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ESCUELA POLITECNICA NACIONAL

FACULTAD DE INGENIERIA ELECTRICA

**ESTUDIO DEL MODELO Y EL CONTROL ACTUAL DE
UNA MAQUINA EXTRUSORA DE P.V.C, DISEÑO Y
SIMULACION DE UNA ALTERNATIVA DE CONTROL**

TESIS PREVIA A LA OBTENCION DEL TITULO DE

INGENIERO EN ELECTRONICA Y CONTROL

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ANEXO A

A.1.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO CERRADO DEL TUNEL ZONA 2

Para el análisis del modelo y el sistema real de control se procede a obtener una expresión matemática que describa su comportamiento

Tiempo en min.	Δ Temperatura en ° C
0	0
1	0,5
2	2
3	4
4	6
5	10
6	13,5
7	15,5
8	17,5
9	18,8
10	19,9
11	20,6
12	21,2
14	22

Tabla A.1.1 Variación de temperatura en función del tiempo (túnel zona 2)

$$C(t) = A + k_1 e^{-t/\tau_1} + k_2 e^{-t/\tau_2} + k_3 e^{-t/\tau_3} + \dots + k_n e^{-t/\tau_n} \quad (\text{A.1})$$

$$C(t) - A = k_1 e^{-t/\tau_1} \quad (\text{A.2})$$

Siendo para este caso, $A = 23$ ° C, valor que corresponde a la variación asumida al variar el set point de entrada. Se obtiene los siguientes valores mostrados en la tabla A.2.

Tiempo (min)	A-c(t)
0	23
1	22,5
2	21
3	19
4	17
5	13
6	9,5
7	7,5
8	5,5
9	4,2
10	3,1
11	2,4

12	1,8
14	1

Tabla A.1.2 Operaciones realizadas según la ecuación A.2

A los valores de $|C(t) - A|$ se los dibuja en escala semilogarítmica, figura A.1.1

La recta que representa mejor los datos esta dada por la ecuación:

$$p_1(x) = a_0 + a_1 \cdot x \quad (\text{A.3})$$

Por el algoritmo de mínimos cuadrados se tiene la siguiente tabla de valores:

$X_j = \text{tiempo (min)}$	$f(t) = k_1 \cdot e^{-t/\tau^1}$	$y_j = \ln(F(t))$	$X_j Y_j$	X_j^2
4	17	2,83	11,333	16
5	13	2,56	12,825	25
6	9,5	2,25	13,508	36
7	7,5	2,01	14,104	49
8	5,5	1,7	13,638	64
9	4,2	1,44	12,916	
10	3,1	1,13	11,314	100
11	2,4	0,88	9,6302	121
12	1,8	0,59	7,0534	144
14	1	0	0	196
$\Sigma X_j = 86$		$\Sigma Y_j = 15,4$	$\Sigma X_j Y_j = 106,321$	$\Sigma X_j^2 = 832$

Tabla A.1.3. Análisis de la regresión para la zona 2 del túnel

$$a_0 = 3,97 \quad k_1 = e^{(a_0)} \quad k_1 = 52,981$$

$$a_1 = -0,283 \quad \tau_1 = 1/a_1 \quad \tau_1 = 3,539$$

La ecuación de $C(t)$ llega a ser:

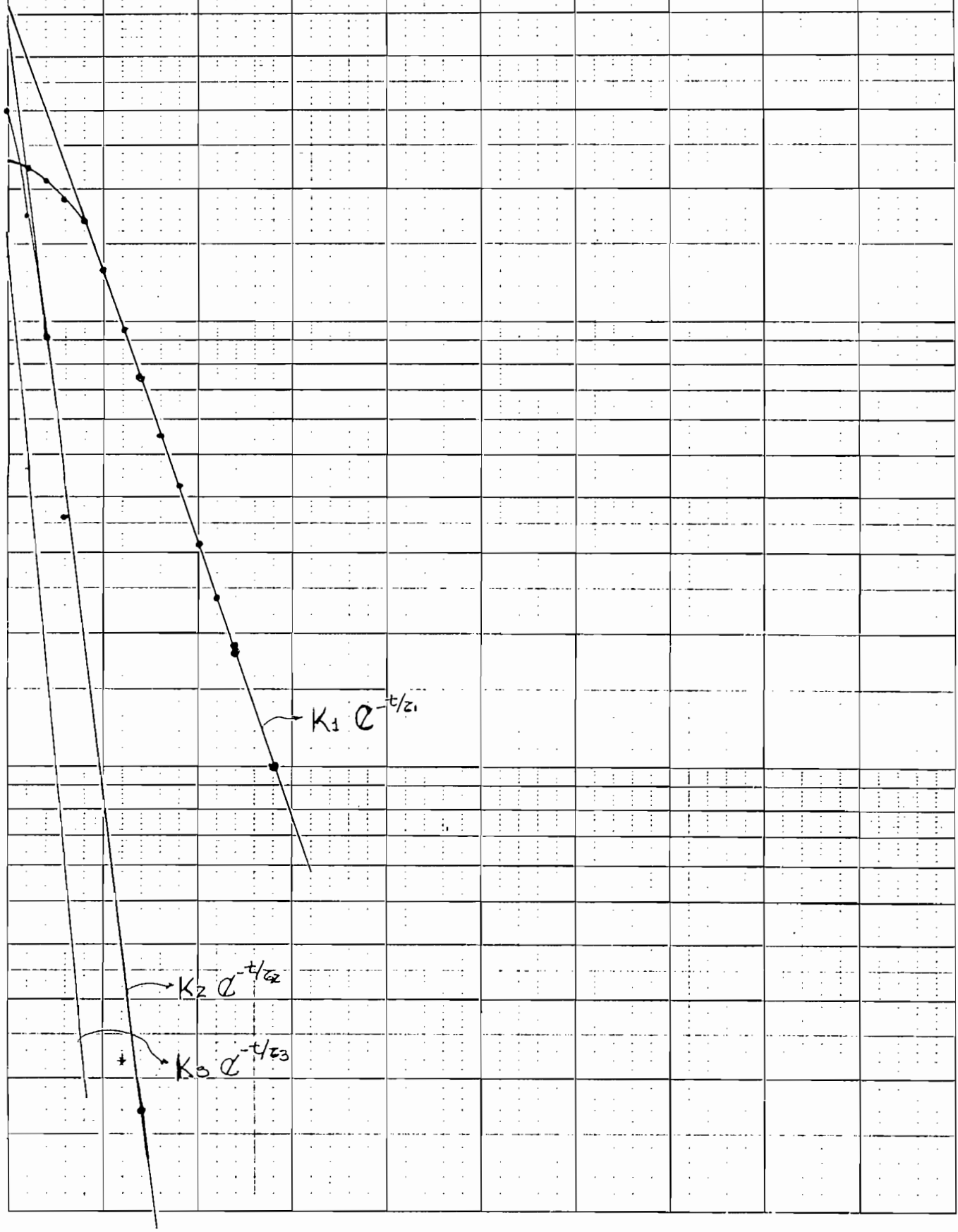
$$C(t) = 23 - 52,981 e^{-t/3,539} + k_2 e^{-t/\tau^2} + k_3 e^{-t/\tau^3} + \dots + k_n e^{-t/\tau^n}$$

$$C(t) - 23 + 52,981 e^{-t/3,539} = k_2 e^{-t/\tau^2} + k_1 e^{-t/\tau^1} + \dots + k_n e^{-t/\tau^n} \quad (\text{A.1.1})$$

Para determinar la constante k_2 , se realiza el mismo procedimiento:

Tiempo (min)	$c(t) - 23 + 52,981 e^{-t/3,539}$
0	29,98
1	17,44
2	9,109
3	3,697
4	0,11
5	-0,1

Figura A.1.1 Gráfica en escala semi logarítmica, para describir a la zona 2 del túnel



6	0,224
7	-0,17

Tabla A.1.4 Datos para encontrar las constantes k_2 y τ_2

De la figura A.1.1 en escala semilogaritmica y de la tabla A.1.4 se observan que la mejor recta pasa por 2 y 7 minutos.

Por lo cual obtiene las siguientes relaciones:

$$\text{Para } t = 2 \text{ min,} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 9,11 \quad (\text{A.1.2})$$

$$\text{Para } t = 7 \text{ min.} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 0,17 \quad (\text{A.1.3})$$

Resolviendo las relaciones A.1.2 y A.1.3, se tiene los valores de $k_2 = 44,788$ y $\tau_2 = 1,395$ min., reemplazando los valores se tiene: $y = k_2 e^{-t/\tau^2} = 44,788 e^{-t/1,395}$

por lo cual se tiene la ecuación para $c(t)$ como:

$$C(t) = 23 - 52,981 e^{-t/3,539} + 44,788 e^{-t/1,395} + k_3 e^{-t/\tau^3} + k_n e^{-t/\tau^n} \quad (\text{A.1.4})$$

Las constantes k_3 y τ_3 se obtienen de la siguiente manera:

De la figura A.1.1 en escala semilogaritmica y de la tabla A.1.5, los puntos para los cuales pasa la mejor recta de $k_3 e^{-t/\tau^3}$ es para 0 y 1 minuto. Por lo tanto se obtiene el siguiente sistema de ecuaciones:

$$\text{Para } t = 0 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 14,807 \quad (\text{A.1.5})$$

$$\text{Para } t = 1 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 4,440 \quad (\text{A.1.6})$$

Tiempo (min)	$c(t) - 23 - 52,981 e^{-t/3,539} + 44,788 e^{-t/1,395}$
0	-7,447009
1	-1,400556
2	0
3	-0,325544
4	-0,448651

Tabla A.1.5 Datos para encontrar las constantes k_3 y τ_3

Resolviendo las ecuaciones A.1.5 y A.1.6 simultáneamente se encuentra que $k_3 = 14,807$ y $\tau_3 = 0,830$ min.

$$y = k_3 e^{-t/\tau^3} = -14,807 e^{-t/0,830}.$$

Luego la ecuación definitiva de la zona 2 del túnel $c_{TZ2}(t)$ es:

$$C_{TZ2}(t) = 23 - 52,981 e^{-t/3,539} + 44,788 e^{-t/1,395} - 14,807 e^{-t/0,830}. \quad (\text{A.1.7})$$

La tabla muestra los valores de la función $C_{TZ2}(t)$ real, medidos en el proceso al variar bruscamente el set point y los valores de la función $C_{TZ2}(t)$ identificada, se puede ver que la diferencia entre las dos funciones es mínima.

Tiempo (min)	C(t) = real	C(t) = identificada
0	0	0
1	0,5	0,5
2	2	2,249
3	4	5,125
4	6	8,321
5	10	11,31
6	13,5	13,87
7	15,5	15,96
8	17,5	17,62
9	18,8	18,91
10	19,9	19,89
11	20,6	20,65
12	21,2	21,22
14	22	21,99

Tabla A.1.6 Valores de $C_{z1}(t)$ medidos en el proceso y $C_{z1}(t)$ identificada.

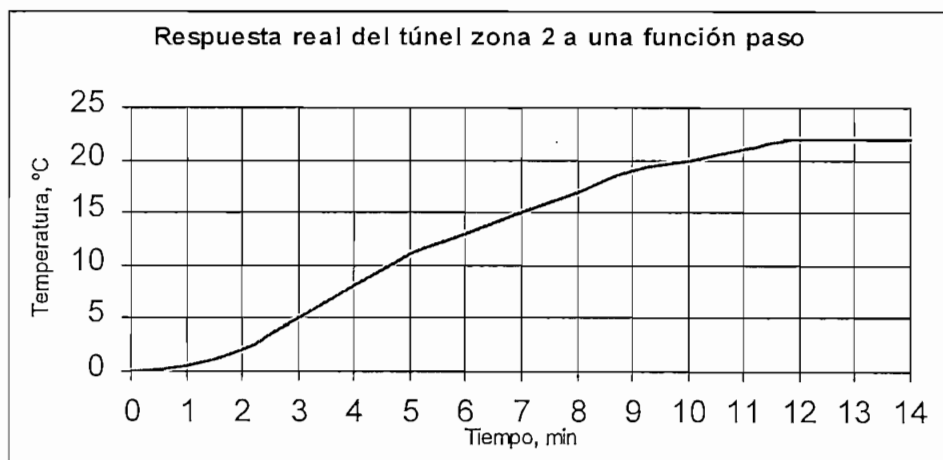


Figura A.1.4 Respuesta real en función del tiempo del túnel zona 2 ante un incremento de temperatura

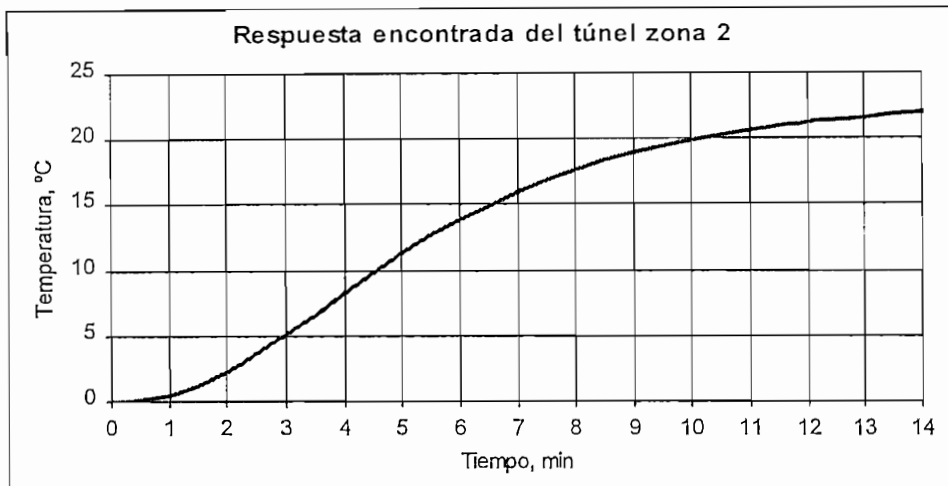


Figura A.1.4 Resposta identificada en función del tiempo del túnel zona 2 ante un incremento de temperatura

Para tener un criterio claro de la bondad del modelo identificado, se utiliza el coeficiente de regresión; los resultados son mostrados en la tabla A.1.7 que se lo expone a continuación:

Tiempo	C(t) real	C(t) ident	$[C(t)_{real} - Y_{promedio}]^2$	$[C(t)_{ident} - Y_{promedio}]^2$
0	0	0	150,1	150,1
1	0,5	0,5	138,1	138,1
2	2	2,249	105,1	100
3	4	5,125	68,06	50,76
4	6	8,321	39,06	15,44
5	10	11,31	5,062	0,88
6	13,5	13,87	1,563	2,639
7	15,5	15,96	10,56	13,79
8	17,5	17,62	27,56	28,82
9	18,8	18,91	42,9	44,29
10	19,9	19,89	58,52	58,44
11	20,6	20,65	69,72	70,55
12	21,2	21,22	80,1	80,53
14	22	21,99	95,06	94,83
			$\Sigma = 891,4$	$\Sigma = 849,1$

Tabla A.1.7 Cálculos para encontrar el coeficiente de regresión.

En la tabla A.1.7 se presentan los cálculos realizados para encontrar el coeficiente de regresión, de la misma que se tiene:

$$\bar{y} = y_{promedio} = 12,25$$

$$r^2 = \frac{849,1}{891,4} = 0,952.$$

Con el cálculo del coeficiente de regresión queda más que ratificada que la función identificada es válida.

Para encontrar la función de transferencia se aplica la transformada de Laplace a la ecuación A.1.7:

$$C_{TZ2}(t) = 23 - 52,981 e^{-t/3,539} + 44,788 e^{-t/1,395} - 14,807 e^{-t/0,830}$$

$$C(s) = \frac{23}{s} - \frac{52,981}{s + \frac{1}{3,539}} + \frac{44,788}{s + \frac{1}{1,395}} - \frac{14,807}{s + \frac{1}{0,830}} \quad (\text{A.1.8})$$

Si la entrada paso es de 30 ° C, entonces:

$$R(s) = \frac{30}{s} \quad (\text{A.1.9})$$

Por tanto la función de transferencia en lazo cerrado definitiva es:

$$\frac{C(s)}{R(s)} = \frac{2,949s^2 - 4,673s + 23}{30(3,539s + 1)(1,395s + 1)(0,830s + 1)}$$

$$\frac{C(s)}{R(s)} = \frac{0,024s^2 - 0,038s + 0,187}{s^3 + 2,203s^2 + 1,405s + 0,244} \quad (\text{A.1.10})$$

A.1.1.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO ABIERTO

La función de transferencia en lazo cerrado de la planta se la obtiene mediante la siguiente relación:

$$\frac{C(s)}{R(s)} = \frac{G_{cir} \cdot G_{act} \cdot G_{iv} \cdot G_{planta}}{1 + G_{cir} \cdot G_{act} \cdot G_{iv} \cdot G_{planta}} \quad (\text{A.4})$$

Despejando la ecuación anterior se tiene:

$$G_{planta} = \frac{\frac{C(s)}{R(s)}}{\left(1 - \frac{C(s)}{R(s)}\right) \cdot G_{ctr} \cdot G_{act} \cdot G_{IV}} = K^* \frac{\frac{C(s)}{R(s)}}{\left(1 - \frac{C(s)}{R(s)}\right)} \quad (\text{A.5})$$

Donde K^* es:

$$K^* = (G_{ctr} \cdot G_{act} \cdot G_{IV})^{-1} \quad (\text{A.6})$$

Los datos del controlador para este análisis fueron:

BP = Banda proporcional = 40%

Con lo cual se tiene que:

$$BP = 100/Kc \Rightarrow Kc = 2.5$$

Donde Kc es la ganancia del controlador, por lo cual se tiene que: $G_{ctr} = 2.5$.

$G_{TV} = 0,01193$, $G_{act} = 1$ se considera un relé ideal.

Reemplazando todos los datos en la ecuación A.6 se tiene:

$$K^* = 2.5 * 0,01193 * 1 = (0,0298)^{-1} = 33,52$$

Con los valores obtenidos en A.1.10 y reemplazando en A.6 se tiene que la función de transferencia en lazo abierto es:

$$G_{planta} = K^* \left(\frac{0,024s^2 - 0,038s + 0,187}{s^3 + 2,179s^2 + 0,662s + 0,057} \right) \quad (\text{A.1.11})$$

donde $K^* = 23,52$

A.2.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO CERRADO DEL TUNEL ZONA 3

Para el análisis del modelo y el sistema real de control se procede a obtener una expresión matemática que describa su comportamiento

Tiempo en min.	Δ Temperatura en ° C
0	0
1	0,2
2	1
3	2
4	3
5	4,2
6	5,3
7	6,1
8	6,8
9	7,4
10	7,8
11	8,2
12	8,5
14	9

Tabla A.2.1 Variación de temperatura en función del tiempo (túnel zona 3)

$$C(t) = A + k_1 e^{-t/\tau_1} + k_2 e^{-t/\tau_2} + k_3 e^{-t/\tau_3} + \dots + k_n e^{-t/\tau_n} \quad (\text{A.1})$$

$$C(t) - A = k_1 e^{-t/\tau_1} \quad (\text{A.2})$$

Siendo para este caso, $A = 10$ ° C, valor que corresponde a la variación asumida al variar el set point de entrada. Se obtiene los siguientes valores mostrados en la tabla A.2.2.

Tiempo (min)	$ A - c(t) $
0	10
1	9,8
2	9
3	8
4	7
5	5,8
6	4,7
7	3,9
8	3,2
9	2,6
10	2,2
11	1,8
12	1,5
14	1

Tabla A.2.2 Operaciones realizadas según la ecuación A.2

A los valores de $|C(t) - A|$ se los dibuja en escala semilogarítmica, figura A.2.1

La recta que representa mejor los datos esta dada por la ecuación:

$$p_1(x) = a_0 + a_1 \cdot x \quad (\text{A.3})$$

Por el algoritmo de mínimos cuadrados se tiene la siguiente tabla de valores:

$X_i = \text{tiempo (min)}$	$f(t) = k_1 \cdot e^{-t/\tau^1}$	$y_i = \text{Ln}(F(t))$	$X_i Y_i$	X_i^2
4	7	7,783	7,783	16
5	5,8	1,758	8,789	25
6	4,7	1,548	9,285	36
7	3,9	1,361	9,526	49
8	3,2	1,163	9,305	64
10	2,2	0,788	7,884	100
11	1,8	0,588	6,465	121
12	1,5	0,405	4,865	144
14	1	0	0	196
$\Sigma X_i = 77$		$\Sigma Y_i = 9,557$	$\Sigma X_i Y_i = 63,906$	$\Sigma X_i^2 = 751$

Tabla A.2.3. Análisis de la regresión para la zona 3 del túnel

$$a_0 = 2,718 \quad k_1 = e^{(a_0)} \quad k_1 = 15,163$$

$$a_1 = -0,193 \quad \tau_1 = 1/a_1 \quad \tau_1 = 5,163$$

La ecuación de $C(t)$ llega a ser:

$$C(t) = 10 - 15,163 e^{-t/5,163} + k_2 e^{-t/\tau^2} + k_3 e^{-t/\tau^3} + \dots + k_n e^{-t/\tau^n}$$

$$C(t) - 10 + 15,163 e^{-t/5,163} = k_2 e^{-t/\tau^2} + k_1 e^{-t/\tau^1} + \dots + k_n e^{-t/\tau^n} \quad (\text{A.2.1})$$

Para determinar la constante k_2 , se realiza el mismo procedimiento:

Tiempo (min)	$c(t) - 10 + 15,163 e^{-t/5,163}$
0	5,163
1	2,693
2	1,293
3	0,4812
4	-0,012
5	-0,042
6	0,043

Tabla A.2.4 Datos para encontrar las constantes k_2 y τ_2

De la figura A.2.1 en escala semilogarítmica y de la tabla A.2.4 se observan que la mejor recta pasa por 2 y 6 minutos.

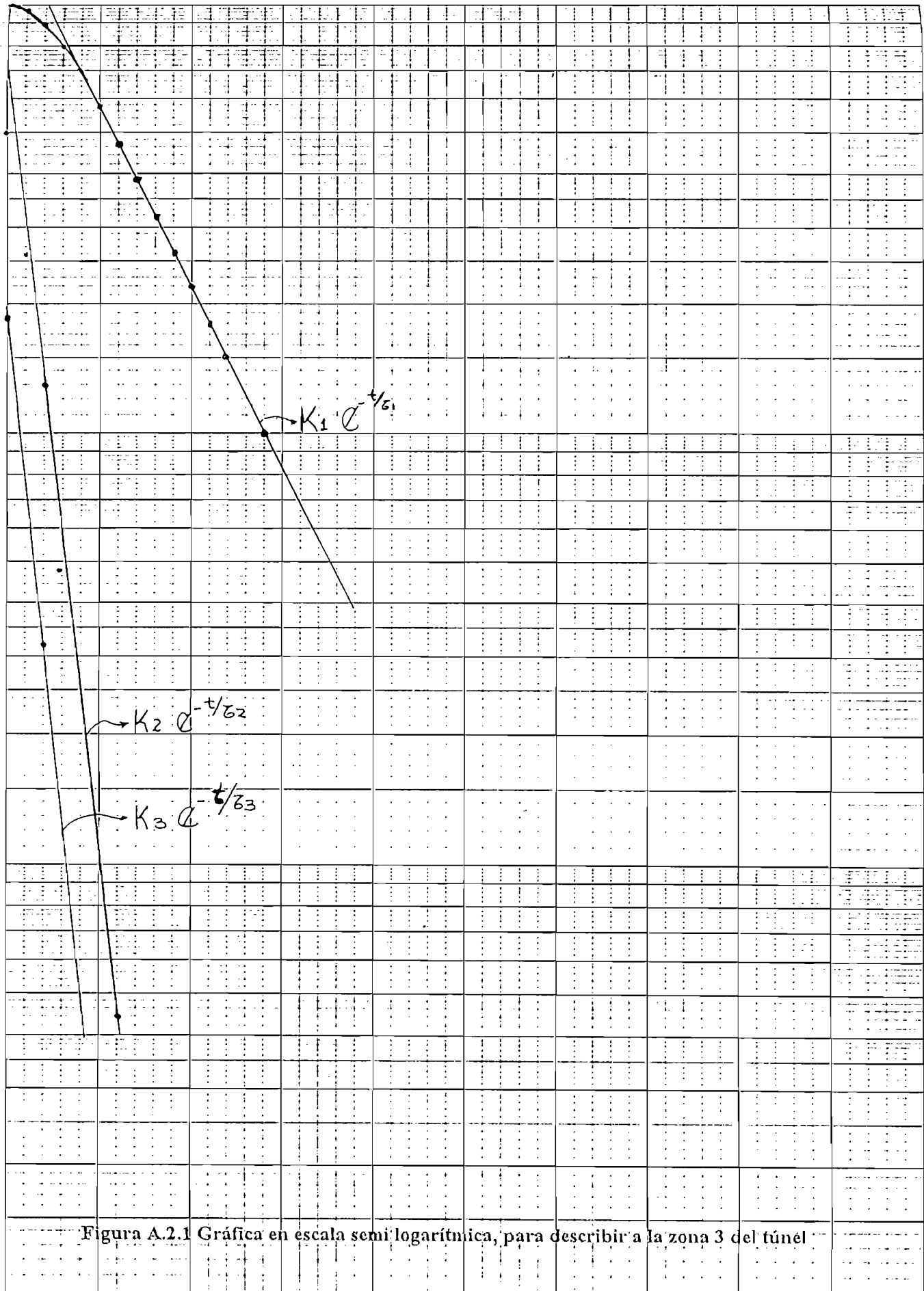


Figura A.2.1 Gráfica en escala semi-logarítmica, para describir a la zona 3 del túnel

Por lo cual obtiene las siguientes relaciones:

$$\text{Para } t = 2 \text{ min.} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 1,293 \quad (\text{A.2.2})$$

$$\text{Para } t = 6 \text{ min.} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 0,043 \quad (\text{A.2.3})$$

Resolviendo las relaciones A.2.2 y A.2.3, se tiene los valores de $k_2 = 7,028$ y $\tau_2 = 1,181$ min, reemplazando los valores se tiene: $y = k_2 e^{-t/\tau^2} = 7,028 e^{-t/1,181}$

por lo cual se tiene la ecuación para $c(t)$ como:

$$C(t) = 10 - 15,163 e^{-t/5,163} + 7,028 e^{-t/1,181} + k_3 e^{-t/\tau^3} + k_n e^{-t/\tau^n} \quad (\text{A.2.4})$$

Las constantes k_3 y τ_3 se obtienen de la siguiente manera:

De la figura A.2.1 en escala semilogaritmica y de la tabla A.2.5, los puntos para los cuales pasa la mejor recta de $k_3 e^{-t/\tau^3}$ es para 0 y 1 minuto. Por lo tanto se obtiene el siguiente sistema de ecuaciones:

$$\text{Para } t = 0 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 1,865 \quad (\text{A.2.5})$$

$$\text{Para } t = 1 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 0,322 \quad (\text{A.2.6})$$

Tiempo (min)	$c(t) - 10 + 15,163 e^{-t/5,163} - 7,028 e^{-t/1,181}$
0	-1,865
1	-0,322
2	0
3	-0,0738
4	-0,250

Tabla A.2.5 Datos para encontrar las constantes k_3 y τ_3

Resolviendo las ecuaciones A.2.5 y A.2.6 simultáneamente se encuentra que $k_3 = 1,865$ y $\tau_3 = 0,569$ min.

$$y = k_3 e^{-t/\tau^3} = 1,865 e^{-t/0,569}$$

Luego la ecuación definitiva de la zona 3 del túnel $c_{TZ3}(t)$ es:

$$C_{TZ3}(t) = 10 - 15,163 e^{-t/5,163} + 7,028 e^{-t/1,181} - 1,865 e^{-t/0,569} \quad (\text{A.2.7})$$

La tabla muestra los valores de la función $C_{TZ3}(t)$ real, medidos en el proceso al variar bruscamente el set point y los valores de la función $C_{TZ3}(t)$ identificada, se puede ver que la diferencia entre las dos funciones es mínima.

