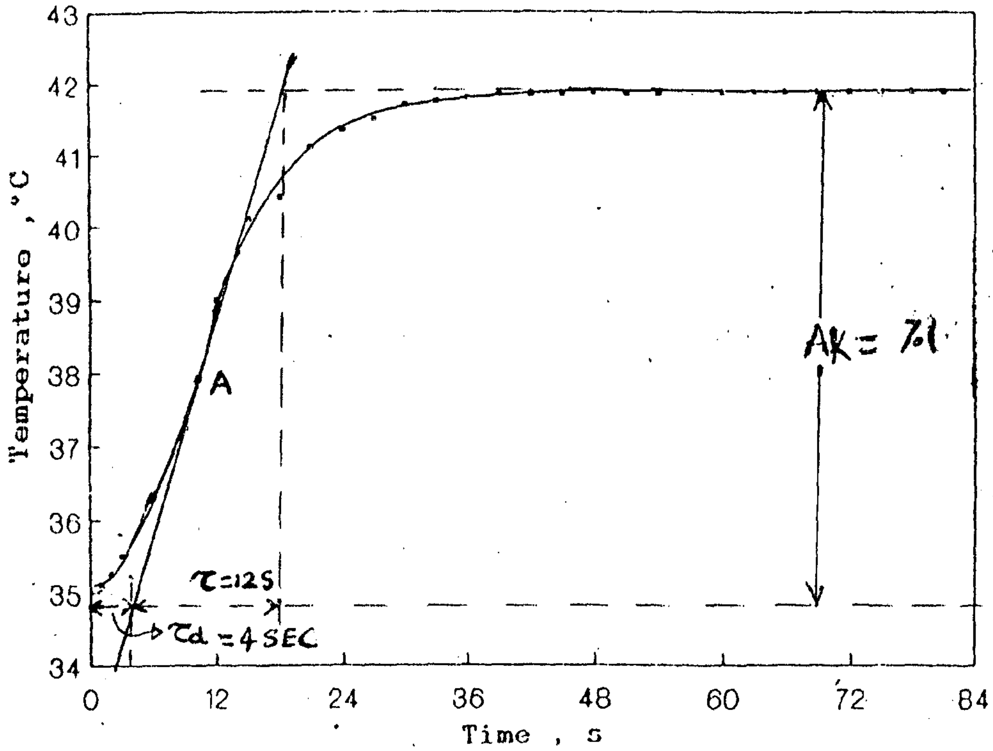


Fig.6.3 (A) Variation of heat exchanger exit temperature with time when a step change in flowrate was given from 3.24 lpm to 1.76 lpm

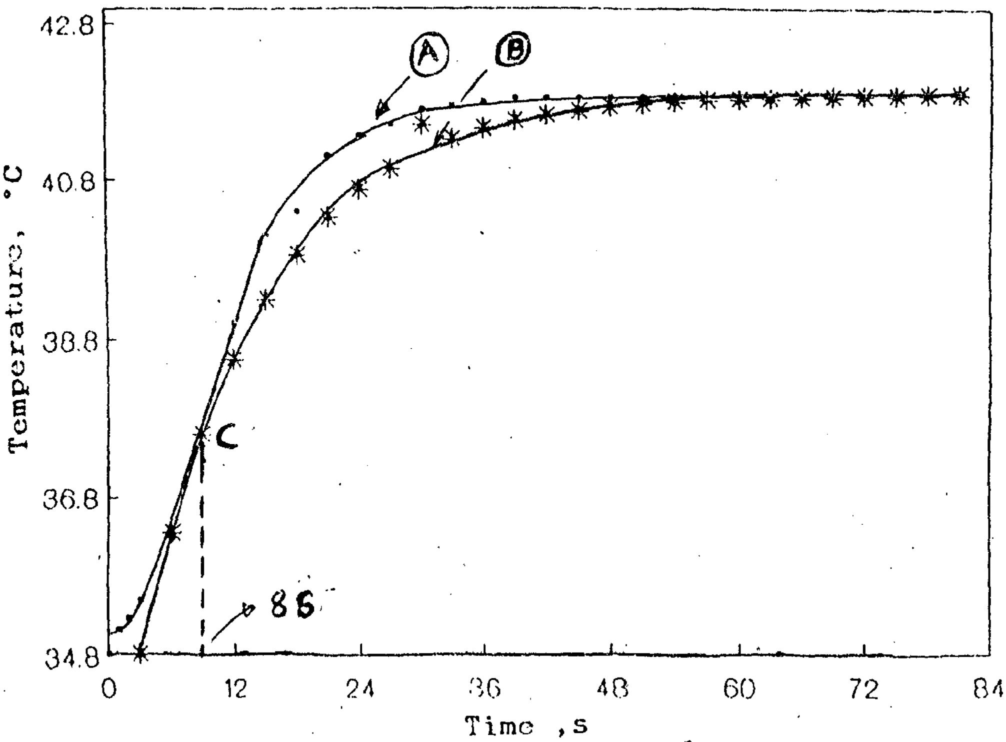


Fig.6.3 (b) Comparison of exit temperature responses of heat exchanger without controller for a step change in flow rate from 3.24 lpm to 1.75 lpm was given (1)obtained from actual experiment (A),(2)obtained from developed model (B)

at the point A (Inflection point). The delay time (τ_d) and the time τ constant were then estimated, (measured from the curve as shown in the Fig. 6.3(a)).

Thus heat exchanger system was assumed to be the Ist order system with time delay. The equation for such model is given as

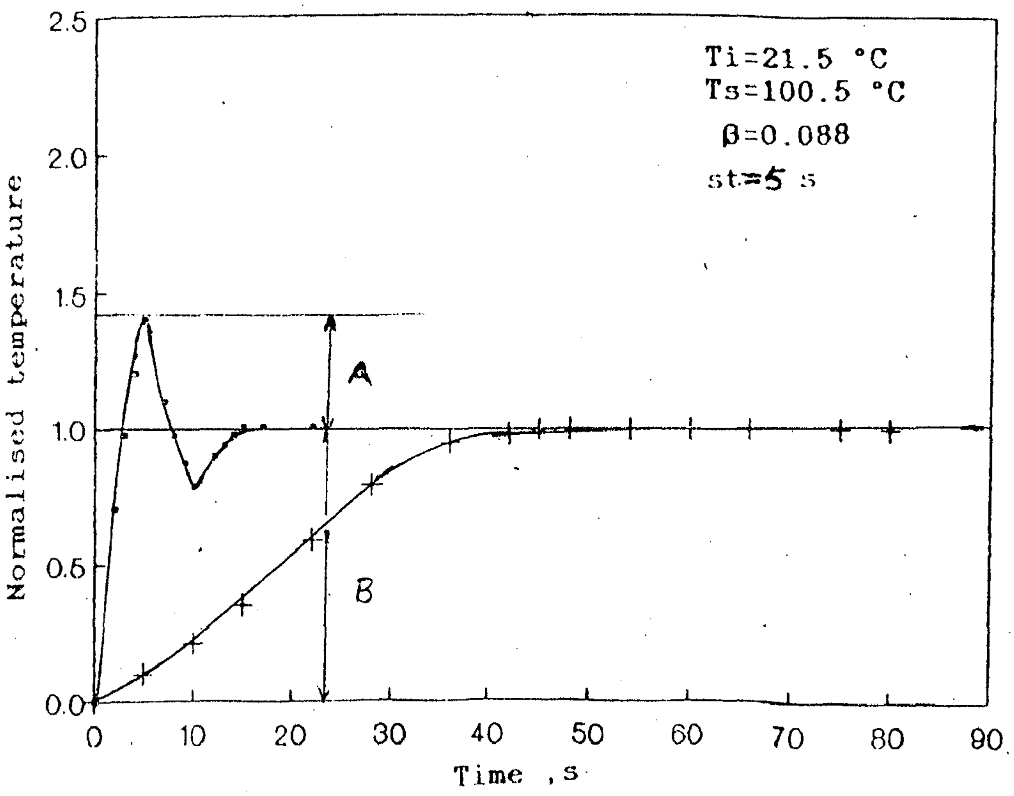
$$Y(t) = 4.769.A.(1-EXP(-(t-4)/12) \quad \text{for } t > td \qquad .. (A)$$
$$= 0 \qquad \text{for } t < td$$

For the development of model please refer to Appendix-C. The response of exit temperature of heat exchanger during experimentation as well as simulation using model given in Equation A were compared in Fig. 6.3(b). From the figure it was clear that it compares well within the practicle limits. From the figure it is also clear that both responses cross each other at point C. This corresponds to 8 sec. Hence the sampling time was fixed around 7 sec. The model thus developed was used to get the exit temperature values theoretically for stepchange in flow rate which was evaluated using ALG-2 in the simulation program. The software for semitheoretical simulation is discussed in Chapter 5. To reduce the overshoot in the exit temperature a derivative term $K_c \tau_d \frac{d}{dt}$ was added to the control action to evaluate required. How rate change for control from ALG-2, the constant ($K_c \tau_d$) estimated after several execution runs is equal to 0.0134.

