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Appendix A

TEMPERATURE/RESISTANCE CHARACTERISTIC OF THE NTC THERMISTOR ITT

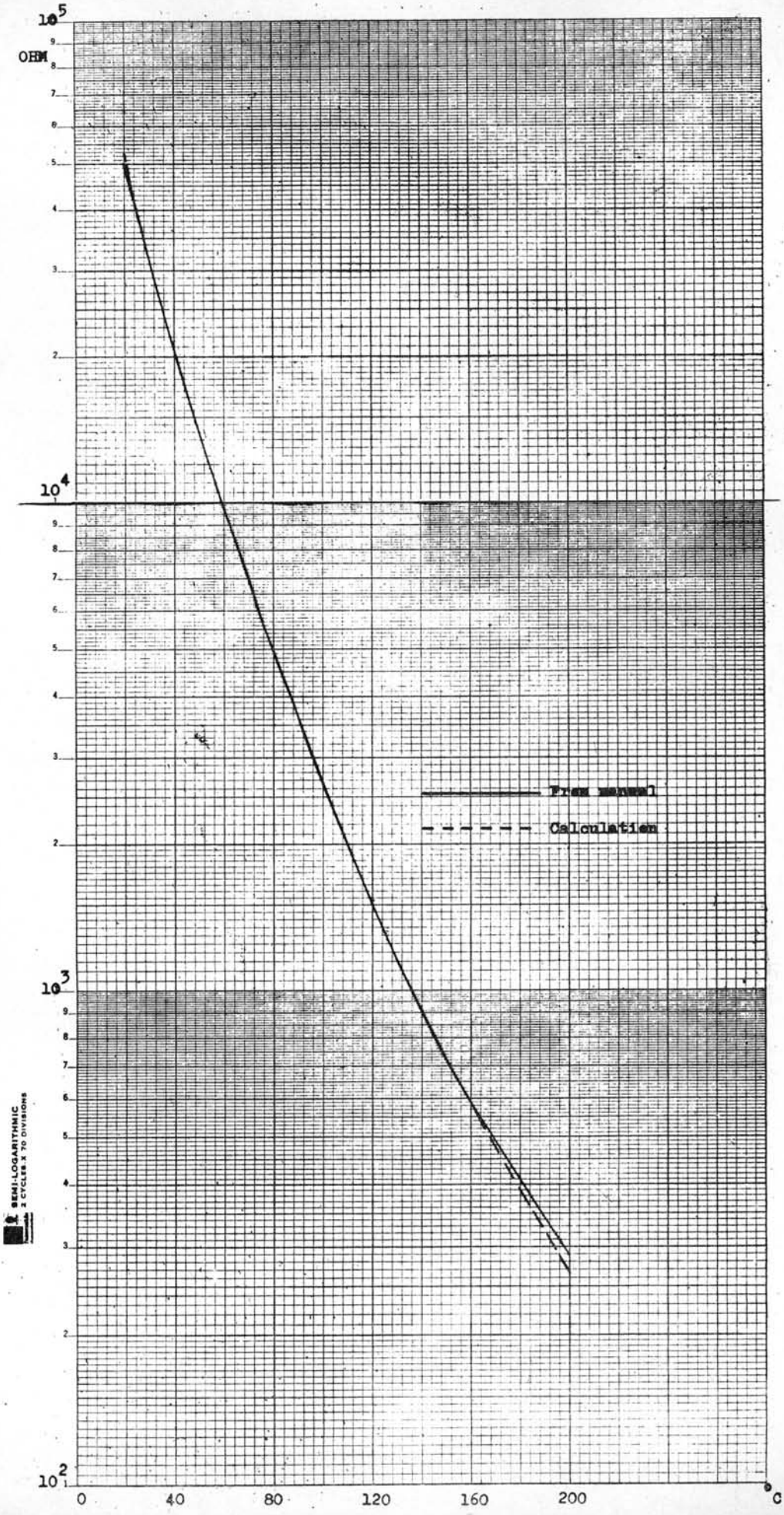
Type : Medium resistance

Code : GL 54

$$R_T = Ae^{B/T}$$

where

A	=	0.0483396	
B	=	4,075	Kelvin
R_{20}	=	50,000	ohms
R_{25}	=	40,000	ohms
R_{min}	=	290	ohms
P_{max}	=	220	mW at 20°C
k	=	1.2	mW/°C


OHM
10^5
10^4
10^3
10^2
9
8
7
6
5
4
3
2
From manual
Calculation
0
40
80
120
160
200
°C
SEMI-LOGARITHMIC
2 CYCLES X 70 DIVISIONS

Appendix B

BRIDGE CIRCUIT CALCULATION

Thermistor, ITT, code GL 54, has electrical data as follows :

B	=	4,075	Kelvin
k	=	1.2	mW/°C
R_{25}	=	40,000	ohms
R_{min}	=	290	ohms

By design the following values :

D	=	0.005	°C
R_b	=	5,000	ohms
E	=	8.40	VDC

From eqn. (3.2)

$$E_d = \sqrt{Dk10^{-3} R_{25}}$$

$$E_d = \sqrt{0.005 \times 1.2 \times 10^{-3} \times 40 \times 10^{3}}$$

$$E_d = \sqrt{0.24}$$

$$E_d = 0.4899 \quad \text{(maximum)}$$

Let $E_d = 0.40$ volts

From eqn. (3.3)

$$I_{Tmin} = \frac{E_d}{R_{25}}$$

$$I_{Tmin} = \frac{0.40}{40}$$

$$I_{Tmin} = 0.010 \quad \text{mA}$$

From eqn. (3.4)

$$V_{min} = I_{Tmin}(R_b + R_{25})$$

$$V_{min} = 0.010(5 + 40)$$

$$V_{min} = 0.45 \quad \text{volts}$$

From eqn. (3.5) and let R_{min} = 1 kilohm

$$I_{rmin} = \frac{V_{min}}{R_b + R_{min}}$$

$$I_{rmin} = \frac{0.45}{5+1}$$

$$I_{Tmin} = 0.075 \quad \text{mA}$$

From eqn. (3.6)