Tiempo (min.)	$C(t) = \text{real}$	$C(t) = \text{identificada}$
0	0	0
1	0,2	0,5
2	1	0,944
3	2	2,064
4	3	3,248
5	4,2	4,344
6	5,3	5,3
7	6,1	6,11
8	6,8	6,787
9	7,4	7,35
10	7,8	7,815
11	8,2	8,199
12	8,5	8,516
14	9	8,992

Tabla A.2.6 Valores de $C_{zi}(t)$ medidos en el proceso y $C_{zi}(t)$ identificada.

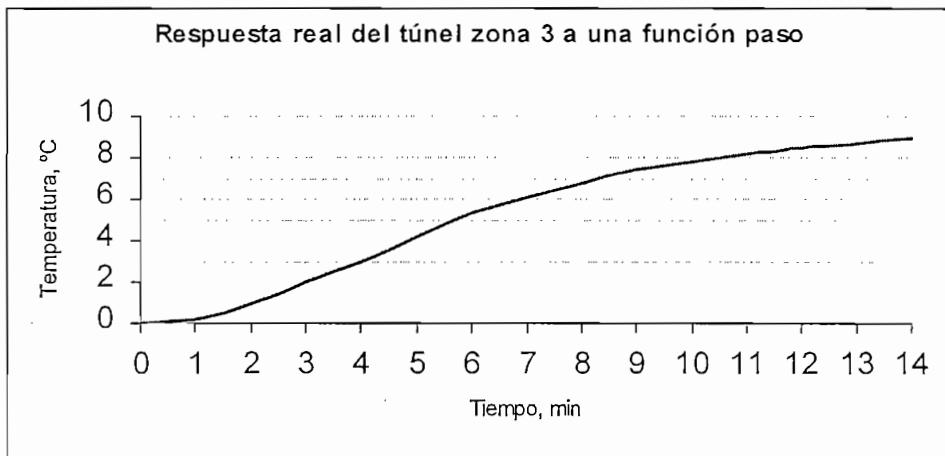


Figura A.2.2 Respuesta real en función del tiempo del túnel zona 3 ante un incremento de temperatura

$$\bar{y} = y_{promedio} = 4,964$$

$$r^2 = \frac{133,2}{134,3} = 0,992.$$

Con el cálculo del coeficiente de regresión queda más que ratificada que la función identificada es válida.

Para encontrar la función de transferencia se aplica la transformada de Laplace a la ecuación A.2.7:

$$C_{TZ,3}(t) = 10 - 15,163 e^{-t/5,163} + 7,028 e^{-t/1,181} - 1,865 e^{-t/0,569}.$$

$$C(s) = \frac{10}{s} - \frac{15,163}{s + \frac{1}{5,163}} + \frac{7,028}{s + \frac{1}{1,181}} - \frac{1,865}{s + \frac{1}{0,569}} \quad (\text{A.2.8})$$

Si la entrada paso es de 30 ° C, entonces:

$$R(s) = \frac{30}{s} \quad (\text{A.2.9})$$

Por tanto la función de transferencia en lazo cerrado definitiva es:

$$\frac{C(s)}{R(s)} = \frac{0,922s^2 - 1,906s + 10}{30(5,163s + 1)(1,181s + 1)(0,569s + 1)}$$

$$\frac{C(s)}{R(s)} = \frac{0,0088s^2 - 0,0182s + 0,0959}{s^3 + 2,796s^2 + 1,990s + 0,287} \quad (\text{A.2.10})$$

A.2.1.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO ABIERTO

Los datos del controlador para este análisis fueron:

BP = Banda proporcional = 40%

BP = 100/Kc ⇒ Kc = 2.5.

Donde Kc es la ganancia del controlador, por lo cual se tiene que: G_{ctr} = 2.5.

$G_{TV} = 0,01193$, $G_{act} = 1$ se considera un relé ideal.

Reemplazando todos los datos en la ecuación A.6 se tiene:

$$K^* = 2.5 * 0,01193 * 1 = (0,0298)^{-1} = 33,52$$

Con los valores obtenidos en A.2.10 y reemplazando en A.6 se tiene que la función de transferencia en lazo abierto es:

$$G_{planta} = K^* \left(\frac{0,0088s^2 - 0,0182s + 0,0959}{s^3 + 2,787s^2 + 0,720s + 0,191} \right) \quad (A.2.11)$$

donde $K^* = 23,52$

A.3.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO CERRADO DEL TUNEL ZONA 4

Para el análisis del modelo y el sistema real de control se procede a obtener una expresión matemática que describa su comportamiento

Tiempo en min.	Δ Temperatura en ° C
0	0
1	0,5
2	2,8
3	5,3
4	8
5	11
6	13,4
7	15
8	16,4
9	17,4
10	18,2
11	18,8
12	19,3
14	20

Tabla A.3.1 Variación de temperatura en función del tiempo (túnel zona 4)

$$C(t) = A + k_1 e^{-t/\tau_1} + k_2 e^{-t/\tau_2} + k_3 e^{-t/\tau_3} + \dots + k_n e^{-t/\tau_n} \quad (\text{A.1})$$

$$C(t) - A = k_1 e^{-t/\tau_1} \quad (\text{A.2})$$

Siendo para este caso, $A = 21$ ° C, valor que corresponde a la variación asumida al variar el set point de entrada. Se obtiene los siguientes valores mostrados en la tabla A.3.2.

Tiempo (min)	A-c(t)
0	21
1	20,5
2	18,2
3	15,7
4	13
5	10
6	7,6
7	6
8	4,6
9	3,6
10	2,8
11	2,2
12	1,7
14	1

Tabla A.3.2 Operaciones realizadas según la ecuación A.2

A los valores de $|C(t) - A|$ se los dibuja en escala semilogarítmica, figura A.3.1

La recta que representa mejor los datos esta dada por la ecuación:

$$p_1(x) = a_0 + a_1 \cdot x \quad (\text{A.3})$$

Por el algoritmo de mínimos cuadrados se tiene la siguiente tabla de valores:

$X_i = \text{tiempo (min)}$	$f(t) = k_1 \cdot e^{-t/\tau_1}$	$y_i = \text{Ln}(F(t))$	$X_i \cdot Y_i$	X_i^2
4	13	2,5649	10,2598	16
5	10	2,3026	11,5129	25
6	7,6	2,0281	12,1689	36
7	6	1,7918	12,5423	49
8	4,6	1,5261	12,2085	64
9	3,6	1,2809	11,5284	81
10	2,8	1,0296	10,2962	100
11	2,2	0,7885	8,67303	121
12	1,7	0,5306	6,36754	144
14	1	0	0	196
$\Sigma X_i = 86$		$\Sigma Y_i = 13,84$	$\Sigma X_i \cdot Y_i = 95,55$	$\Sigma X_i^2 = 832$

Tabla A.3.3. Análisis de la regresión para la zona 4 del túnel

$$a_0 = 3,570 \quad k_1 = e^{(a_0)} \quad k_1 = 35,549$$

$$a_1 = -0,254 \quad \tau_1 = 1/a_1 \quad \tau_1 = 3,933$$

La ecuación de $C(t)$ llega a ser:

$$C(t) = 21 - 35,549 e^{-t/3,933} + k_2 e^{-t/\tau_2} + k_3 e^{-t/\tau_3} + \dots + k_n e^{-t/\tau_n}$$

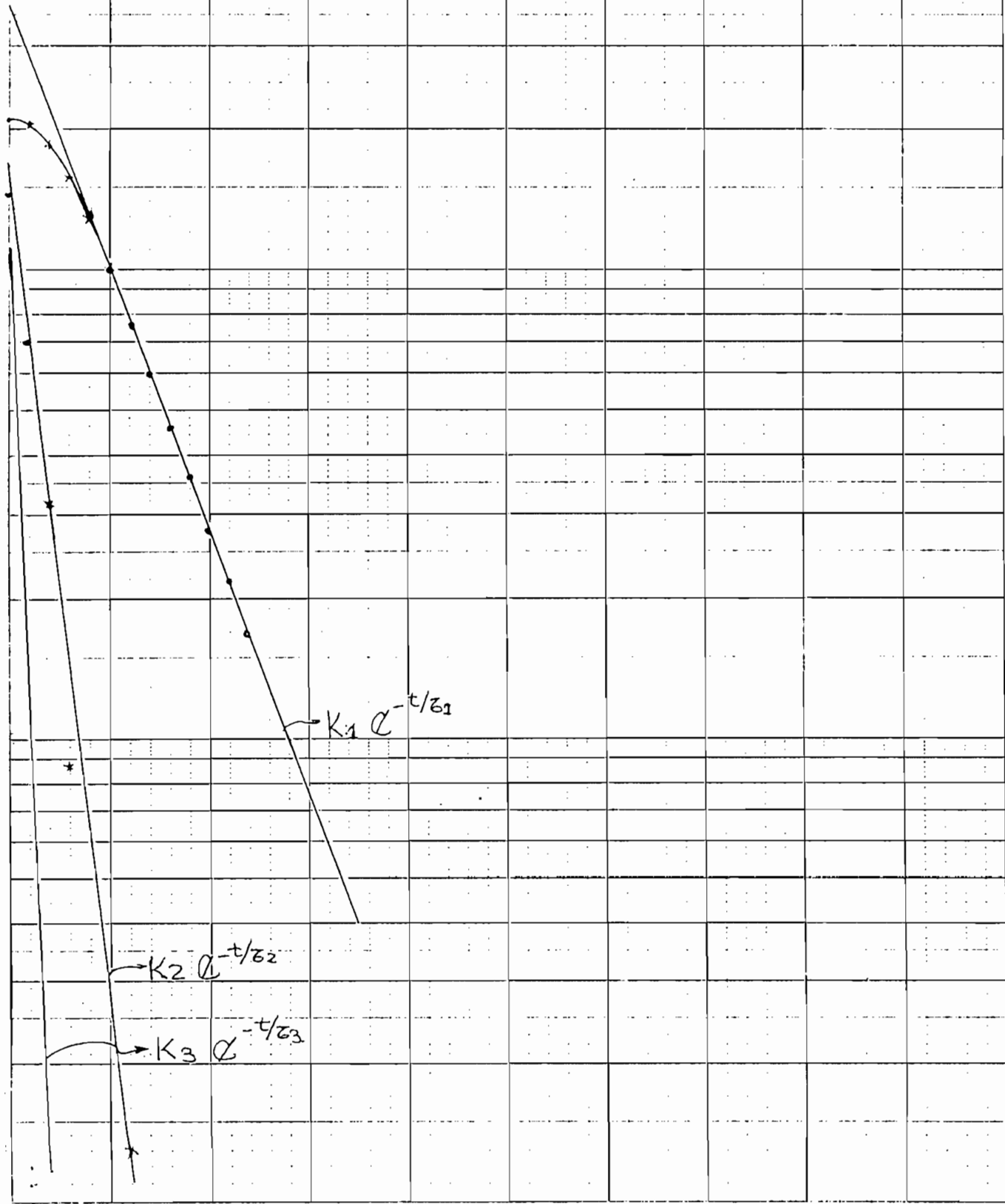
$$C(t) - 21 + 35,549 e^{-t/3,933} = k_2 e^{-t/\tau_2} + k_1 e^{-t/\tau_1} + \dots + k_n e^{-t/\tau_n} \quad (\text{A.3.1})$$

Para determinar la constante k_2 , se realiza el mismo procedimiento:

Tiempo (min)	$c(t) - 21 + 35,549 e^{-t/3,933}$
0	14,55
1	7,069
2	3,179
3	0,879
4	-0,143
5	-0,029
6	0,132

Tabla A.3.4 Datos para encontrar las constantes k_2 y τ_2

Figura A.3.1 Gráfica en escala semi logarítmica, para describir a la zona 4 del túnel



De la figura A.2.1 en escala semilogaritmica y de la tabla A.3.4 se observan que la mejor recta pasa por 2 y 6 minutos.

Por lo cual obtiene las siguientes relaciones:

$$\text{Para } t = 2 \text{ min.} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 3,179 \quad (\text{A.3.2})$$

$$\text{Para } t = 6 \text{ min.} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 0,132 \quad (\text{A.3.3})$$

Resolviendo las relaciones A.3.2 y A.3.3, se tiene los valores de $k_2 = 15,594$ y $\tau_2 = 1,259$ min, reemplazando los valores se tiene: $y = k_2 e^{-t/\tau^2} = 15,594 e^{-t/1,259}$

por lo cual se tiene la ecuación para $c(t)$ como:

$$C(t) = 21 - 35,549 e^{-t/3,933} + 15,594 e^{-t/1,259} + k_3 e^{-t/\tau^3} + k_n e^{-t/\tau^n} \quad (\text{A.3.4})$$

Las constantes k_3 y τ_3 se obtienen de la siguiente manera:

De la figura A.3.1 en escala semilogaritmica y de la tabla A.3.5, los puntos para los cuales pasa la mejor recta de $k_3 e^{-t/\tau^3}$ es para 0 y 1 minuto. Por lo tanto se obtiene el siguiente sistema de ecuaciones:

$$\text{Para } t = 0 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 1,044 \quad (\text{A.3.5})$$

$$\text{Para } t = 1 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 0,018 \quad (\text{A.3.6})$$

Tiempo (min)	$c(t) - 21 + 35,549 e^{-t/3,933} - 15,594 e^{-t/1,259}$
0	-1,044
1	-0,018
2	0
3	-0,561
4	-0,794

Tabla A.3.5 Datos para encontrar las constantes k_3 y τ_3

Resolviendo las ecuaciones A.3.5 y A.3.6 simultáneamente se encuentra que $k_3 = 1,044$ y $\tau_3 = 0,248$ min.

$$y = k_3 e^{-t/\tau^3} = 1,044 e^{-t/0,248}$$

Luego la ecuación definitiva de la zona 4 del túnel $c_{TZ4}(t)$ es:

$$C_{TZ4}(t) = 21 - 35,549 e^{-t/3,933} + 15,594 e^{-t/1,259} - 1,044 e^{-t/0,248} \quad (\text{A.3.7})$$

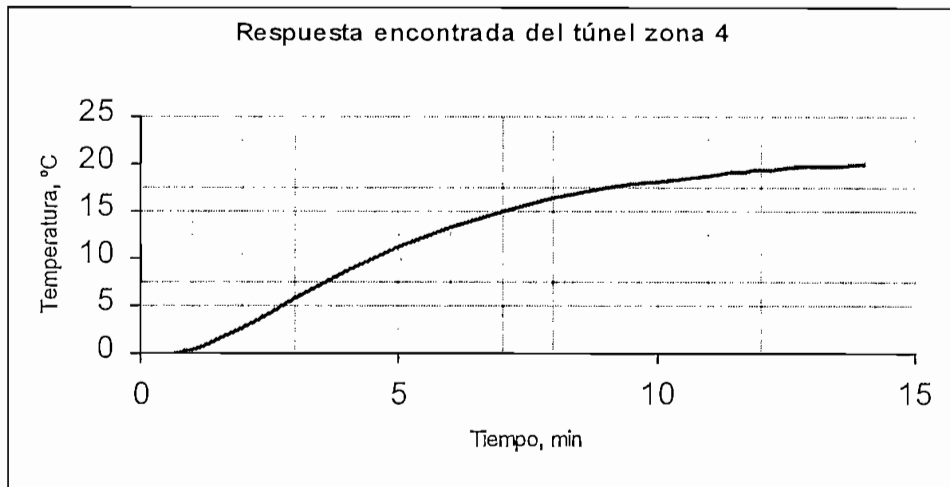


Figura A.3.3 Respuesta identificada en función del tiempo del túnel zona 4 ante un incremento de temperatura

Para tener un criterio claro de la bondad del modelo identificado, se utiliza el coeficiente de regresión; los resultados son mostrados en la tabla A.3.7 que se lo expone a continuación:

Tiempo	C(t) real	C(t) ident	$[C(t)_{\text{real}} - Y_{\text{promedio}}]^2$	$[C(t)_{\text{ident}} - Y_{\text{promedio}}]^2$
0	0	0	140,8	140,8
1	0,5	0,463	129,1	130
2	2,8	2,808	82,16	82,02
3	5,3	5,862	43,09	36,03
4	8	8,794	14,93	9,425
5	11	11,32	0,747	0,292
6	13,4	13,4	2,358	2,362
7	15	15,06	9,833	10,24
8	16,4	16,38	20,57	20,37
9	17,4	17,41	30,64	30,71
10	18,2	18,21	40,14	40,26
11	18,8	18,83	48,1	48,58
12	19,3	19,32	55,29	55,58
14	20	19,99	66,19	66,01
			$\Sigma = 684,1$	$\Sigma = 673$

Tabla A.3.7 Cálculos para encontrar el coeficiente de regresión.

En la tabla A.3.7 se presentan los cálculos realizados para encontrar el coeficiente de regresión, de la misma que se tiene:

$$\bar{y} = y_{promedio} = 11,864$$

$$\gamma^2 = \frac{673}{684,1} = 0,983.$$

Con el cálculo del coeficiente de regresión queda más que ratificada que la función identificada es válida.

Para encontrar la función de transferencia se aplica la transformada de Laplace a la ecuación A.3.7:

$$C_{TZ4}(t) = 21 - 35,549 e^{-t/3,933} + 15,594 e^{-t/1,259} - 1,044 e^{-t/0,248}.$$

$$C(s) = \frac{21}{s} - \frac{35,549}{s + \frac{1}{3,933}} + \frac{15,594}{s + \frac{1}{1,259}} - \frac{1,044}{s + \frac{1}{0,248}} \quad (\text{A.3.8})$$

Si la entrada paso es de 30 ° C, entonces:

$$R(s) = \frac{30}{s} \quad (\text{A.3.9})$$

Por tanto la función de transferencia en lazo cerrado definitiva es:

$$\frac{C(s)}{R(s)} = \frac{1,068s^2 - 6,178s + 21}{30(3,933s + 1)(1,259s + 1)(0,248s + 1)}$$

$$\frac{C(s)}{R(s)} = \frac{0,0288s^2 - 0,167s + 0,569}{s^3 + 5,079s^2 + 4,426s + 0,813} \quad (\text{A.3.10})$$

A.2.1.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO ABIERTO

Los datos del controlador para este análisis fuerón:

BP = Banda proporcional = 40%

BP = 100/Kc \Rightarrow Kc = 2.5.

Donde Kc es la ganancia del controlador, por lo cual se tiene que: $G_{ctr} = 2.5$.

$G_{tv} = 0,01193$, $G_{act} = 1$ se considera un relé ideal.

Reemplazando todos los datos en la ecuación A.6 se tiene:

$$K^* = 2.5 * 0,01193 * 1 = (0,0298)^{-1} = 33,52$$

Con los valores obtenidos en A.3.10 y reemplazando en A.6 se tiene que la función de transferencia en lazo abierto es:

$$G_{Planta} = K^* \left(\frac{0,0288s^2 - 0,167s + 0,569}{s^3 + 5,050s^2 + 0,909s + 0,244} \right) \quad (A.3.11)$$

donde $K^* = 23,52$

A.4.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO CERRADO DEL CABEZAL ZONA 1

Para el análisis del modelo y el sistema real de control se procede a obtener una expresión matemática que describa su comportamiento

Tiempo en min.	Δ Temperatura en ° C
0	0
1	1
2	2
3	3
4	4
5	5,3
6	6,1
7	7,1
8	7,7
9	8,3
10	8,8
11	9,2
12	9,6
13	9,9
14	10
15	10,5
16	10,8
20	11

Tabla A.4.1 Variación de temperatura en función del tiempo (cabezal zona 1)

$$C(t) = A + k_1 e^{-t/\tau_1} + k_2 e^{-t/\tau_2} + k_3 e^{-t/\tau_3} + \dots + k_n e^{-t/\tau_n} \quad (\text{A.1})$$

$$C(t) - A = k_1 e^{-t/\tau_1} \quad (\text{A.2})$$

Siendo para este caso, $A = 11,5$ ° C, valor que corresponde a la variación asumida al variar el set point de entrada. Se obtiene los siguientes valores mostrados en la tabla A.4.2.

Tiempo (min)	$ A - c(t) $
0	11,5
1	10,5
2	9,5
3	8,5
4	7,5
5	6,2
6	5,4
7	4,4
8	3,8
9	3,2
10	2,7

11	2,3
12	1,9
13	1,6
14	1,5
15	1
16	0,7
20	0,5

Tabla A.4.2 Operaciones realizadas según la ecuación A.2

A los valores de $|C(t) - A|$ se los dibuja en escala semilogarítmica, figura A.4.1

La recta que representa mejor los datos esta dada por la ecuación:

$$p_1(x) = a_0 + a_1 \cdot x \quad (\text{A.3})$$

Por el algoritmo de mínimos cuadrados se tiene la siguiente tabla de valores:

$X_i = \text{tiempo (min)}$	$f(t) = k_1 \cdot e^{-t/\tau}$	$y_i = \ln(F(t))$	$X_i Y_i$	X_i^2
4	7,5	2,0149	8,05961	16
5	6,2	1,8245	9,12275	25
6	5,4	1,6864	10,1184	36
7	4,4	1,4816	10,3712	49
8	3,8	1,335	10,68	64
9	3,2	1,1632	10,4684	81
10	2,7	0,9933	9,93252	100
11	2,3	0,8329	9,162	121
12	1,9	0,6419	7,70225	144
14	1,5	0,4055	5,67651	196
15	1	0	0	225
20	0,5	-0,6931	-13,863	400
$\Sigma X_i = 121$		$\Sigma Y_i = 11,685$	$\Sigma X_i Y_i = 77,430$	$\Sigma X_i^2 = 1457$

Tabla A.4.3. Análisis de la regresión para la zona 1 del cabezal

$$a_0 = 2,693 \quad k_1 = e^{(a_0)} \quad k_1 = 14,781$$

$$a_1 = -0,170 \quad \tau_1 = 1/a_1 \quad \tau_1 = 5,863$$

La ecuación de $C(t)$ llega a ser:

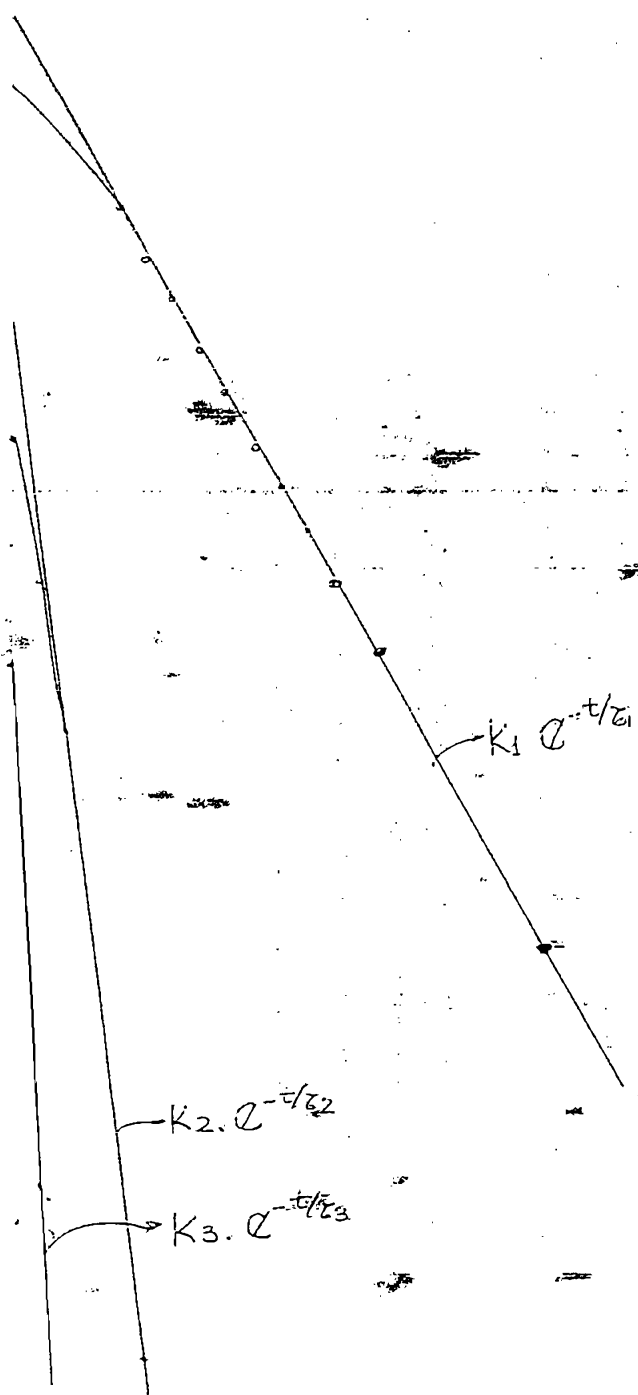
$$C(t) = 11,5 - 14,781 e^{-t/5,863} + k_2 e^{-t/\tau^2} + k_3 e^{-t/\tau^3} + \dots + k_n e^{-t/\tau^n}$$

$$C(t) - 11,5 + 14,781 e^{-t/5,863} = k_2 e^{-t/\tau^2} + k_1 e^{-t/\tau^1} + \dots + k_n e^{-t/\tau^n} \quad (\text{A.4.1})$$

Para determinar la constante k_2 , se realiza el mismo procedimiento:

Tiempo (min)	$c(t) - 11,5 + 14,781 e^{-t/5,863}$
0	3,282
1	1,964
2	1,01

Figura A.4.1 Gráfica en escala semi-logarítmica, para describir a la zona 1 del cabezal



3	0,362
4	-0,027
5	0,101
6	-0,087

Tabla A.4.4 Datos para encontrar las constantes k_2 y τ_2

De la figura A.4.1 en escala semilogaritmica y de la tabla A.4.4 se observan que la mejor recta pasa por 2 y 6 minutos.