From the practical point of view, keeping the response time of motorised valve in mind it was possible to reduce sampling time to 7 seconds only. A further decrease in sampling time produces operational difficulty in the process. However the simulation results as shown in the Fig 6.7 shows it clearly that better results can be obtained by reducing the sampling time upto 1.3 sec. In this case the settling time is around 4 sec.

Keeping the sampling period at 7 sec, simulation runs were carried out to optimize parameter β . The starting value of β selected for simulation was evaluated theoreticaly. (Evaluation is done in the Appendix B, section B.3). The theoretical value was found to be 0.119. A slight shifting in value to 0.088 gave the best results and was considered optimum for present experimental work. The table C.3 shows the value of different parameters taken for experimentation.

The experiments were carried out for a step change in set point from 34° to 37°C. The variation of exist temperatures of the heat exchanger was normalised and plotted with simulated results for the same conditions' & with the response of the exit temperature subjected to identical step input in flow rate without controller. From the Fig.6.4 it is clear that the experimental transient temperature project tracks the simulation profile, but with a slight lag in time. This may be due to simple Ist order model with time delay taken for the simulation purpose. The experimental exit temperature shows an overhoot of about 38% & settles to the desired temperatures after 15 seconds where as without controller it takes around 45 seconds to reach to 97% of desired temperature. A close watch on the fig 6.5 shows



Comparison of exit temperatures of heat exchanger with and without controller when a step change of 3 °C / 0.72 lpm was given

Fig.6.4

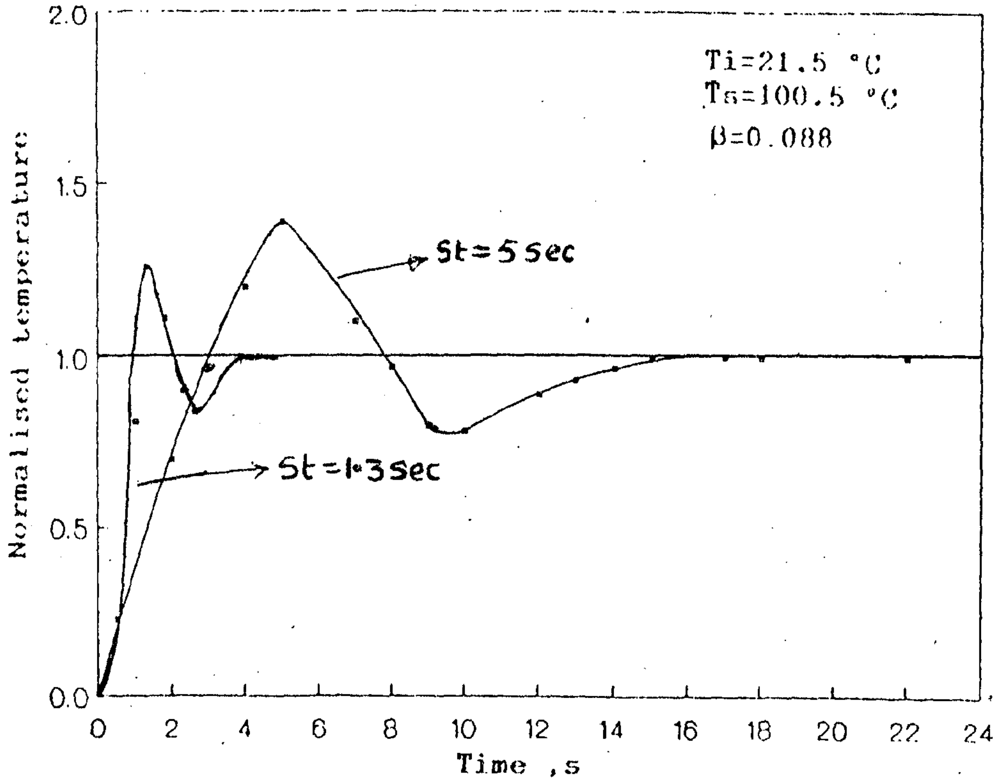


Fig.6.5 Effect of sampling time,st,on transient exit temperature of heat exchanger when step change in set point was given from 34 °C to 37 °C

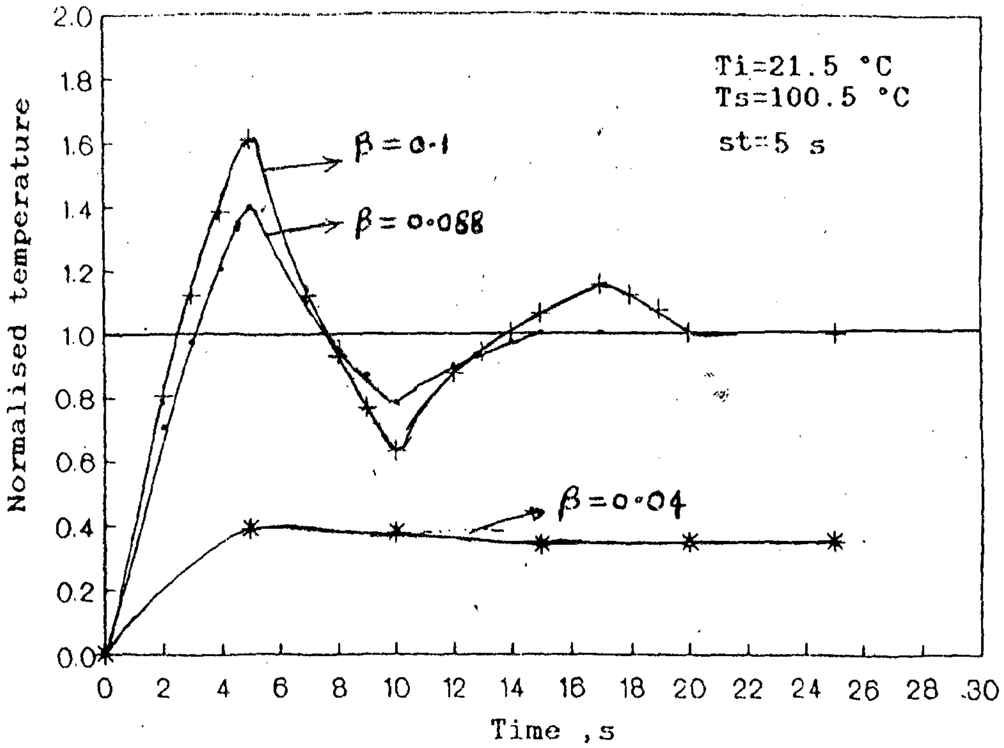


Fig.6.6 Effect of parameter β on transient exit temperature of heat exchanger when a step change in set point was given from 34 °C to 37 °C