$$R_d = \frac{E - V_{min}}{I_{Tmin} + I_{rmin}}$$

$$R_d = \frac{8.40 - 0.45}{0.010 + 0.075}$$

$$= \frac{7.95}{0.085}$$

$$= 93.5$$

Let $R_d = 94$ kilohms

Then : $R_d = 94$ kilohms

$R_b = 5$ kilohms

$E = 8.40$ VDC

precision effected by self-heat of the thermistor is not more than $0.005^{o}C$

Appendix C

RELAY CHARACTERISTICS BY

EXPERIMENTAL MEASUREMENT

Bridge resistance in kilohm				Output bridge voltage in mV					
Ref. leg, r	Thermistor leg, R_T			Open e_1	Close e_2	Diff. e_2-e_1	Open e_{11}	Close e_{22}	Diff. $e_{22}-e_{11}$
	Min.	Max.	Mean						
1.00	0.622	1.046	0.834	-16.8	1.8	18.6	-	-	-
1.05	0.679	1.081	0.880	-14.2	1.3	15.5	-	-	-
1.10	0.772	1.132	0.952	-12.2	1.1	13.3	-14.3	2.3	16.6
1.15	0.849	1.175	1.012	-10.9	0.8	11.7	-12.8	2.4	15.2
1.20	0.932	1.220	1.076	-10.0	0.7	10.7	-11.5	2.2	13.7
1.25	0.995	1.261	1.128	- 8.9	0.1	9.0	-10.3	2.1	12.4
1.30	1.068	1.300	1.184	- 8.2	0.0	8.2	- 9.7	1.6	11.3
1.35	1.123	1.345	1.234	- 7.7	-0.1	7.6	- 8.5	1.4	9.9
1.40	1.192	1.392	1.292	- 6.8	-0.2	6.6	- 8.0	1.7	9.7
1.45	1.270	1.442	1.356	- 6.1	-0.4	5.7	- 6.9	1.6	8.5
1.50	1.333	1.485	1.409	- 5.4	-0.7	4.7	- 6.0	1.6	7.6
1.6	1.421	1.569	1.495	- 5.0	-1.0	4.0	- 5.4	1.2	6.6
1.7	1.572	1.656	1.614	- 3.8	-1.0	2.8	- 4.3	1.2	5.5
1.8	1.685	1.757	1.721	- 3.5	-1.1	2.4	- 3.9	1.1	5.0
1.9	1.805	1.855	1.830	- 2.8	-1.3	1.5	- 3.3	1.1	4.4
2.0	1.914	1.946	1.930	- 2.5	-1.5	1.0	- 2.9	1.0	3.9
2.1	2.03	2.06	2.045	- 2.3	-1.5	0.8	- 2.6	1.0	3.6
2.2	2.12	2.14	2.130	- 2.2	-1.6	0.6	- 2.4	1.0	3.4
2.3	2.22	2.24	2.230	- 2.1	-1.7	0.4	- 2.4	0.6	3.0
2.4	2.32	2.34	2.330	- 1.9	-1.5	0.4	- 2.3	0.5	2.8
2.5	2.43	2.44	2.435	- 1.8	-1.5	0.3	- 2.1	0.5	2.6

Appendix D

CONTROLLED TEMPERATURE OF THE OVEN BY THE CONTROLLER

(measured by mercury thermometer)

Reference bridge resistance, r in kilohm	Supplied power in W	Controlled temperature in ^{o}C				$\frac{\Delta T}{2T}$ in %
		T_{min}	T_{max}	ΔT $T_{max} - T_{min}$	T	
1.00	-	-	-	-	-	-
1.05	-	-	-	-	-	-
1.10	500	131.0	148.8	17.8	139.9	6.36
1.15	500	129.5	143.5	14.0	136.5	5.13
1.20	500	128.0	139.2	11.2	133.6	4.19
1.25	500	127.5	136.5	9.0	132.0	3.41
1.30	480	126.0	133.2	7.2	129.6	2.78
1.35	480	124.8	130.8	6.0	127.8	2.35
1.40	430	123.2	129.0	5.8	126.1	2.30
1.45	390	122.0	126.8	4.8	124.4	1.93
1.50	390	120.8	125.0	4.2	122.9	1.71
1.6	390	118.8	122.0	3.2	120.4	1.33
1.7	350	116.5	119.5	3.0	118.0	1.27
1.8	350	114.5	116.3	1.8	115.4	0.78
1.9	310	112.8	114.2	1.4	113.5	0.62
2.0	310	110.8	112.0	1.2	111.4	0.54
2.1	310	109.2	110.2	1.0	109.7	0.46
2.2	275	107.8	108.8	1.0	108.3	0.46
2.3	275	106.5	107.5	1.0	107.0	0.47
2.4	275	105.1	105.9	0.8	105.5	0.38
2.5	275	104.0	104.5	0.5	104.25	0.24

Appendix E

THERMAL TIME CONSTANT
WHEN TEMPERATURE IS INCREASING

Supplied power,	$P = 400$	watts
Initial temperature of the oven,	$T_i = 30.5^\circ$	C
Ambient temperature,	$T_o = 30.5^\circ$	C
Steady-state oven temperature,	$T_{ss} = 149.5^\circ$	C

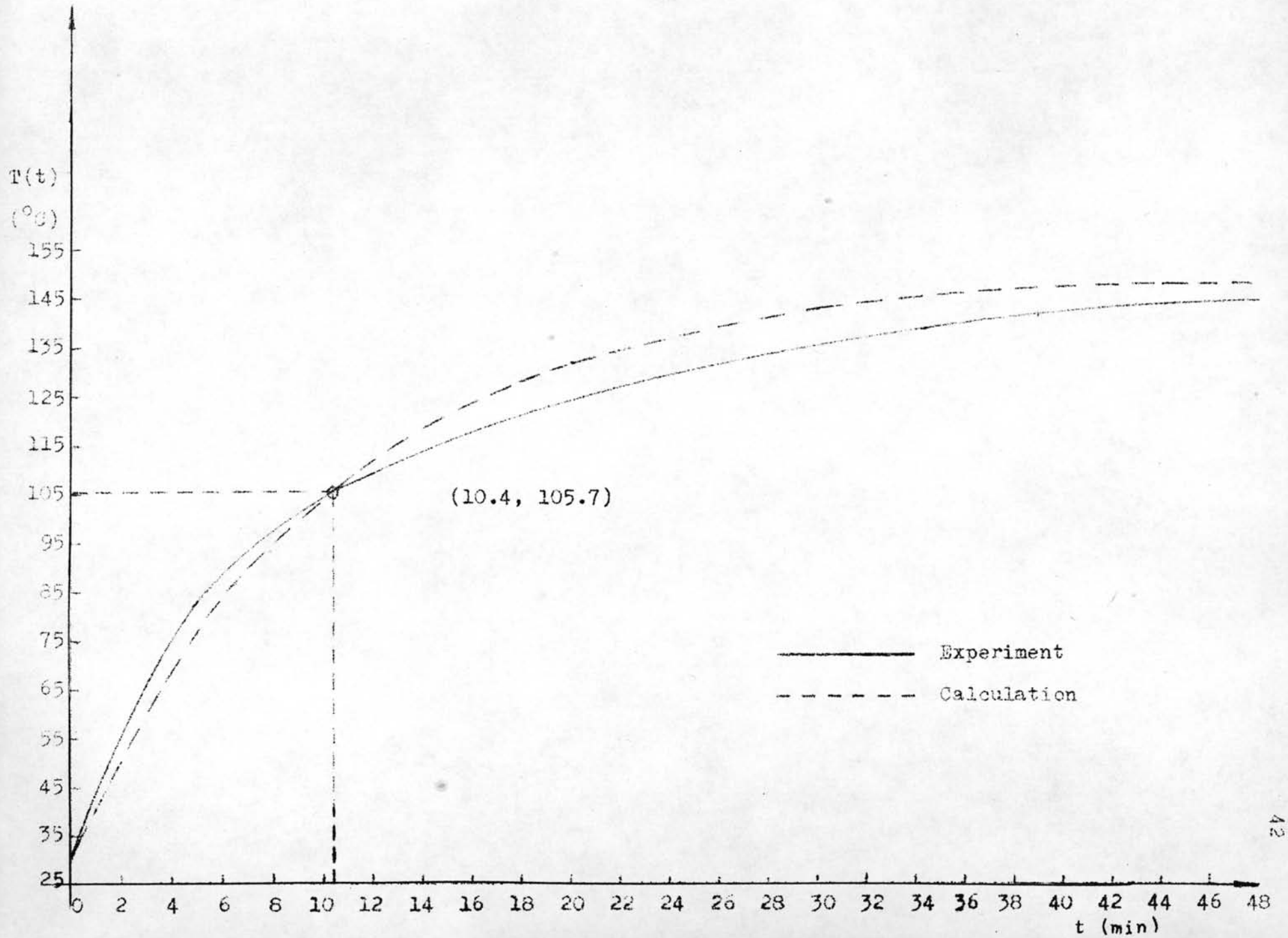
At $t = \tau$:

$$T(\tau) = (T_{ss} - T_o)(1 - e^{-1}) + T_o$$

$$T(\tau) = (149.5 - 30.5)(1 - 0.36788) + 30.5$$

$$T(\tau) = 105.7^\circ \text{ C}$$

Then $\tau = 10.4$ min


T(t)
(°C)
155
145
135
125
115
105
95
85
75
65
55
45
35
25
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48
t (min)
(10.4, 105.7)
Experiment
Calculation

Appendix F

THERMAL TIME CONSTANT
WHEN TEMPERATURE IS DECREASING

Supplied power, $P = 0$ watt

Initial temperature of the oven, $T_i = 150^{\circ}$ C

Ambient temperature, $T_o = 32^{\circ}$ C

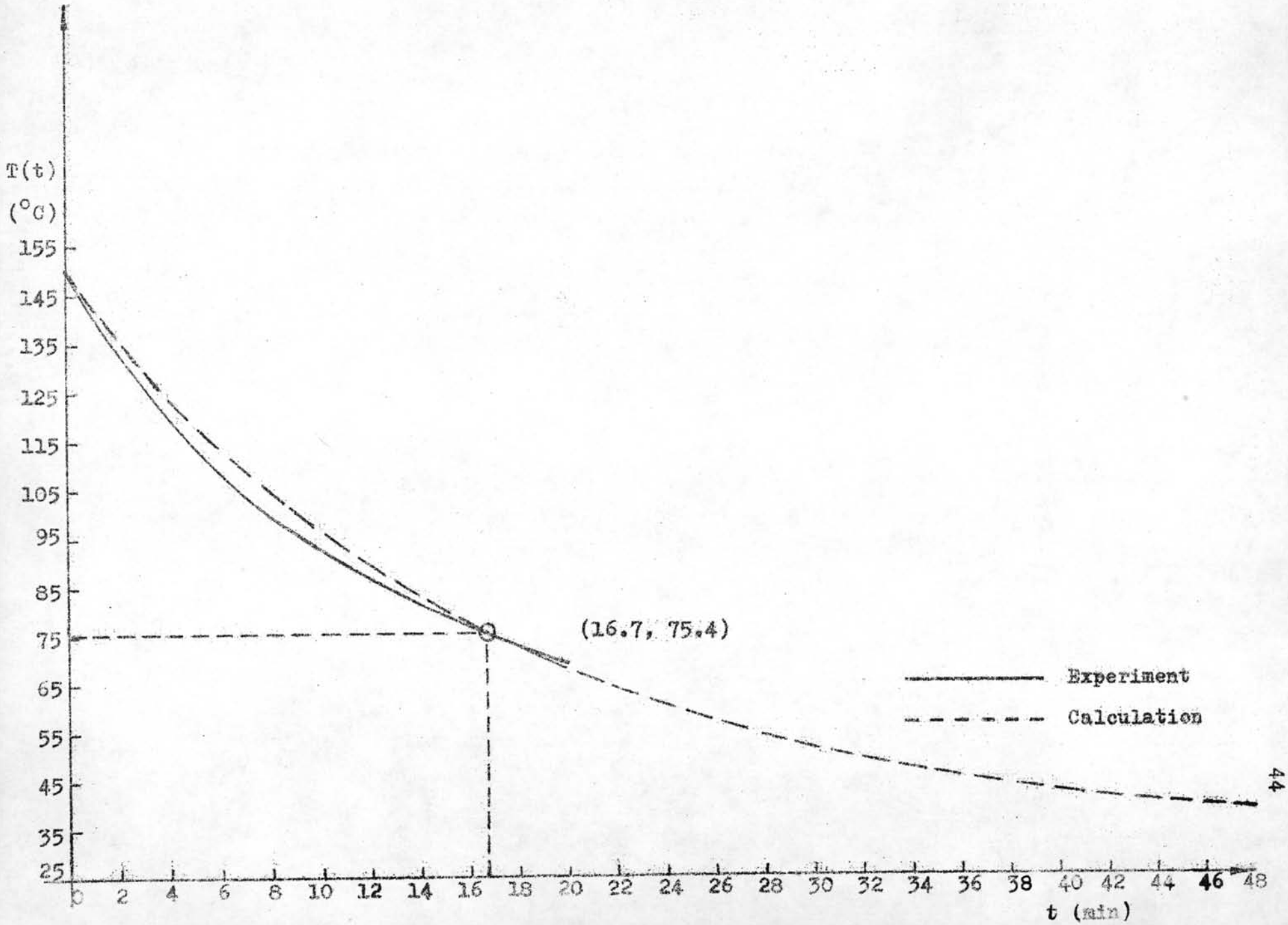
At $t = \tau$:

$$T(\tau) = (T_i - T_o)e^{-1} + T_o$$

$$T(\tau) = (150 - 32) \times 0.36788 + 32$$

$$T(\tau) = 75.4^{\circ} \text{ C}$$

Then $\tau = 16.7$ min


T(t)
(°C)
155
145
135
125
115
105
95
85
75
65
55
45
35
25
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
t (min)
(16.7, 75.4)
Experiment
Calculation
44

Appendix G

EXPERIMENTAL RESULTS ON TIME CHARACTERISTICS OF THE SYSTEM

Remarks :

1. Ambient temperature T_o is measured by and read out from alcoholic thermometer.
2. Time t is read out from digital electric clock.
3. Oven temperature T(t) is measured by and read out from mercury thermometer.
4. Rate of change of the oven temperature $\dot{T}(t)$ is calculated from eqns. (2.16) and (2.19) as follows :