Por lo cual obtiene las siguientes relaciones:

$$\text{Para } t = 2 \text{ min.} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 1,009 \quad (\text{A.4.2})$$

$$\text{Para } t = 6 \text{ min.} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 0,101 \quad (\text{A.4.3})$$

Resolviendo las relaciones A.4.2 y A.4.3, se tiene los valores de $k_2 = 4,686$ y $\tau_2 = 1,303$ min, reemplazando los valores se tiene: que $y = k_2 e^{-t/\tau^2} = 4,686 e^{-t/1,303}$

por lo cual se tiene la ecuación para $c(t)$ como:

$$C(t) = 11,5 - 14,781 e^{-t/5,863} + 4,686 e^{-t/1,303} + k_3 e^{-t/\tau^3} + k_n e^{-t/\tau^n} \quad (\text{A.4.4})$$

Las constantes k_3 y τ_3 se obtienen de la siguiente manera:

De la figura A.4.1 en escala semilogaritmica y de la tabla A.4.5, los puntos para los cuales pasa la mejor recta de $k_3 e^{-t/\tau^3}$ es para 0 y 1 minuto. Por lo tanto se obtiene el siguiente sistema de ecuaciones:

$$\text{Para } t = 0 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 1,044 \quad (\text{A.3.5})$$

$$\text{Para } t = 1 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 0,018 \quad (\text{A.3.6})$$

Tiempo (min)	$c(t) - 11,5 + 14,781 e^{-t/5,863} - 4,686 e^{-t/1,303}$
0	-1,404
1	-0,211
2	0
3	-0,106
4	-0,245

Tabla A.4.5 Datos para encontrar las constantes k_3 y τ_3

Resolviendo las ecuaciones A.4.5 y A.4.6 simultáneamente se encuentra que $k_3 = 1,404$ y $\tau_3 = 0,528$ min.

$$y = k_3 e^{-t/\tau^3} = -1,404 e^{-t/0,528}.$$

Luego la ecuación definitiva de la zona 1 del cabezal $c_{CZ1}(t)$ es:

$$C_{CZ1}(t) = 11,5 - 14,781 e^{-t/5,863} + 4,686 e^{-t/1,303} - 1,404 e^{-t/0,528}. \quad (\text{A.4.7})$$

La tabla muestra los valores de la función $C_{CZ1}(t)$ real, medidos en el proceso al variar bruscamente el setpoint y los valores de la función $C_{CZ1}(t)$ identificada, se puede ver que la diferencia entre las dos funciones es mínima.

Tiempo (min)	C(t) = real	C(t) = identificada
0	0	0
1	1	1
2	2	1,968
3	3	3,102
4	4	4,244
5	5,3	5,3
6	6,1	6,234
7	7,1	7,042
8	7,7	7,732
9	8,3	8,319
10	8,8	8,816
11	9,2	9,236
12	9,6	9,591
13	9,9	9,89
14	10	10,14
15	10,5	10,36
16	10,8	10,53
20	11	11,01

Tabla A.4.6 Valores de $C_{z1}(t)$ medidos en el proceso y $C_{z1}(t)$ identificada.

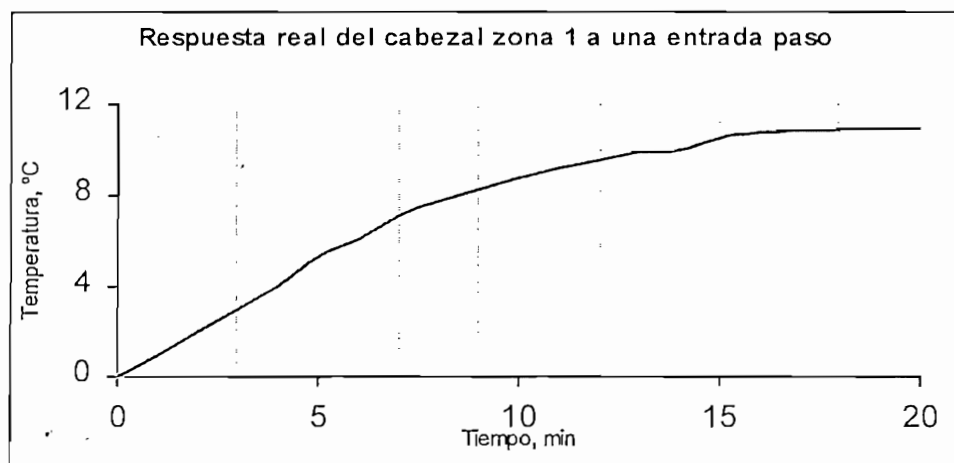


Figura A.4.2 Resposta real en función del tiempo del cabezal zona 1 ante un incremento de temperatura

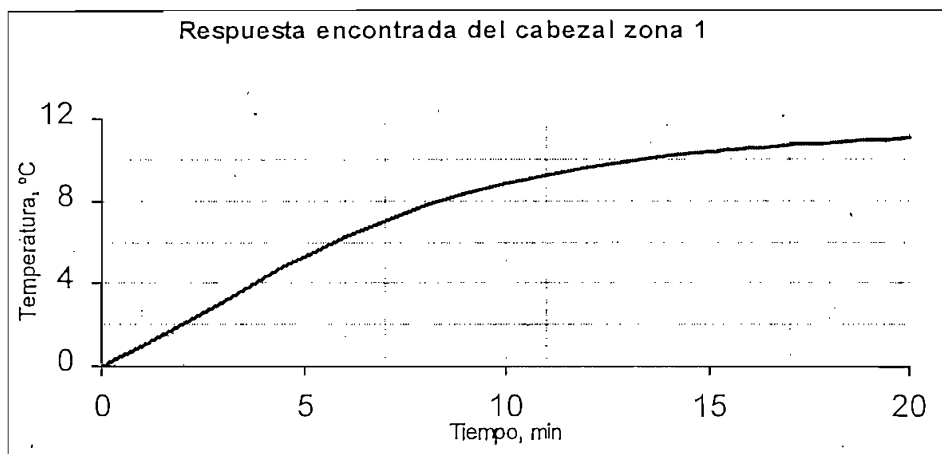


Figura A.4.3 Resposta identificada en función del tiempo del cabezal zona 1 ante un incremento de temperatura

Para tener un criterio claro de la bondad del modelo identificado, se utiliza el coeficiente de regresión; los resultados son mostrados en la tabla A.4.7 que se lo expone a continuación:

Tiempo	C(t) real	C(t) ident	$[C(t)_{\text{real}} - Y_{\text{promedio}}]^2$	$[C(t)_{\text{ident}} - Y_{\text{promedio}}]^2$
0	0	0	47,69	47,69
1	1	1	34,88	34,88
2	2	1,968	24,06	24,38
3	3	3,102	15,25	14,47
4	4	4,244	8,442	7,082
5	5,3	5,3	2,578	2,578
6	6,1	6,234	0,649	0,451
7	7,1	7,042	0,038	0,019
8	7,7	7,732	0,631	0,684
9	8,3	8,319	1,944	1,999
10	8,8	8,816	3,589	3,651
11	9,2	9,236	5,264	5,432
12	9,6	9,591	7,26	7,21
13	9,9	9,89	8,967	8,906
14	10	10,14	9,576	10,48
15	10,5	10,36	12,92	11,9
16	10,8	10,53	15,17	13,17
20	11	11,01	16,76	16,86
			$\Sigma = 215,7$	$\Sigma = 211,8$

Tabla A.4.7 Cálculos para encontrar el coeficiente de regresión.

En la tabla A.4.7 se presentan los cálculos realizados para encontrar el coeficiente de regresión, de la misma que se tiene:

$$\bar{y} = y_{promedio} = 6,906$$

$$\gamma^2 = \frac{211,8}{215,7} = 0,982.$$

Con el cálculo del coeficiente de regresión queda más que ratificada que la función identificada es válida.

Para encontrar la función de transferencia se aplica la transformada de Laplace a la ecuación A.4.7:

$$C_{TZ4}(t) = 11,5 - 14,781 e^{-t/5,863} + 4,686 e^{-t/1,303} - 1,404 e^{-t/0,528}.$$

$$C(s) = \frac{11,5}{s} - \frac{14,781}{s + \frac{1}{5,863}} + \frac{4,686}{s + \frac{1}{1,303}} - \frac{1,404}{s + \frac{1}{0,528}} \quad (\text{A.4.8})$$

Si la entrada paso es de 30 ° C, entonces:

$$R(s) = \frac{30}{s} \quad (\text{A.4.9})$$

Por tanto la función de transferencia en lazo cerrado definitiva es:

$$\frac{C(s)}{R(s)} = \frac{6,394s^2 - 7,179s + 11,5}{30(5,863s + 1)(1,303s + 1)(0,528s + 1)}$$

$$\frac{C(s)}{R(s)} = \frac{0,0528s^2 + 0,059s + 0,095}{s^3 + 2,831s^2 + 1,907s + 0,247} \quad (\text{A.4.10})$$

A.4.1.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO ABIERTO

Los datos del controlador para este análisis fueron:

BP = Banda proporcional = 40%

BP = 100/Kc \Rightarrow Kc = 2.5.

Donde Kc es la ganancia del controlador, por lo cual se tiene que: $G_{ctr} = 2.5$.

A.5.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO CERRADO DEL CABEZAL ZONA 2

Para el análisis del modelo y el sistema real de control se procede a obtener una expresión matemática que describa su comportamiento

Tiempo en min.	Δ Temperatura en ° C
0	0
1	0,5
2	1
3	1,5
4	2
5	2,7
6	3,5
7	4
8	4,5
9	4,9
10	5,2
11	5,6
12	5,8
13	6,1
14	6,3
15	6,4
16	6,6
20	7

Tabla A.5.1 Variación de temperatura en función del tiempo (cabezal zona 2)

$$C(t) = A + k_1 e^{-t/\tau_1} + k_2 e^{-t/\tau_2} + k_3 e^{-t/\tau_3} + \dots + k_n e^{-t/\tau_n} \quad (\text{A.1})$$

$$C(t) - A = k_1 e^{-t/\tau_1} \quad (\text{A.2})$$

Siendo para este caso, $A = 7,5$ ° C, valor que corresponde a la variación asumida al variar el set point de entrada. Se obtiene los siguientes valores mostrados en la tabla A.5.2.

Tiempo (min)	A-c(t)
0	7,5
1	7
2	6,5
3	6
4	5,5
5	4,8
6	4
7	3,5
8	3
9	2,6
10	2,3

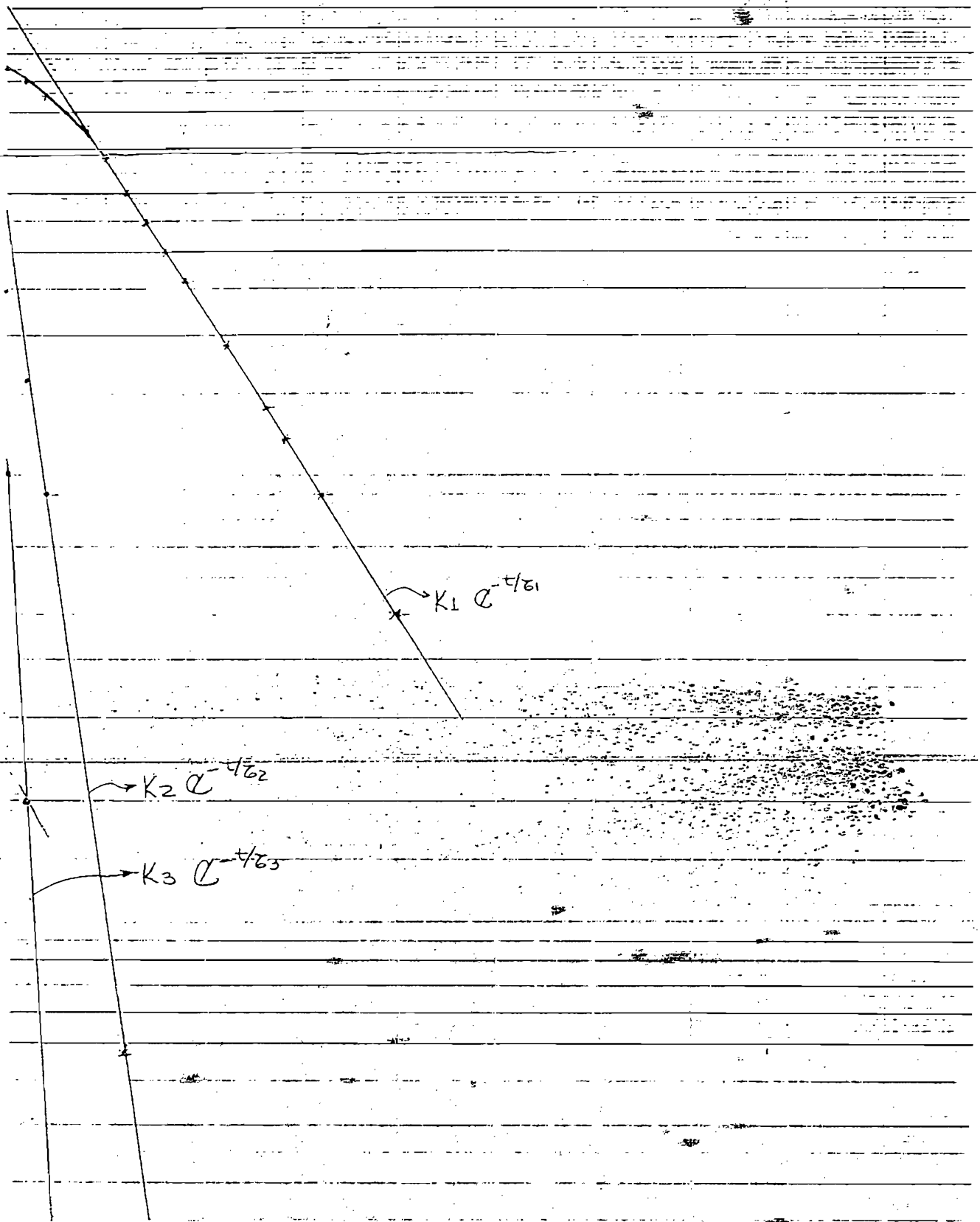


Figura A.5.1 Gráfica en escala semi logarítmica, para describir a la zona 2 del cabezal

0	2,518
1	1,617
2	0,912
3	0,376
4	-0,016
5	-0,082
6	0,058

Tabla A.5.4 Datos para encontrar las constantes k_2 y τ_2

De la figura A.5.1 en escala semilogaritmica y de la tabla A.5.4 se observan que la mejor recta pasa por 2 y 6 minutos.

Por lo cual obtiene las siguientes relaciones:

$$\text{Para } t = 2 \text{ min.} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 0,912 \quad (\text{A.5.2})$$

$$\text{Para } t = 6 \text{ min.} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 0,058 \quad (\text{A.5.3})$$

Resolviendo las relaciones A.5.2 y A.5.3, se tiene los valores de $k_2 = 3,618$ y $\tau_2 = 1,451$ min, reemplazando los valores se tiene que: $y = k_2 e^{-t/\tau^2} = 3,618 e^{-t/1,451}$

por lo cual se tiene la ecuación para $c(t)$ como:

$$C(t) = 7,5 - 10,017 e^{-t/6,639} + 3,618 e^{-t/1,451} + k_3 e^{-t/\tau^3} + k_n e^{-t/\tau^n} \quad (\text{A.5.4})$$

Las constantes k_3 y τ_3 se obtienen de la siguiente manera:

De la figura A.5.1 en escala semilogaritmica y de la tabla A.5.5, los puntos para los cuales pasa la mejor recta de $k_3 e^{-t/\tau^3}$ es para 0 y 1 minuto. Por lo tanto se obtiene el siguiente sistema de ecuaciones:

$$\text{Para } t = 0 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 1,100 \quad (\text{A.5.5})$$

$$\text{Para } t = 1 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 0,199 \quad (\text{A.5.6})$$

Tiempo (min)	$c(t) - 7,5 + 10,017 e^{-t/6,639} - 3,618 e^{-t/1,451}$
0	-1,100
1	-0,199
2	0
3	-0,082
4	-0,245

Tabla A.5.5 Datos para encontrar las constantes k_3 y τ_3

Resolviendo las ecuaciones A.5.5 y A.5.6 simultáneamente se encuentra que $k_3 = 1,100$ y $\tau_3 = 0,586$ min.

$$y = k_3 e^{-t/\tau^3} = -1,100 e^{-t/0,586}.$$

Luego la ecuación definitiva de la zona 2 del cabezal $C_{CZ2}(t)$ es:

$$C_{CZ2}(t) = 7,5 - 10,017 e^{-t/6,639} + 3,618 e^{-t/1,451} - 1,100 e^{-t/0,586}. \quad (\text{A.5.7})$$

La tabla muestra los valores de la función $C_{CZ2}(t)$ real, medidos en el proceso al variar bruscamente el setpoint y los valores de la función $C_{CZ2}(t)$ identificada, se puede ver que la diferencia entre las dos funciones es mínima.

Tiempo (min)	C(t) = real	C(t) = identificada
0	0	0
1	0,5	0,5
2	1	0,964
3	1,5	1,576
4	2	2,244
5	2,7	2,898
6	3,5	3,5
7	4	4,039
8	4,5	4,512
9	4,9	4,925
10	5,2	5,282
11	5,6	5,591
12	5,8	5,857
13	6,1	6,087
14	6,3	6,284
15	6,4	6,454
16	6,6	6,6
20	7	7,007

Tabla A.5.6 Valores de $C_{z1}(t)$ medidos en el proceso y $C_{z1}(t)$ identificada.

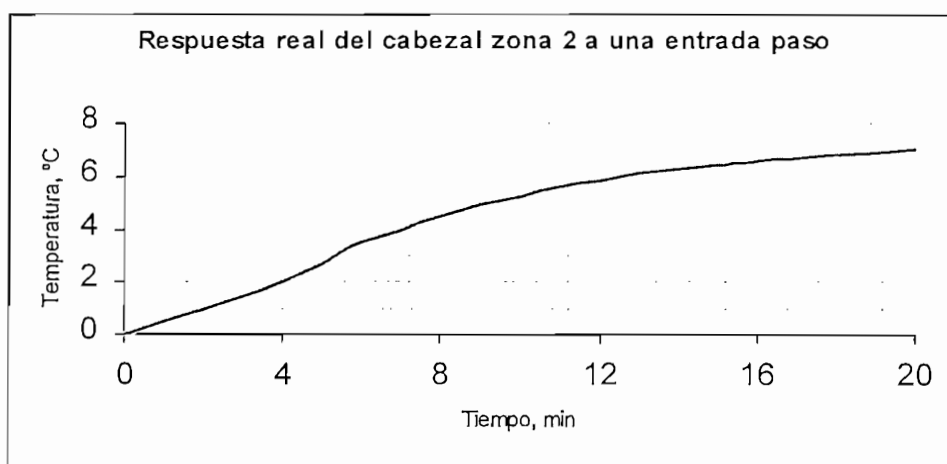


Figura A.5.2 Resposta real en función del tiempo del cabezal zona 2 ante un incremento de temperatura

$$\bar{y} = y_{promedio} = 4,089$$

$$\gamma^2 = \frac{87,7}{88,8} = 0,987.$$

Con el cálculo del coeficiente de regresión queda más que ratificada que la función identificada es válida.

Para encontrar la función de transferencia se aplica la transformada de Laplace a la ecuación A.5.7:

$$C_{CZ2}(t) = 7,5 - 10,017 e^{-t/6,639} + 3,618 e^{-t/1,451} - 1,100 e^{-t/0,586}.$$

$$C(s) = \frac{7,5}{s} - \frac{10,017}{s + \frac{1}{6,639}} + \frac{3,618}{s + \frac{1}{1,451}} - \frac{1,100}{s + \frac{1}{0,586}} \quad (\text{A.5.8})$$

Si la entrada paso es de 30 ° C, entonces:

$$R(s) = \frac{30}{s} \quad (\text{A.5.9})$$

Por tanto la función de transferencia en lazo cerrado definitiva es:

$$\frac{C(s)}{R(s)} = \frac{5,050s^2 + 3,171s + 7,5}{30(6,639s + 1)(1,451s + 1)(0,586s + 1)}$$

$$\frac{C(s)}{R(s)} = \frac{0,029s^2 + 0,018s + 0,044}{s^3 + 2,546s^2 + 1,536s + 0,177} \quad (\text{A.5.10})$$

A.5.1.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO ABIERTO

Los datos del controlador para este análisis fuerón:

BP = Banda proporcional = 40%

BP = 100/Kc \Rightarrow Kc = 2.5.

Donde Kc es la ganancia del controlador, por lo cual se tiene que: $G_{ctr} = 2.5$.

$G_{tv} = 0,01193$, $G_{act} = 1$ se considera un relé ideal.

Reemplazando todos los datos en la ecuación A.6 se tiene:

$$K^* = 2.5 * 0,01193 * 1 = (0,0298)^{-1} = 33,52$$

Con los valores obtenidos en A.5.10 y reemplazando en A.5 se tiene que la función de transferencia en lazo abierto es:

$$G_{planta} = K^* \left(\frac{0,029s^2 + 0,018s + 0,044}{s^3 + 2,516s^2 + 0,603s + 0,132} \right) \quad (A.5.11)$$

donde $K^* = 23,52$

A.6.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO CERRADO DEL CABEZAL ZONA 3

Para el análisis del modelo y el sistema real de control se procede a obtener una expresión matemática que describa su comportamiento

Tiempo en min.	Δ Temperatura en ° C
0	0
1	0,1
2	1
3	1,5
4	1,8
5	2,3
6	3,4
7	4,2
8	5
9	5,7
10	6,2
11	6,7
12	7,1
13	7,4
14	7,8
17	8,4
22	9

Tabla A.6.1 Variación de temperatura en función del tiempo (cabezal zona 3)

$$C(t) = A + k_1 e^{-t/\tau_1} + k_2 e^{-t/\tau_2} + k_3 e^{-t/\tau_3} + \dots + k_n e^{-t/\tau_n} \quad (\text{A.1})$$

$$C(t) - A = k_1 e^{-t/\tau_1} \quad (\text{A.2})$$

Siendo para este caso, $A = 9,5$ ° C, valor que corresponde a la variación asumida al variar el set point de entrada. Se obtiene los siguientes valores mostrados en la tabla A.6.2.

Tiempo (min)	A-c(t)
0	9,5
1	9,4
2	8,5
3	8
4	7,7
5	7,2
6	6,1
7	5,3
8	4,5
9	3,8
10	3,3
11	2,8

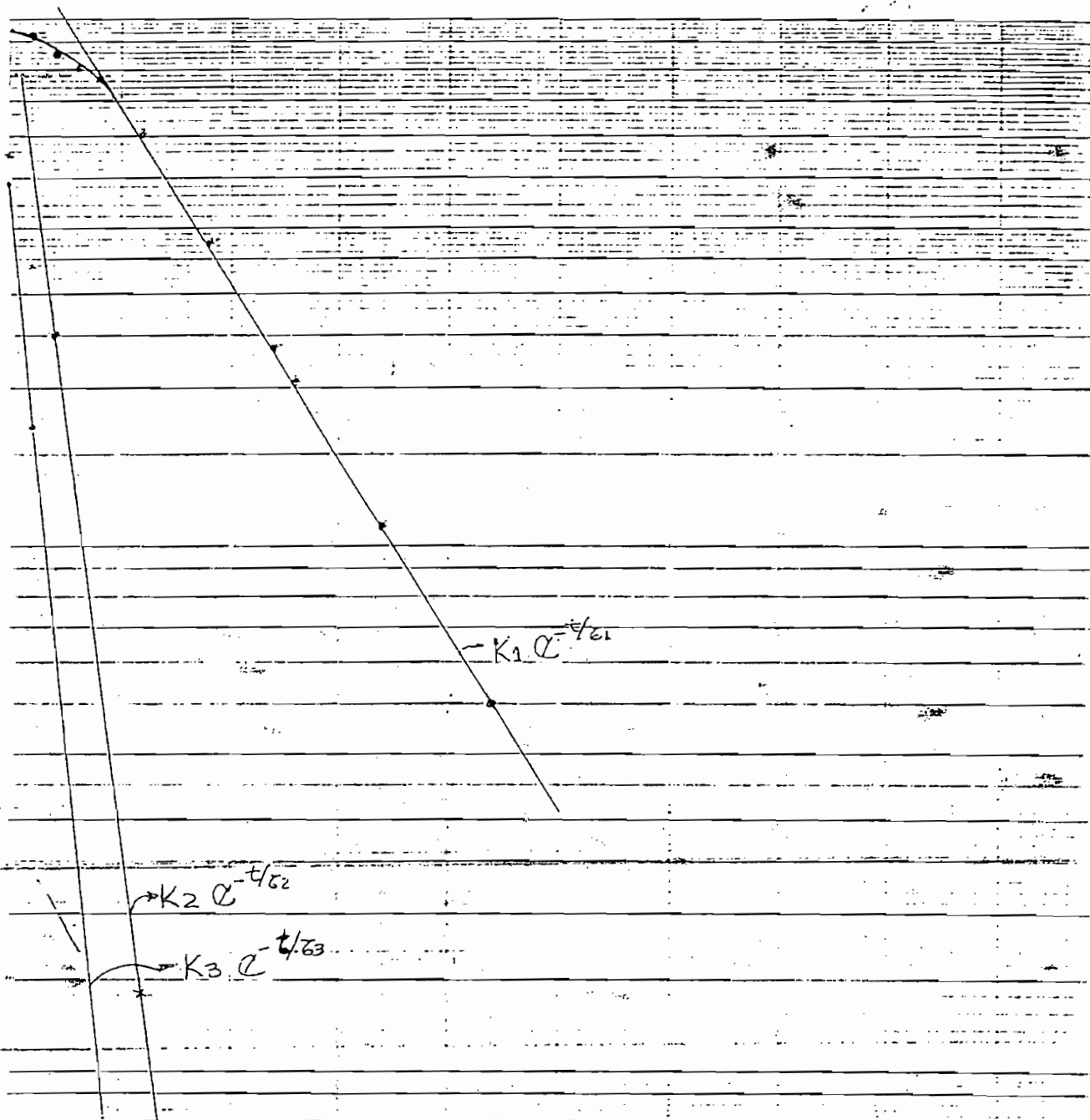


Figura A.6.1 Gráfica en escala semi-logarítmica, para describir a la zona 3 del cabezal

6	-0,144
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Tabla A.6.4 Datos para encontrar las constantes k_2 y τ_2

De la figura A.6.1 en escala semilogaritmica y de la tabla A.6.4 se observan que la mejor recta pasa por 2 y 6 minutos.