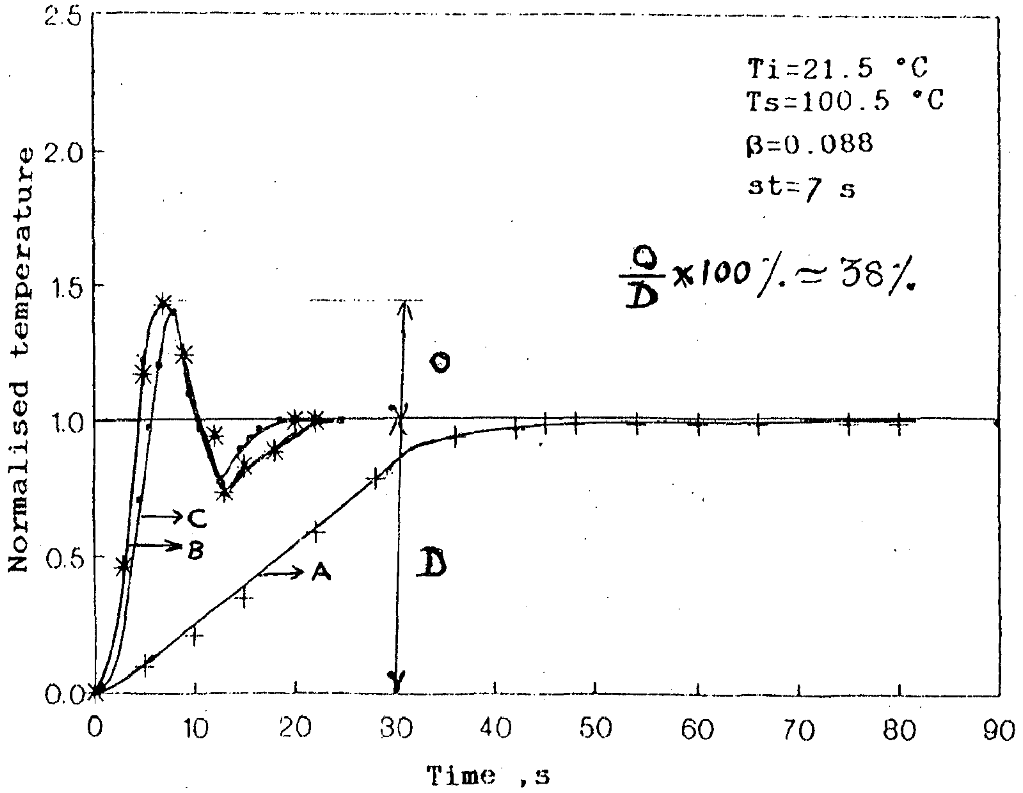


Fig.6.7 Comparison of transient exit temperatures of heat exchanger (1) without controller (A), (2) with controller (B), (3) from simulation (C)

that the settling time of controller can be reduced drastically to a value of 4 seconds by reducing the sampling time. But this was not possible due to low response time of motororised valve in the present investigation. Hence it was concluded that the control algorithm is powerful enough to control the exit temperature of heat exchanger provided a better controlled valve is used. In actual practice in the industrial heat exchangers where the time constants of heat exchangers are pretty large (of the tune of few minutes) this controller can be proved to be the effective one.

CHAPTER - 7

CONCLUSIONS AND RECOMMENDATIONS

Conclusions & recommendations emerged out of the present work are discussed below.

(1) IBM compatible PC/XT proved to be suitable for temperature control of water in heat exchanger.

(2) The algorithm suggested by Mutharsan & Coughnower with slight modification ; was found to be effective for temperature control in case of heat exchanger.

(3) The time delay of the stepper motor controlled valve proved to be bottleneck in reducing the settling time.

(4) The Integrated Circuit temperature sensors AD590 proved to very effective and convenient for temperature sensing.

Recommendations:

(1) Valve delay in case of stepper motor controlled valve should be reduced to minimum possible. This can be achieved by using steppermotor of higher torque as well as by reducing the friction at the motor-shaft valve coupling. If this is done the sampling period can be reduced significantly.

(2) Controlled valve for controlling steam flow into the heat exchanger should be incorporated into the scheme. This will make it possible to study the effect of load changes on exit temperature response.

(3) Scheme using an electric heater wound on the tube instead of a shell should be used for better experimentation. The supply to the heater can be controlled with the help of Triac Controlled supply developed by using analog signal obtained from PC/XT.

REFERENCES

1. J. Fuhrman, R. Mutharsan and D. Coughanowr., 'Computer Control of a Distributed Parameter System', Industrial Engg., Chemical Process Design & Development, 1980, 19, Pages 537-546.

2. R. Mutharsan and D. Coughanowr, 'Feedback Direct Digital Control Algorithm for a class of Distributed Parameter System', Industrial Engg., Chemical Process Design & Development, Volume 13, No. 2, 1974.

3. Gilber Held, 'IBM PC & PC XT User's Reference Manual', Second Edition, B.P.B. Publication, 1987.

4. Vinytics Peripherals Pvt. Ltd., Delhi, User's Manual, AD/DA Card.

5. Vinytics Peripherals Pvt.Ltd., Delhi, User's Manual, I/O, Timer Card.

APPENDIX A

A.1 I/O Timer Card:

This card consists of the following important chips. Two PPI chips 8255, one Timer chip 8253. One, dual 1 of 4 decoder chip 74LS139, and one octal bus transciever chip 74LS245. The connector description of the 26 pin connectors provided on the card is given below.

Connector Description of 26 Pin connectors of I/O-TIMER card

Pin No	J1	J2	J3
1	P1C4	P2C4	5 VOLT
2	P1C5	P2C5	5VOLT
3	P1C2	P2C2	GND
4	P1C3	P2C3	GND
5	P1C0	P2C0	CLOCK IN 0
6	P1C1	P2C1	GATE CONT 0
7	P1B6	P2B6	CLOCK OUT 0
8	P1B7	P2B7	CLOCK IN 1
9	P1B4	P2B4	GATE CONT 1
10	P1B5	P2B5	CLOCK OUT 1
11	P1B2	P2B2	CLOCK IN 2
12	P1B3	P2B3	GATE CONT 2
13	P1B0	P2B0	CLOCK OUT 2
14	P1B1	P2B1	NC
16	P1A7	P2A7	NC
17	P1A4	P2A4	NC
18	P1A5	P2A5	NC
19	P1A2	P2A2	NC
20	P1A3	P2A3	NC
21	P1A0	P2A0	NC
22	P1A1	P2A1	NC
23	P1C6	P2C6	NC
24	P1C7	P2C7	NC
25	GND	GND	NC
26	GND	GND	NC

A.2 AD/DA CARD

This is high precision data conversion system. The card contains DAC 7521 which is a 12 bit high resolution D to A convertor. CMOS chip CD4067 is used to select single channel out of 16 channels.

The pin configuration of 25 pin D type connector provided on the card is given below.

25 Pin D TYPE CONNECTOR (AD/DA CARD)

Pin No.	Used as
1	GND
2	Analog output
3	5 volt
4	GND
5	I0
6	I1
7	I2
8	I3
9	I4
10	I5
11	I6
12	I7
13	+ 12 VOLT
14	GND
15	NC
16	GND
17	I15
18	I14
19	I13
20	I12
21	I11
22	I10
23	I09
24	I08
25	- 12 VOLT

A·3

BASIC FEATURES OF AD590

1. Linear current output:1 A/ ^{o}K

2. Wide range: - 55^{o}C to + 150^{o}C

3. Two-terminal device: Voltage in/current out

4. Laser trimmed to $\pm$0.5^{o}C calibration accuracy (AD590M)

5.

5. Excellent linearity $\pm$ 0.5^{o}C over full range (AD590M)

6. Wide power supply range: +4V to +30V

7. Sensor isolation from case

8. Low cost

APPENDIX - B

Derivation of hyperbolic partial differential equation used in the derivation of control algorithm.

Consider the Fig. B.1 which shows the inner tube of heat exchanger.

In the figure, $X(z,t)$ is a temperature which is function of time and distance along the inner tube, $V(t)$ is velocity and z is the distance along the tube.

Consider the differential element of length dz as shown in the figure. Temperature at this section be $X(z,t)$. Temperature at the inlet of tube will be $X(0,t)$, while at the exit the temperature of water will be represented by $X(\ell,t)$.

Area of cross section A of the tube will be

$A_c = \frac{\pi di^2}{4}$, where di is the inner diameter of tube.

