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Introduction

In the study of atmospheric boundary layer the data is collected using, usually an instrumented tower of desired height. The instruments are arranged either in a geometric or in a logarithmic height. Though towers of varying heights are available in the Institute to probe the surface atmosphere interfacial region i.e., up to a height of 1 meter above the surface level, a moving platform to carry light weight sensor was planned. The objective of the plan is to move the sensor up and down with the desired timings. To move the sensors up and down a stepper motor was chosen as a moving device. The stepper motor is a device which needs special circuit to drive it in the desired speed and direction. Though such circuits are available commercially, their cost is very high. In the Institute, attempts were made to design these driving circuits using components available in the laboratory.

In this report, details of the circuitry required for the stepper motor are described and at the end of the report, use of a temperature sensor and its performance in the field is described.

1)Details of the Stepper Motor

Unlike other motors, the stepper motor requires pulses to control its speed and direction.

a) Stepper Motor and its Functioning [1]

A stepper motor is an electromechanical device which actuates a train of step angular movements in response to a train of input pulses on a one-to-one basis; one step being actuated by one input pulse. The shaft of the motor rotates in equal increments when a train of input pulses is applied. To control the direction and number of steps, appropriate pulses are applied to the stator windings of the motor. There are two most common types of stepper motors:

(i) Permanent magnet type and (ii) Variable reluctance type.

(i)Permanent magnet type

It has stator (coil) and a rotor on which permanent magnets are attached with alternate north and south poles. The number of these permanent poles, (sometimes they are called teeth) may vary from 6 to 50. Each stator pole has two coils wound in opposite directions, so that it can be made either a north or a south pole as decided by the applied pulse. This type of winding is known as bifiller pole winding. A typical stepper motor with four poles on the stator and 6 teeth on the rotor is shown in fig. 1. A typical bifiller pole winding is shown in fig. 2.

As shown in Fig 2, X and Y are two coils on the same pole. M and N are also coils on the same pole at diametrically opposite position. Resistance R is used to reduce the electrical intertia of the highly inductive windings.

Referring to Fig. 1, if the pole A is made a north pole, pole C is made a south pole and the permanent south pole No.1 of the rotor will stand just below pole A of the stator. To give a clockwise motion, the supply of poles A and C is switched off and the poles B and D are energised. The pole B is made a south pole and D a north pole. Now the permanent north pole No.2 of the rotor comes just below the pole B. In the next step, the pole C is made a north pole and A as south pole. After this, D is made a south pole and B a north pole . Again the pole A is made a north pole and C a south pole and whole sequence is repeated. In this order poles are energised to a give a clockwise rotation. To rotate the rotor anticlockwise , after making A pole a north-pole and B a south pole, D is made south pole and B a north pole. Thus each time a stepper motor is actuated, it moves its shaft by a precise angular movement.

Very often a stepper motor having 1.8 step angle has 50 teeth on the rotor and it has 8 poles on the stator. A movement of 0.9 step can be achieved by a proper excitation. The advantage of such a discrete movement is that one always knows the position of the rotor shaft by counting the steps or vice versa.

(ii) Variable reluctance type

In this type of motor, the rotor does not carry permanent poles. The stator and rotor are made of soft iron punchings. There are 3 phase windings on the stator. These consecutive poles on the stator are called three phases. A variable reluctance stepper motor must have at least three phases in order to have control over the direction in which the step is moved. If there are 3 phases on the rotor there must be equal number of sections/winding on the stator. Thus the rotor and the stator will have the same number of teeth which means that the tooth pitch on the stator and rotor is the same. Although 4 or 5 phase motors are common, motors with as many as eight phases are also available . For an "n" phase motor, the stator teeth are displaced by 1/n of the tooth pitch from section to section. If any one phase of the winding is energised with a DC signal, the magnetomotive force set up will position the motor such that the teeth of the rotor section under the excited phase are aligned opposite to the teeth on the excited phase of the stator. This is the position of the minimum reluctance , and the motor is in stable equilibrium. Switching on the next stator coil in sequence will turn the motor in one direction and a sequence opposite to the above will make the motor to move in opposite direction.

In the present experiment a stepper motor of the following specifications is used.

1) Type - Permanent Magnet

2) Torque - 3 kg-cm

3) Input - 6 volts D.C

4) Current - 1.4 A/phase

5) Step movement - 1.8

6) Number of teeth on the rotor - 50

7) Coils - 4 (1, 2, 3, 4)

The basic coil connections of the stepper motor are shown in fig. 3. White and Black wires are the common points of the coils; Red, Orange, Blue and Green are identified for coils 1, 2, 3 and 4 respectively.

Referring to fig.2 in position 1 of the switch, the coils red and blue are energised and the motor rotates in a clockwise direction. In position 2 of the switch, coils orange and green are excited and the motor rotates in the anticlockwise direction.