Por lo cual obtiene las siguientes relaciones:

$$\text{Para } t = 2 \text{ min.} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 2,498 \tag{A.6.2}$$

$$\text{Para } t = 6 \text{ min.} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 0,144 \tag{A.6.3}$$

Resolviendo las relaciones A.6.2 y A.6.3, se tiene los valores de $k_2 = 10,401$ y $\tau_2 = 1,402$ min, reemplazando los valores se tiene: $y = k_2 e^{-t/\tau^2} = 10,401 e^{-t/1,402}$

por lo cual se tiene la ecuación para $c(t)$ como:

$$C(t) = 9,5 - 14,945 e^{-t/6,521} + 10,401 e^{-t/1,402} + k_3 e^{-t/\tau^3} + k_n e^{-t/\tau^n} \tag{A.6.4}$$

Las constantes k_3 y τ_3 se obtienen de la siguiente manera:

De la figura A.6.1 en escala semilogaritmica y de la tabla A.6.5, los puntos para los cuales pasa la mejor recta de $k_3 e^{-t/\tau^3}$ es para 0 y 1 minuto. Por lo tanto se obtiene el siguiente sistema de ecuaciones:

$$\text{Para } t = 0 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 4,956 \tag{A.6.5}$$

$$\text{Para } t = 1 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 1,676 \tag{A.6.6}$$

Tiempo (min)	$c(t) - 9,5 + 14,945 e^{-t/6,521} - 10,401 e^{-t/1,402}$
0	-4,956
1	-1,676
2	0
3	0,210
4	-0,2065

Tabla A.6.5 Datos para encontrar las constantes k_3 y τ_3

Resolviendo las ecuaciones A.6.5 y A.6.6 simultáneamente se encuentra que $k_3 = 4,956$ y $\tau_3 = 0,922$ min.

$$y = k_3 e^{-t/\tau^3} = 4,956 e^{-t/0,922}$$

Luego la ecuación definitiva de la zona 3 del cabezal $c_{CZ3}(t)$ es:

$$C_{CZ3}(t) = 9,5 - 14,945 e^{-t/6,521} + 10,401 e^{-t/1,402} - 4,956 e^{-t/0,922} \quad (\text{A.6.7})$$

La tabla muestra los valores de la función $C_{CZ3}(t)$ real, medidos en el proceso al variar bruscamente el setpoint y los valores de la función $C_{CZ3}(t)$ identificada, se puede ver que la diferencia entre las dos funciones es mínima.

Tiempo (min)	C(t) = real	C(t) = identificada
0	0	0
1	0,1	0,1
2	1	0,433
3	1,5	1,098
4	1,8	1,942
5	2,3	2,829
6	3,4	3,681
7	4,2	4,459
8	5	5,151
9	5,7	5,757
10	6,2	6,283
11	6,7	6,737
12	7,1	7,128
13	7,4	7,465
14	7,8	7,754
15	8	8,002
16	8,2	8,215
17	8,4	8,397
22	9	8,988

Tabla A.6.6 Valores de $C_{z1}(t)$ medidos en el proceso y $C_{z1}(t)$ identificada.

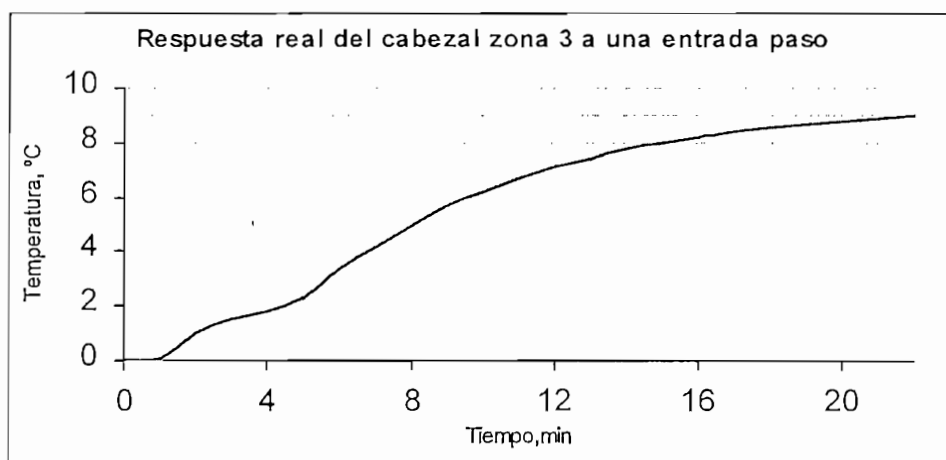


Figura A.6.2 Respuesta real en función del tiempo del cabezal zona 3 ante un incremento de temperatura

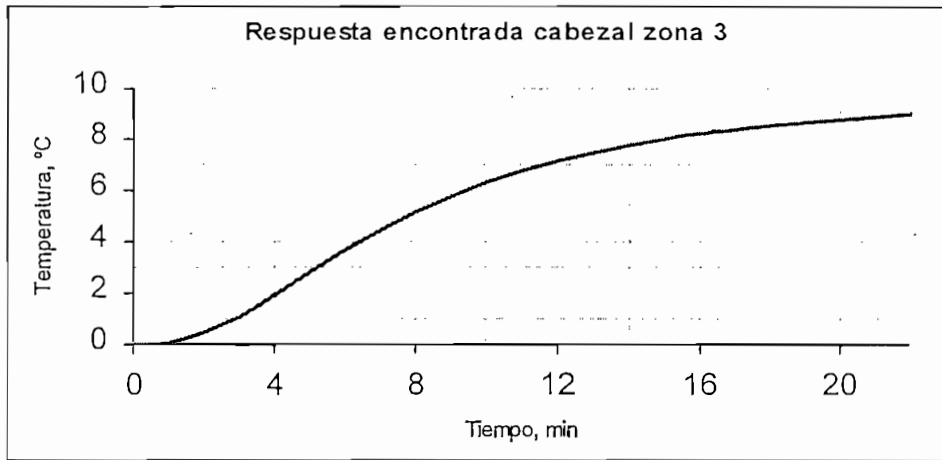


Figura A.6.3 Respuesta identificada en función del tiempo del cabezal zona 3 ante un incremento de temperatura

Para tener un criterio claro de la bondad del modelo identificado, se utiliza el coeficiente de regresión; los resultados son mostrados en la tabla A.6.7 que se lo expone a continuación:

Tiempo	C(t) real	C(t) ident	$[C(t)_{real} - Y_{promedio}]^2$	$[C(t)_{ident} - Y_{promedio}]^2$
0	0	0	24,37	24,37
1	0,1	0,1	23,4	23,4
2	1	0,433	15,5	20,29
3	1,5	1,098	11,81	14,74
4	1,8	1,942	9,84	8,972
5	2,3	2,829	6,953	4,442
6	3,4	3,681	2,362	1,578
7	4,2	4,459	0,543	0,228
8	5	5,151	0,004	0,046
9	5,7	5,757	0,582	0,672
10	6,2	6,283	1,596	1,812
11	6,7	6,737	3,109	3,241
12	7,1	7,128	4,679	4,803
13	7,4	7,465	6,067	6,391
14	7,8	7,754	8,198	7,935
15	8	8,002	9,383	9,394
16	8,2	8,215	10,65	10,74
17	8,4	8,397	11,99	11,98
22	9	8,988	16,51	16,41
			$\Sigma = 167,5$	$\Sigma = 171,4$

Tabla A.6.7 Cálculos para encontrar el coeficiente de regresión.

En la tabla A.6.7 se presentan los cálculos realizados para encontrar el coeficiente de regresión, de la misma que se tiene:

$$\bar{y} = y_{promedio} = 4,937$$

$$\gamma^2 = \frac{171,4}{167,5} = 1,023.$$

Con el cálculo del coeficiente de regresión queda más que ratificada que la función identificada es válida.

Para encontrar la función de transferencia se aplica la transformada de Laplace a la ecuación A.6.7:

$$C_{CZ3}(t) = 9,5 - 14,945 e^{-t/6,521} + 10,401 e^{-t/1,402} - 4,956 e^{-t/0,922}.$$

$$C(s) = \frac{9,5}{s} - \frac{14,945}{s + \frac{1}{6,521}} + \frac{10,401}{s + \frac{1}{1,402}} - \frac{4,956}{s + \frac{1}{0,922}} \quad (\text{A.6.8})$$

Si la entrada paso es de 30 ° C, entonces:

$$R(s) = \frac{30}{s} \quad (\text{A.6.9})$$

Por tanto la función de transferencia en lazo cerrado definitiva es:

$$\frac{C(s)}{R(s)} = \frac{2,064s^2 - 3,415s + 9,5}{30(6,521s + 1)(1,402s + 1)(0,922s + 1)}$$

$$\frac{C(s)}{R(s)} = \frac{0,008s^2 - 0,013s + 0,037}{s^3 + 1,950s^2 + 1,048s + 0,118} \quad (\text{A.6.10})$$

A.4.1.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO ABIERTO

Los datos del controlador para este análisis fuerón:

BP = Banda proporcional = 40%

BP = 100/Kc \Rightarrow Kc = 2.5.

Donde Kc es la ganancia del controlador, por lo cual se tiene que: $G_{ctr} = 2.5$.

$G_{tv} = 0,01193$, $G_{act} = 1$ se considera un relé ideal.

Reemplazando todos los datos en la ecuación A.6 se tiene:

$$K^* = 2.5 * 0,01193 * 1 = (0,0298)^{-1} = 33,52$$

Con los valores obtenidos en A.6.10 y reemplazando en A.5 se tiene que la función de transferencia en lazo abierto es:

$$G_{planta} = K^* \left(\frac{0,008s^2 - 0,013s + 0,037}{s^3 + 1,942s^2 + 0,546s + 0,080} \right) \quad (\text{A.6.11})$$

donde $K^* = 23,52$

A.7.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO CERRADO DEL CABEZAL ZONA 4

Para el análisis del modelo y el sistema real de control se procede a obtener una expresión matemática que describa su comportamiento

Tiempo en min.	Δ Temperatura en ° C
0	0
1	0,5
2	1
3	1,5
4	2
5	2,8
6	3,4
7	4
8	4,5
9	5
10	5,4
11	5,7
12	6,1
13	6,3
14	6,6
15	6,8
16	7
19	7,5
25	8

Tabla A.7.1 Variación de temperatura en función del tiempo (cabezal zona 4)

$$C(t) = A + k_1 e^{-t/\tau_1} + k_2 e^{-t/\tau_2} + k_3 e^{-t/\tau_3} + \dots + k_n e^{-t/\tau_n} \quad (\text{A.1})$$

$$C(t) - A = k_1 e^{-t/\tau_1} \quad (\text{A.2})$$

Siendo para este caso, $A = 8,5$ ° C, valor que corresponde a la variación asumida al variar el set point de entrada. Se obtiene los siguientes valores mostrados en la tabla A.7.2.

Tiempo (min)	$ A - c(t) $
0	8,5
1	8
2	7,5
3	7
4	6,5
5	5,7
6	5,1
7	4,5

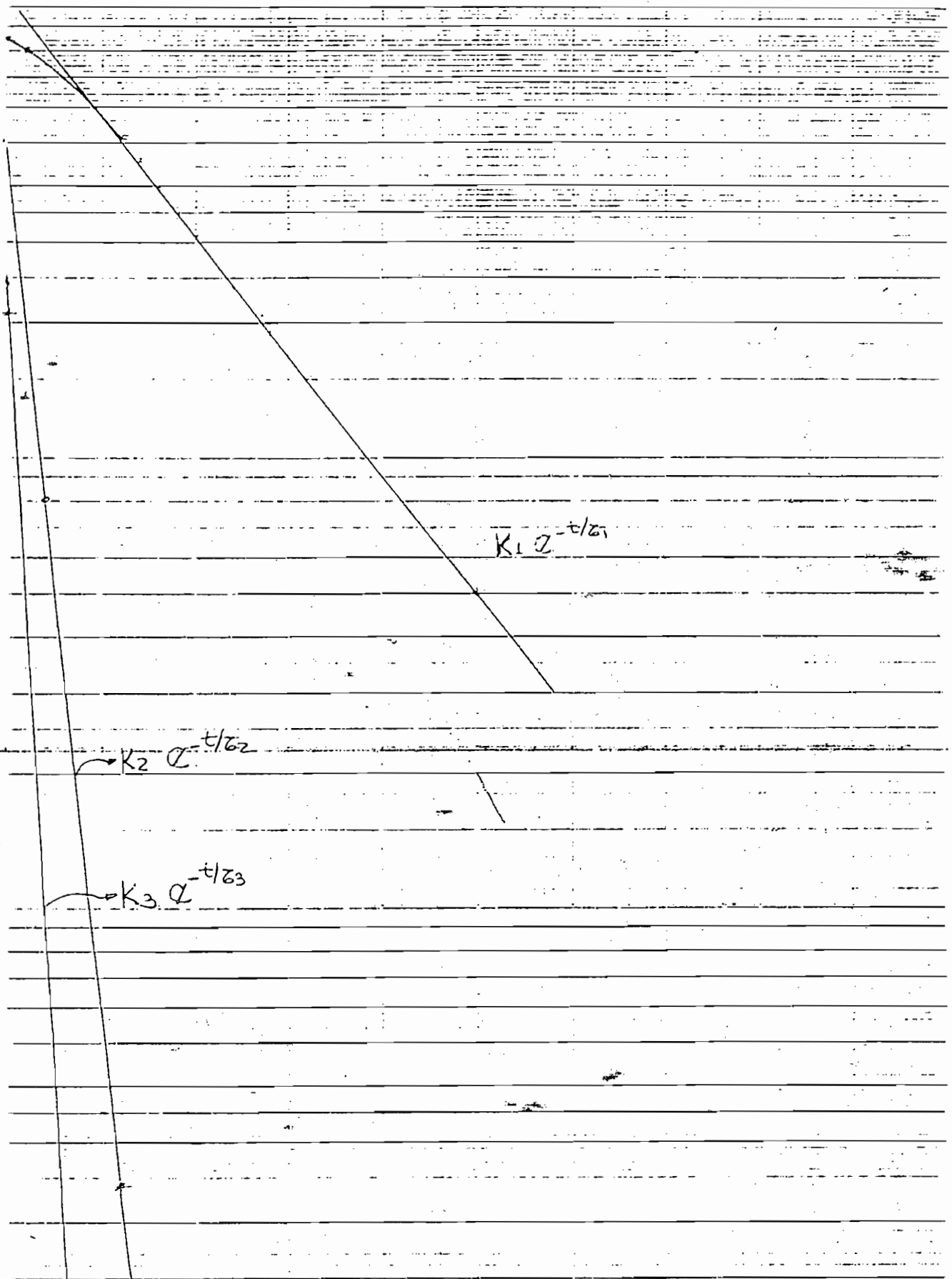


Figura A.7.1 Gráfica en-escala semi logarítmica; para describir a la zona 4 del cabezal-

Para determinar la constante k_2 , se realiza el mismo procedimiento:

Tiempo (min)	$c(t) - 8,5 + 10,609 e^{-t/8,138}$
0	2,109
1	1,383
2	0,798
3	0,338
4	-0,01
5	0,039
6	-0,024

Tabla A.7.4 Datos para encontrar las constantes k_2 y τ_2

De la figura A.7.1 en escala semilogaritmica y de la tabla A.7.4 se observan que la mejor recta pasa por 2 y 6 minutos.

Por lo cual obtiene las siguientes relaciones:

$$\text{Para } t = 2 \text{ min.} \quad \Rightarrow \left| k_2 e^{-t/\tau^2} \right| = 0,797 \quad (\text{A.7.2})$$

$$\text{Para } t = 6 \text{ min.} \quad \Rightarrow \left| k_2 e^{-t/\tau^2} \right| = 0,024 \quad (\text{A.7.3})$$

Resolviendo las relaciones A.7.2 y A.7.3, se tiene los valores de $k_2 = 4,578$ y $\tau_2 = 1,144$ min, reemplazando los valores se tiene: que $y = k_2 e^{-t/\tau^2} = 4,578 e^{-t/1,144}$

por lo cual se tiene la ecuación para $c(t)$ como:

$$C(t) = 8,5 - 10,609 e^{-t/8,138} + 4,578 e^{-t/1,144} + k_3 e^{-t/\tau^3} + \dots + k_n e^{-t/\tau^n} \quad (\text{A.7.4})$$

Las constantes k_3 y τ_3 se obtienen de la siguiente manera:

De la figura A.7.1 en escala semilogaritmica y de la tabla A.7.5, los puntos para los cuales pasa la mejor recta de $k_3 e^{-t/\tau^3}$ es para 0 y 1 minuto. Por lo tanto se obtiene el siguiente sistema de ecuaciones:

$$\text{Para } t = 0 \text{ min.} \quad \Rightarrow \left| k_3 e^{-t/\tau^3} \right| = 2,469 \quad (\text{A.6.5})$$

$$\text{Para } t = 1 \text{ min.} \quad \Rightarrow \left| k_3 e^{-t/\tau^3} \right| = 0,528 \quad (\text{A.6.6})$$

Tiempo (min)	$c(t) - 8,5 + 10,609 e^{-t/8,138} - 4,578 e^{-t/1,144}$
0	-2,469
1	-0,528
2	0

3	0,005
4	-0,149

Tabla A.7.5 Datos para encontrar las constantes k_3 y τ_3

Resolviendo las ecuaciones A.7.5 y A.7.6 simultáneamente se encuentra que $k_3 = 2,469$ y $\tau_3 = 0,648$ min.

$$y = k_3 e^{-t/\tau_3} = -2,469 e^{-t/0,648}$$

Luego la ecuación definitiva de la zona 4 del cabezal $c_{CZ4}(t)$ es:

$$C_{CZ4}(t) = 8,5 - 10,609 e^{-t/8,138} + 4,578 e^{-t/1,144} - 2,469 e^{-t/0,648} \quad (\text{A.7.7})$$

La tabla muestra los valores de la función $C_{CZ4}(t)$ real, medidos en el proceso al variar bruscamente el setpoint y los valores de la función $C_{CZ4}(t)$ identificada, se puede ver que la diferencia entre las dos funciones es mínima.

Tiempo (min)	C(t) = real	C(t) = identificada
0	0	0
1	0,5	0,5
2	1	0,887
3	1,5	1,47
4	2	2,144
5	2,8	2,817
6	3,4	3,448
7	4	4,021
8	4,5	4,534
9	5	4,991
10	5,4	5,396
11	5,7	5,754
12	6,1	6,072
13	6,3	6,352
14	6,6	6,601
15	6,8	6,82
16	7	7,015
19	7,5	7,473
25	8	8,008

Tabla A.7.6 Valores de $C_{z1}(t)$ medidos en el proceso y $C_{z1}(t)$ identificada.

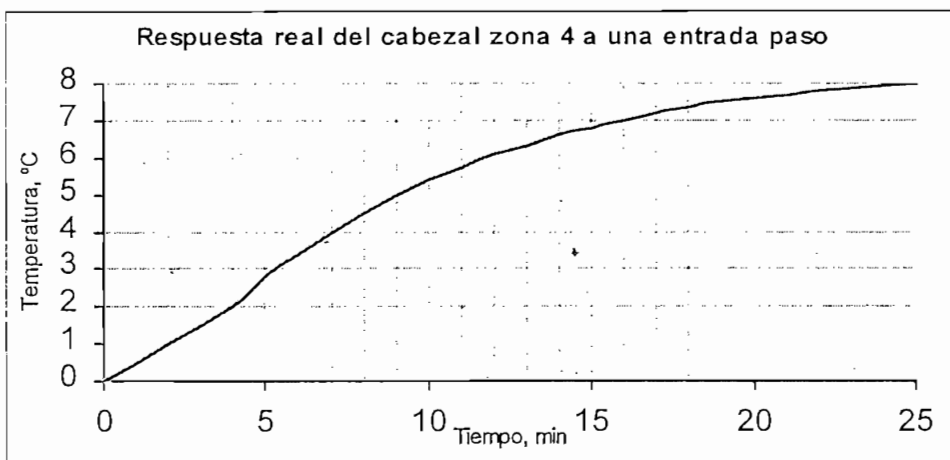


Figura A.7.2 Respuesta real en función del tiempo del cabezal zona 3 ante un incremento de temperatura

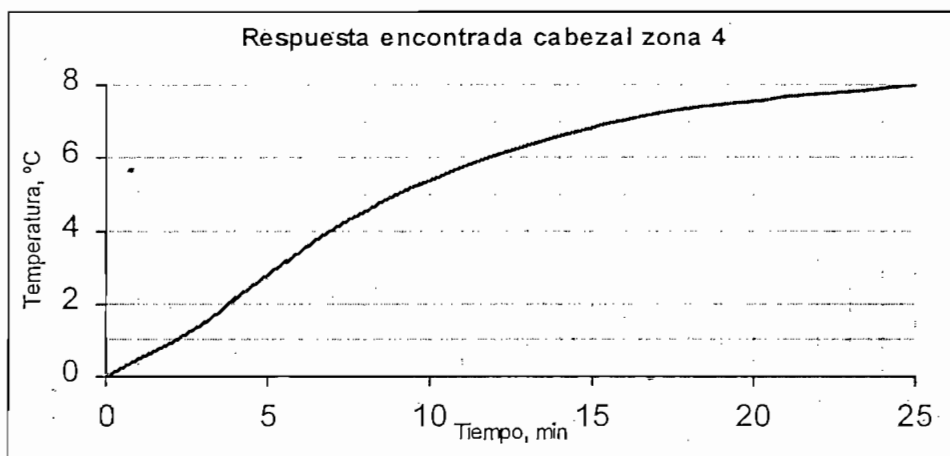


Figura A.7.3 Respuesta identificada en función del tiempo del cabezal zona 3 ante un incremento de temperatura

Para tener un criterio claro de la bondad del modelo identificado, se utiliza el coeficiente de regresión; los resultados son mostrados en la tabla A.7.7 que se lo expone a continuación:

Tiempo	C(t) real	C(t) ident	$[C(t)_{real} - Y_{promedio}]^2$	$[C(t)_{ident} - Y_{promedio}]^2$
0	0	0	19,59	19,59
1	0,5	0,5	15,42	15,42
2	1	0,887	11,74	12,53
3	1,5	1,47	8,563	8,737
4	2	2,144	5,887	5,209
5	2,8	2,817	2,645	2,588
6	3,4	3,448	1,053	0,957
7	4	4,021	0,182	0,164
8	4,5	4,534	0,005	0,012
9	5	4,991	0,329	0,319

10	5,4	5,396	0,948	0,94
11	5,7	5,754	1,622	1,764
12	6,1	6,072	2,801	2,707
13	6,3	6,352	3,511	3,71
14	6,6	6,601	4,725	4,728
15	6,8	6,82	5,634	5,731
16	7	7,015	6,624	6,699
19	7,5	7,473	9,448	9,279
25	8	8,008	12,77	12,83
			$\Sigma = 113,5$	$\Sigma = 113,9$

Tabla A.7.7 Cálculos para encontrar el coeficiente de regresión.

En la tabla A.7.7 se presentan los cálculos realizados para encontrar el coeficiente de regresión, de la misma que se tiene:

$$\bar{y} = y_{promedio} = 4,426$$

$$\gamma^2 = \frac{113,9}{113,5} = 1,003.$$

Con el cálculo del coeficiente de regresión queda más que ratificada que la función identificada es válida.

Para encontrar la función de transferencia se aplica la transformada de Laplace a la ecuación A.7.7:

$$C_{CZ4}(t) = 8,5 - 10,609 e^{-t/8,138} + 4,578 e^{-t/1,144} - 2,469 e^{-t/0,648}.$$

$$C(s) = \frac{8,5}{s} - \frac{10,609}{s + \frac{1}{8,138}} + \frac{4,578}{s + \frac{1}{1,144}} - \frac{2,469}{s + \frac{1}{0,648}} \quad (\text{A.7.8})$$

Si la entrada paso es de 30 °C, entonces:

$$R(s) = \frac{30}{s} \quad (\text{A.7.9})$$

Por tanto la función de transferencia en lazo cerrado definitiva es:

$$\frac{C(s)}{R(s)} = \frac{6,706s^2 + 1,715s + 8,5}{30(8,138s + 1)(1,144s + 1)(0,648s + 1)}$$

$$\frac{C(s)}{R(s)} = \frac{0,036s^2 + 0,009s + 0,046}{s^3 + 2,538s^2 + 1,643s + 0,165} \quad (\text{A.7.10})$$

A.4.1.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO ABIERTO

Los datos del controlador para este análisis fueron:

BP = Banda proporcional = 40%

BP = 100/Kc \Rightarrow Kc = 2.5.

Donde Kc es la ganancia del controlador, por lo cual se tiene que: $G_{ctr} = 2.5$.

$G_{tv} = 0,01193$, $G_{act} = 1$ se considera un relé ideal.

Reemplazando todos los datos en la ecuación A.6 se tiene:

$$K^* = 2.5 * 0,01193 * 1 = (0,0298)^{-1} = 33,52$$

Con los valores obtenidos en A.7.10 y reemplazando en A.5 se tiene que la función de transferencia en lazo abierto es:

$$G_{planta} = K^* \left(\frac{0,036s^2 + 0,009s + 0,046}{s^3 + 2,501s^2 + 0,653s + 0,118} \right) \quad (\text{A.7.11})$$

donde $K^* = 23,52$

A.8.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO CERRADO DEL CABEZAL ZONA 5

Para el análisis del modelo y el sistema real de control se procede a obtener una expresión matemática que describa su comportamiento

Tiempo en min.	Δ Temperatura en ° C
0	0
1	0,5
2	1
3	2
4	3
5	4
6	4,8
7	5,5
8	6,1
9	6,6
10	7
11	7,3
12	7,7
13	8
14	8,2
15	8,4
16	8,6
20	9

Tabla A.8.1 Variación de temperatura en función del tiempo (cabezal zona 5)

$$C(t) = A + k_1 e^{-t/\tau_1} + k_2 e^{-t/\tau_2} + k_3 e^{-t/\tau_3} + \dots + k_n e^{-t/\tau_n} \quad (\text{A.1})$$

$$C(t) - A = k_1 e^{-t/\tau_1} \quad (\text{A.2})$$

Siendo para este caso, $A = 9,5$ ° C, valor que corresponde a la variación asumida al variar el set point de entrada. Se obtiene los siguientes valores mostrados en la tabla A.8.2.