Volume of the differential element will be $= A_c \, dz$

Circumferential area of element will be $= \pi \, di.dz$

Now, Heat accumulated $H_a(t)$ in the differential element between time t and t+dt will be equal to

$$(Adz\,\rho).Cp(X(z,t) + \frac{\delta X}{\delta t}.dt) - A.dz.\rho.Cp\; X(z,t)|$$

$$\therefore \quad H_a(t) = Adz \cdot \rho \cdot Cp\left(\frac{\delta X}{\delta t} \right) \quad .. \quad (I)$$

Sensible heat entering the differential element $H_i(t)$ will be

$$H_i(t) = A\; V(t).\,\rho\,.Cp.X(z,t)$$

Sensible heat carried out of the differential element $H_o(t)$ will be

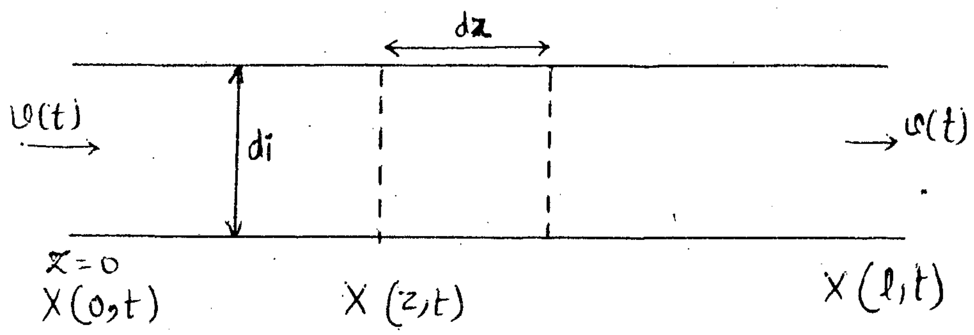


FIG B·1: INNER TUBE OF HEAT EXCHANGER WITH DIFFERENTIAL ELEMENT

$$H_o(t) = A.V(t).\rho.Cp\left[X(z,t) + \frac{\partial X}{oz}.dz\right]$$

Now, heat transferred $H_T(t)$ will be given as

$$H_T(t) = U\,di\,[X(z,t)]dz$$

$$= \frac{4\ U\ dz\ A}{di}[X(z,t)]$$

where U is the heat transferred/unit area/unit time/unit temperature.

$\therefore$ Heat accumulated will be

$$H_a(t) = H_i(t) - H_o(t) - H_T(t)$$

$$= -Adz.\rho.Cp.V(t)\frac{\partial X(z,t)}{\partial z} . \frac{4\ U\ A\ dz}{di}[X(z,t)] \quad \text{.. (II)}$$

Equating (I) & (II) get,

$$\frac{\partial X(z,t)}{\partial t} = -V(t)\frac{\partial X(z,t)}{\partial z} - \frac{4U\ A\ dz}{di}[X(z,t)]$$

$$\frac{\partial X(z,t)}{\partial t} = -V(t)\frac{\partial X(z,t)}{\partial z} - \frac{X(z,t) \times 4U}{di\ Cp.\rho} \quad \text{.. (III)}$$

Now overall heat transfer coefficient U is given as $U = U_o(1+m(\theta)^b$; where U_o is heat transfer coefficient at initial velocity V_o.

Dimensionless heat transfer parameter β is given as

$$\beta = \frac{U_o\ A_s}{V\rho A_c\ Cp} \quad \text{.. (IV)}$$

hence $\beta = \dfrac{U_o\ \ didz}{V\rho\dfrac{di^2}{4}.Cp} = \dfrac{U_o\ 4\ dz}{V\rho Cp\ di}$

Putting value of U we get

$$\beta = \frac{U\ 4\ dz}{(1+m(\Theta))^{b} V\quad Cp\ di} \qquad \text{.. (V)}$$

$\therefore$ Euqation III can be written as

$$\frac{\delta X(z,t)}{\delta t} = -V(t)\,\frac{\delta X(z,t)}{\delta z} - \beta\,(\,1+m(\Theta))^{b}\,X(z,t)$$

Expressing V(t) in dimensionless form we get

$$\frac{\delta X(z,t)}{\delta t} + (1+m(\Theta))\,\frac{\delta X(z,t)}{\delta z} = -\,\beta(1+m(\Theta))^{b}\,X(z,t)\ .$$

APPENDIX C

C.1 Determination of overall heat transfer coefficient for various flowrate.

The values of overall heat transfer coefficients at various flowrates are tabulated as below

$T_s = 101.83^{\circ}C, \quad T_i = 22^{\circ}C$

S.No.	T $^{\circ}C$	Flowrate ℓpm	LMTD	U K.Cal/hr m^2 $^{\circ}C$
1.	30.7	5.4545	76.396	1177.548
2.	31.4	5.042	76.032	1181.709
3.	35.3	3.012	73.9798	1065.039
4.	38.5	2.4	72.265	1038.826
5.	41.5	1.7544	70.631	918.218

Computations of U for various flow rate are as given below -

Heat transfered is given as

$$Q = U.As.LMTD = m.Cp.(T-T_i) \qquad .. (I)$$

where LMTD is given as

$$LMTD = \frac{(T_s - T_i) - (T_s - T)}{\ln\left(\frac{T_s - T_i}{T_s - T}\right)}$$

eqn.(I) can be written as

$$U = \frac{m.Cp.(T-T_i)}{A_s.LMTD}$$

for Ist reading

$m = 5.4545\ \ell pm = 5.4545\ Kg/m$ (ρ water = 1.0 gm/cc)

$Cp = 1\ KCal/Kg^{\circ}C$, $A_s = 0.012\ m^2$, $T = 30.7^{\circ}C$,

$T_i = 22^{\circ}C$ & $T_s = 101.83^{\circ}C$.

$\therefore \; U_1 = 1177.548$ KCal/hr m^{o}C

In the similar fashion values of U for other values of flow rates can be evaluated.

C.2 Determination of dimensionless parameter b:

Coefficient b relates overall heat transfer. coefficient at any flow rate, with that at initial flow rate (velocity) by the equation

$$U = U_o \left(1 + m(\theta)\right)^b$$

where m(Θ) is given as

$$m(\theta) = \frac{v - v_o}{v_o}$$

Velocity is related with the flow rate by equation

$$v = \frac{\text{Flow rate } (\ell pm)}{\text{Area of cross section } (cm^2)} \left(\frac{cm}{sec}\right)$$

In the present work reference or initial velocity is chosen to be corresponding to 35.3^{o}C.

The values of U, v, m(Θ) & b can be tabulated as below

S.No.	U KCal/hrm^{2o}C	v Cm/min	m(Θ)	b
1	1177.55	3.89×10^3	0.627	0.205
2	1181.71	3.86×10^3	0.613	0.217
3	1065.04	2.391×10^3	0	-
4	1038.8	1.84×10^3	-0.231	0.0985
5	918.2	1.34×10^3	-0.439	0.257

Calculations of $m(\theta)$, v & b are done as below.

<u>for Ist reading</u>:

$$v_1 = \frac{5.4545\times10^3}{1.307} = 3.89\times10^3 \text{ Cm/min}$$

Now $$v_o = \frac{3.125\times10^3}{1.307} = 2.391 \times 10^3 \text{ Cm/min}$$

hence $$m(\theta)_1 = \frac{v_1 - v_o}{v_o} = 0.627$$

Now value of u at $v = v_o$

$$= 1065.039 \text{ KCal/hr m}^2 \ {}^oC$$

Now b is related as follows -

$$v_i = v_o(1+m(\theta))^b$$

$$\therefore \quad b_1 = \frac{\ln(v_1/v_o)}{m(1+m(\theta)_1)} = 0.2054$$

The values of b for remaining values of velocities can be computed similarly.