Thus, it is necessary to generate pulses so that the motor rotates in a proper direction and at a proper speed. There are different types of circuits available commercially. They can be bought and used with the stepper motor but the cost involved is very exhorbitant. A circuit of current rating useful for the present motor usually costs more than Rs.10,000/-.

The circuit described below is less expensive and costs less than Rs.2,000/-. Also, the circuit is made versatile to start and stop the rotation at desired time, and the predetermined delay in changing the direction is also incorporated in the circuit. Usually, while designing the stepper motor driving circuits, care must be taken to minimize the coil current and such methods are also available [2].

2. Details of the circuitry

Fig.4 shows the block diagram of the entire circuitry of the stepper motor driver circuit. It consists of the following sub circuits as shown in the block diagram.

i) Timer

ii) Logic Driver

iii Decoder

iv) Current Amplifier

The complete circuit details of the stepper motor drive are shown fig. 5. IC1 constitutes a timer circuit, IC2 and IC3 form NAND gates/Logic driver and decide the combination of pulses. The outputs of 1C2 & 1C3 are connected to 1C4 which is a decoder circuit. The output of this decoder circuit drives the transistor where the stepper motor coils are connected in the collector as loads. These four transistors form the current amplifier.

(i) Timer circuit

The timer circuit consists of CD 4060 [3] which is basically 14 stage binary counter. It has a 40 Mhz oscillating frequency.The oscillator frequency can be set with the help of RC combinations connected at Pins 9, 10, and 11. In the present experiment following values were utilized for the C, R1, R2

C = 0.47 F

R1 = 12.06 k (variable)

R2 = 9.96 k (fixed)

With the above combination an oscillation frequency of 105 c/s is obtained. This corresponds to a period 9.5 x 10 secs. Fig. 6 shows the timing diagram for different outputs of the CD 4060. For the present work, the outputs, Q 4, Q5 & Q14 are considered. As shown in fig 6. Q4 remains in" 1" state from 8-16 secs. Whereas Q5 remains in 1 state from 16-32 secs. whereas Q14, remains in 0 state till 8192 sec. and then goes to 1 state

This discussion holds good with the consideration that the initial Q0 output is of 1 sec duration. As mentioned above the pulse width is 9.5 x 10 sec. With this as primary pulse, The first reset pulse (fig 5) appears at 9.5 x 10 sec. Whereas Q4, Q5, Q14 outputs appear at 152 x 10 sec, 304 x 10 sec and 77.8 sec respectively. Basically Q4 pulse is the driving pulse which controls entire functioning of stepper motor.

As mentioned in the functioning of stepper motor, each pulse rotates the stepper motor by 1.8. Thus 200 pulses are required to rotate the rotor by 360. Considering the basic pulse width (152 x 10 sec), the time required for one full rotation of the rotor would be 200 x 152 x 10 = 30.4 sec.

(ii) Logic Driver

The pulses from Q4, Q5, Q14 are connected to next stage ie. IC2 and IC3 which consists of IC 7400. Each IC 7400 contains 4 NAND gates. Outputs Q4, Q5 and Q14 from the timer circuit are connected to various inputs of IC2, IC3 as shown in fig.5. The outputs of different NAND gates of IC2 are identified as A B C D and whereas the outputs of IC3 are identified as a b c d.

Fig. 7 shows the details of the NAND gates connections. As mentioned earlier the outputs of 1C2 are identified as A B C and D .Similarly IC 3-gates outputs are identified as a b c d final outputs D and d are connected to control inputs A and B of the Decoder (IC 4052), as shown in fig. 5.

The truth table of the logic driver circuit is shown in Table 1. It is broadly divided into two parts I and II, depending upon the Q14 output. Part I belongs to the truth table when the Q14 output is low "0" and part II when Q14 is high "1". Thus, Q14 pulse is the primary pulse which controls the direction of stepper motor rotation. When the Q14 pulse is present the entire sequence of outputs D and d get changed and lead to the reversal of the direction of stepper motor rotation.

(iii) Decoder

IC4 4052 (3) is dual 4 channel analog decoder. It has two binary control inputs A and B and an inhibit input.The two binary input signals select 1 or 4 pairs of channels to be turned on. Pin no. 9 (B) and 10 (A) are the control inputs of 4052. Pin No. 1, 5, 2 and 4 are the output points. Pin 3 is to be supplied with + 5 volts supply for decoding purpose whereas for encoding purpose it is to be taken as output point. In the present experiment it is connected to a + 5 volts supply. The truth table for Decoder 4052, with two control inputs A and B from IC2 and IC3 is given in Table II. The decoder outputs Qo , Q1 , Q2 and Q3 correspond to pin No. 1 , 5 , 2 and 4 respectively.