   (1) $\dot{T}_s(t) = -\frac{1}{\tau}\left[T(t) - \frac{P}{G} - T_o\right]$

   (2) $\dot{T}_c(t) = -\frac{1}{\tau}\left[T(t) - T_o\right]$

5. The controlled temperatures are read at maximum and minimum temperature and at change-state relay points.

Appendix G 1/7

Date 12.12.1975 at 17.30

r = 1.30 kilohm P = 480 watts

$T_i = T_o = 30.0^{\circ}$ C

Time, t (min)	Oven temperature, T(t) ($^{\circ}$C)	Rate of change of the oven temperature, $\dot{T}(t)$ ($^{\circ}$C/min)
0.00	30.0	9.57
3.15	70.0	6.62
4.15	80.0	5.88
5.52	90.0	5.15
7.15	100.0	4.41
9.85	110.0	3.67
11.38	115.0	3.30
13.08	120.0	2.93
14.98	125.0	2.56
19.43	132.9	1.98
19.43	132.9	1.98
20.25	128.5	- 5.90
20.77	126.0	- 5.75
22.82	132.5	2.01
22.82	132.5	2.01
23.58	128.5	- 5.90
24.13	126.2	- 5.76
26.20	132.6	2.00
26.33	132.9	1.98
27.03	128.5	- 5.90
27.55	126.2	- 5.76
29.70	132.9	1.98
29.88	133.0	1.97
30.57	128.5	- 5.90
31.08	126.2	- 5.76

Time, t (min)	Oven temperature, T(t) (^{o}C)	Rate of change of the oven temperature, $\dot{T}(t)$ (^{o}C/min)
33.37	133.0	1.97
33.55	133.1	1.96
34.23	128.5	- 5.90
34.82	126.2	- 5.76
37.07	132.9	1.98
37.23	133.0	1.97
37.93	128.5	- 5.90
38.45	126.0	- 5.75
40.67	132.7	1.99
40.83	132.9	1.98
41.55	128.5	- 5.90
42.07	126.2	- 5.76
44.23	132.9	1.98
44.40	133.0	2.19
45.12	128.5	- 5.90
45.67	126.2	- 5.76
47.78	132.8	1.99
47.93	133.0	1.97
48.67	128.5	- 5.90
49.32	126.2	- 5.76
51.30	132.8	1.99
51.50	133.0	1.97
52.23	128.5	- 5.90
52.87	126.0	- 5.75

Appendix G 2/7

Date 13.12.1975 at 09.10

r = 1.35 kilohm P = 480 watts

$T_i = T_o = 26.8^{\circ}$ C

Time, t (min)	Oven temperature, T(t) ($^{\circ}$C)	Rate of change of the oven temperature, $\dot{T}(t)$ ($^{\circ}$C/min)
0.00	26.8	9.57
3.50	70.0	6.38
4.48	80.0	5.65
5.90	90.0	4.91
7.83	100.0	4.17
10.38	110.0	3.43
12.25	115.0	3.06
14.07	120.0	2.70
16.17	125.0	2.33
18.93	130.5	1.92
18.93	130.5	1.92
19.67	127.0	- 6.00
20.17	124.5	- 5.85
22.40	130.4	1.93
22.50	130.5	1.92
23.25	126.5	- 5.97
23.67	124.5	- 5.85
25.73	130.4	1.93
25.98	130.7	1.91
26.67	126.5	- 5.97
27.17	124.5	- 5.85
29.10	130.2	1.94
29.25	130.5	1.92

Time, t (min)	Oven temperature, T(t) (^{o}C)	Rate of change of the oven temperature, $\dot{T}(t)$ (^{o}C/min)
29.97	126.8	- 6.00
30.48	124.7	- 5.86
32.27	130.2	1.94
32.52	130.7	1.91
33.20	126.8	- 6.00
33.67	124.5	- 5.85
35.58	130.5	1.92
35.78	130.9	1.89
36.47	126.8	- 6.00
36.92	124.8	- 5.87
38.50	130.3	1.94
38.73	130.9	1.89
39.43	126.8	- 6.00
40.00	125.0	- 5.88
41.45	130.6	1.91
41.67	130.8	1.90
42.37	126.8	- 6.00
42.92	124.8	- 5.87
44.55	130.6	1.91
44.78	130.9	1.89
45.50	126.8	- 6.00
46.17	124.5	- 5.85
47.60	130.5	1.92
47.83	130.8	1.90
48.58	126.5	- 5.97
49.05	124.7	- 5.86

Appendix G 3/7

Date 13.12.1975 at 12.20

r = 1.40 kilohm P = 430 watts

$T_i = T_c = 27.5^{\circ}$ C

Time, t (min)	Oven temperature, T(t) ($^{\circ}$C)	Rate of change of the oven temperature, $\dot{T}(t)$ ($^{\circ}$C/min)
0.00	27.5	8.94
3.73	70.0	5.80
5.02	80.0	5.06
6.75	90.0	4.33
9.25	100.0	3.59
12.58	110.0	2.85
14.58	115.0	2.48
16.93	120.0	2.11
19.97	125.0	1.74
23.72	129.0	1.45
23.93	129.2	1.43
24.55	125.5	- 5.87
25.23	122.8	- 5.71
28.43	129.0	1.45
28.62	129.0	1.45
29.27	125.4	- 5.86
29.87	123.0	- 5.72
32.73	129.0	1.45
32.92	129.0	1.45
33.60	125.3	- 5.86
34.25	123.0	- 5.72
36.55	129.0	1.45
36.72	129.1	1.44

Time, t (min)	Oven temperature, T(t) (°C)	Rate of change of the oven temperature, $\dot{T}(t)$ (°C/min)
37.38	125.6	- 5.87
38.07	123.1	- 5.72
40.23	129.0	1.45
40.43	129.0	1.45
41.12	125.4	- 5.86
41.78	123.0	- 5.72
43.77	129.0	1.45
43.97	129.0	1.45
44.73	125.3	- 5.86
45.32	123.0	- 5.72
47.52	129.0	1.45
47.70	129.2	1.43
48.43	125.3	- 5.86
49.17	123.0	- 5.72
51.40	129.2	1.43
51.67	129.4	1.42
52.25	125.5	- 5.87
52.90	123.2	- 5.73
55.18	129.2	1.43
55.38	129.4	1.42
56.10	125.5	- 5.87
56.75	123.2	- 5.73
59.08	129.2	1.43
59.23	129.4	1.42
60.03	125.5	- 5.87
60.67	123.1	- 5.72