It is seen that b is slightly varying for different values of outlet temperatures. So the average value of b is computed as below,

$$b = \frac{b_1 + b_2 + b_3 + b_4}{4} = 0.1945$$

C.3 <u>The different parameters of the system evaluated are listed as below</u> -

1) Coefficient b = 0.1945

2) Initial velocity = v_o = 2.3909 x 10^3 Cm/min

3) Area of cross section of inner tube (A_c) = 1.307 cm^2

4) Area of surface (Root area) available for heat transfer A_s = 0.012 m^2

5) Specific heat capacity of water = 1 $KCal/kg^oC$

6) Length of heat exchanger (length between inlet temperature probe & outlet temperature probe) L = 71 Cm

7) Overall heat transfer coefficient (U_o) at $v = v_o$ = 1065.04 Kcal/ hr m^2 ^oC

8) Dimensionless minimum velocity V_{min}

$$= \frac{500 \text{ (m/min)}}{2.391 \times 10^3 \text{ cm/min}}$$

$$= 0.2091$$

9) Dimensionless heat transfer parameter

$$\beta = \frac{U_o \; A_s}{A_c x C_p x v_o x \; o}$$

$$= 0.119$$

10) Dimensionless time variable

$$\theta = \frac{t \cdot v_o}{L}$$

hence θ = 0.5612 t/sec

11) Dimensionless temperature variable X is given as

$$X = \frac{(T_s - T)}{(T_s - T_i)}$$

C.4 <u>Development of the model used for the simulation</u>

The heat exchanger system was assumed to the Ist order system with time delay. The equation for such system is given as

$$Y(t) = A\,K\,(1-EXP(-(t-\tau d/\tau) \quad \text{for} \quad t > \tau d$$

$$= 0 \quad \text{for} \quad t < \tau d$$

where Y(t) is the instantaneous temperature, the constant K is characteristic for the system, while A is the step change in flow rate. The values of A, K, τ_d & τ can be evaluated as below. To the reaction curve in Fig. 6.3 a tangent was drawn at the inflection point A, and time constant τ & τ_d were found out as in the figure. The reaction curve is drawn for the step change of 1.488 lpm. As measured from the figure AK = 7.1 (total change in temperature) Hence value of K for the present system was evaluated to be equal to 4.769.

APPENDIX D

Table D.1 Variation of inlet temperature probe output with temperature when supply to probe was +12 Vdc

Temperature °C	Probe 1 Output, Vdc
21.8	2.91
22.9	2.916
24	2.926
25	2.936
26.1	2.945
27	2.955
28.1	2.967
29.2	2.977
30.1	2.987
32.1	3.006
33	3.016
34.7	3.032
36.2	3.047
37	3.055
38	3.065
39.1	3.075
40.1	3.085

Table D.2 Variation of steam temperature probe output with temperature when supply to probe was +12 Vdc

Temperature °C	Probe 2 Output, Vdc
91.7	3.61
93	3.642
94	3.652
96	3.673
97.1	3.683
98	3.693
99	3.704
99.8	3.717

Table D.3 Variation in outlet temperature probe with temp.when supply to probe was at +12 Vdc

Temperature °C	Probe 3 Output, Vdc
27.5	3.003
29	3.018
30	3.027
31.2	3.039
32.1	3.048
33.4	3.061
35	3.077
36.5	3.091
37.6	3.102
39	3.116
40.5	3.132
42.3	3.149
44.2	3.169
45.5	3.18
47.5	3.196
48.5	3.211
50	3.226

Table D.4 Variation in output voltage of 10-turn pot. when supply to the pot. was at +5 Vdc

Valve position angle, Degrees	Output of 10 turn pot., Vdc
10	0.024
60	0.079
120	0.155
180	0.23
240	0.317
300	0.39
360	0.47
400	0.526
460	0.608
520	0.666
580	0.744
640	0.826
700	0.89
760	0.97
800	1.027
900	1.16
1000	1.286
1360	1.755
1720	2.22
2100	2.7

Table D.5 Variation in flow rate with valve position

S.No	Valve pos. deg.	decreasing flowrate lpm	increasing flowrate lpm
1	140	1.37	0.8
2	160	1.57	0.822
3	180	1.75	0.937
4	200	1.98	1.132
5	220	2.17	1.333
6	240	2.26	1.463
7	260	2.4	1.666
8	280	2.53	
9	300	2.64	1.818
10	320	2.81	2.069
11	340	2.95	2.4
12	360	3.06	2.609
13	380	3.12	2.727
14	400	3.24	2.857
15	420	3.37	3
16	440	3.53	3.158
17	500	3.79	3.529
18	540	3.97	
19	580	4.11	3.75
20	640	4.34	4.0
21	740	4.34	4.0
22	900	4.82	
23	1100	5.04	
24	1260	5.08	
25	1620	5.22	
26	1920	5.35	
27	2200	5.45	

Table D.6 Variation in exit tempearture with flowrate

S.No.	Flowrate lpm	T °C
1	1.373	47.5
2	1.57	44.5
3	1.75	41.5
4	1.98	39.8
5	2.17	39.6
6	2.26	39.2
7	2.4	38.5
8	2.53	37.9
9	2.64	37.3
10	2.81	37
11	2.95	36.5
12	3.06	35.7
13	3.12	35.3
14	3.24	34.8
15	3.37	34.6
16	3.53	34.5
17	3.79	33.5
18	3.97	33.5
19	4.11	33
20	4.35	32.5
21	4.69	32.2
22	4.82	31.9
23	5.04	31.4
24	5.08	30.9
25	5.33	30.9
26	5.36	30.8
27	5.45	30.7

Table D.7 Variation in exit temperature with time (without controller) when step change in setpoint was given from 34.7 °C to 41.9 °C

S.No.	Time s	Temperature °C
1	0	34.8
2	1	35.1
3	2	35.25
4	3	35.5
5	6	36.3
6	9	37.25
7	12	39
8	15	40.1
9	18	40.4
10	21	41.1
11	24	41.35
12	27	41.5
13	30	41.7
14	33	41.75
15	36	41.8
16	39	41.85
17	42	41.85
19	45	41.85
20	48	41.86
21	51	41.86
22	54	41.86
23	57	41.87
24	60	41.87
25	63	41.88
26	66	41.88
27	69	41.88
28	72	41.88
29	75	41.89
30	78	41.9
31	81	41.9

Table D.8 Variation in exit temp. when step change in set point was given from 34.3 °C to 37 °C (Ti=21.5 °C & Ts= 100.5 °C)

Time s	simulated T, °C	actual T, °C
0	34.3	34.3
2		35.37
3	36.28	
4		36.919
5	37.51	
7	37.6	38.49
8		37.29
9	38.19	
10	37.29	
11	36.907	
12		36.83
13		36.2
14	36.68	
15	36.805	36.49
16	36.907	
17		36.907
18	37.05	36.664
19	37.05	37.15
22	37.05	37.15

Table D.9 Variation of simulated exit temp. subject to a set point change from 34.3 °C to 37 °C for different sampling periods (Ti=21.5 °C, Ts= 100.5 °C)

Time s	T °C st=1.3 s	T °C st=5 s
0	34.3	34.3
0.5	34.68	
1	36.42	
1.3	37.77	
1.8	37.327	
2		36.2
2.3	36.7	
2.6	36.508	
3.0		36.9
3.1	36.68	
3.9	37.05	
4		37.6
5		38.1
7		37.2
8		36.9
9		36.4
10		36.3
12		36.68
13		36.805
14		36.9
15		36.9
18		36.9

Table D.10 Variation of simulated exit temp. subject to a set point change from 34.3 °C to 37 °C for different values of β (Ti=21.5 °C, Ts=100.5 °C)

Time s	T °C, β=0.1	T °C, β=0.088	T °C, β=0.02
0	34.3	34.3	34.3
2	36.12	36.6	
3	36.92	37.36	
4	37.6	38.14	
5	38.2	38.824	35.17
7	36.3	37.36	
8	36.907	36.79	
9	36.61	36.31	
10	36.35	35.89	35.14
12	36.68	36.62	
13	36.805	36.817	
14	36.9	37.05	
15	37.1		35.02
17	37.1		
18			
19			
20			35.05
22			35.06