(iv) Current Amplifier

Output points 1, 5, 2 and 4 of the Decoder circuit are connected to the base of four sets of Darlington transistor pairs T1, T2, T3 and T4. The first transistor in the Darlington pair is 2N 3440 and the second one being 2 N 3773. The transistor 2N 3440 is a medium level power transistor delivering 1 watt power (maximum) and has a hfe of 40. The transistor 2 N 3773 can deliever 30 A current and it has a hfe of 30. Though this much high current rating of the transistor is not required, due to ready availability of this transistor, it was utilised in the circuit. Four coils of the stepper motor, Red, Orange, Blue and Green are connected in the collector of the transistors, T5, T6, T7 and T8 respectively. Whenever there is a '1' pulse at the base of the transistor, the particular darlington pair transistor conducts and the particular coil in the collector circuit is energised. A + 6 volts supply is used for stepper motor, whereas the rest of the circuitry operates on + 5 volts supply.

3) Moving Platform

Once the desired rate of rotation/direction of the stepper motor is achieved, the design of the moving platform is easy. The motor was fixed on a heavy stand. A 1" aluminium square was fixed on a heavy stand as shown in fig. 8, which shows the schematic diagram of the setup. On the rotor portion of the motor a stepup gear system was designed to have a 1:2 ratio of rotation. Thus the secondary gear will rotate with double the speed of the main gear. On the secondary gear a pulley was fixed so that a belt can be fitted on it. Similarly pulley was fixed on the aluminium rod at 1 meter distance from the top of the heavy stand. For coupling purpose another pulley was on the aluminium rod so that with the help of 3 pulley system, the belt movement becomes easy.

The fig. 8 shows the moving platform with stepper motor in the Laboratory. A three terminal thermistor was fixed on the belt so that in the beginning of the cycle, the thermistor is just touching the surface of soil and later it moves up on the belt. The time taken by the sensor to move from surface to 1 meter level is 150 sec. On the return path also it takes same time. Fig. 9 shows the moving platform in the laboratory.

As far as electronics is concerned towards the position attainable by the platform corresponding to known rotations of stepper motor, there cannot be any error. The accuracy of the position is better than 0.1 % . But due to mechanical problems like slight slip of the thread on the pulley may lead to some errors. This is purely a mechanical problem only. The overall accuracy of the position is better than + 1 % . Thus the repeatability of the position will also be of the same order +1%.

4. Data analysis

The above set up was used for four days continuously at IITM Pashan campus. Some of the results obtained by this system are shown in Fig. 10a, 10b, 10c and 10d. In fig. 10a shows the temperature variations between ground (G) and 1 meter above the ground, during midnight hours. It may be observed that between 0020-0040, 0045-0100 hrs, the entire one meter atmospheric surface boundary layer has reduced to a steady state and shows no variation in temperature.

Fig.10 b shows the build up of temperature in one meter thick atmospheric surface layer. It may be observed that after sunrise the increase in temperature is quite fast. The temperature near the surface increases from 22.8 to 27.0 within a span of roughly 40 minutes.

Fig 10 c shows the temperature variations during 0700-0800 hrs. An increase of $5^{o}-6^{o}C$ temperature change is observed in the said layer.

Fig. 10 d shows the variations in temperature during peak convective activity. Though, as a slab, the one meter thick layer may have a thoroughly mixed nature, but there is a lot of turbulence, as seen by the temprature variations of the order 6-8 C in the said layer. Fig. 10b, c and d shows the variation in temperature recorded during 0600-0700 hrs, 0700-0800 hrs and 1200-1300 hrs on 20.05.92.

Acknowledgements:

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References:

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4. Malvino A.P., "Digital Computer Electronics", Tata McGraw-Hill Publishing Company, New Delhi, 1984, pp 34-36.

TABLE I

Q4	Q14	Q5	A $=\overline{Q4.Q14}$	B $=\overline{Q4.A}$	C $=\overline{A.Q14}$	D $=\overline{B.C}$	a $=\overline{Q14.Q5}$	b $=\overline{Q5.a}$	c $=\overline{Q14.a}$	d $=\overline{b.c}$
0	0	0	1	1	1	0	1	1	1	0
1	0	0	1	0	1	1	1	1	1	0
0	0	1	1	1	1	0	1	1	0	1
1	0	1	1	0	1	1	1	1	0.	1
0	1	0	1	1	0	1	1	0	1	1
1	1	0	0	1	1	0	1	0	1	1
0	1	1	1	1	0	1	0	1	1	0
1	1	1	0	1	1	0	0	1	1	0

TABLE II

Truth Table for Clockwise Rotation

Control inputs		Decoder Output				Motor Terminal			
B	A	Q3(4)	Q2(2)	Q1(5)	Q0(1)	Red	Blue	Orange	Green
0	0	0	0	0	1	1	0	0	0
0	1	0	0	1	0	0	1	0	0
1	0	0	1	0	0	0	0	1	0
1	1	1	0	0	0	0	0	0	1

Truth Table for Anticlockwise rotation

Control inputs		Decoder Output				Motor Terminal			
B	A	Q3(4)	Q2(2)	Q1(5)	Q0(1)	Red	Blue	Orange	Green
1	1	1	0	0	0	0	0	0	1
1	0	0	1	0	0	0	0	1	0
0	1	0	0	1	0	0	1	0	0
0	0	0	0	0	1	1	0	0	0

Schematic diagram of Stepper Motor

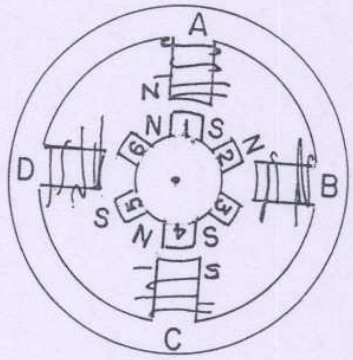


Fig. 1.