Appendix G 4/7

Date 13.12.1975 at 15.00

r = 1.45 kilohm P = 390 watts

$T_i = T_o = 29.0^\circ$ C

Time, t (min)	Oven temperature, T(t) ($^\circ$C)	Rate of change of the oven temperature, $\dot{T}(t)$ ($^\circ$C/min)
0.00	29.0	8.34
4.05	70.0	5.32
5.55	80.0	4.58
7.78	90.0	3.84
10.73	100.0	3.10
15.12	110.0	2.36
18.07	115.0	2.00
21.75	120.0	1.63
28.00	125.0	1.26
30.12	126.0	1.18
30.30	126.0	1.18
30.68	123.8	- 5.68
31.58	121.2	- 5.52
36.07	127.2	1.10
36.17	127.4	1.08
36.75	124.3	- 5.71
37.50	121.6	- 5.54
41.00	127.2	1.10
41.13	127.4	1.08
41.68	124.2	- 5.70
42.47	121.6	- 5.54
46.23	127.2	1.10
46.38	127.2	1.10

Time, t (min)	Oven temperature, T(t) (^{o}C)	Rate of change of the oven temperature, $\dot{T}(t)$ (^{o}C/min)
46.93	124.2	- 5.70
47.62	122.0	- 5.57
51.00	127.4	1.08
51.12	127.5	1.07
51.72	124.2	- 5.70
52.33	122.0	- 5.57
55.43	127.2	1.10
55.60	127.3	1.09
56.17	124.2	- 5.70
56.85	121.8	- 5.56
60.02	127.2	1.10
60.17	127.4	1.08
60.70	124.2	- 5.70
61.33	122.2	- 5.58
64.38	127.6	1.06
64.53	127.8	1.05
65.22	124.2	- 5.70
65.92	121.9	- 5.56
68.30	127.0	1.11
68.45	127.0	1.11
69.05	124.0	- 5.69
69.62	121.9	- 5.56
72.10	127.0	1.11
72.25	127.0	1.11
72.82	124.2	- 5.70
73.55	122.0	- 5.57

Appendix G 5/7

Date 14.12.1975 at 08.10

r = 1.50 kilohm P = 390 watts

$T_i = T_o = 25.0^{\circ}$ C

Time, t (min)	Oven temperature, T(t) ($^{\circ}$C)	Rate of change of the oven temperature, $\dot{T}(t)$ ($^{\circ}$C/min)
0.00	25.0	8.34
4.50	70.0	5.02
6.15	80.0	4.28
8.48	90.0	3.54
11.70	100.0	2.81
13.85	105.0	2.44
16.70	110.0	2.07
19.70	115.0	1.70
23.33	120.0	1.33
27.90	125.0	0.96
28.08	125.0	0.96
28.42	123.0	- 5.87
29.20	120.6	- 5.72
32.00	125.0	0.96
32.18	125.0	0.96
32.55	123.0	- 5.87
33.30	120.9	- 5.74
35.47	124.8	0.98
35.67	124.8	0.98
36.02	123.0	- 5.87
36.83	120.8	- 5.74
39.07	125.0	0.96
39.28	125.0	0.96

Time, t (min)	Oven temperature, T(t) (°C)	Rate of change of the oven temperature, $\dot{T}(t)$ (°C/min)
39.70	123.0	- 5.87
40.38	120.8	- 5.74
42.88	125.0	0.96
43.00	125.1	0.96
43.47	123.0	- 5.87
44.18	120.9	- 5.74
46.25	124.8	0.98
46.40	124.8	0.98
46.85	122.8	- 5.86
47.50	120.7	- 5.73
49.95	125.0	0.96
50.12	125.1	0.96
50.58	123.0	- 5.87
51.25	120.3	- 5.69
53.52	124.9	0.97
53.70	125.0	0.96
54.12	123.0	- 5.87
54.83	120.7	- 5.73
57.03	125.0	0.96
57.23	125.0	0.96
57.67	123.0	- 5.87
58.42	120.9	- 5.74
60.38	124.8	0.98
60.53	124.9	0.97
61.00	122.8	- 5.86
61.70	120.7	- 5.73

Appendix G 6/7

Date 14.12.1975 at 11.00

r = 1.6 kilohm P = 390 watts

$T_i = T_o = 26.5^{\circ}$ C

Time, t (min)	Oven temperature, T(t) ($^{\circ}$C)	Rate of change of the oven temperature, $\dot{T}(t)$ ($^{\circ}$C/min)
0.00	26.5	8.34
4.25	70.0	5.13
5.72	80.0	4.39
7.92	90.0	3.66
11.00	100.0	2.92
13.05	105.0	2.55
15.70	110.0	2.18
18.28	115.0	1.81
21.78	120.0	1.44
23.33	122.0	1.29
23.50	122.0	1.29
23.88	120.8	- 5.65
24.58	118.4	- 5.50
26.55	122.1	1.29
26.75	122.2	1.28
27.23	120.7	- 5.64
27.83	118.5	- 5.51
29.90	122.1	1.29
30.08	122.3	1.27
30.50	120.8	- 5.65
31.17	118.7	- 5.52
32.92	122.1	1.29
33.17	122.3	1.27

Time, t (min)	Oven temperature, T(t) (°C)	Rate of change of the oven temperature, $\dot{T}(t)$ (°C/min)
33.58	120.8	- 5.65
34.17	118.8	- 5.53
35.75	122.1	1.29
35.88	122.2	1.28
36.38	120.8	- 5.65
36.90	118.9	- 5.53
38.42	122.1	1.29
38.58	122.2	1.28
39.05	120.8	- 5.65
39.67	119.0	- 5.54
41.12	122.0	1.29
41.27	122.1	1.29
41.68	120.8	- 5.65
42.35	118.9	- 5.53
43.72	121.9	1.30
43.92	122.0	1.29
44.33	120.8	- 5.65
44.95	118.8	- 5.53
46.37	121.9	1.30
46.58	122.0	1.29
47.02	120.7	- 5.64
47.52	118.9	- 5.53
48.93	122.1	1.29
49.00	122.3	1.27
49.55	120.7	- 5.64
50.17	118.9	- 5.53

Appendix G 7/7

Date 14.12.1975 at 17.30

r = 1.25 kilohm P = 500 watts

$T_i = T_o = 27.0^\circ$ C

Time, t (min)	Oven temperature, T(t) ($^\circ$C)	Rate of change of the oven temperature, $\dot{T}(t)$ ($^\circ$C/min)
0.00	27.0	9.84
3.20	70.0	6.67
4.20	80.0	5.93
5.45	90.0	5.19
7.12	100.0	4.45
9.42	110.0	3.71
12.58	120.0	2.98
14.40	125.0	2.61
17.00	130.0	2.34
20.00	135.0	1.87
20.42	135.5	1.83
20.50	135.5	1.83
21.30	130.0	- 6.17
21.92	127.0	- 5.99
24.93	135.4	1.84
25.07	135.6	1.82
25.88	129.8	- 6.16
26.45	127.1	- 5.99
29.25	136.0	1.80
29.42	136.2	1.78
30.28	130.0	- 6.17
30.87	127.1	- 5.99
33.63	136.0	1.80
33.78	136.0	1.80