APPENDIX - E

ANVL

```
1 OPEN ANGVOL.DAT FOR OUTPUT AS #1
2 GOSUB 5
3 GOSUB 2000:A$=INKEY$:IF A$="S" THEN GOTO 3000
4 REM***************************MOTROT***************************
5 GOSUB 250:E1=E
10 PORT=&H1F0:PRINT"ANGLE=":INPUT ANGLE: EA=ANGLE*.00129
11 EB=EA:PRINT EB
12 IF EA<.645 THEN GOTO 1000
15 IF E1<EA GOTO 145:REM PRINT E1,EA
20 IF ABS(E1-EA)<.00903 THEN GOTO 90
25 PORT=&H1F0:OUT PORT+3,&H80
30 OUT PORT+0,&HFA:GOSUB 100
40 OUT PORT+0,&HF6:GOSUB 100
50 OUT PORT+0,&HF5:GOSUB 100
60 OUT PORT+0,&HF9:GOSUB 100
70 A$=INKEY$:IF A$<>"" THEN GOTO 90
80 GOSUB 250:E1=E:GOTO 15
90 IF EA=EB THEN GOTO 95:EA=EB
93 EA=EB:GOTO 15
95 PORT=&H1F0:OUT PORT+0,&HFF:FOR I= 1 TO 100:NEXT I:GOSUB 250:END

110 FOR I=1 TO 10:NEXT I
120 RETURN
140 IF EA>E1 THEN GOTO 15
145 IF ABS(E1-EA)<.00903 THEN GOTO 90'int fun givs  one more on -ve side
150 PORT=&H1F0:OUT PORT+3,&H80
160 OUT PORT+0,&HF9:GOSUB 100
170 OUT PORT+0,&HF5:GOSUB 100
180 OUT PORT+0,&HF6:GOSUB 100
190 OUT PORT+0,&HFA:GOSUB 100
200 A$=INKEY$:IF A$<>"" THEN GOTO 90
210 GOSUB 250:E1=E:GOTO 145
250 PORT=632
255 I=0
260 GOSUB 310
270 B=INP(PORT+2):C=INP(PORT+1)
280 E=((B-16*(INT(B/16)))*256+C)/450
290 RETURN
310 OUT PORT+3,0
320 OUT PORT+0,I
330 FOR J=1 TO 7:A=INP(PORT+4):NEXT
340 FOR J=1 TO 7:A=INP(PORT+5):NEXT

350 RETURN
1000 EA=.645:PRINT EA:GOTO 15
2010 I=0
2020 GOSUB 2090
2030 B=INP(PORT+2):C=INP(PORT+3)
2040 D=(B-16*(INT(B/16)))*256+C:E=D/450
2050 TO=(E-2.725)/.01
2060 WRITE #1,TO
2070 RETURN
3000 END
Ok
```

FLTM

```
80 OPEN "TEMP.DAT" FOR OUTPUT AS #1
100 GOSUB 700:GOSUB 800
150 GOSUB 430:WRITE T,#1:A$=INKEY$:IF A$<>"" THEN GOTO 150
200 GOTO 100
430 REM **************************TEMPREAD SUB*******************************
440 CLS :PORT=632
450 FOR I=1 TO 3
460 GOSUB 540
470 B=INP(PORT+2):C=INP(PORT+1)
480 D=(B-16*(INT(B/16)))*256+C:E=D/450'read voltages at ad1,ad2,ad3
490 ON I GOTO 500,510,520
500 LOCATE I+5,25:PRINT "INLET TEMP IS",(E-2.69868)/9.720001E-03:GOTO 590
510 LOCATE I+5,25:PRINT "STEAM TEMP IS",(E-2.6958)/.0101562:GOTO 600
520 LOCATE I+5,25:PRINT "OUTLET TEMP IS",(E-2.725)/.01:GOTO 610
530 REM***************************INTIALIZE AD**********************
540 OUT PORT+3,0
550 OUT PORT+0,I
560 FOR J=1 TO 7:A=INP(PORT+4):NEXT
570 FOR J=1 TO 7:A=INP(PORT+5):NEXT
580 RETURN:REM*************************************************
590 TI=(E-2.69868)/9.720001E-03:GOTO 620'convert voltages into equivallent
600 TS=(E-2.6958)/.0101562:GOTO 620'temperatures using the characteristic
610 T= (E-2.725)/.01'equations for various probes
620 NEXT I:RETURN:REM****************************************************
700 PRINT "FR",FR:REM****************************ANGLE CALC******************
************
710 IF FR>1.9802 THEN GOTO 730
720 ANGLE=-1279.681475#+5865.234912#*FR-8090.9431691#*FR^2+2755.4579589#*FR^3+21
57.6940811#*FR^4-932.61604119#*FR^5-714.38636772#*FR^6+271.50887141#*FR^7+112.61
0723#*FR^8-43.897917779#*FR^9:GOTO 780
730 IF FR>3.2432 THEN GOTO 750
740 ANGLE=123.713875#+5118.4392341#*FR-6682.6290921#*FR^2+2388.7543607#*FR^3+54.
191885833#*FR^4-29.765926261#*FR^5-55.103950857#*FR^6-4.2545462927#*FR^7+8.95077
86625#*FR^8-1.3152774788#*FR^9:GOTO 780
750 IF FR>5.042 THEN GOTO 770
760 ANGLE=310053.46373#-344908.47712#*FR+118635.33154#*FR^2+342.95851787#*FR^3-7
826.34595616#*FR^4+750.35697#*FR^5+325.73137139#*FR^6-78.563273591#*FR^7+5.30488
74686#*FR^8-.036180891963#*FR^9:GOTO 780
770 ANGLE=-153198.315#+21175.2244#*FR+3847.46336#*FR^2+225.4254064#*FR^3+51.5855
5*FR^4-16.40983602#*FR^5-4.9264009#*FR^6-.5453093511#*FR^7+.087953759711#*FR^8+.
0144066789#*FR^9
```

```
780 PRINT ANGLE:REM GOTO 700:goto 360'return after calculating angle positon for
 required flow rate
800 REM****************************ANGLE MOT***********************************
805 GOSUB 1080:E1=E'read the voltage at 10 turn helical potentiometer
810 PORT=&H1F0:PRINT "ANGLE=",ANGLE:EA=ANGLE*.00129'find voltage for new angle
840 IF E1<EA GOTO 1000'check if clk-wise or anticlk-wise rotation is required
850 IF ABS(E1-EA)<.00903 THEN GOTO 930'check if finale has reached
860 PORT=&H1F0:OUT PORT+3,&H80'select the port as output port
870 OUT PORT+0,&HFA:GOSUB 970'send signals
880 OUT PORT+0,&HF6:GOSUB 970'for single
890 OUT PORT+0,&HF5:GOSUB 970'step in anti-clk-wise
900 OUT PORT+0,&HF9:GOSUB 970'direction
910 A$=INKEY$:IF A$<>"" THEN GOTO 930
920 GOSUB 1080:E1=E:GOTO 840
930 PORT=&H1F0:OUT PORT+0,&HFF'degenerate the stepper motor windings
940 GOTO 365'go back to main progarm
960 REM******************SUB DELAY***********************
970 FOR I=1 TO 10:NEXT I
980 RETURN:REM*******************************************
990 IF EA>E1 THEN GOTO 840
6070 IF A$="C" THEN GOTO 7500
6080 GOTO 6050
6090 CLS:END
6900 CLS:LOCATE 7,23:PRINT "PLEASE MAKE SURE ABOUT FOLLOWING"
6910 LOCATE 9,23:PRINT "*********************************"'display manual
6920 LOCATE 11,20:PRINT "* WATER CONTINUOUSLY INTO"'commands to be
6930 LOCATE 12,20:PRINT "  THE OVER HEAD TANK"'performed
6940 LOCATE 14,20:PRINT "* STEAM GENERATER CONTAINS SUFFICIENT"
6950 LOCATE 15,20:PRINT "  AMOUNT OF WATER"
6960 LOCATE 17,20:PRINT "* ELECTRIC HEATERS OF STEAM GENERATER"
6970 LOCATE 18,20:PRINT "  ARE ON"
6980 LOCATE 20,20:PRINT "* STEAM TEMPERATURE HAS INCREASED ABOVE"
6990 LOCATE 21,20:PRINT "  100 Deg. C"
7000 LOCATE 23,20:PRINT "PRESS 'B' TO GO BACK"
7010 B$=INKEY$:IF B$="B" THEN GOTO 6000'check if 'b' has been pressed
7020 FOR I=1 TO 100:NEXT I:LOCATE 23,20:PRINT "                    "
7025 FOR I=1 TO 100:NEXT I'delay for blinking the messege
7030 GOTO 7000
7500 RETURN
```