Tiempo (min)	A-c(t)
0	9,5
1	9
2	8,5
3	7,5
4	6,5
5	5,5
6	4,7
7	4
8	3,4
9	2,9
10	2,5

11	2,2
12	1,8
13	1,5
14	1,3
15	1,1
16	0,9
20	0,5

Tabla A.8.2 Operaciones realizadas según la ecuación A.2

A los valores de $|C(t) - A|$ se los dibuja en escala semilogarítmica, figura A.8.1

La recta que representa mejor los datos esta dada por la ecuación:

$$p_1(x) = a_0 + a_1 \cdot x \quad (\text{A.3})$$

Por el algoritmo de mínimos cuadrados se tiene la siguiente tabla de valores:

$X_i = \text{tiempo (min)}$	$f(t) = k_1 \cdot e^{-t/\tau^1}$	$y_i = \text{Ln}(F(t))$	$X_i Y_i$	X_i^2
4	6,5	1,871	7,487	16
5	5,5	1,704	8,523	25
7	4	1,386	9,704	49
8	3,4	1,223	9,790	64
9	2,9	1,064	9,582	81
10	2,5	0,916	9,162	100
12	1,8	0,587	7,053	144
13	1,5	0,405	5,271	169
15	1,1	0,085	1,429	225
20	0,5	-0,693	-13,862	400
$\Sigma X_i = 103$		$\Sigma Y_i = 8,563$	$\Sigma X_i Y_i = 63,906$	$\Sigma X_i^2 = 1273$

Tabla A.8.3. Análisis de la regresión para la zona 5 del cabezal

$$a_0 = 2,510 \quad k_1 = e^{(a_0)} \quad k_1 = 12,307$$

$$a_1 = -0,160 \quad \tau_1 = 1/a_1 \quad \tau_1 = 6,227$$

La ecuación de $C(t)$ llega a ser:

$$C(t) = 9,5 - 12,307 e^{-t/6,227} + k_2 e^{-t/\tau^2} + k_3 e^{-t/\tau^3} + \dots + k_n e^{-t/\tau^n}$$

$$C(t) - 9,5 + 12,307 e^{-t/6,227} = k_2 e^{-t/\tau^2} + k_1 e^{-t/\tau^1} + \dots + k_n e^{-t/\tau^n} \quad (\text{A.8.1})$$

Para determinar la constante k_2 , se realiza el mismo procedimiento:

Tiempo (min)	$c(t) - 9,5 + 12,307 e^{-t/6,227}$
0	2,807
1	1,481
2	0,426

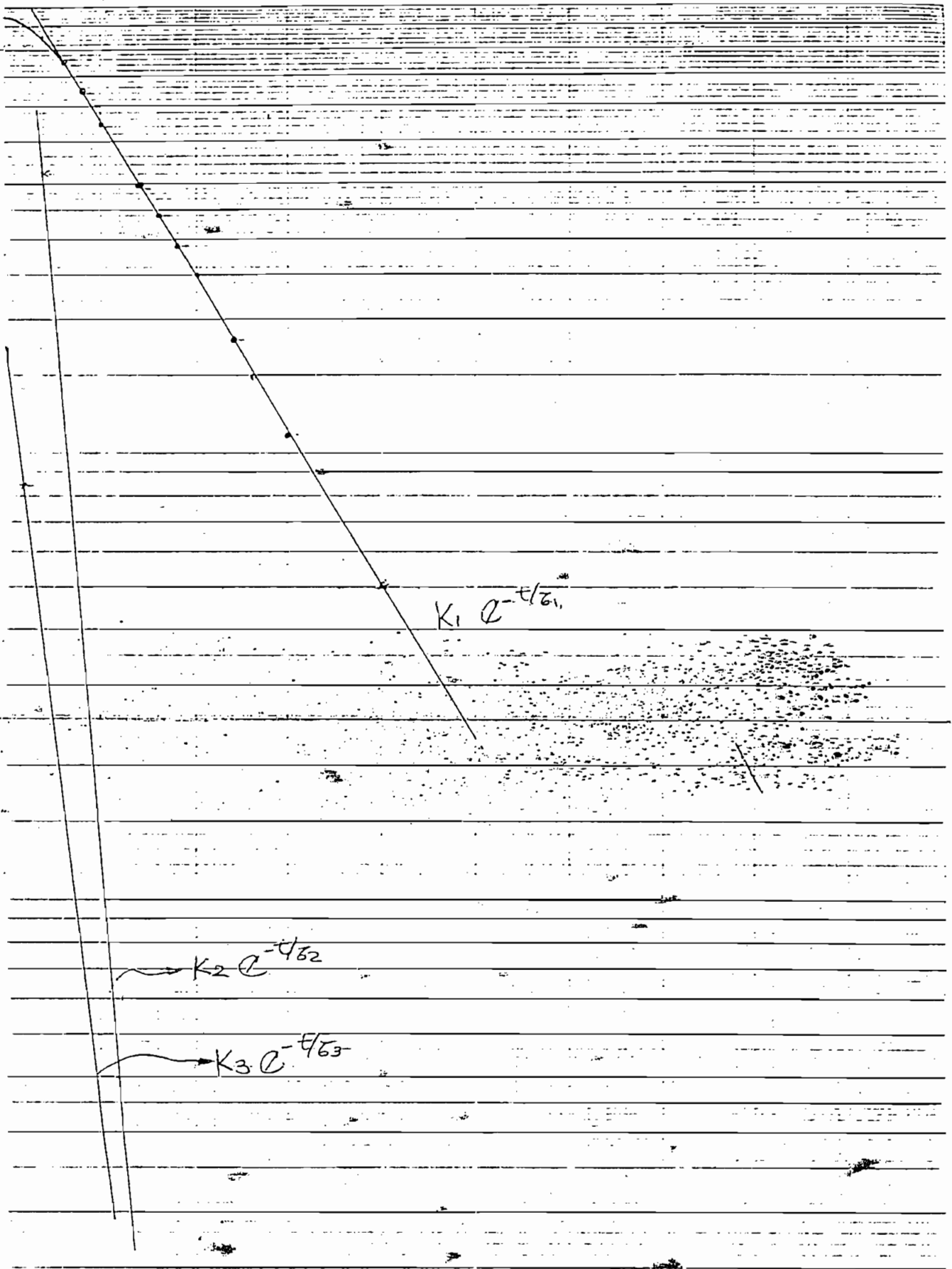


Figura A.8.1 Gráfica en escala semi-logarítmica, para describir a la zona 5 del cabezal...

5 10 15 20 25 30

3	0,102
4	-0,025
5	0,014
6	-0,003

Tabla A.8.4 Datos para encontrar las constantes k_2 y τ_2

De la figura A.8.1 en escala semilogaritmica y de la tabla A.8.4 se observan que la mejor recta pasa por 2 y 6 minutos.

Por lo cual obtiene las siguientes relaciones:

$$\text{Para } t = 2 \text{ min.} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 0,426 \quad (\text{A.8.2})$$

$$\text{Para } t = 6 \text{ min.} \quad \Rightarrow |k_2 e^{-t/\tau^2}| = 0,003 \quad (\text{A.8.3})$$

Resolviendo las relaciones A.8.2 y A.8.3, se tiene los valores de $k_2 = 4,564$ y $\tau_2 = 0,843$ min., reemplazando los valores se tiene: $y = k_2 e^{-t/\tau^2} = 4,564 e^{-t/0,843}$

por lo cual se tiene la ecuación para $c(t)$ como:

$$C(t) = 9,5 - 12,307 e^{-t/6,227} + 4,564 e^{-t/0,843} + k_3 e^{-t/\tau^3} + k_n e^{-t/\tau^n} \quad (\text{A.8.4})$$

Las constantes k_3 y τ_3 se obtienen de la siguiente manera:

De la figura A.8.1 en escala semilogaritmica y de la tabla A.8.5, los puntos para los cuales pasa la mejor recta de $k_3 e^{-t/\tau^3}$ es para 0 y 1 minuto. Por lo tanto se obtiene el siguiente sistema de ecuaciones:

$$\text{Para } t = 0 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 1,757 \quad (\text{A.8.5})$$

$$\text{Para } t = 1 \text{ min.} \quad \Rightarrow |k_3 e^{-t/\tau^3}| = 0,085 \quad (\text{A.8.6})$$

Tiempo (min.)	$c(t) - 9,5 + 12,307 e^{-t/6,227} - 4,564 e^{-t/0,843}$
0	-1,757
1	0,085
2	0
3	-0,027
4	-0,065

Tabla A.8.5 Datos para encontrar las constantes k_3 y τ_3

Resolviendo las ecuaciones A.8.5 y A.8.6 simultáneamente se encuentra que $k_3 = 1,757$ y $\tau_3 = 0,331$ min.

$$y = k_3 e^{-t/\tau^3} = -1,757 e^{-t/0,331}.$$

Luego la ecuación definitiva de la zona 5 del cabezal $C_{CZ5}(t)$ es:

$$C_{CZ5}(t) = 9,5 - 12,307 e^{-t/6,227} + 4,564 e^{-t/0,843} - 1,757 e^{-t/0,331}. \quad (\text{A.8.7})$$

La tabla muestra los valores de la función $C_{CZ5}(t)$ real, medidos en el proceso al variar bruscamente el set point y los valores de la función $C_{CZ5}(t)$ identificada, se puede ver que la diferencia entre las dos funciones es mínima.

Tiempo (min)	C(t) = real	C(t) = identificada
0	0	0
1	0,5	0,328
2	1	0,995
3	2	2,027
4	3	3,065
5	4	3,997
6	4,8	4,807
7	5,5	5,501
8	6,1	6,094
9	6,6	6,599
10	7	7,029
11	7,3	7,395
12	7,7	7,708
13	8	7,973
14	8,2	8,200
15	8,4	8,393
16	8,6	8,557
20	9	9,000

Tabla A.8.6 Valores de $C_{z1}(t)$ medidos en el proceso y $C_{z1}(t)$ identificada.

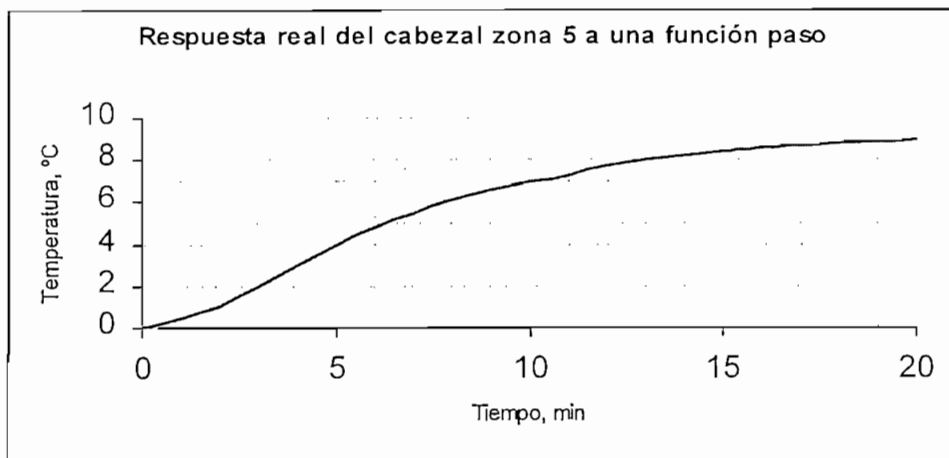


Figura A.8.2 Resposta real en función del tiempo del cabezal zona 5 ante un incremento de temperatura

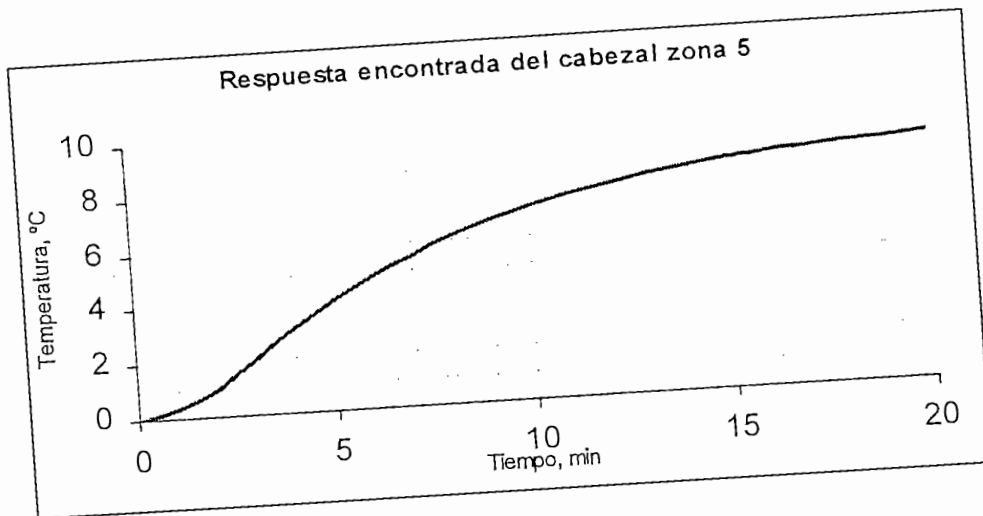


Figura A.8.3 Resposta identificada en función del tiempo del cabezal zona 5 ante un incremento de temperatura

Para tener un criterio claro de la bondad del modelo identificado, se utiliza el coeficiente de regresión; los resultados son mostrados en la tabla A.8.7 que se lo expone a continuación:

Tiempo	C(t) real	C(t) ident	$[C(t)_{\text{real}} - Y_{\text{promedio}}]^2$	$[C(t)_{\text{ident}} - Y_{\text{promedio}}]^2$
0	0	0	29,46	29,46
1	0,5	0,328	24,28	26,01
2	1	0,995	19,61	19,64
3	2	2,027	11,75	11,56
4	3	3,065	5,894	5,582
5	4	3,997	2,039	2,044
6	4,8	4,807	0,394	0,385
7	5,5	5,501	0,005	0,005
8	6,1	6,094	0,452	0,444
9	6,6	6,599	1,374	1,372
10	7	7,029	2,472	2,565
11	7,3	7,395	3,505	3,873
12	7,7	7,708	5,163	5,199
13	8	7,973	6,616	6,482
14	8,2	8,200	7,685	7,687
15	8,4	8,393	8,834	8,793
16	8,6	8,557	10,06	9,794
20	9	9,000	12,76	12,79
			$\Sigma = 152,4$	$\Sigma = 153,7$

Tabla A.8.7 Cálculos para encontrar el coeficiente de regresión.

En la tabla A.8.7 se presentan los cálculos realizados para encontrar el coeficiente de regresión, de la misma que se tiene:

$$\bar{y} = y_{promedio} = 5,428$$

$$\gamma^2 = \frac{153,7}{152,4} = 1,008.$$

Con el cálculo del coeficiente de regresión queda más que ratificada que la función identificada es válida.

Para encontrar la función de transferencia se aplica la transformada de Laplace a la ecuación A.8.7:

$$C_{TZ.3}(t) = 9,5 - 12,307 e^{-t/6,227} + 4,564 e^{-t/0,843} - 1,757 e^{-t/0,331}.$$

$$C(s) = \frac{9,5}{s} - \frac{12,307}{s + \frac{1}{6,227}} + \frac{4,564}{s + \frac{1}{0,843}} - \frac{1,757}{s + \frac{1}{0,331}} \quad (A.8.8)$$

Si la entrada paso es de 30 ° C, entonces:

$$R(s) = \frac{30}{s} \quad (A.8.9)$$

Por tanto la función de transferencia en lazo cerrado definitiva es:

$$\frac{C(s)}{R(s)} = \frac{3,257s^2 - 3,047s + 9,5}{30(6,227s + 1)(0,843s + 1)(0,331s + 1)}$$

$$\frac{C(s)}{R(s)} = \frac{0,062s^2 - 0,0583s + 0,181}{s^3 + 4,363s^2 + 4,250s + 0,574} \quad (A.8.10)$$

A.2.1.- OBTENCIÓN DE LA FUNCIÓN DE TRASFERENCIA EN LAZO ABIERTO

Los datos del controlador para este análisis fuerón:

BP = Banda proporcional = 40%

BP = 100/Kc \Rightarrow Kc = 2.5.

Donde Kc es la ganancia del controlador, por lo cual se tiene que: $G_{ctr} = 2.5$.

$G_{tv} = 0,01193$, $G_{act} = 1$ se considera un relé ideal.

Reemplazando todos los datos en la ecuación A.6 se tiene:

$$K^* = 2.5 * 0,01193 * 1 = (0,0298)^{-1} = 33,52$$

Con los valores obtenidos por A.8.10 y reemplazando en A.5 se tiene que la función de transferencia en lazo abierto es:

$$G_{planta} = K^* \left(\frac{0,062s^2 - 0,0583s + 0,181}{s^3 + 4,300s^2 + 1,001s + 0,392} \right) \quad (\text{A.8.11})$$

donde $K^* = 23,52$

ANEXO B

ANEXO B

COMPENSACIONES

B.1.- Diseño de la compensación utilizando el Lugar Geométrico de las Raíces

Para determinar el producto de la función $G(s) \cdot H(s)$, se vuelve al diagrama de bloques simplificado, de la figura B.1.

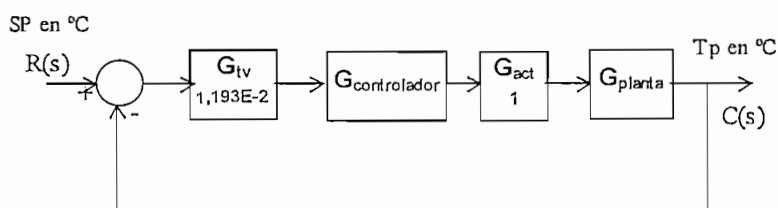


Figura B.1.- Diagrama de bloques simplificado del lazo de control de la extrusora

Para las zonas del extrusor se tiene el conjunto de ecuaciones.

Zona de extrusión	Ecuación en lazo abierto
Túnel zona 2	$G_{TZ2} = K \cdot \left(\frac{0,0239s^2 - 0,379s + 0,186}{s^3 + 2,179s^2 + 0,662s + 0,568} \right)$
Túnel zona 3	$G_{TZ3} = K \cdot \left(\frac{0,00885s^2 - 0,183s + 0,959}{s^3 + 2,787s^2 + 0,720s + 0,191} \right)$
Túnel zona 4	$G_{TZ4} = K \cdot \left(\frac{0,0289s^2 - 0,167s + 0,569}{s^3 + 5,050s^2 + 0,909s + 0,244} \right)$
Cabezal zona 1	$G_{CZ1} = K \cdot \left(\frac{0,0528s^2 + 0,059s + 0,095}{s^3 + 2,779s^2 + 0,665s + 0,153} \right)$
Cabezal zona 2	$G_{CZ2} = K \cdot \left(\frac{0,0298s^2 + 0,018s + 0,044}{s^3 + 2,516s^2 + 0,603s + 0,132} \right)$
Cabezal zona 3	$G_{CZ3} = K \cdot \left(\frac{0,00815s^2 - 0,013s + 0,037}{s^3 + 1,942s^2 + 0,546s + 0,081} \right)$

Cabezal zona 4	$G_{Cz4} = K^* \left(\frac{0,0369s^2 + 0,009s + 0,046}{s^3 + 2,501s^2 + 0,653s + 0,118} \right)$
Cabezal zona 5	$G_{Cz5} = K^* \left(\frac{0,0623s^2 - 0,058s + 0,181}{s^3 + 4,301s^2 + 1,001s + 0,392} \right)$

Tabla B.1.1 Funciones de transferencia de la máquina extrusora de pvc

Donde $K^* = 33,53$

$$G_{(s)} \times H_{(s)} = (0,01193) (1) [33,53 (G_{planta})] \quad (B.1)$$

La ecuación puede ser generalizada, por lo tanto, esta llega a ser:

$$G_{(s)} H_{(s)} = K (G_{planta}) \quad (B.2)$$

Los polos y ceros de lazo abierto son:

ZONA	POLOS			CEROS	
	P1	P2	P3	Z1	Z2
TUNEL 2	-1,835	-0,172 + j 0,037	-0,172 - j 0,037	-0,792 + j 2,677	-0,792 - j 2,677
TUNEL 3	-2,533	-0,127 + j 0,244	-0,127 - j 0,244	1,033 + j 3,126	1,033 - j 3,126
TUNEL 4	-4,87	-0,088 + j 0,205	-0,088 - j 0,205	2,890 + j 3,360	2,890 - j 3,360
CABEZAL 1	-2,541	-0,119 + j 0,214	-0,119 - j 0,214	-0,561 + j 1,217	-0,561 - j 1,217
CABEZAL 2	-2,276	-0,119 + j 0,209	-0,119 - j 0,209	-0,313 + j 1,177	-0,313 - j 1,177
CABEZAL 3	-1,638	-0,151 + j 0,162	-0,151 - j 0,162	0,827 + j 1,979	0,827 - j 1,979
CABEZAL 4	-2,232	-0,134 + j 0,187	-0,134 - j 0,187	-0,127 + j 1,118	-0,127 - j 1,118
CABEZAL 5	-4,078	-0,111 + j 0,289	-0,111 - j 0,289	-4,078 + j 1,642	-4,078 - j 1,642

Tabla B.1.2 Polos y ceros de las funciones de transferencia de la máquina extrusora

Según el lugar geométrico de las raíces, se tiene que el sistema es estable en el rango de ganancia de: $0 \leq K \leq K_c$.

ZONA	$0 < (K_c) (1,193E-2) (1) (33,53) <$	$0 < K_c <$
TUNEL 2	5,36	13,4
TUNEL 3	12,736	31,825
TUNEL 4	7,74	19,35
CABEZAL 1		
CABEZAL 2		

CABEZAL 3	16,069	40,172
CABEZAL 4		
CABEZAL 5	9,661	24,15

Tabla B.1.3 Rango de ganancia según el LGR de las zonas de la máquina extrusora

Donde:

K_c : Ganancia del controlador

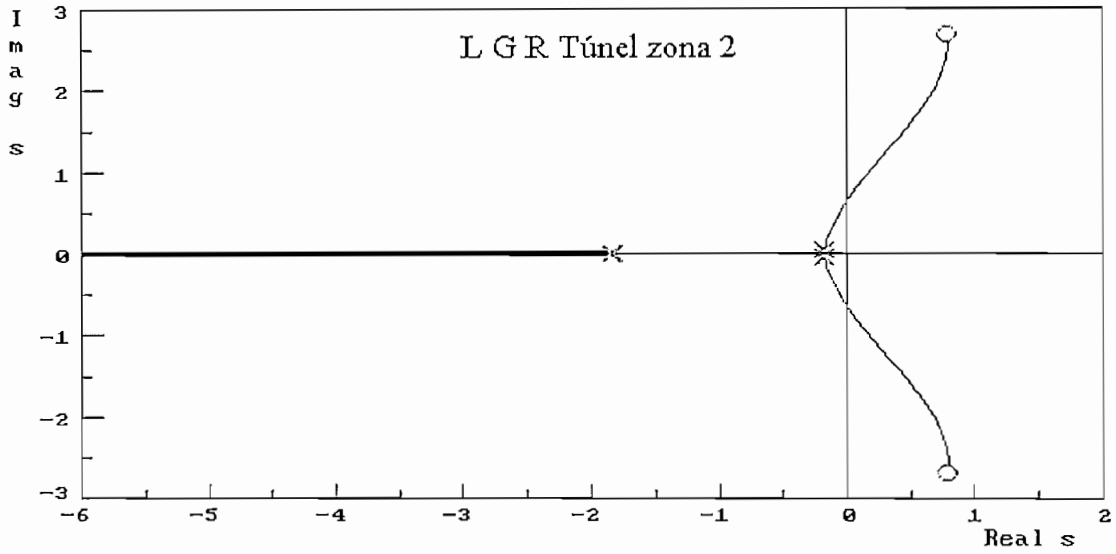


Figura B.1.2. Lugar geométrico de las raíces para $G(s)H(s)$ del túnel zona 2 de la extrusora

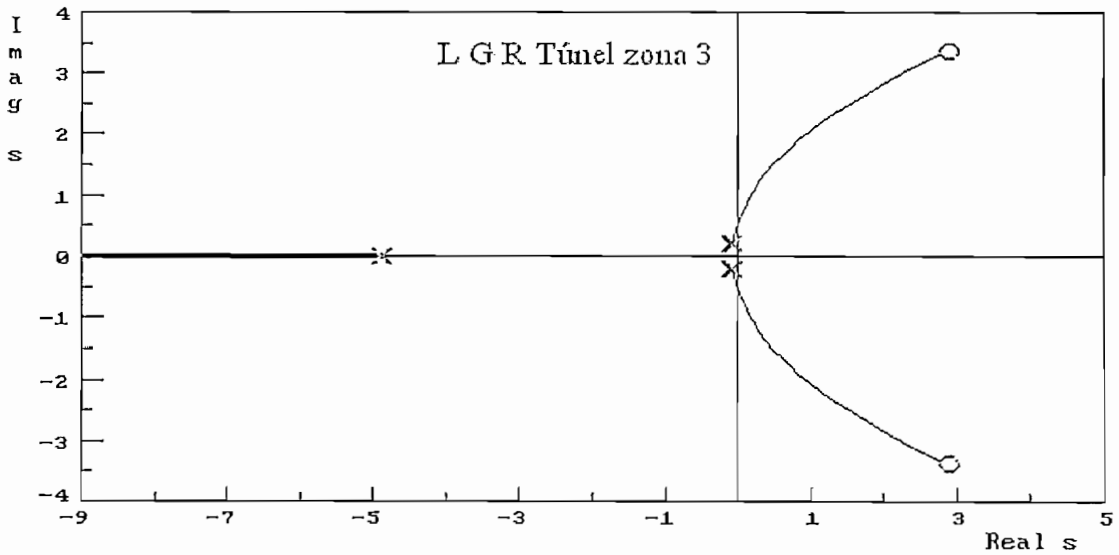


Figura B.1.3. Lugar geométrico de las raíces para $G(s)H(s)$ del túnel zona 3 de la extrusora

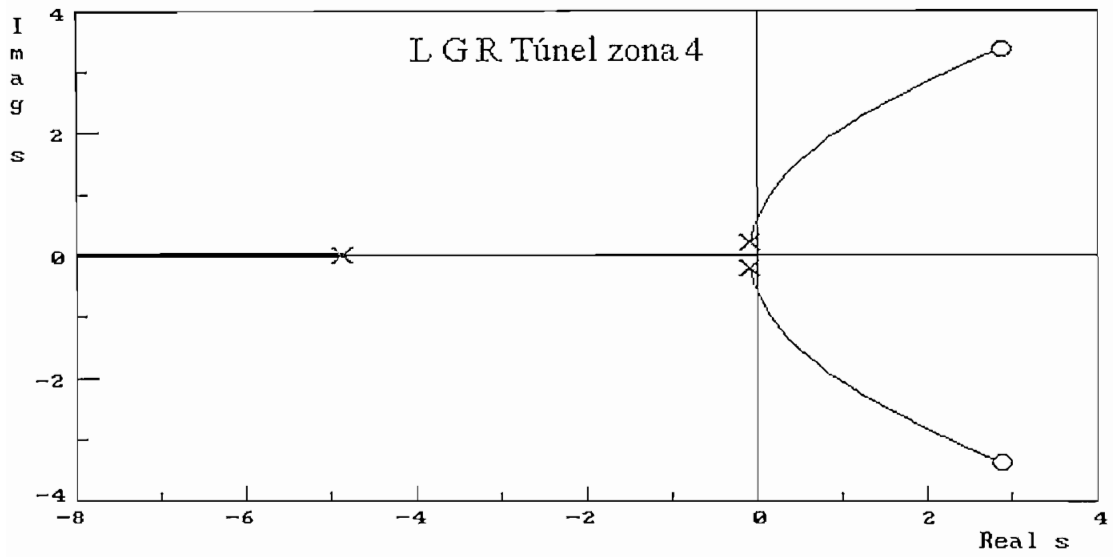


Figura B.1.4. Lugar geométrico de las raíces para $G(s)H(s)$ del túnel zona 4 de la extrusora