Time, t (min)	Oven temperature, T(t) (°C)	Rate of change of the oven temperature, $\dot{T}(t)$ (°C/min)
34.63	130.0	- 6.17
35.27	127.4	- 6.01
38.10	136.0	1.80
38.23	136.1	1.79
39.13	129.9	- 6.16
39.68	127.1	- 5.99
42.48	136.1	1.79
42.60	136.2	1.78
43.58	129.7	- 6.15
44.17	126.9	- 5.98
47.12	136.0	1.80
47.23	136.1	1.79
48.17	129.9	- 6.16
48.67	127.5	- 6.02
51.32	136.0	1.80
51.45	136.1	1.79
52.37	129.9	- 6.16
52.92	127.3	- 6.00
55.35	135.7	1.82
55.52	135.9	1.80
56.37	129.9	- 6.16
56.90	127.6	- 6.02
59.38	136.1	1.79
59.50	136.2	1.78
60.47	129.9	- 6.16
60.93	127.5	- 6.02

Appendix H

COMPUTER PROGRAM FOR CALCULATION THE TEMPERATURE CONTROL SYSTEM

The computer program is written to calculate the oven temperature T(t), rate of change of the oven temperature $\dot{T}_s(t)$ and $\dot{T}_c(t)$, thermistor resistance R_T, output bridge voltage e, maximum temperature T_{max}, and minimum temperature T_{min} which have been previously given in the text and are written for convenience as follows :

(1) $T(t) = \frac{P}{G} - \frac{P}{G}e^{-t/\tau} + (T_i - T_o)e^{-t/\tau} + T_o$

(2) $\dot{T}_s(t) = -\frac{1}{\tau}\left[-\frac{P}{G}e^{-t/\tau} + (T_i - T_o)e^{-t/\tau}\right]$

(3) $\dot{T}_c(t) = -\frac{1}{\tau}(T_i - T_o)e^{-t/\tau}$

(4) $R_T = A\, e^{B/T}$ and $R_T = AT^C\, e^{B/T}$

(5) $$e = \frac{ER_b(R_T - r)}{R_d\left[(R_b + R_T) + (R_b + r)\right] + (R_b + R_T)(R_b + r)}$$

(6) If $e = e_{11}$: $T = T_{max}$

(7) If $e = e_{22}$: $T = T_{min}$

```
      C     STUDY OF TEMPERATURE CONTROL SYSTEM USING NTC THERMISTORS
      C
      C     EQUATIONS:
      C               1. OF NTC THERMISTORS
      C                  RTO = A*TK**C*EXP(BK/TK)
      C               2. OF THERMAL PLANTS
      C                  2.1      TC = PW/BWPC - PW/BWPC/EXP(TM/TORSM)
      C                                + (TCI - TCA)/EXP(TM/TORCM) + TCA
      C                  2.2 TDOTSC = PW/BWPC/EXP(TM/TORSM)/TORSM
      C                                - (TCI - TCA)/EXP(TM/TORCM)/TORCM
      C                  2.3  TDOTC = - (TCI - TCA)/EXP(TM/TORCM)/TORCM
      C               3. OF UNBALANCED BRIDGES
      C                  EBV = (EV*RBO*(RTO - REFO))/(RDO*((RBO + REFO)
      C                        + (RBO + RTO)) + (RBO + REFO)*(RBO + RTO))
      C
001           INTEGER BLANK, DOT, X
002           DIMENSION LINE(51)
      C
      C     READ PLOTTING SYMBOLS
      C
003           READ (2, 99) BLANK, DOT, X
004        99 FORMAT (3A1)
      C
      C     READ PARAMETERS OF EACH SYSTEM:
      C     1. OF NTC THERMISTOR
      C        RESISTANCE AT 25 DEGREE CELSIUS.......R25O, OHM
      C        CONSTANT.................................  A, -
      C        B-VALUE..................................  BK, DEGREE KELVIN
      C        CONSTANT.................................  C, -
      C     2. OF THERMAL PLANT
      C        THERMAL CONDUCTANCE OF INSULATION.....BWPC, WATT/DEGREE CELSIUS
      C        THERMAL TIME CONSTANT, WHEN SUPPLY POWER....TORSM, MINUTE
      C        THERMAL TIME CONSTANT, WHEN CUT-OFF POWER...TORCM, MINUTE
      C        THERMAL SUPPLIED POWER.....................  PW, WATT
      C        INITIAL TEMPERATURE....................... TCI, DEGREE CELSIUS
      C        AMBIENT TEMPERATURE....................... TCA, DEGREE CELSIUS
      C        STEP TIME OF COMPUTATION.................. TSM, MINUTE
      C        MAXIMUM DESIGNED TEMPERATURE FOR.......
      C                                  PLOTTING.......TCMX, DEGREE CELSIUS
      C        MINIMUM DESIGNED TEMPERATURE FOR.......
      C                                  PLOTTING.......TCMN, DEGREE CELSIUS
      C     3. OF UNBALANCED BRIDGE
      C        SUPPLIED VOLTAGE.........................  EV, VOLT
      C        RESISTANCE FOR DROP-OUT VOLTAGE........ RDO, OHM
      C        RESISTANCE FOR BALANCING VOLTAGE....... RBO, OHM
      C        RESISTANCE FOR REFERENCE...............REFO, OHM
      C        LIMITE OF SUPPLYING POWER..............SPLV, VOLT
      C        LIMITE OF CUTTING-OFF POWER............CPLV, VOLT
      C     4. LIMITE OF COMPUTATION...................  NL, -
      C        CONTROLLER FOR WRITING RESULTS.........NCWR, -
      C
005           READ (2, 105) R250, A, BK, C
006        105 FORMAT (F10.0, E20.0, 2F10.0)
007           READ (2, 110) BWPC, TORSM, TORCM, PW, TCI, TCA, TSM, TCMX, TCMN
010        110 FORMAT (F10.0, 2F5.0, 6F10.0)
011           READ (2, 115) EV, RDO, RBO, REFO, SPLV, CPLV
012        115 FORMAT (6F10.0)
013           READ (2, 116) NL, NCWR
014        116 FORMAT (2I5)
```