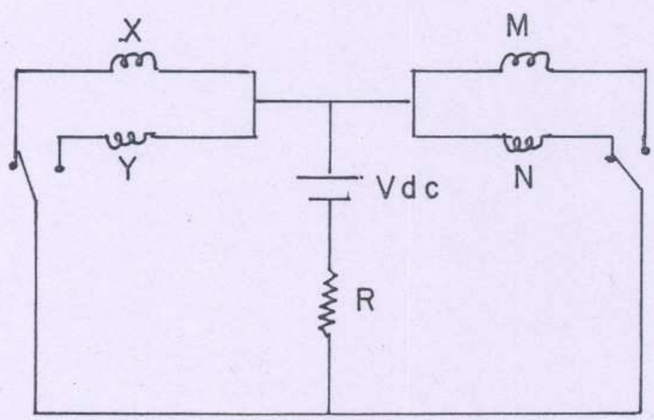
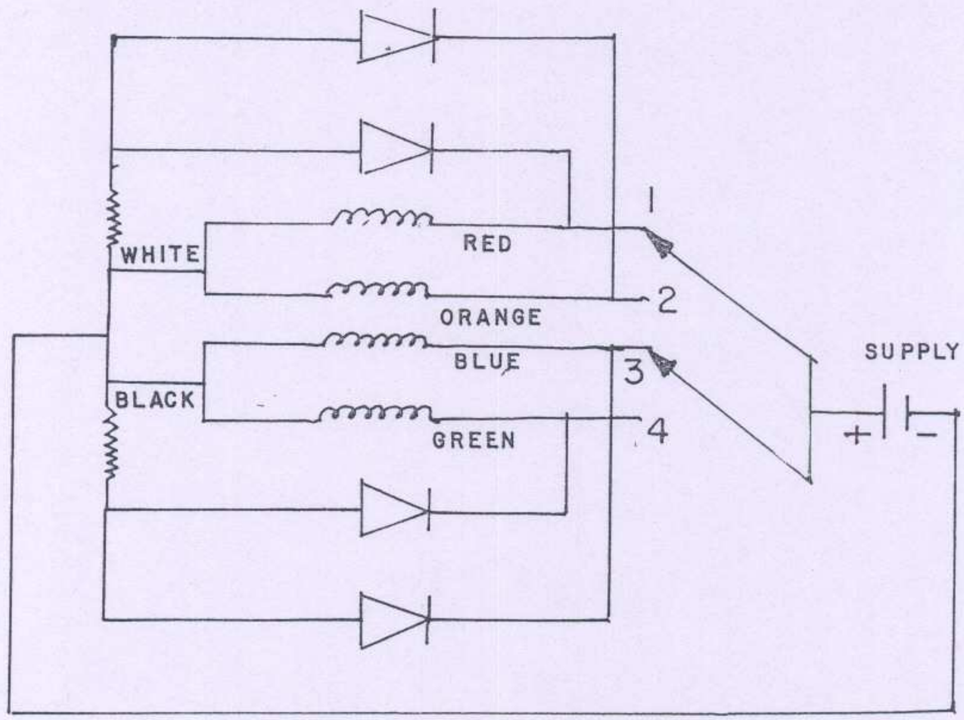


Fig. 2.

Stepper motor layout



Specifications

Supply Voltage —— + 6V D.C.