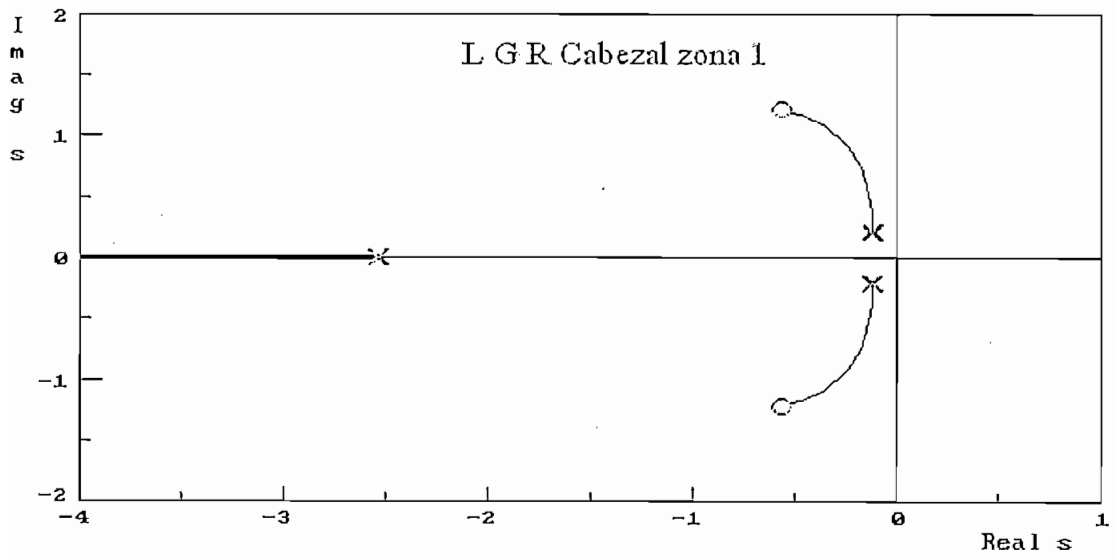


Figura B.1.5. Lugar geométrico de las raíces para $G(s)H(s)$ del cabezal zona 1 de la extrusora

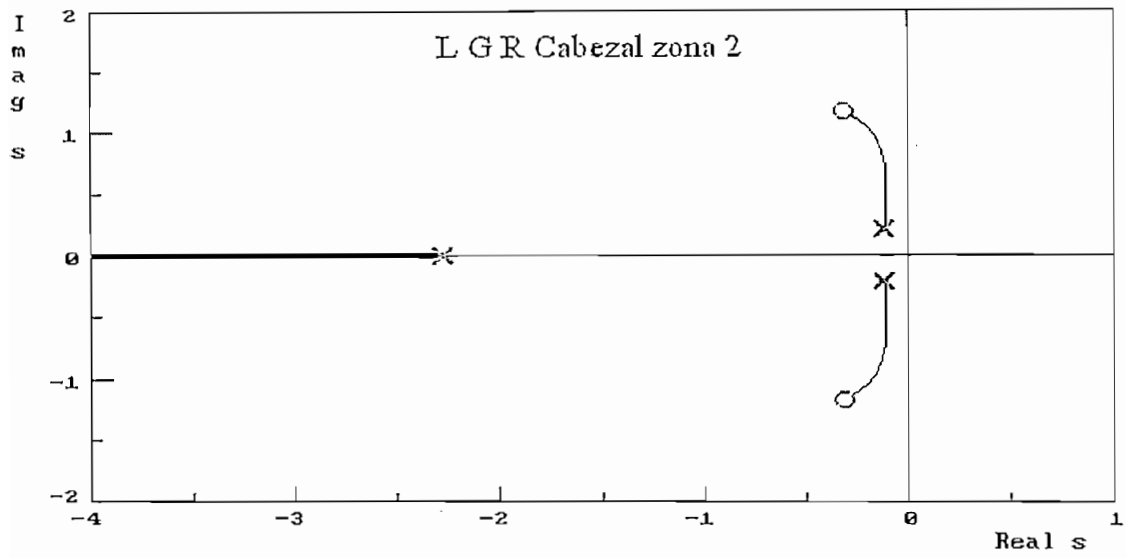


Figura B.1.6. Lugar geométrico de las raíces para $G_{(s)} H_{(s)}$ del cabezal zona 2 de la extrusora

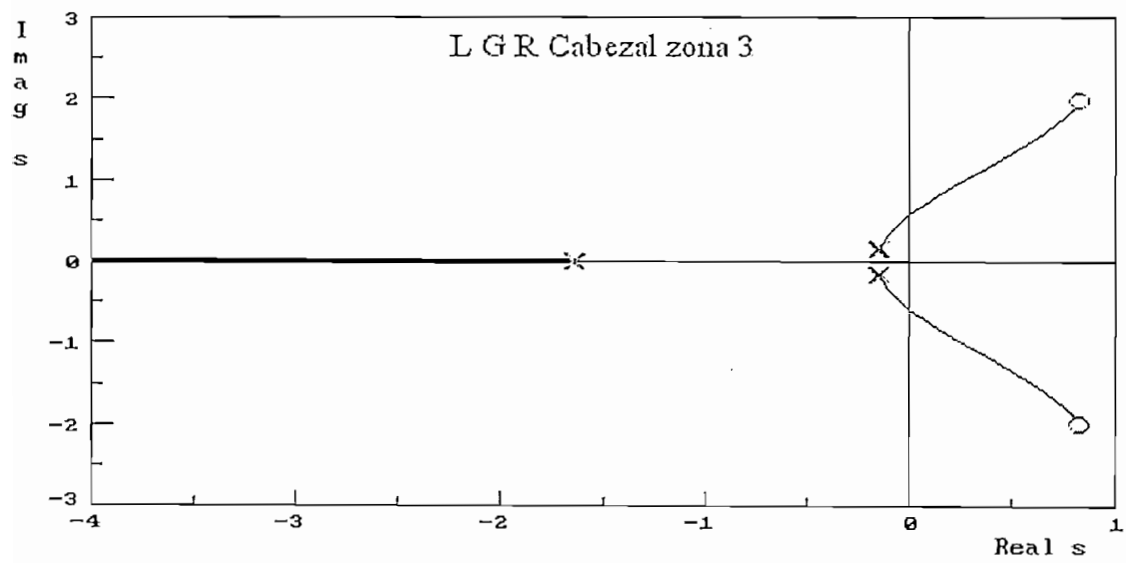


Figura B.1.7. Lugar geométrico de las raíces para $G_{(s)} H_{(s)}$ del cabezal zona 3 de la extrusora

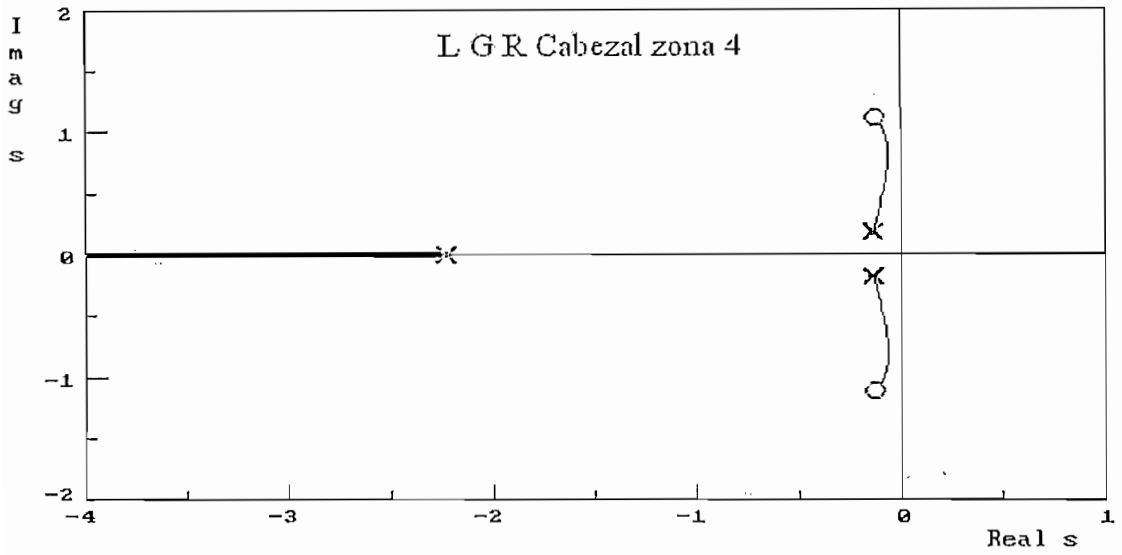


Figura B.1.8. Lugar geométrico de las raíces para $G(s)H(s)$ del cabezal zona 4 de la extrusora

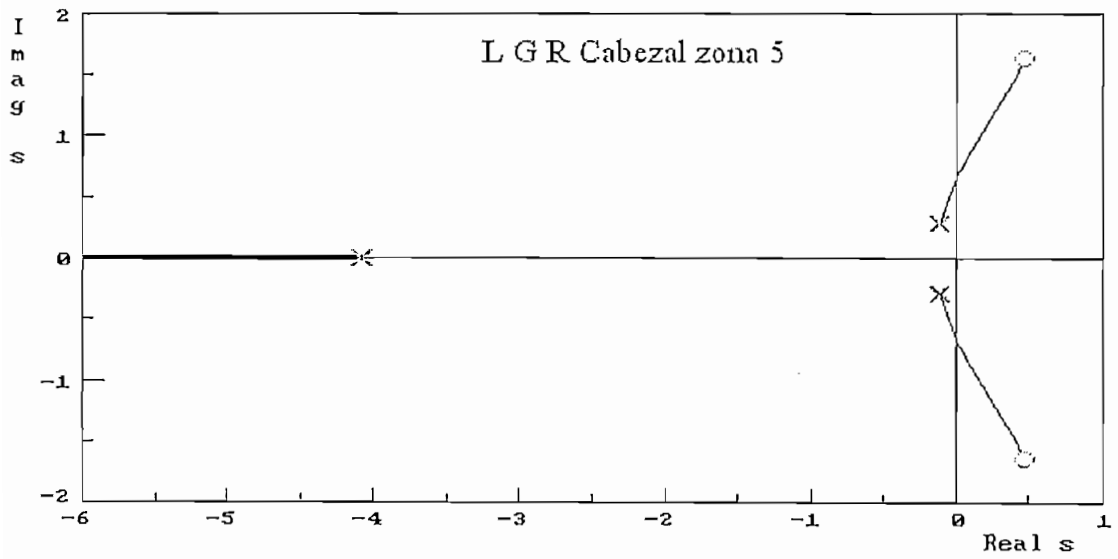


Figura B.1.9. Lugar geométrico de las raíces para $G(s)H(s)$ del cabezal zona 5 de la extrusora

B.2- Diseño del control proporcional integral derivativo PID en el tiempo

$$U(s) = \left[kp + \frac{ki}{s} + s kd \right] E(s) \quad (\text{B.3})$$

De la ecuación B.3 se tiene:

$$\frac{U(s)}{E(s)} = \frac{kd}{s} \left[s^2 + \frac{kp}{kd}s + \frac{ki}{kd} \right] \quad (\text{B.4})$$

Las funciones de transferencia muestran un par de polos complejos conjugados, los mismos que se procederá a cancelarlos mediante la ecuación B.4, para la cual de tiene las funciones de transferencia:

Zona de extrusión	Ecuación en lazo abierto
Túnel 2	$G_{TZ2} = 0,4 \left(\frac{0,0239s^2 - 0,379s + 0,186}{(s + 1,835)(s^2 + 0,344s + 0,030)} \right)$
Túnel 3	$G_{TZ3} = 0,4 \left(\frac{0,00885s^2 - 0,183s + 0,959}{(s + 2,533)(s^2 + 0,254s + 0,075)} \right)$
Túnel 4	$G_{TZ4} = K^* \left(\frac{0,0289s^2 - 0,167s + 0,569}{(s + 4,87)(s^2 + 0,176s + 0,050)} \right)$
Cabezal 1	$G_{CZ1} = K^* \left(\frac{0,0528s^2 + 0,059s + 0,095}{(s + 2,541)(s^2 + 0,238s + 0,059)} \right)$
Cabezal 2	$G_{CZ2} = K^* \left(\frac{0,0298s^2 + 0,018s + 0,044}{(s + 2,276)(s^2 + 0,238s + 0,057)} \right)$
Cabezal 3	$G_{CZ3} = 0,4 \left(\frac{0,00815s^2 - 0,013s + 0,037}{(s + 1,638)(s^2 + 0,302s + 0,049)} \right)$
Cabezal 4	$G_{CZ4} = 0,4 \left(\frac{0,0369s^2 + 0,009s + 0,046}{(s + 2,232)(s^2 + 0,268s + 0,052)} \right)$

Cabezal 5	$G_{czs} = 0,4 \left(\frac{0,0623s^2 - 0,058s + 0,181}{(s + 4,078)(s^2 + 0,222s + 0,095)} \right)$
-----------	---

Tabla B.2.1 Funciones de transferencia en lazo abierto de la máquina extrusora de pvc

Por lo que se iguala los polos conjugados con el controlador PID, se tiene:

Zona de extrusión	Controlador PID
Túnel 2	$s^2 + \frac{kp}{kd}s + \frac{ki}{kd} = s^2 + 0,344s + 0,030$
Túnel 3	$s^2 + \frac{kp}{kd}s + \frac{ki}{kd} = s^2 + 0,254s + 0,075$
Túnel 4	$s^2 + \frac{kp}{kd}s + \frac{ki}{kd} = s^2 + 0,176s + 0,050$
Cabezal 1	$s^2 + \frac{kp}{kd}s + \frac{ki}{kd} = s^2 + 0,238s + 0,059$
Cabezal 2	$s^2 + \frac{kp}{kd}s + \frac{ki}{kd} = s^2 + 0,238s + 0,057$
Cabezal 3	$s^2 + \frac{kp}{kd}s + \frac{ki}{kd} = s^2 + 0,302s + 0,049$
Cabezal 4	$s^2 + \frac{kp}{kd}s + \frac{ki}{kd} = s^2 + 0,268s + 0,052$
Cabezal 5	$s^2 + \frac{kp}{kd}s + \frac{ki}{kd} = s^2 + 0,222s + 0,0095$

Tabla B.2.2 Cancelación de polos conjugados por el controlador digital

Donde se obtiene las siguientes relaciones:

Zona de extrusión	Controlador PID
Túnel 2	$\frac{k_p}{k_d} = 0,344 \Rightarrow k_p = 0,344 k_d$ $\frac{k_i}{k_d} = 0,030 \Rightarrow k_i = 0,030 k_d$
Túnel 3	$k_p = 0,254 k_d$; $k_i = 0,075 k_d$
Túnel 4	$k_p = 0,176 k_d$; $k_i = 0,050 k_d$
Cabezal 1	$k_p = 0,238 k_d$; $k_i = 0,059 k_d$
Cabezal 2	$k_p = 0,238 k_d$; $k_i = 0,057 k_d$
Cabezal 3	$k_p = 0,302 k_d$; $k_i = 0,049 k_d$
Cabezal 4	$k_p = 0,268 k_d$; $k_i = 0,052 k_d$
Cabezal 5	$k_p = 0,222 k_d$; $k_i = 0,095 k_d$

Tabla B.2.3 Relaciones del controlador digital y las zonas de la máquina extrusora

Donde las ecuaciones dependen del valor de k_d , el mismo se obtiene mediante el lugar geométrico de las raíces del sistema compensado, mostrado en la figuras

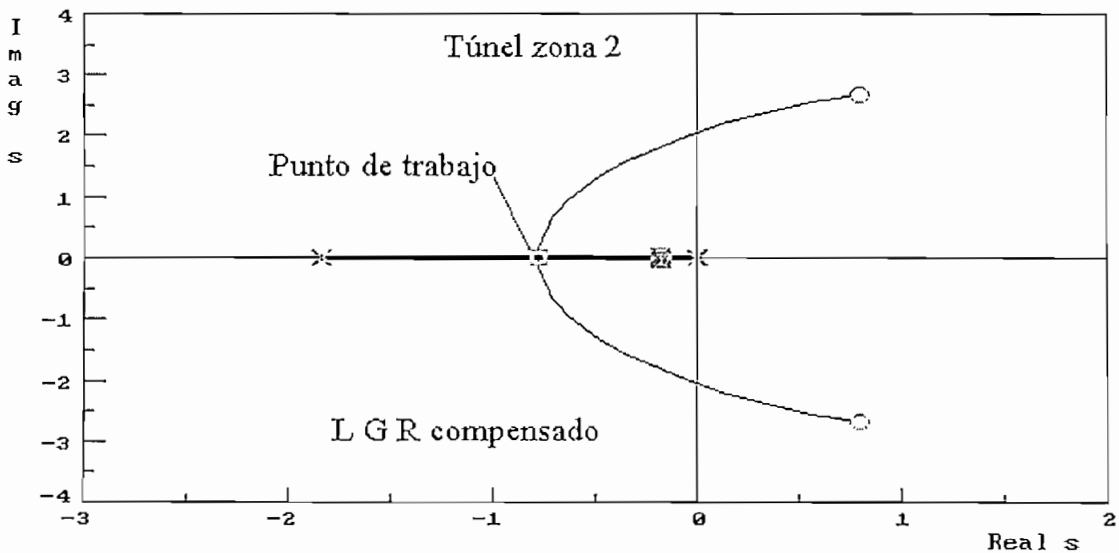


Figura B.2.1 Lugar geométrico de las raíces compensado de la zona 2 del túnel con compensación del controlador PID

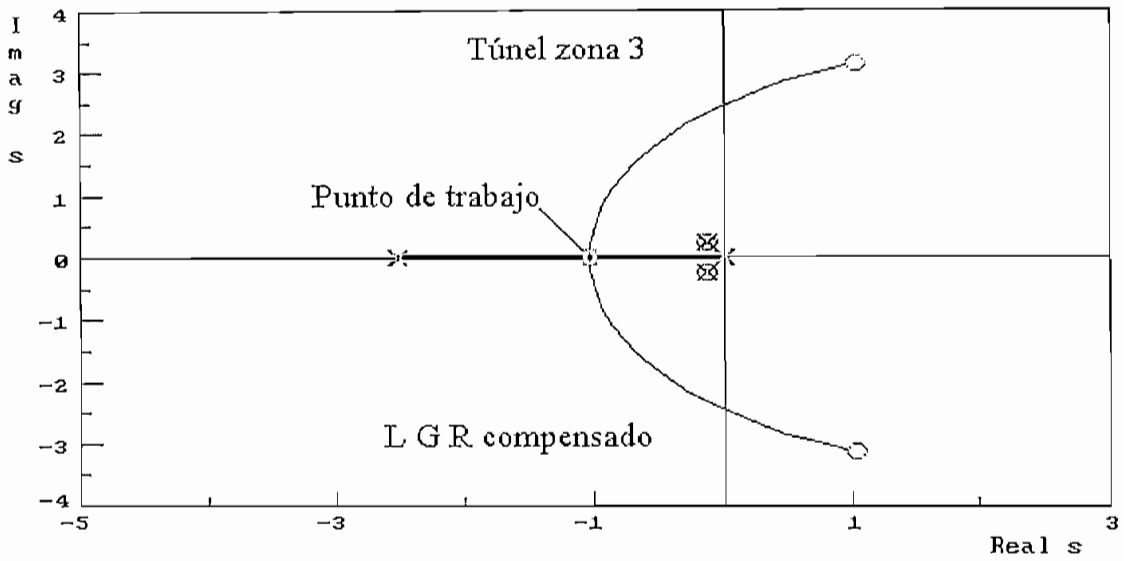


Figura B.2.2 Lugar geométrico de las raíces compensado de la zona 3 del túnel con compensación del controlador PID

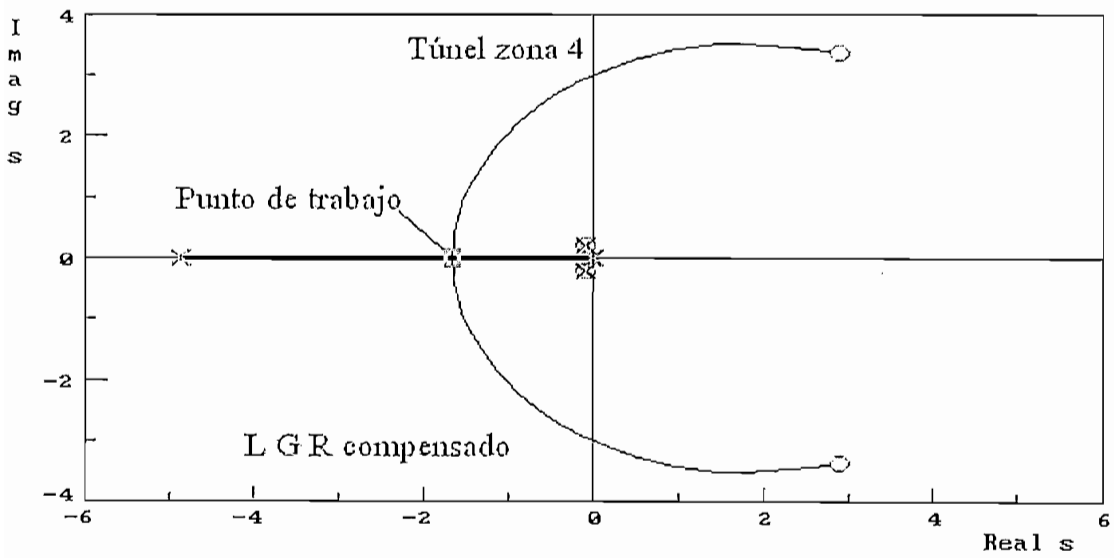


Figura B.2.3 Lugar geométrico de las raíces compensado de la zona 4 del túnel con compensación del controlador PID

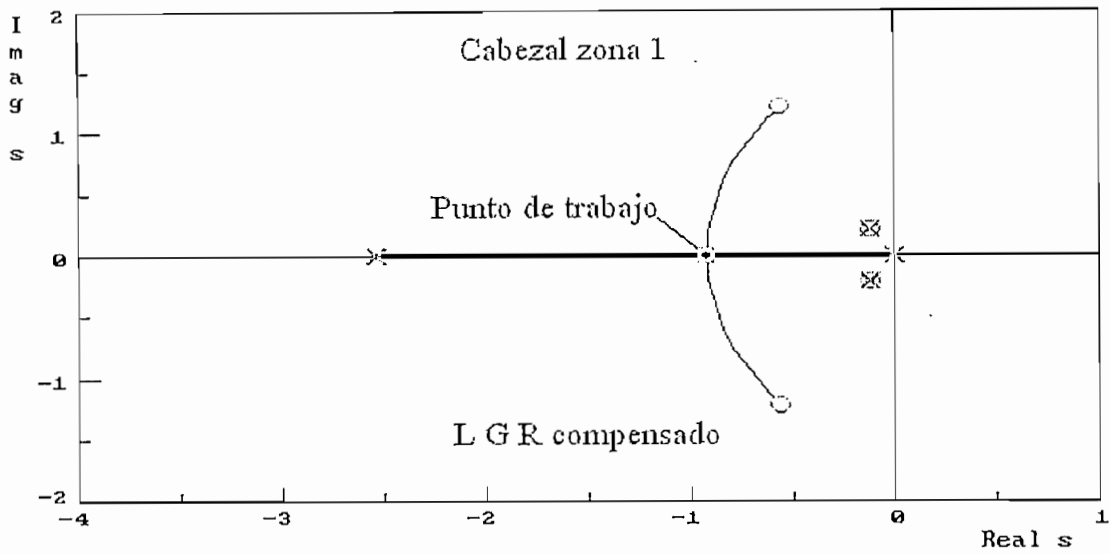


Figura B.2.4 Lugar geométrico de las raíces compensado de la zona 1 del cabezal con compensación del controlador PID

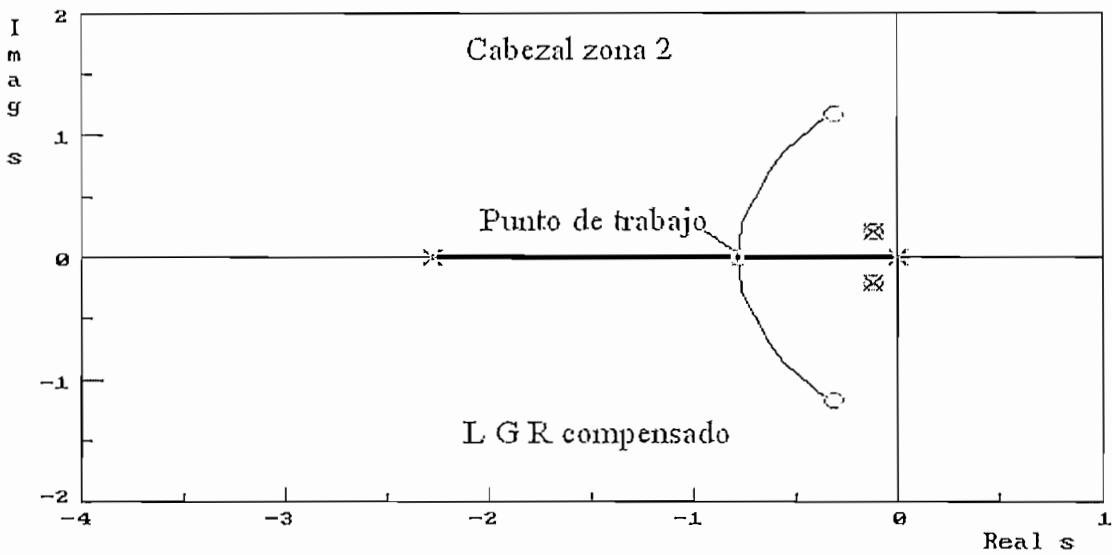


Figura B.2.5 Lugar geométrico de las raíces compensado de la zona 2 del cabezal con compensación del controlador PID

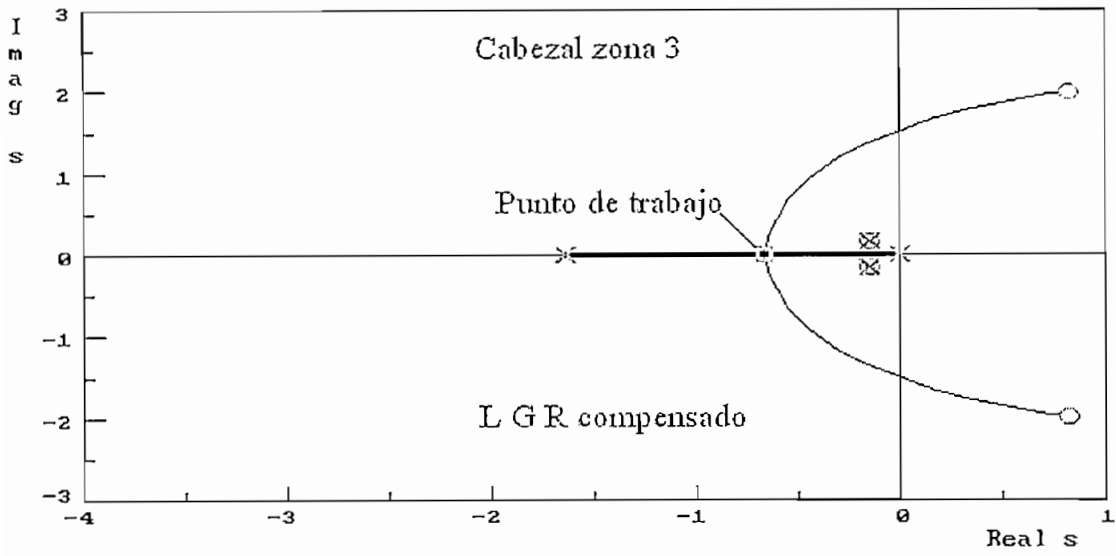


Figura B.2.6 Lugar geométrico de las raíces compensado de la zona 3 del cabezal con compensación del controlador PID