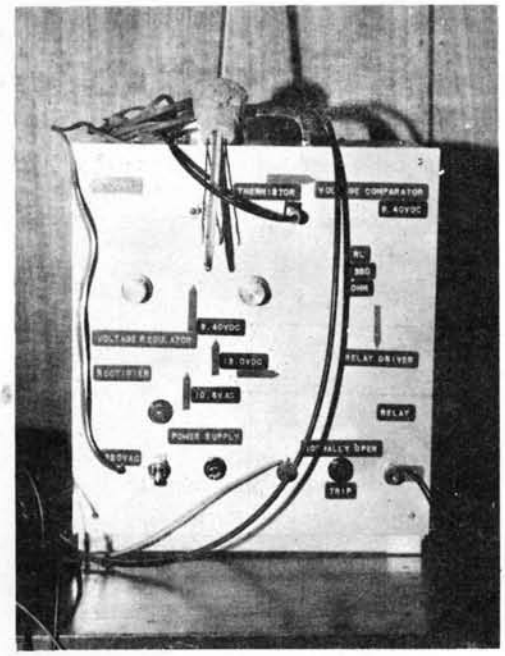
```
      C
      C     WRITE TITLE
      C
015         WRITE (3, 120)
016       120 FORMAT (58H STUDY OF TEMPERATURE CONTROL SYSTEM USING NTC THERMIST
           1ORS//11H EQUATIONS:/11X, 21H1. OF NTC THERMISTORS/14X, 24HRTO = A*
           2TK**C*EXP(BK/TK)/11X, 20H2. OF THERMAL PLANTS/14X, 78H2.1      TC =
           3 PW/BWPC - PW/BWPC/EXP(TM/TORSM) + (TCI - TCA)/EXP(TM/TORCM) + TCA
           4/14X, 74H2.2 TDOTSC = PW/BWPC/EXP(TM/TORSM)/TORSM - (TCI - TCA)/EX
           5P(TM/TORCM)/TORCM/14X, 46H2.3  TDOTC = - (TCI - TCA)/EXP(TM/TORCM)
           6/TORCM)
017         WRITE (3, 121)
020       121 FORMAT (11X, 24H3. OF UNBALANCED BRIDGES/14X, 89HEBV = (EV*RBO*(RT
           1O - REFO))/(RDO*((R3O + REFO) + (RBO + RTO)) + (RBO + REFO)*(RBO +
           2 RTO)))
      C
      C     WRITE PARAMETERS OF THE SYSTEM
      C
021         WRITE (3, 125) R25O, A, BK, C
022       125 FORMAT (34H3PARAMETERS OF THE NTC THERMISTOR:/10X, 40HRESISTANCE A
           1T 25 DEGREE CELSIUS,  R25O =, F15.2, 6H  OHMS/33X, 17HCONSTANT,
           2  A =, E15.6, 3H  -/34X, 16HB-VALUE,     BK =, F15.2, 15H  DEGREE K
           3ELVIN/33X, 17HCONSTANT,      C =, E15.6, 3H  -)
023         WRITE (3, 130) BWPC, TORSM, TORCM, PW, TCI, TCA, TSM
024       130 FORMAT (33H3PARAMETERS OF THE THERMAL PLANT:/8X, 42HTHERMAL CONDUC
           1TANCE OF INSULATION,  BWPC =, F15.2, 22H  WATTS/DEGREE CELSIUS/50H
           2 THERMAL TIME CONSTANT, WHEN SUPPLY POWER, TORSM =, F15.2, 9H  MIN
           3UTES/50H THERMAL TIME CONSTANT, WHEN CUT-OFF POWER,TORCM =, F15.2,
           4 9H  MINUTES/19X, 31HTHERMAL SUPPLIED POWER,     PW =, F15.2, 7H  W
           5ATTS/22X, 28HINITIAL TEMPERATURE,   TCI =, F15.2, 16H  DEGREE CELS
           6IUS/22X, 28HAMBIENT TEMPERATURE,   TCA =, F15.2, 16H  DEGREE CELSI
           7US/17X, 33HSTEP TIME OF COMPUTATION,   TSM =, E15.6, 9H  MINUTES)
025         WRITE (3, 131) TCMX, TCMN
026       131 FORMAT (50H MAXIMUN DESIGNED TEMPERATURE FOR PLOTTING, TCMX =, F15
           1.2, 16H  DEGREE CELSIUS/50H MINIMUM DESIGNED TEMPERATURE FOR PLOTT
           2ING, TCMN =, F15.2, 16H  DEGREE CELSIUS)
027         WRITE (3, 135) EV, RDO, RBO, REFO, SPLV, CPLV
030       135 FORMAT (33H3PARAMETERS OF UNBALANCED BRIDGE:/25X, 25HSUPPLIED VOLT
           1AGE,     EV =, F15.2, 7H  VOLTS/10X, 40HRESISTANCE FOR DROP-OUT VOL
           2TAGE,    RDO =, F15.2, 6H  OHMS/9X, 41HRESISTANCE FOR BALANCING VOL
           3TAGE,    RBO =, F15.2, 6H  OHMS/17X, 33HRESISTANCE FOR REFERENCE,
           4REFO =, F15.2, 6H  OHMS/16X, 34HLIMITE OF SUPPLYING POWER,  SPLV =
           5, F15.4, 7H  VOLTS/14X, 36HLIMITE OF CUTTING-OFF POWER,  CPLV =, F
           615.4, 7H  VOLTS)
031         WRITE (3, 137) NL, NCWR
032       137 FORMAT (1H3, 19X, 30HLIMITE OF COMPUTATION,     NL =, I5, 3H  -/11X
           1, 39HCONTROLLER FOR WRITING RESULTS,  NCWR =, I5, 3H  -)
      C
      C     WRITE HEAD OF RESULTS
      C     PRINT A LINE OF DOTS WHICH WILL BE AXIS OF PLANT TEMPERATURE
      C
033         DO 6 K = 1, 51
034       6 LINE(K) = DOT
035         WRITE (3, 140) LINE
036       140 FORMAT (12H4CALCULATION, 1X, 6H TIME , 1X, 17HPLANT TEMPERATURE, 5
           13X, 39HRATE OF CHANGE OF THE PLANT TEMPERATURE/5X, 3HNO., 5X, 6H (
           2MIN), 2X, 16H(DEGREE CELSIUS), 1X, 51A1, 9X, 24H(DEGREE CELSIUS PE
           3R MIN))
      C
      C     BLANK THE LINE
      C
```

```
037           DO 7 K = 1, 51
040         7 LINE(K) = BLANK
          C
          C     PUT A DOT IN LINE(1) WHICH WILL BE AXIS OF TIME
          C
041           LINE(1) = DOT
          C
          C     BEGIN TO COMPUTE (TIME = 0.000 MIN) AT INITIAL TEMPERATURE
          C
042            K = 51
043            N = 1
044           TM = 0.
045          OTM = TM
046           TC = TCI
          C
          C     COMPUTE EV*RBO = ERB, RBO + REFO = RBFO, TCMX - TCMN = DTMXMN,
          C             PW/BWPC = O1, TDOT = O1/EXP(OTM/TORSM)/TORSM - (TCI - TCA)
          C             /EXP(OTM/TORCM)/TORCM
          C
047            ERB = EV*RBO
050           RBFO = RBO + REFO
051          DTMXMN = TCMX - TCMN
052              O1 = PW/BWPC
053           TDOT = O1/EXP(OTM/TORSM)/TORSM - (TCI - TCA)/EXP(OTM/TORCM)/TORCM
          C
          C     COMPUTE RESISTANCE OF THE THERMISTOR, RTO
          C
054           DO 5 J = 1, NL
055           TK = TC + 273.15
056           IF (C) 10, 15, 10
057        10 RTO = A*TK**C*EXP(BK/TK)
060           GO TO 20
061        15 RTO = A*EXP(BK/TK)
          C
          C     COMPUTE OUTPUT VOLTAGE OF THE BRIDGE, EBV
          C
062        20 EBV = (ERB*(RTO - REFO))/(RDO*(RBFO + RBO + RTO) + RBFO*(RBO + RTO
             1))
          C
          C     COMPUTE DESIRED LOCATION OF PLOTTING SYMBOL
          C
063           IF (TC.LT.TCMN) GO TO 8
064           K = 50.0*(TC - TCMN)/DTMXMN + 1.5
          C
          C     PUT X IN SELECTED LOCATION
          C
065           LINE(K) = X
066        8 IF (J.LT.NCWR) GO TO 200
          C
          C     WRITE RESULTS
          C
067           WRITE (3, 145) J, TM, TC, LINE, TDOT
070      145 FORMAT (3X, I5, 4X, F7.2, 8X, F10.2, 1X, 51A1, 9X, E12.5)
          C
          C     PUT A BLANK IN THE SELECTED LOCATION, WHICH MIGHT HAVE BEEN ON
          C     TIME AXIS
          C
071           LINE(K) = BLANK
          C
          C     PUT A DOT BACK IN TIME AXIS, IN CASE IT WAS BLANKED
          C
```