Current ———— 1·4 A/Phase

Torque ———— 3 Kg.−Cm

Fig. 3

BLOCK DIAGRAM OF THE SYSTEM

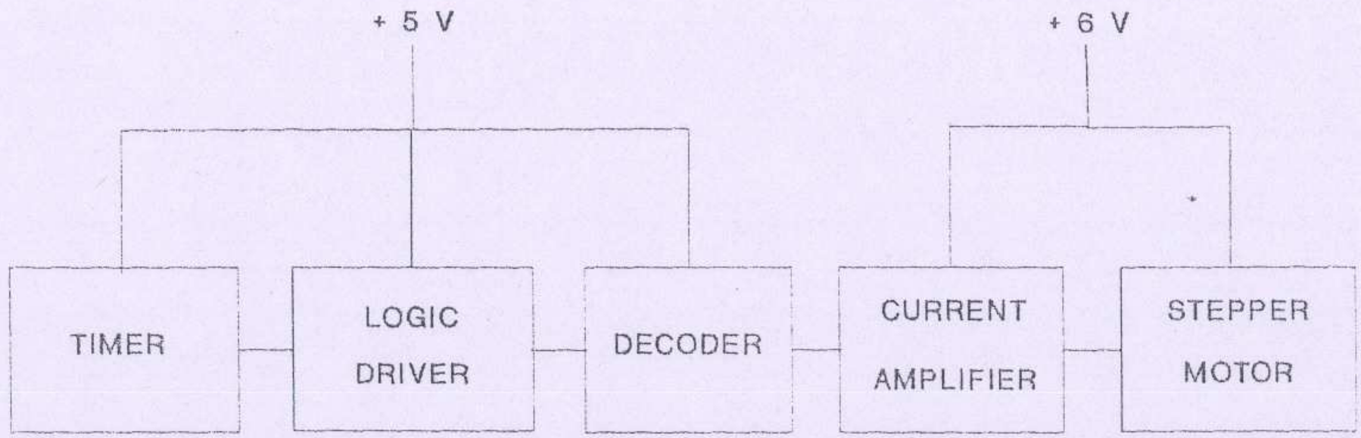
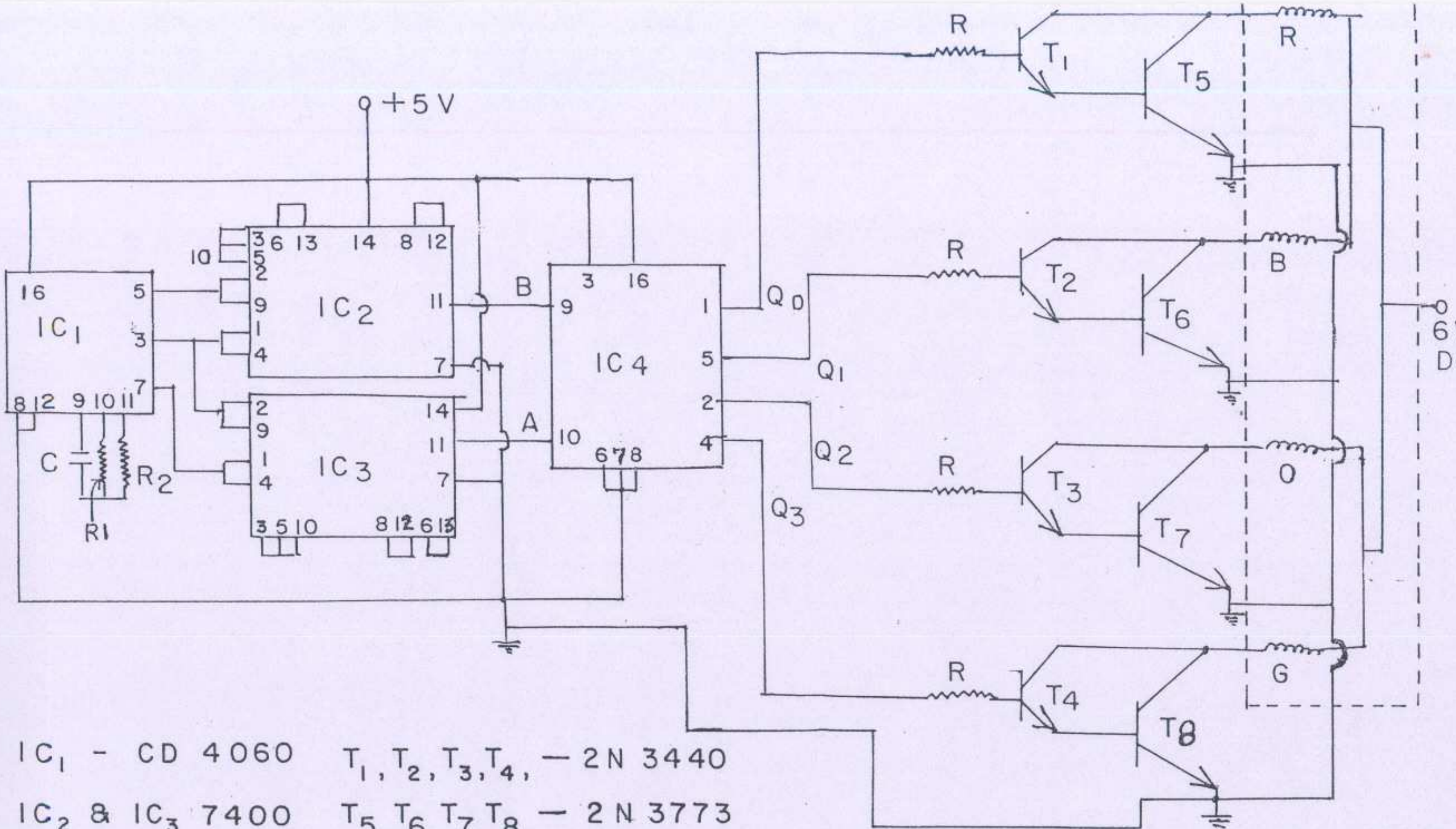
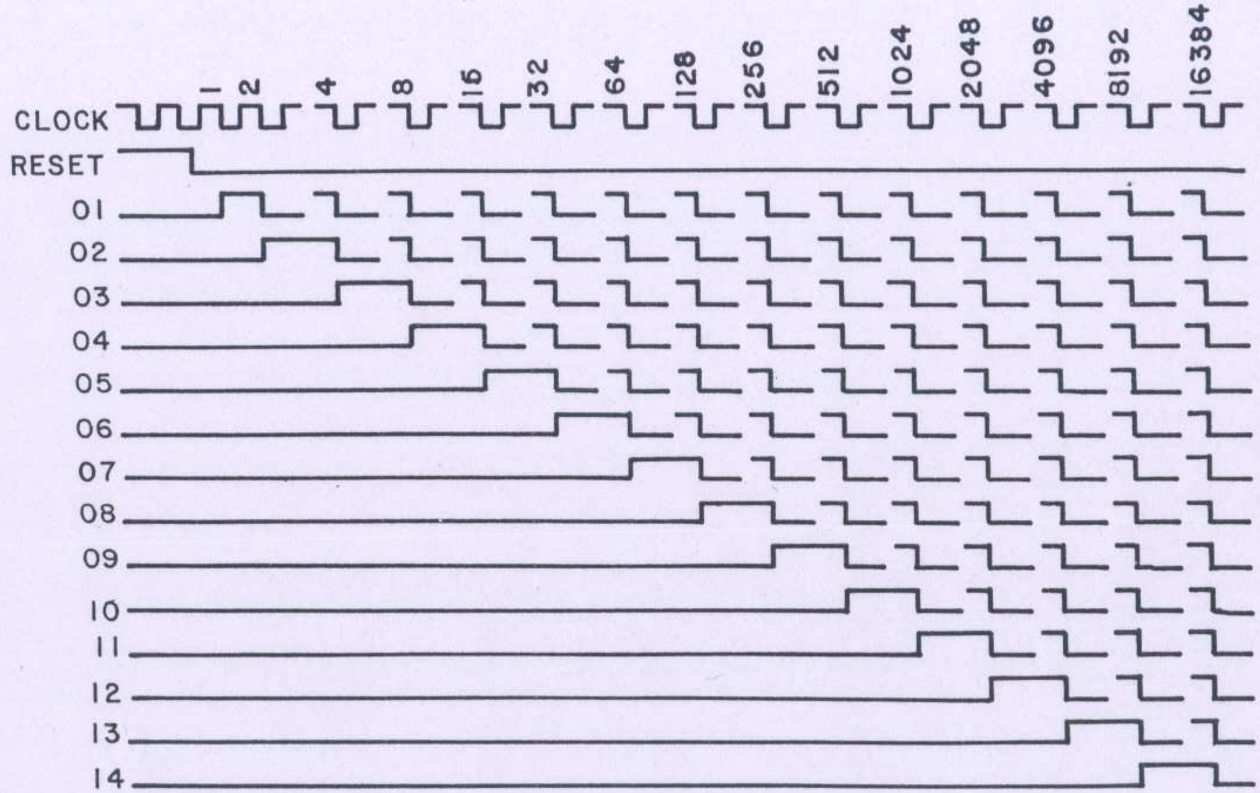