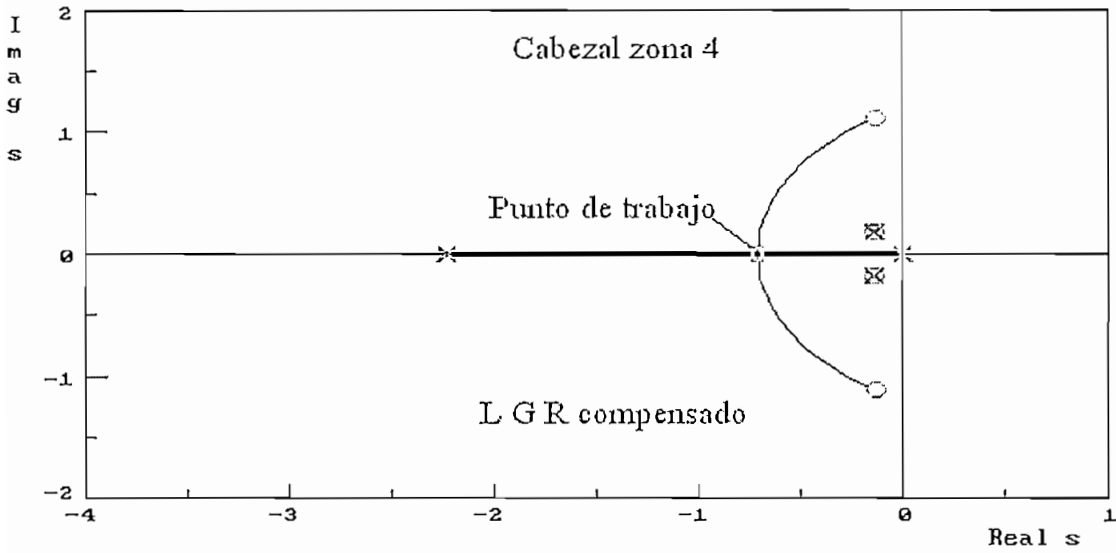


Figura B.2.7 Lugar geométrico de las raíces compensado de la zona 4 del cabezal con compensación del controlador PID

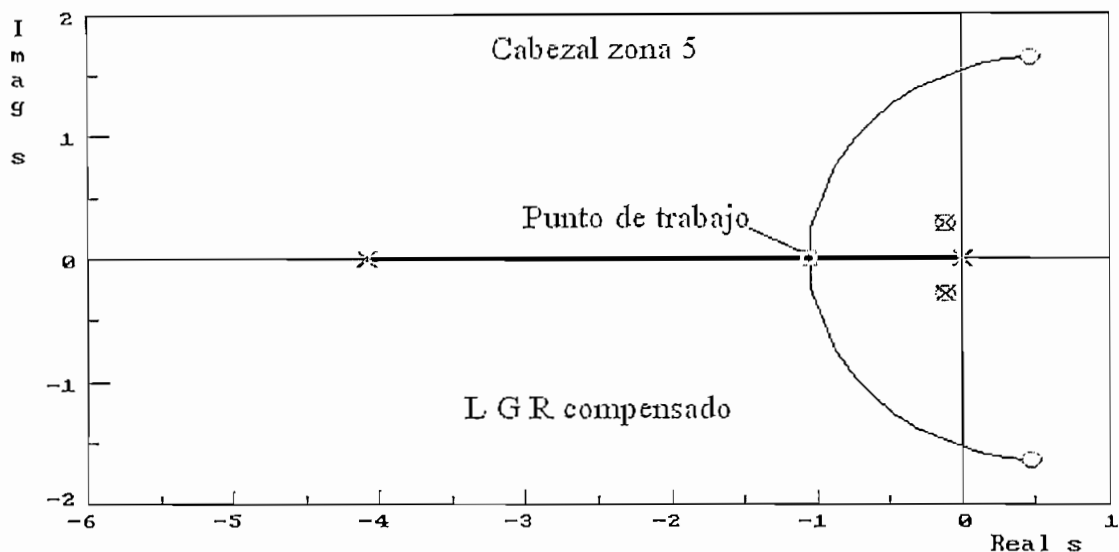


Figura B.2.8 Lugar geométrico de las raíces compensado de la zona 5 del cabezal con compensación del controlador PID

Mediante el lugar geométrico de las raíces de la figura 4.18, se obtiene el valor de ganancia para el cual el sistema tiene un índice de amortiguamiento (ξ) igual a 1, este valor es medido en el LGR. Por lo que se tiene:

Zona de extrusión	Controlador PID
Túnel 2	$K_{\varepsilon=1} = 3,562 = 0,4 * kd \Rightarrow kd = 8,905$ $kp = 3,063$; $ki = 0,276$
Túnel 3	$K_{\varepsilon=1} = 12,47 = 0,4 * kd \Rightarrow kd = 31,17$ $kp = 7,93$; $ki = 2,362$
Túnel 4	$K_{\varepsilon=1} = 5,751 = 0,4 * kd \Rightarrow kd = 14,377$ $kp = 2,535$; $ki = 0,72$
Cabezal 1	$K_{\varepsilon=1} = 17,51 = 0,4 * kd \Rightarrow kd = 43,775$ $kp = 10,44$; $ki = 2,633$
Cabezal 2	$K_{\varepsilon=1} = 24,43 = 0,4 * kd \Rightarrow kd = 61,07$ $kp = 14,61$; $ki = 3,562$
Cabezal 3	$K_{\varepsilon=1} = 12,92 = 0,4 * kd \Rightarrow kd = 32,30$ $kp = 9,803$; $ki = 1,596$

Cabezal 4	$K_{e=1} = 18,31 = 0,4 * kd \Rightarrow kd = 45,92$ $kp = 12,344$; $ki = 2,439$
Cabezal 5	$K_{e=1} = 10,20 = 0,4 * kd \Rightarrow kd = 25,5$ $kp = 5,661$; $ki = 2,45$

Tabla B.2.4 Constantes del controlador digital para la máquina extrusora

Las figuras muestra la respuesta en el tiempo, con la acción del controlador en las zonas del extrusor.

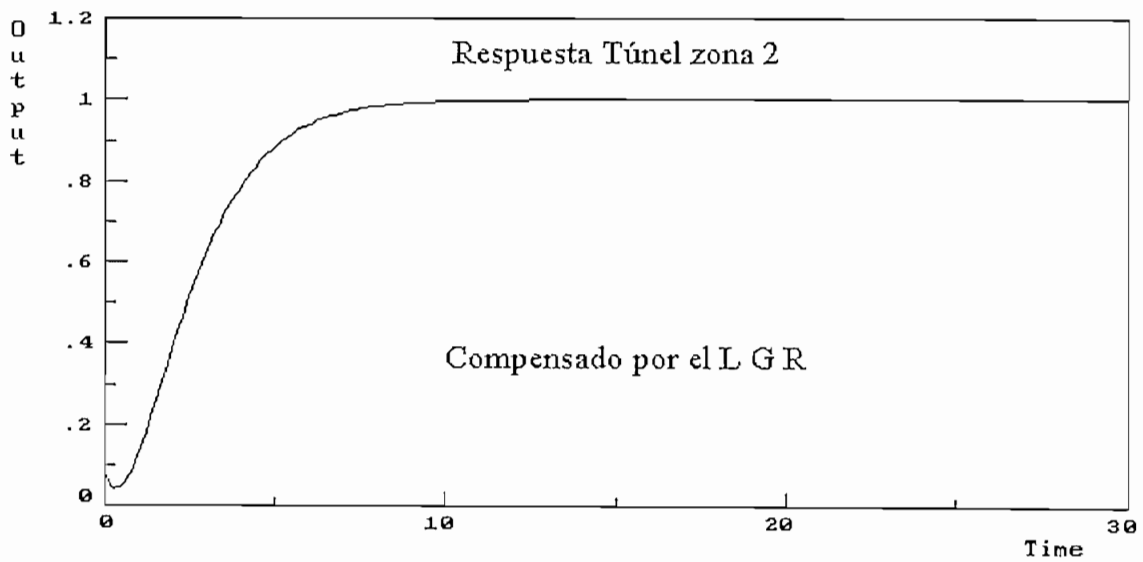


Figura B2.9 Respuesta en el tiempo de la zona 2 del túnel con compensación del controlador PID

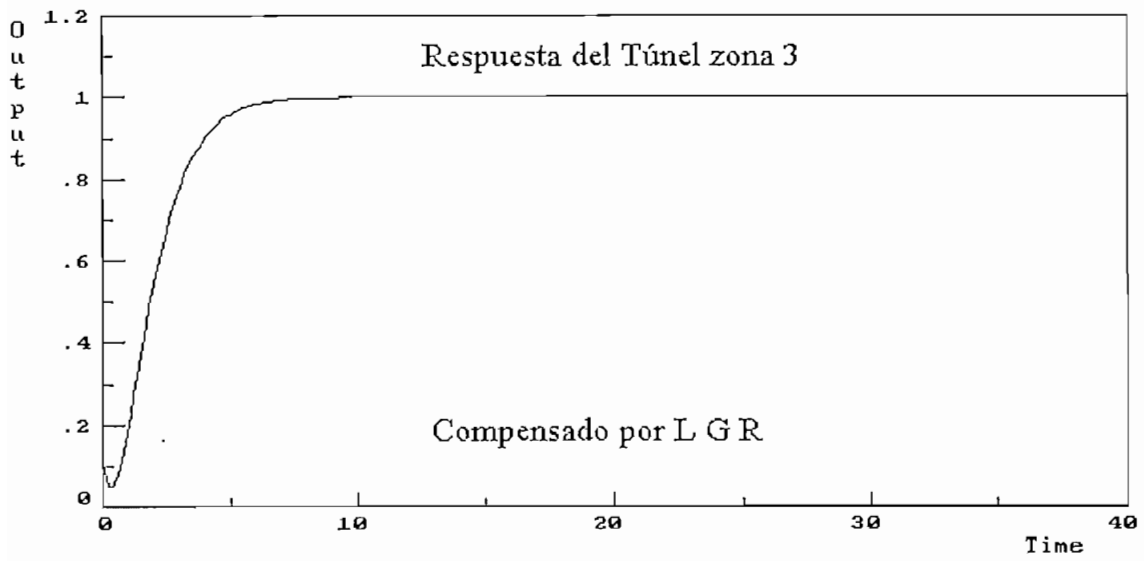


Figura B2.10 Respuesta en el tiempo de la zona 3 del túnel con compensación del controlador PID

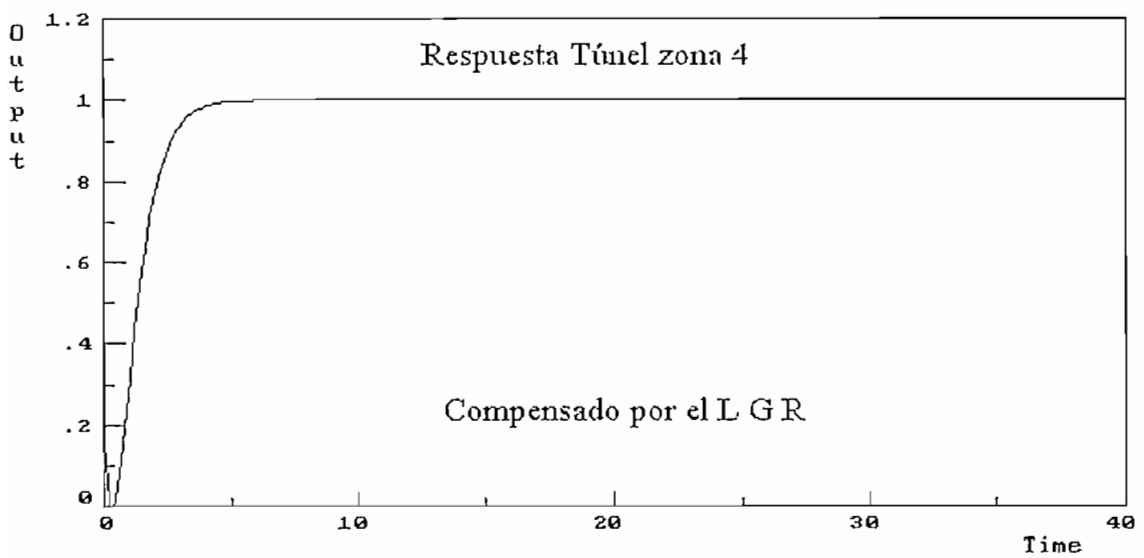


Figura B2.11 Respuesta en el tiempo de la zona 4 del túnel con compensación del controlador PID

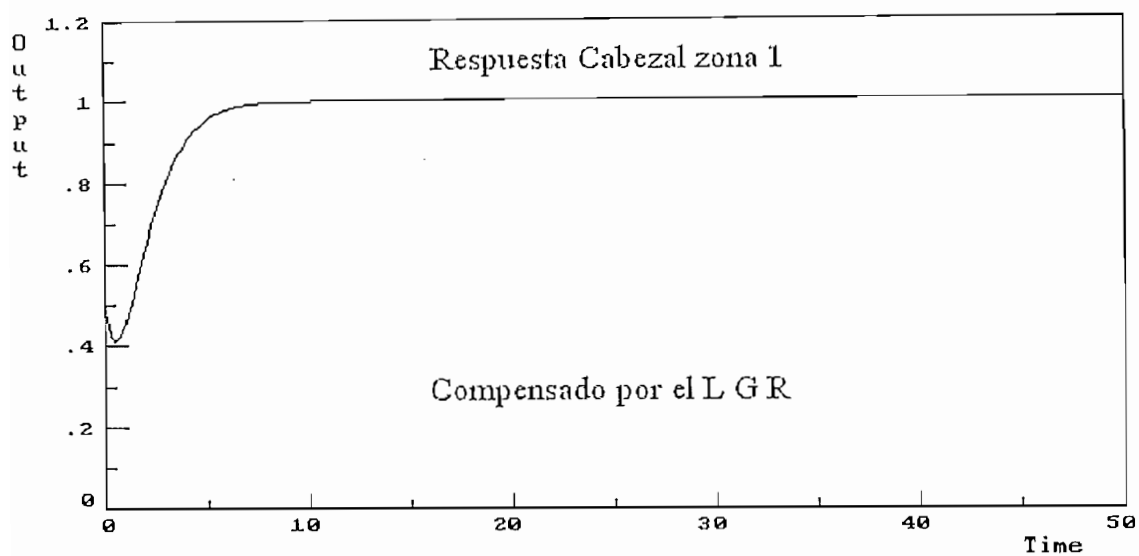


Figura B2.12 Respuesta en el tiempo de la zona 1 del cabezal con compensación del controlador PID

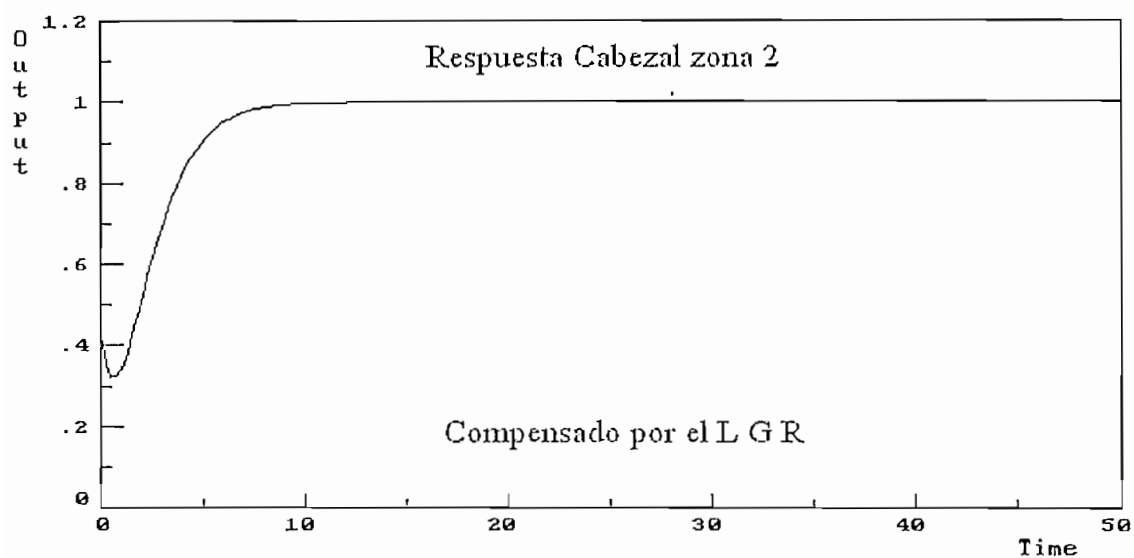


Figura B2.13 Respuesta en el tiempo de la zona 2 del cabezal con compensación del controlador PID

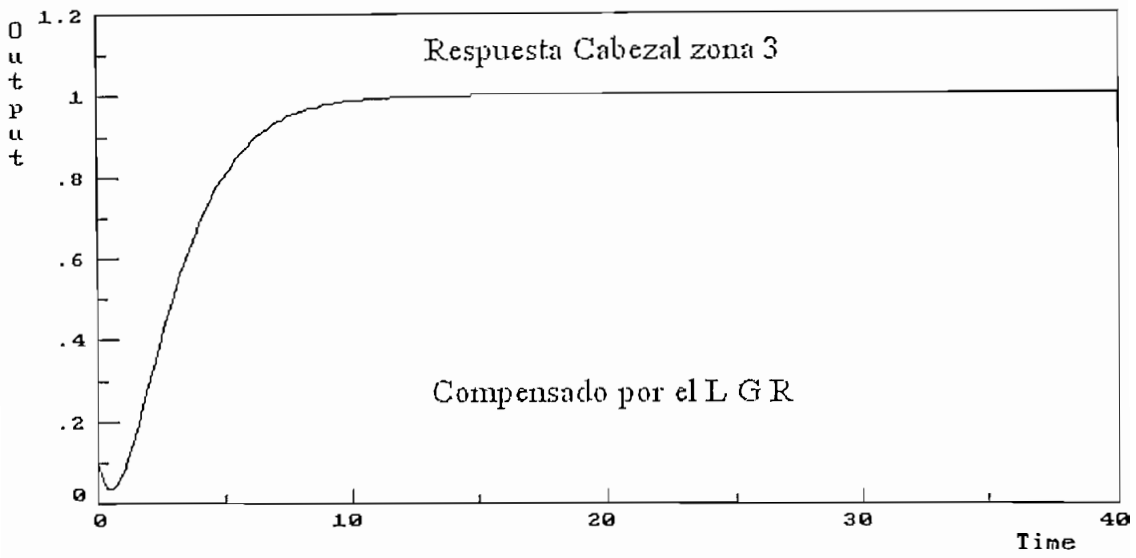


Figura B2.14 Respuesta en el tiempo de la zona 3 del cabezal con compensación del controlador PID

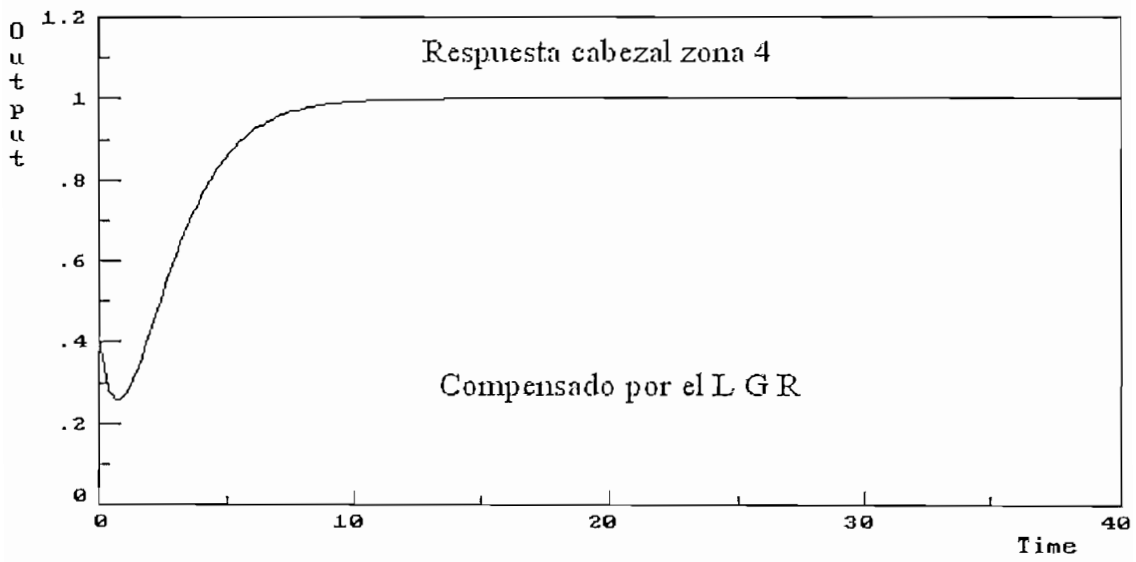


Figura B2.15 Respuesta en el tiempo de la zona 4 del cabezal con compensación del controlador PID

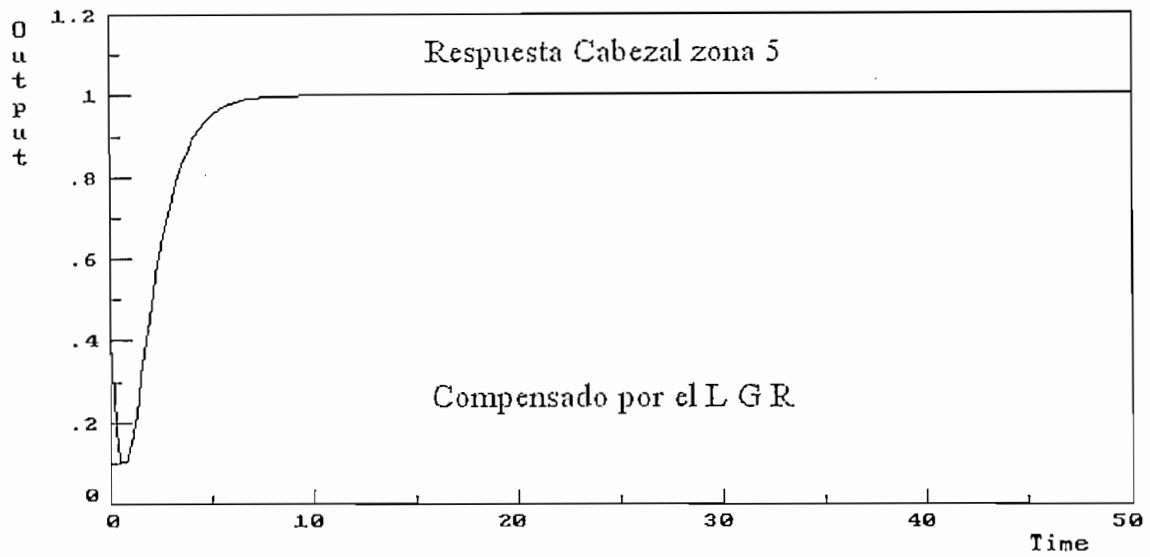


Figura B2.16 Respuesta en el tiempo de la zona 5 del cabezal con compensación del controlador PID

La función no inicia en el cruce por las características especiales de la función de transferencia en lazo cerrado, resultando las especificaciones siguientes:

M_p máximo sobrenivel porcentual

t_s tiempo de establecimiento con criterio del 5% en minutos

E_p error de posición

Zona extrusora	k_p	k_i	k_d	M_p (%)	t_s (min)	E_p
T Z 1	12,43	0,86	12,43	0	5,78	0
T Z 2	3,06	0,27	8,9	0	6,27	0
T Z 3	7,93	2,36	31,17	0	4,74	0
T Z 4	2,53	0,72	14,37	0	3,14	0
C Z 1	10,44	2,63	43,77	0	4,92	0
C Z 2	14,61	3,56	61,07	0	6,03	0
C Z 3	9,8	1,59	32,3	0	7,63	0
C Z 4	12,34	2,43	45,92	0	6,83	0
C Z 5	5,661	2,45	25,5	0	5	0

Tabla B.2.5 Valores de constantes del PID y características obtenidas de las zonas de extrusión

B.3- Compensación utilizando el Lugar Geométrico de las Raíces discreto

Para trabajar en el lugar geométrico de la raíces en primer lugar se procede a discretizar las funciones de transferencia en lazo abierto, anteponiendo un muestreador de primer orden “Zero order Hold”, con un valor de periodo $T=1$.

Zona de extrusión	Ecuación en lazo abierto
Túnel 2	$G_{TZ2} = K^* \left[0,017 \left(\frac{z^2 + 1,911z + 1,121}{(z - 0,159)(z^2 - 1,682z + 0,708)} \right) \right]$
Túnel 3	$G_{TZ3} = K^* \left[0,007 \left(\frac{z^2 + 2,299z + 0,911}{(z - 0,079)(z^2 - 1,708z + 0,775)} \right) \right]$
Túnel 4	$G_{TZ4} = K^* \left[0,017 \left(\frac{z^2 + 4,358z + 0,858}{(z - 0,007)(z^2 - 1,792z + 0,838)} \right) \right]$
Cabezal 1	$G_{CZ1} = K^* \left[0,038 \left(\frac{z^2 - 0,539z + 0,337}{(z - 0,078)(z^2 - 1,734z + 0,788)} \right) \right]$
Cabezal 2	$G_{CZ2} = K^* \left[0,018 \left(\frac{z^2 - 0,664z + 0,493}{(z - 0,102)(z^2 - 1,735z + 0,787)} \right) \right]$
Cabezal 3	$G_{CZ3} = K^* \left[0,003 \left(\frac{z^2 + 1,543z + 1,911}{(z - 0,194)(z^2 - 1,695z + 0,738)} \right) \right]$
Cabezal 4	$G_{CZ4} = K^* \left[0,018 \left(\frac{z^2 - 0,802z + 0,664}{(z - 0,107)(z^2 - 1,717z + 0,764)} \right) \right]$
Cabezal 5	$G_{CZ5} = K^* \left[0,015 \left(\frac{z^2 - 0,414z + 0,095}{(z - 0,016)(z^2 - 1,715z + 0,800)} \right) \right]$

Tabla B.3.1 Funciones de transferencia discretas de la máquina extrusora de pvc

Para determinar el producto de la función $G(z) \cdot H(z)$, se vuelve al diagrama de bloques simplificado, así:

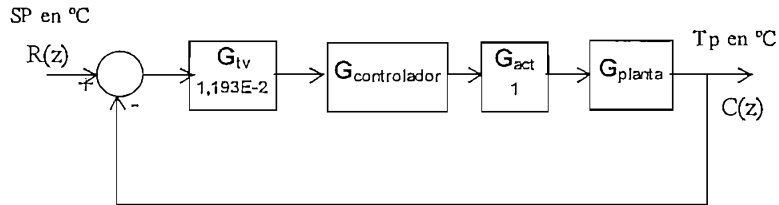


Figura B.3.1.- Diagrama de bloques simplificado del lazo de control de la extrusora

Se generaliza el procedimiento, pues para las otras zonas, el proceso es similar y solo se presentan los resultados.

$$G_{(z)}xH_{(z)} = (0,01193)(33,53)x[G_{planta}] \quad (B.3.1)$$

La ecuación B3.1 puede ser generalizada para cualquier valor de ganancia, por lo tanto, esta llega a ser:

$$G_{(z)} H_{(z)} = K (G_{planta}) \quad (B.3.2)$$

Los polos y ceros de lazo abierto son:

ZONA	POLOS			CEROS	
	P1	P2	P3	Z1	Z2
TUNEL 2	0,159	-0,841 + j 0,026	-0,841 - j 0,026	0,955 + j 0,456	0,955 - j 0,456
TUNEL 3	0,079	-0,854 + j 0,213	-0,854 - j 0,213	1,79	0,508
TUNEL 4	0,007	-0,896 + j 0,187	-0,896 - j 0,187	4,151	0,206
CABEZAL 1	0,078	-0,867 + j 0,190	-0,867 - j 0,190	-0,269 + j 0,551	-0,269 - j 0,551
CABEZAL 2	0,102	-0,867 + j 0,185	-0,867 - j 0,185	-0,332 + j 0,618	-0,332 + j 0,618
CABEZAL 3	0,194	-0,847 + j 0,140	-0,847 - j 0,140	0,771 + j 1,147	0,771 - j 1,147
CABEZAL 4	0,107	-0,858 + j 0,164	-0,858 - j 0,164	-0,401 + j 0,709	-0,401 - j 0,709
CABEZAL 5	0,016	-0,857 + j 0,254	-0,857 - j 0,254	0,207 + j 1,025	0,207 - j 1,025

Tabla B.3.2 Polos y ceros de las funciones de transferencia de la máquina extrusora

Según el lugar geométrico de las raíces, se tiene que el sistema es estable en el rango de ganancia de: $0 \leq K \leq K_c$.