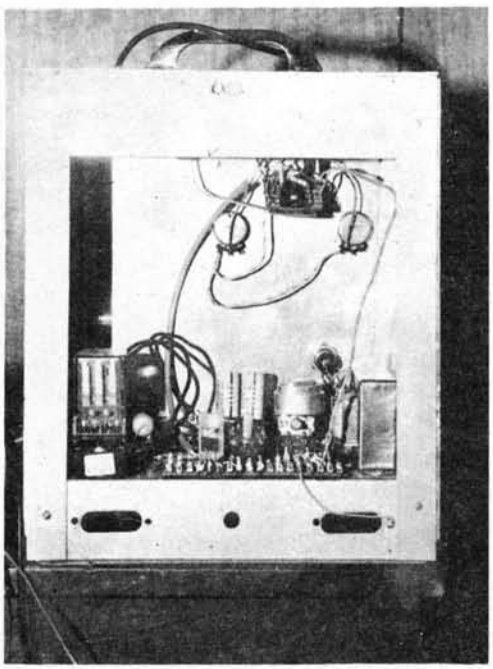
```
072           LINE(1) = DOT
              C
              C     GO ON COMPUTING THE TEMPERATURE OF THE SYSTEM
              C
073         200 TM = TM + TSM
074             IF (N - 1) 25, 30, 25
075          30 IF (EBV - CPLV) 35, 35, 40
076          40 IF (N.EQ.2) OTM = 0.
077             IF (N.EQ.2) TCI = TC
100             OTM = OTM + TSM
101              02 = EXP(OTM/TORSM)
102              03 = EXP(OTM/TORCM)
103              04 = 01/02
104              05 = (TCI - TCA)/03
105              TC = 01 - 04 + 05 + TCA
106             TDOT = 04/TORSM - 05/TORCM
107               N = 1
110             GO TO 5
111          25 IF (EBV - SPLV) 35, 40, 40
112          35 IF (N.EQ.1) OTM = 0.
113             IF (N.EQ.1) TCI = TC
114             OTM = OTM + TSM
115              02 = (TCA - TCI)/EXP(OTM/TORCM)
116              TC = TCA - 02
117             TDOT = 02/TORCM
120               N = 2
121           5 CONTINUE
122             STOP
123             END
```

Appendix I

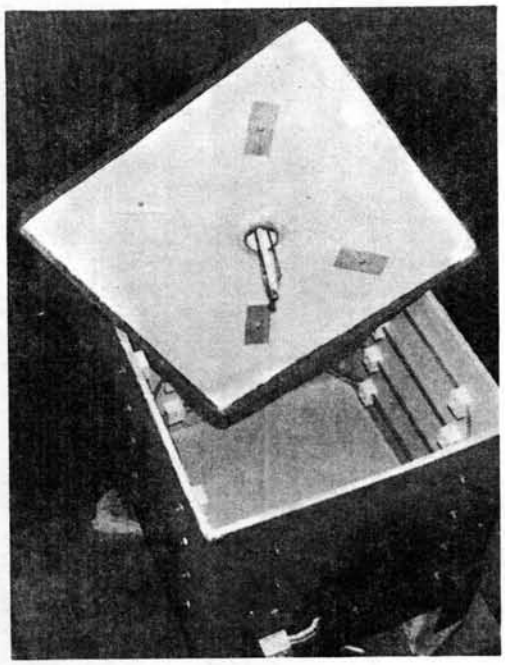
PHOTOGRAPHES OF THE CONSTRUCTED CONTROLLER



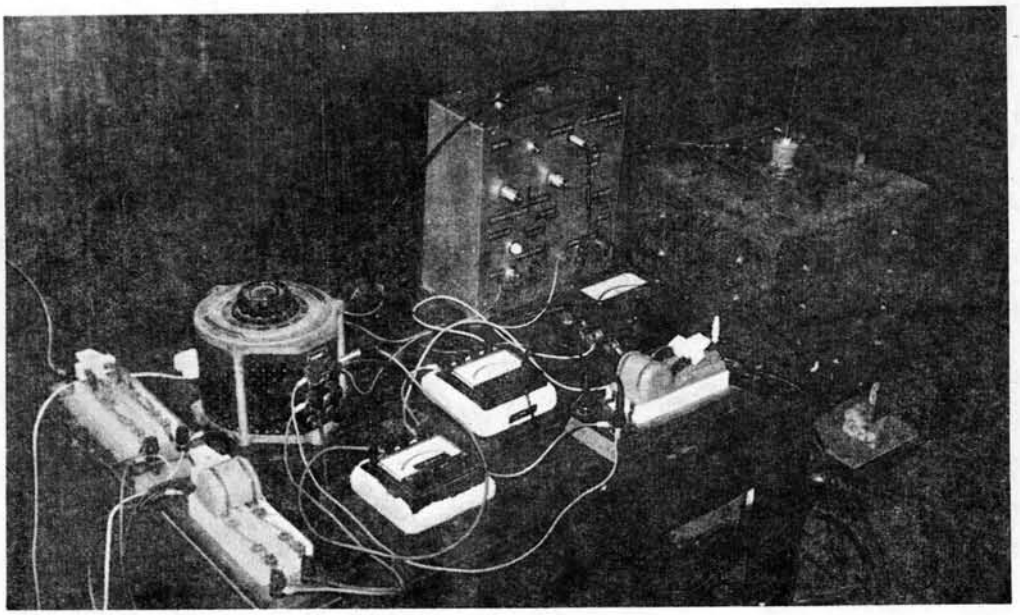
◀ FRONT VIEW OF CONTROLLER



◀ REAR VIEW OF CONTROLLER



◀ EXPERIMENTAL ELECTRIC OVEN



EXPERIMENTAL SETUP OF TEMPERATURE CONTROL SYSTEM

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