SIMULATION

```
80 OPEN "S.DAT" FOR OUTPUT AS #3
90  T=34:T1=T:PRINT T:OPEN "SIMU2.DAT" FOR OUTPUT AS #2
100 DIM V(6):R=0!:FOR I=1 TO 6:V(1)=1!:PRINT V(1):NEXT I
110 OPEN "SAMP.DAT" FOR OUTPUT AS #1:FOR I=1 TO 6:WRITE #1,V(I):NEXT I:CLOSE #1
120 SAMP=3.8:B1=.9:BETA=.088001:TS=100.5:TI=21.5:VO=3.125:INPUT XS1
122 T5=T:T4=T
125 IF XS1<T GOTO 2400
127 WRITE #2,T:XS=XS1+3
130 WRITE #2,T:GOSUB 2100:IF ABS(XS1-T1)<.5 THEN GOTO 3000:PRINT TI,TS,T,"VO",VO
135 PRINT "VO",VO:PRINT "err=",T5-T4,"t5",T5,"t4",T4
140 XSET=(TS-XS)/(TS-TI):XT=(TS-T)/(TS-TI):PRINT "XSET & XT",XSET,XT
150 R=0:FOR I=1 TO 6:R=R+V(I)*SAMP:
160 IF R>1 GOTO 180
170 NEXT I:GOTO 270
180 K=I-1:SUM=R-V(I)*SAMP:PRINT "SUM=",SUM,"R=",R
190 LAMB=(1-SUM)/(V(K+1)*(SAMP-SVD)):PRINT "LAMB=",LAMB,"SAMP=",SAMP
200 GOSUB 290:PRINT "SUM1=",SUM1:REM GOTO 2000
210 SIG=SUM1*(SAMP-SVD)+V(K+1)^B1*LAMB*(SAMP-SVD):PRINT "SIG=",SIG
220 VNEW1=(1!/BETA*LOG(XT*EXP(BETA*SIG)/XSET))^(.1/(B1-1!))
225 VNEW=VNEW1-(T5-T4)*3.35001E-03/.25
230 PRINT "I=",I,"K=",K
240 OPEN "SAMP.DAT" FOR OUTPUT AS #1
250 FOR I=0 TO 4:V(6-I)=V(6-I-1):NEXT I:V(1)=VNEW
260 FOR I=1 TO 6:WRITE #1,V(I):NEXT I:CLOSE #1:FOR I=1 TO 6:PRINT V(I):NEXT I
265 GOTO 330
270 PRINT "SAMPLING PERIOD TOO SMALL TRY ANOTHER VALUE":INPUT SAMP:GOTO 150
280 REM**************************SUMMATION SUM******************************
290 SUM1=0!:M=K
300 FOR I=1 TO M:SUM1=V(I)^B1+SUM1:NEXT I:PRINT "SUM1=",SUM1:PRINT V(1),V(2),B
310 RETURN
320 REM*VO=1.7445**********************************************************
330 V=VNEW*VO
340 FR1=V*1.307:FR2=1.307*V(2)*VO :DFR=FR2-FR1:PRINT "dFR=",DFR
350 IF DFR<0 THEN GOTO 730
365 IF DFR>0 THEN GOTO 700
700 REM INPUT "FR",FR:REM*******************************ANGLE CALC*****************
****************
705 FOR I= 0 TO 10 STEP 5
710 S(I)=T1+(3.7*DFR)*(1-2.71828^(-I/12)):WRITE #3,S(I),I
715 NEXT I
720 T=S(10):T1=T:PRINT T:T4=T5:T5=T:GOTO 130
730 FOR I=0 TO 10 STEP 5
750 Z(I)=T1+(3.7*DFR)*(1-2.71828^(-I/12)):WRITE #3,Z(I),I
755 NEXT I
760 T=Z(10):T1=T:PRINT T:T4=T5:T5=T:GOTO 130
2000 END
2100 TIME$="00"
2110 X$=TIME$
2120 MIN$=MID$(X$,4,2)
2130 MIN=VAL(MIN$)
2140 SEC$=MID$(X$,7,2)
2150 SEC=VAL(SEC$)
2160 IF MIN=0 AND SEC=5 THEN GOTO 2190
2170 GOTO 2110
2190 RETURN
3000 CLOSE #2:END
```