Fig. 4



IC_1 -	CD 4060	T_1, T_2, T_3, T_4,	— 2N 3440
IC_2 & IC_3	7400	T_5, T_6, T_7, T_8	— 2N 3773
IC_4	HC 4052	R - 10 KΩ	
C -	0·47 μF		
R_2 -	9·96 kΩ		
R_1 -	12-06 kΩ		

Fig. 5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RESET
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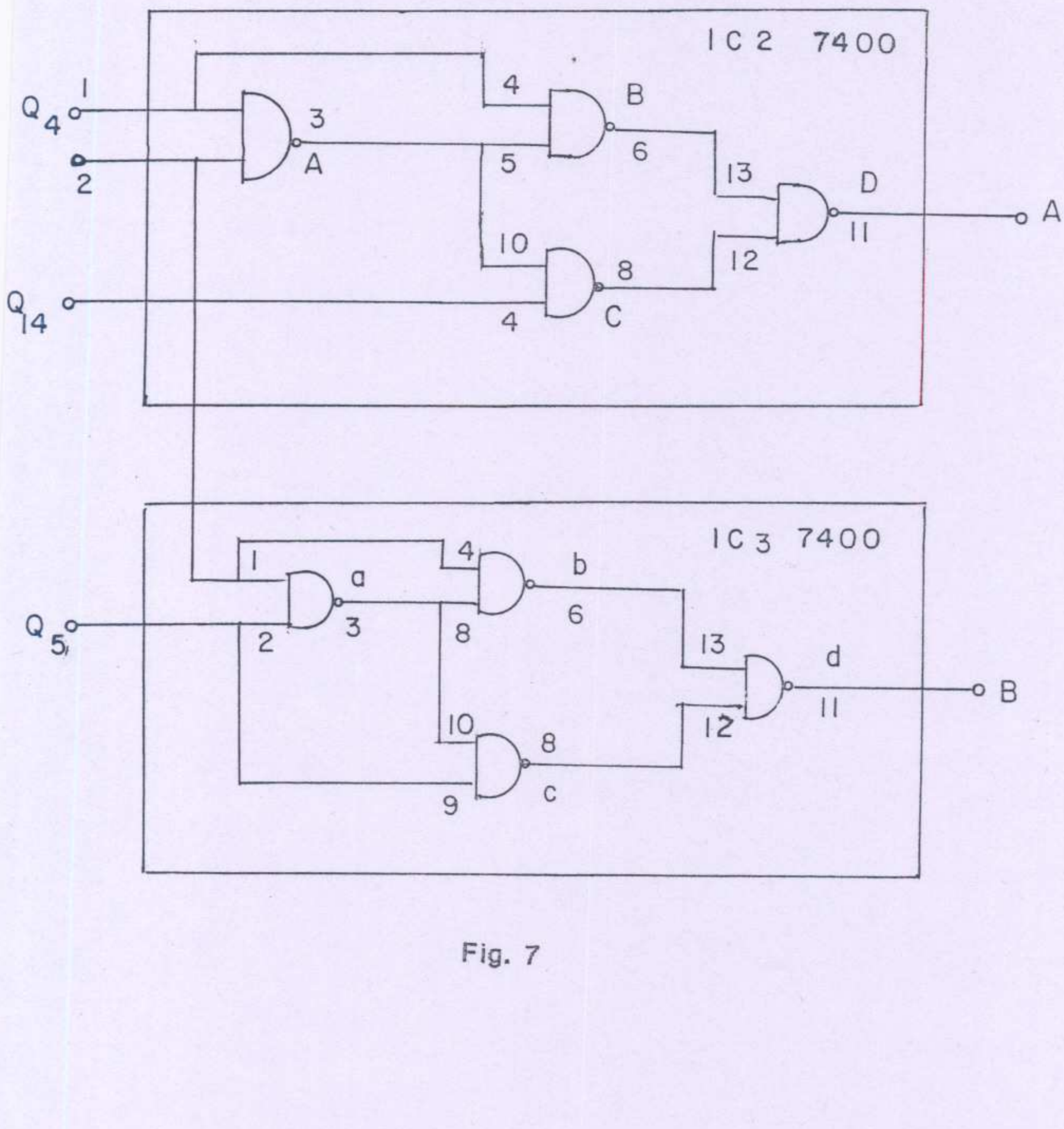
02
03
04
05
06
07
08
09
10
11
12
13
14
1
2
4
8
16
32
64
128
256
512
1024
2048
4096
8192
16384

Fig, 6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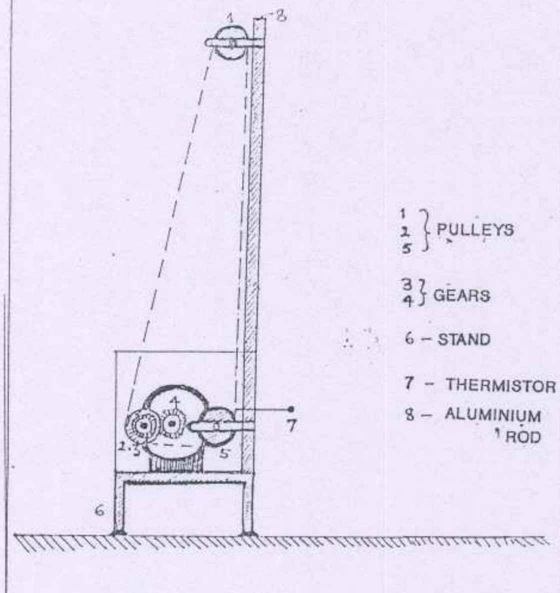
Q4
1
2
3
A
4
5
B
6
13
D
11
A
10
8
12
Q14
4
C
IC 3 7400
1
a
4
b
6
Q5
2
3
8
13
d
11
B
10
8
12
9
c