MAIN

```
80 GOSUB 6000'divert to display main menu
90 GOSUB 430'read the temperatures
100 DIM V(7):R=0!:FOR I=1 TO 7:V(I)=1!:PRINT V(I):NEXT I
110 OPEN "SAMP.DAT" FOR OUTPUT AS #1:FOR I=1 TO 7:WRITE #1,V(I):NEXT I:CLOSE #1
115 OPEN "tem.dat" FOR OUTPUT AS #2
120 SAMP=3.55:B1=.9:BETA=7.500001E-02:V0=3.125:INPUT XS1
130 WRITE #2,T'write T into file temp.dat
135 GOSUB 2100:GOSUB 430:IF ABS(XS1-T)<.5 THEN GOTO 2000:PRINT TI,TS,T'read temp
eratures after a time delay
140 XSET=(TS-XS)/(TS-TI):XT=(TS-T)/(TS-TI):PRINT "XSET & XT",XSET,XT'convert int
o dimension less form
150 R=0:FOR I=1 TO 7:R=R+V(I)*SAMP:
160 IF R>1 GOTO 180
170 NEXT I:GOTO 270
180 K=I-1:SUM=R-V(I)*SAMP:PRINT "SUM=",SUM,"R=",R
190 LAMB=(1-SUM)/(V(K+1)*(SAMP-SVD):PRINT "LAMB=",LAMB,"SAMP=",SAMP
200 GOSUB 290:PRINT "SUM1=",SUM1:REM GOTO 2000
210 SIG=SUM1*(SAMP-SVD)+V(K+1)^B1*LAMB*SAMP:PRINT "SIG=",SIG
220 VNEW=(1!/BETA*LOG(XT*EXP(BETA*SIG)/XSET))^(.1/(B1-1!)):PRINT "VNEW=",VNEW
230 PRINT "I=",I,"K=",K
250 FOR I=0 TO 5:V(7-I)=V(7-I-1):NEXT I:V(1)=VNEW

260 FOR I=1 TO 7:WRITE #1,V(I):NEXT I:CLOSE #1:FOR I=1 TO 7:PRINT V(I):NEXT I
265 GOTO 330
270 PRINT "SAMPLING PERIOD TOO SMALL TRY ANOTHER VALUE":INPUT SAMP:GOTO 150
280 REM**************************SUMMATION SUM*******************************
290 SUM1=0!:M=K
300 FOR I=1 TO M:SUM1=V(I)^B1+SUM1:NEXT I:PRINT "SUM1=",SUM1:PRINT V(1),V(2),B
310 RETURN
320 REM*V0=1.7445*********************************************************
330 V=VNEW*V0'calculate new velocity value
340 FR=V*1.307:FR2=1.307*V(2)*V0:DFR=FR-FR2:PRINT "dfr=",DFR
345 IF DFR>0 THEN GOTO 5000:GOTO 700'check if increase or decrease in flow rate
is required & rotate the motor after calculating the new position
360 PRINT ANGLE:GOTO 800
365 GOTO 130
430 REM ****************************TEMPREAD SUB*****************************
440 CLS :PORT=632
450 FOR I=1 TO 3
460 GOSUB 540
470 B=INP(PORT+2):C=INP(PORT+1)
480 D=(B-16*(INT(B/16)))*256+C:E=D/450'read voltages at ad1,ad2,ad3
490 ON I GOTO 500,510,520
500 LOCATE I+5,25:PRINT "INLET TEMP IS",(E-2.69868)/9.720001E-03:GOTO 590
510 LOCATE I+5,25:PRINT "STEAM TEMP IS",(E-2.6958)/.0101562:GOTO 600
520 LOCATE I+5,25:PRINT "OUTLET TEMP IS",(E-2.725)/.01:GOTO 610
530 REM***************************INTIALIZE AD**********************
540 OUT PORT+3,0
550 OUT PORT+0,1
560 FOR J=1 TO 7:A=INP(PORT+4):NEXT
570 FOR J=1 TO 7:A=INP(PORT+5):NEXT
580 RETURN:REM**********************************************
590 TI=(E-2.69868)/9.720001E-03:GOTO 620'convert voltages into equivallent
600 TS=(E-2.6958)/.0101562:GOTO 620'temperatures using the characteristic
610 T= (E-2.725)/.01'equations for various probes
620 NEXT I:RETURN:REM**********************************************************
700 PRINT "FR",FR:REM**************************ANGLE CALC*********************
```

```
************
710 IF FR>1.9802 THEN GOTO 730
720 ANGLE=-1279.681475#+5865.234912#*FR-8090.9431691#*FR^2+2755.4579589#*FR^3+21
57.6940811#*FR^4-932.61604119#*FR^5-714.38636772#*FR^6+271.50887141#*FR^7+112.61
0723#*FR^8-43.897917779#*FR^9:GOTO 780
730 IF FR>3.2432 THEN GOTO 750
740 ANGLE=123.713875#+5118.4392341#*FR-6682.6290921#*FR^2+2388.7543607#*FR^3+54.
191885833#*FR^4-29.765926261#*FR^5-55.103950857#*FR^6-4.2545462927#*FR^7+8.95077
86625#*FR^8-1.31527747B8#*FR^9:GOTO 780


750 IF FR>5.042 THEN GOTO 770
760 ANGLE=310053.46373#-344908.47712#*FR+118635.33154#*FR^2+342.95851787#*FR^3-7
826.34595616#*FR^4+750.35697#*FR^5+325.73137139#*FR^6-78.563273591#*FR^7+5.30488
74686#*FR^8-.036180891963#*FR^9:GOTO 780
770 ANGLE=-153198.315#+21175.2244#*FR+3847.46336#*FR^2+225.4254064#*FR^3+51.5855
5*FR^4-16.40983602#*FR^5-4.9264009#*FR^6-.5453093511#*FR^7+.08795375971l#*FR^8+.
0144066789#*FR^9
780 PRINT ANGLE:REM GOTO 700:goto 360'return after calculating angle positon for
 required flow rate
800 REM*****************************ANGLE MOT*********************************
805 GOSUB 1080:E1=E'read the voltage at 10 turn helical potentiometer
810 PORT=&H1F0:PRINT "ANGLE=",ANGLE:EA=ANGLE*.00129'find voltage for new angle
840 IF E1<EA GOTO 1000'check if clk-wise or anticlk-wise rotation is required
850 IF ABS(E1-EA)<.00903 THEN GOTO 930'check if finale has reached
860 PORT=&H1F0:OUT PORT+3,&H80'select the port as output port
870 OUT PORT+0,&HFA:GOSUB 970'send signals
880 OUT PORT+0,&HF6:GOSUB 970'for single
890 OUT PORT+0,&HF5:GOSUB 970'step in anti-clk-wise
900 OUT PORT+0,&HF9:GOSUB 970'direction
910 A$=INKEY$:IF A$<>"" THEN GOTO 930
920 GOSUB 1080:E1=E:GOTO 840
930 PORT=&H1F0:OUT PORT+0,&HFF'degenerate the stepper motor windings
940 GOTO 365'go back to main progarm
960 REM******************SUB DELAY***********************
970 FOR I=1 TO 10:NEXT I
980 RETURN:REM*****************************************
990 IF EA>E1 THEN GOTO 840
1000 IF ABS(E1-EA)<.00903 THEN GOTO 930
1010 PORT=&H1F0:OUT PORT+3,&H80
1020 OUT PORT+0,&HF9:GOSUB 970'send signal
1030 OUT PORT+0,&HF5:GOSUB 970'for single
1040 OUT PORT+0,&HF6:GOSUB 970'step in clk-wise
1050 OUT PORT+0,&HFA:GOSUB 970'direction
1060 A$=INKEY$:IF A$<>"" THEN GOTO 930
1070 GOSUB 1080:E1=E:GOTO 1000
1075 REM********************VOLTAGE*********************
1080 PORT=632:I=0
1085 GOSUB 540:B=INP(PORT+2)
1090 C=INP(PORT+1)
1095 E=((B-16*(INT(B/16)))*256+C)/450:RETURN:REM**********
2000 CLOSE #2:END
2100 TIME$="00"
2110 X$=TIME$
2120 MIN$=MID$(X$,4,2)
```

```
2140 SEC$=MID$(X$,7,2)
2150 SEC=VAL(SEC$)
2160 IF MIN=0 AND SEC=7 THEN GOTO 2190'check if 7 seconds have elapsed
2170 GOTO 2110
2190 RETURN
5000 REM INPUT "fr=",FR'calculate angle position for increasing order of
5010 IF FR>1.132 THEN GOTO 5030'flow rate
5020 ANGLE=64781.649269#-276161.57248#*FR+406034.61166#*FR^2-202023.81816#*FR^3-
31649.03713#*FR^4+39138.2349#*FR^5:GOTO 5080
5030 IF FR>2.609 THEN GOTO 5060
5040 ANGLE=1873.2049789#-5513.9416901#*FR+6753.7039071#*FR^2-3910.5820515#*FR^3+
1096.8161968#*FR^4-119.69922997#*FR^5:GOTO 5080
5060 ANGLE=-7852.4152801#+8835.4227887#*FR-3329.0757181#*FR^2+439.6368991#*FR^3+
13.56890686#*FR^4-5.1120397335#*FR^5:GOTO 5080
5080 PRINT ANGLE
5090 GOTO 360
5999 REM***************************SGNON*************************
6000 CLS:LOCATE 9,25:PRINT "HEAT EXCHANGER READY"'display initial
6010 LOCATE 13,25:PRINT "PRESS 'H' FOR OP-MANUAL"'message on
6020 LOCATE 15,25:PRINT "PRESS 'C' TO CONTINUE"'screen
6030 LOCATE 17,25:PRINT "PRESS 'A' TO ABORT"
6040 LOCATE 11,25:PRINT "***********************"
6050 A$=INKEY$:IF A$="A" THEN GOTO 6090
6060 IF A$="H" THEN GOTO 6900
6070 IF A$="C" THEN GOTO 7500
6080 GOTO 6050
6090 CLS:END
6900 CLS:LOCATE 7,23:PRINT "PLEASE MAKE SURE ABOUT FOLLOWING"
6910 LOCATE 9,23:PRINT "*********************************"'display manual
6920 LOCATE 11,20:PRINT "* WATER CONTINUOUSLY INTO"'commands to be
6930 LOCATE 12,20:PRINT "  THE OVER HEAD TANK"'performed
6940 LOCATE 14,20:PRINT "* STEAM GENERATER CONTAINS SUFFICIENT"
6950 LOCATE 15,20:PRINT "  AMOUNT OF WATER"
6960 LOCATE 17,20:PRINT "* ELECTRIC HEATERS OF STEAM GENERATER"
6970 LOCATE 18,20:PRINT "  ARE ON"
6980 LOCATE 20,20:PRINT "* STEAM TEMPERATURE HAS INCREASED ABOVE"
6990 LOCATE 21,20:PRINT "  100 Deg. C"
7000 LOCATE 23,20:PRINT "PRESS 'B' TO GO BACK"
7010 B$=INKEY$:IF B$="B" THEN GOTO 6000'check if 'b' has been pressed
7020 FOR I=1 TO 100:NEXT I:LOCATE 23,20:PRINT "                          "
7025 FOR I=1 TO 100:NEXT I'delay for blinking the messege
7030 GOTO 7000

7500 RETURN
```