Fig. 7



Schematic diagram of moving platform.
Fig. 8

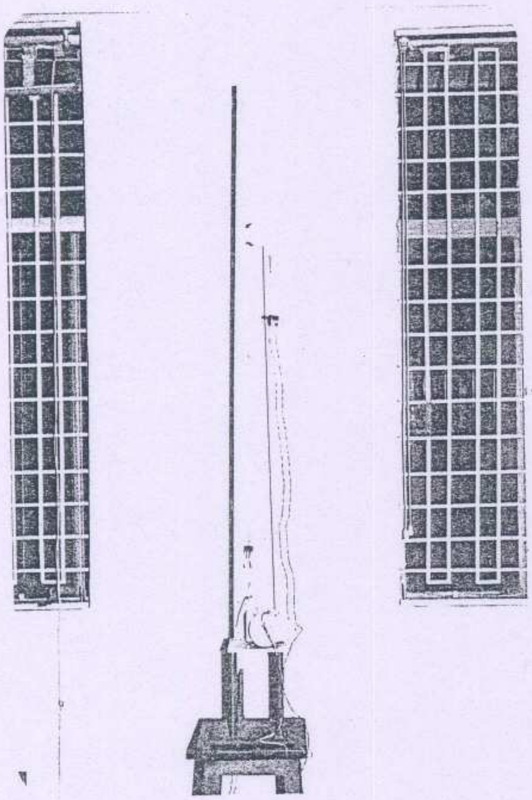
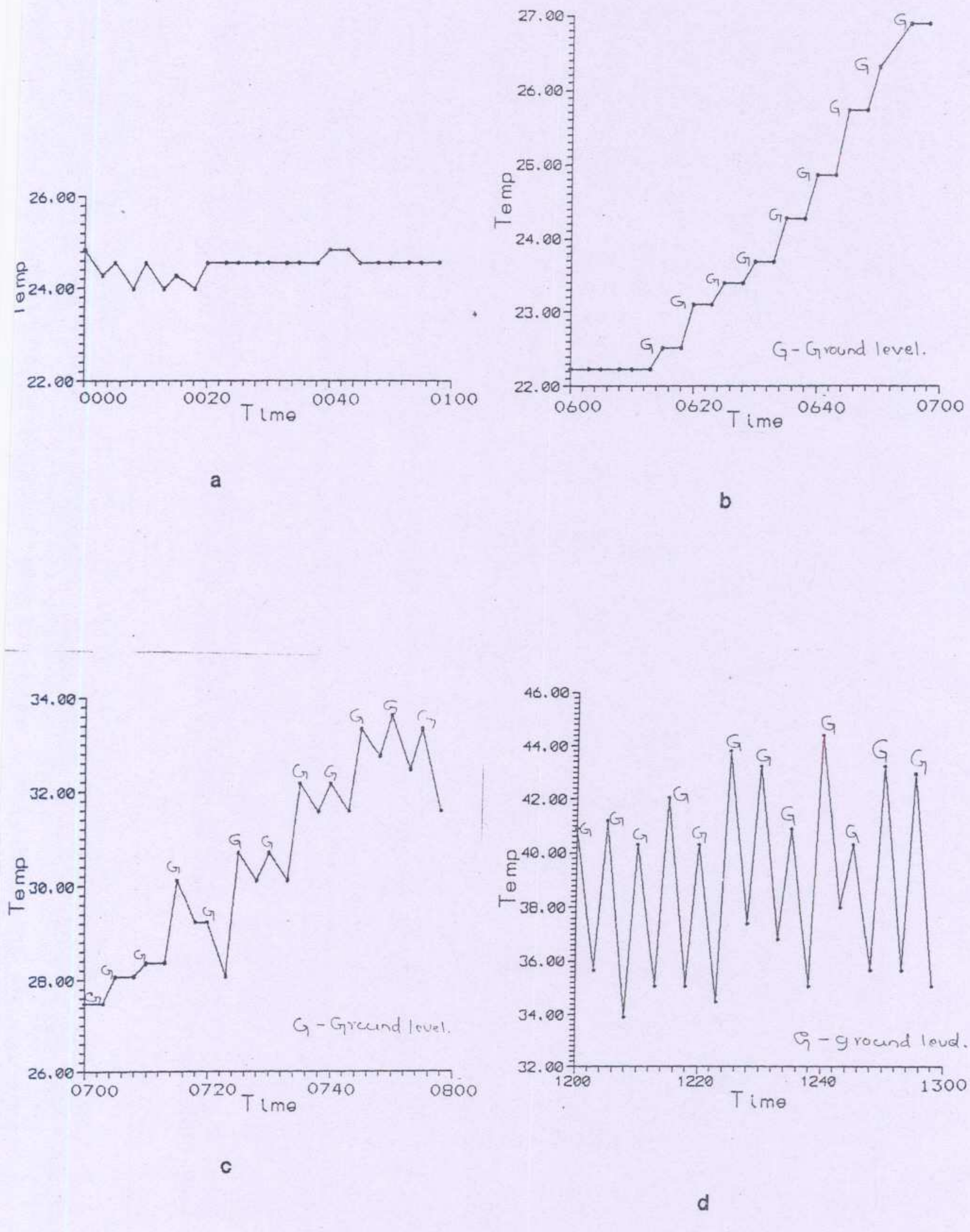


Fig.9



Temp
Time
0000
0020
0040
0100
22.00
24.00
26.00
a
Temp
Time
0600
0620
0640
0700
22.00
23.00
24.00
25.00
26.00
27.00
G - Ground level.
b
Temp
Time
0700
0720
0740
0800
26.00
28.00
30.00
32.00
34.00
G - Ground level.
c
Temp
Time
1200
1220
1240
1300
32.00
34.00
36.00
38.00
40.00
42.00
44.00
46.00
G - ground level.
d

Fig.10