ZONA	$0 < (K_c) (1,193E-2) (1) (33,53) <$	$0 < K_c <$
TUNEL 2	3,64	9,1
TUNEL 3	3,16	7,9
TUNEL 4	6,93	17,32
CABEZAL 1		
CABEZAL 2		
CABEZAL 3	10,66	26,65
CABEZAL 4		
CABEZAL 5	5,40	13,5

Tabla B.3.3 Rango de ganancia según el LGR de las zonas de la máquina extrusora

Donde:

K_c : Ganancia del controlador

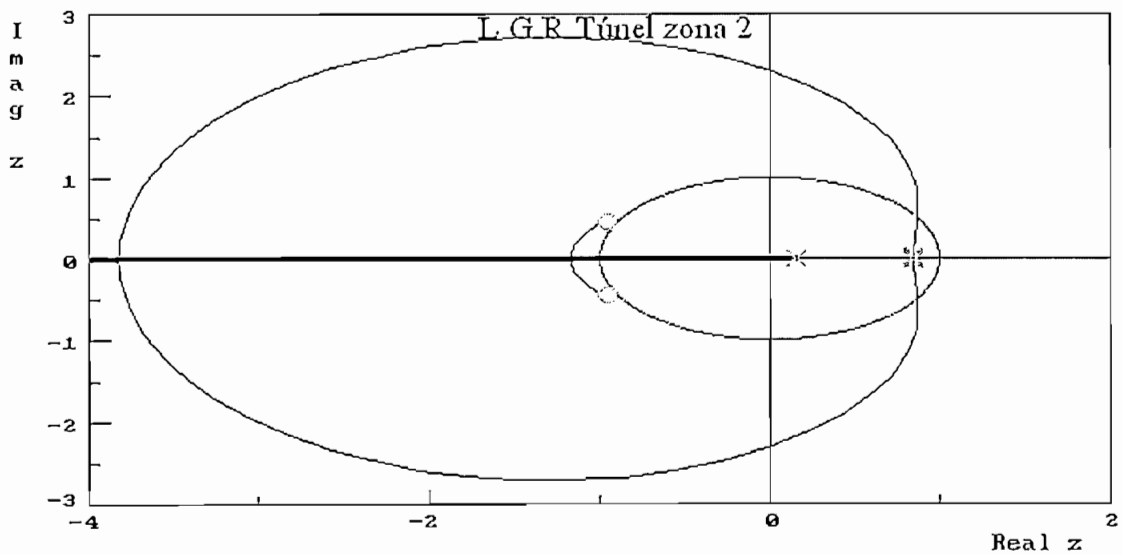


Figura B.3.2. Lugar geométrico de las raíces para $G_{(s)} H_{(s)}$ del túnel zona 2 de la extrusora

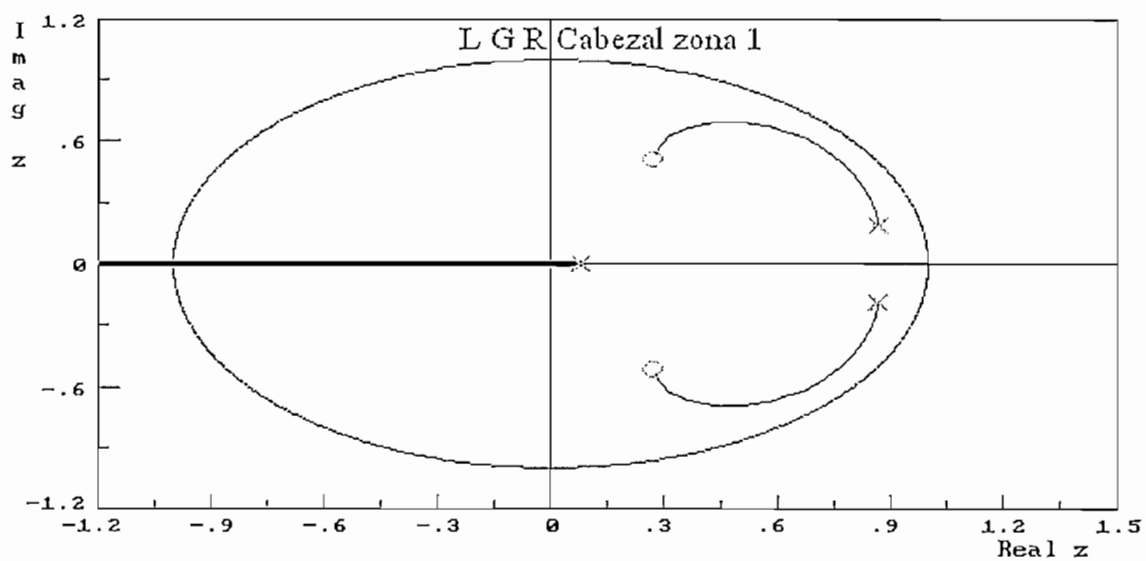


Figura B.3.5. Lugar geométrico de las raíces para $G_{(z)} H_{(z)}$ del cabezal zona 1 de la extrusora

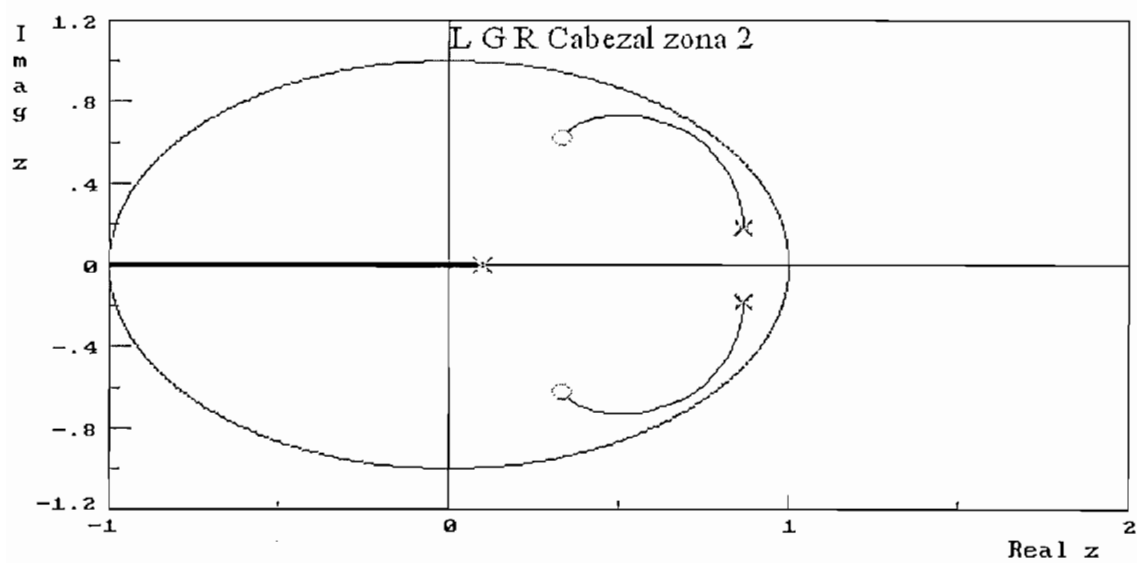


Figura B.3.6. Lugar geométrico de las raíces para $G_{(z)} H_{(z)}$ del cabezal zona 2 de la extrusora

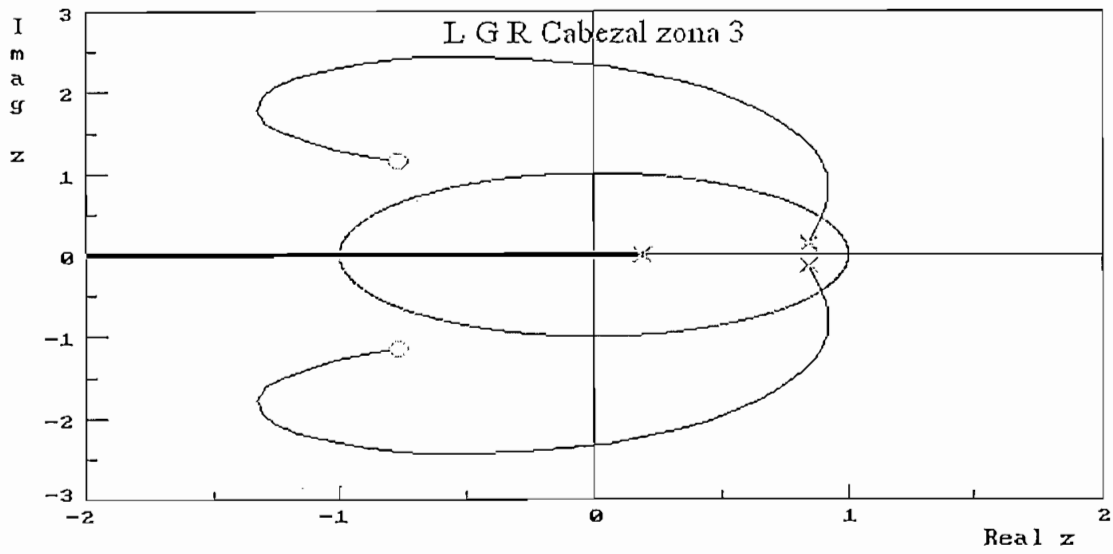


Figura B.3.7. Lugar geométrico de las raíces para $G_{(s)} H_{(s)}$ del cabezal zona 3 de la extrusora

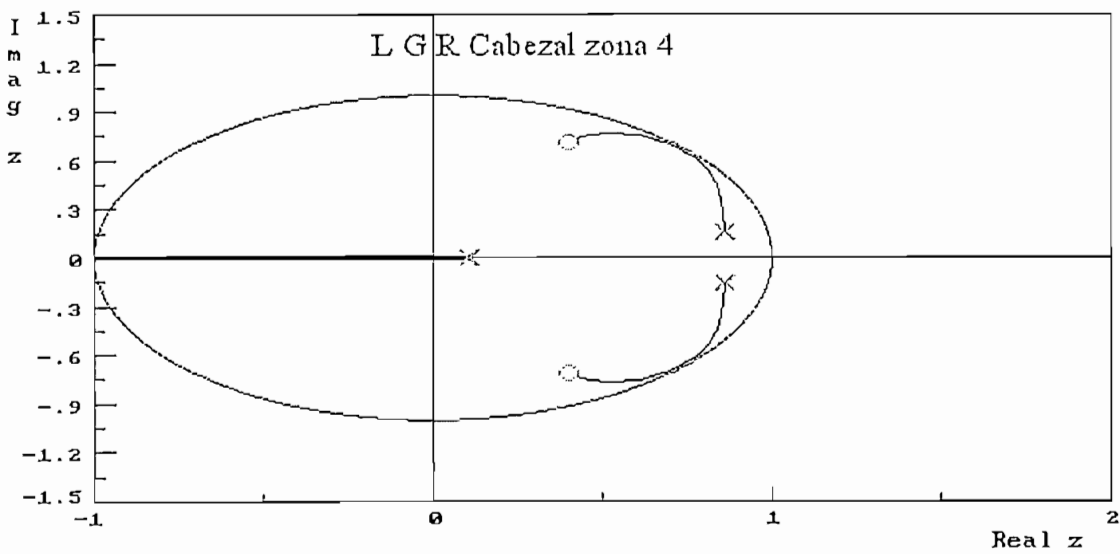


Figura B.3.8. Lugar geométrico de las raíces para $G_{(s)} H_{(s)}$ del cabezal zona 4 de la extrusora

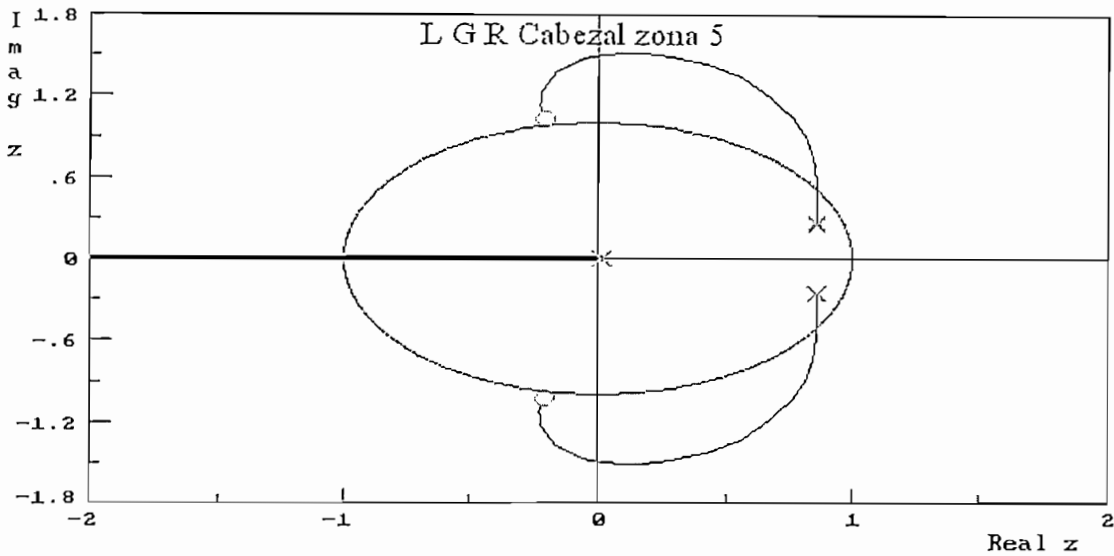


Figura B.3.9. Lugar geométrico de las raíces para $G_{(z)} H_{(z)}$ del cabezal zona 5 de la extrusora

B.4.- Diseño del control proporcional integral PID discreto

El controlador PID discreto tiene la siguiente función de transferencia:

$$G_{PID(z)} = kp + ki \frac{T}{2} \frac{z+1}{z-1} + kd \frac{z-1}{Tz} \quad (B.4.1)$$

$$G_{PID(z)} = \left(\frac{2kpT + kiT^2 + 2kd}{2T} \right) \left(\frac{z^2 + \frac{kiT^2 - 2kpT - 4kd}{2kpT + kiT^2 + 2kd}z + \frac{2kd}{2kpT + kiT^2 + 2kd}}{z^2 - z} \right) \quad (B.4.2)$$

Siendo kp = ganancia proporcional

ki = constante integral.

kd = constante derivativa.

De la ecuación B.4.2 se tiene la siguiente relación:

$$G_{PID(z)} = K1 \left(\frac{z^2 + K2z + K3}{z^2 - z} \right) \quad (B.4.3)$$

Donde:

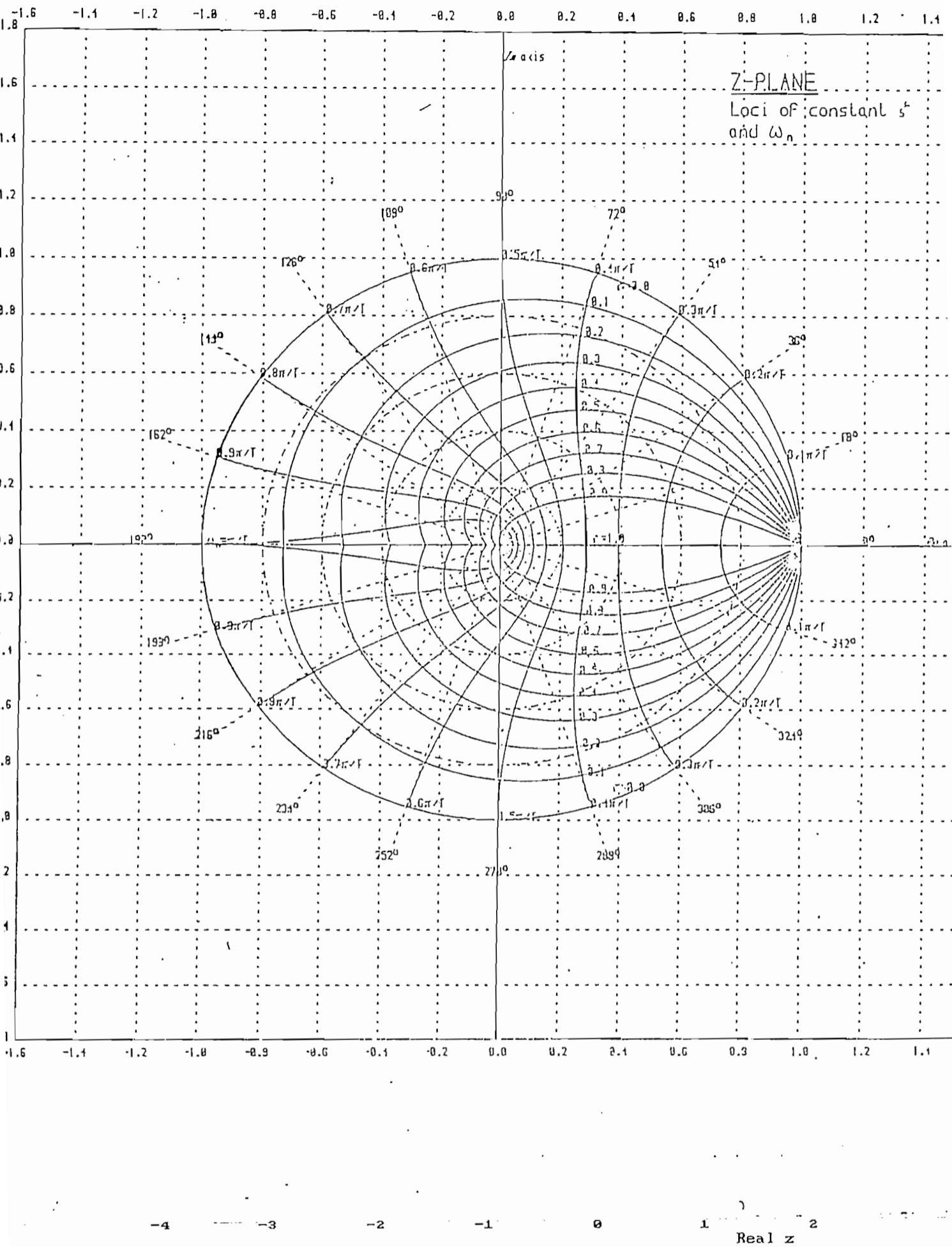
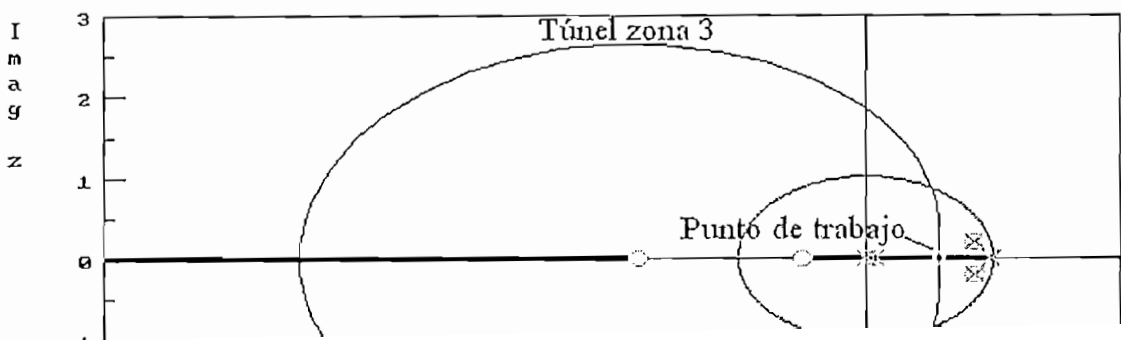


Figura B.4.1 Lugar geométrico de las raíces para el sistema compensado de la zona 2 del túnel



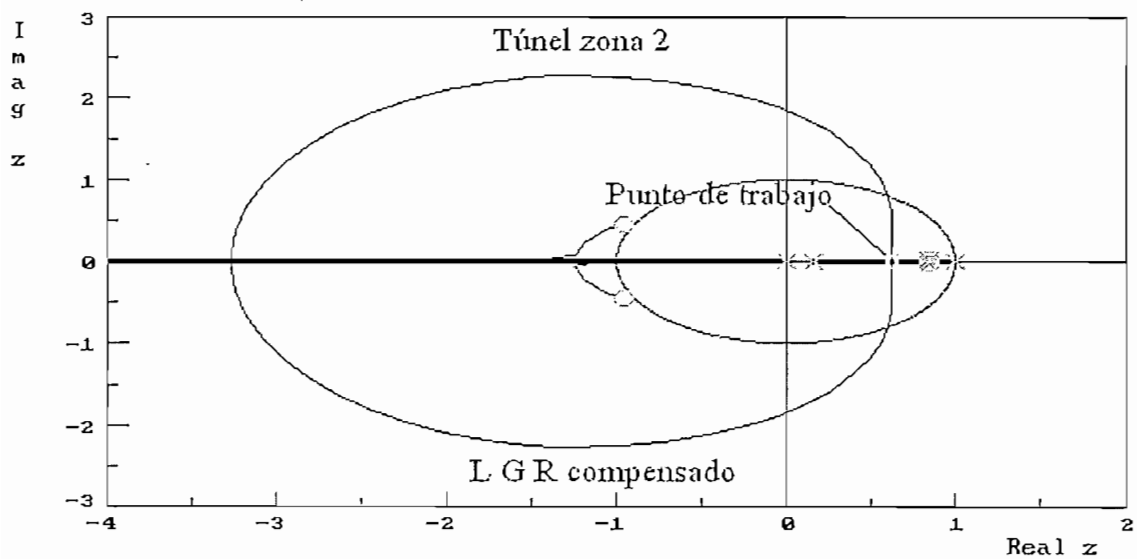


Figura B.4.1 Lugar geométrico de las raíces para el sistema compensado de la zona 2 del túnel

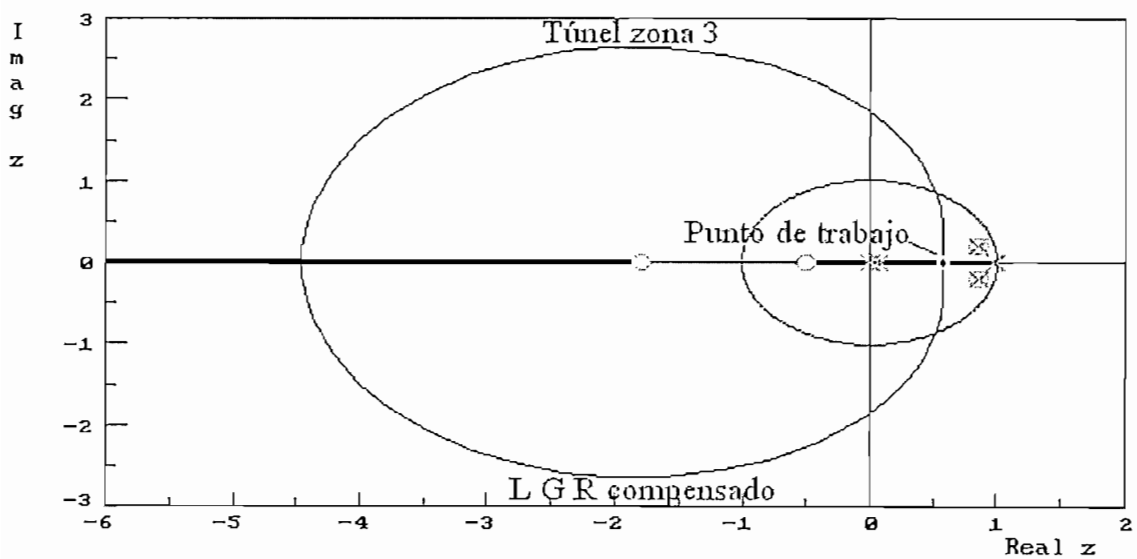


Figura B.4.2 Lugar geométrico de las raíces para el sistema compensado de la zona 3 del túnel

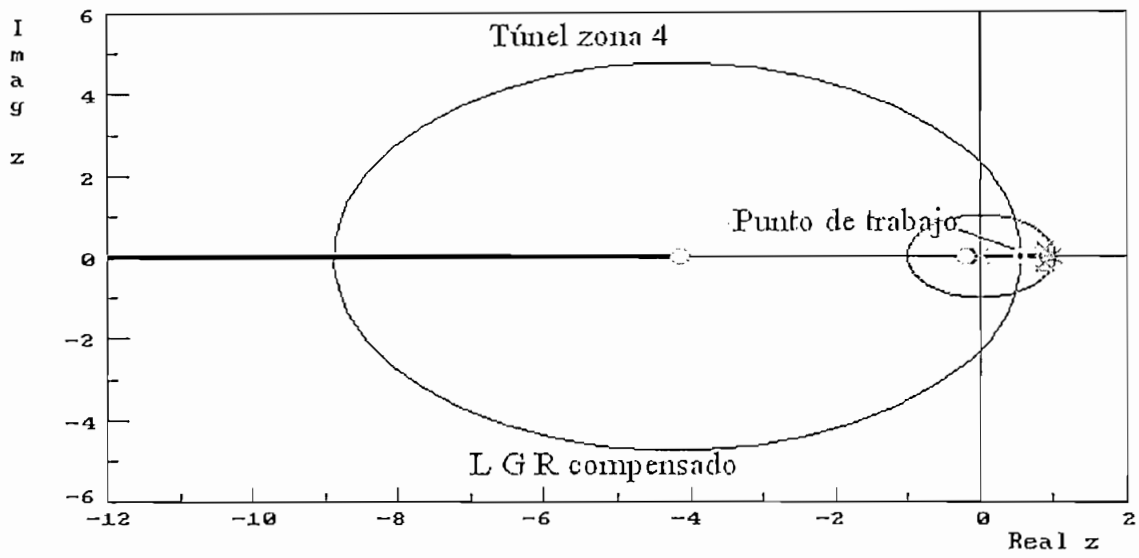


Figura B.4.3 Lugar geométrico de las raíces para el sistema compensado de la zona 4 del túnel

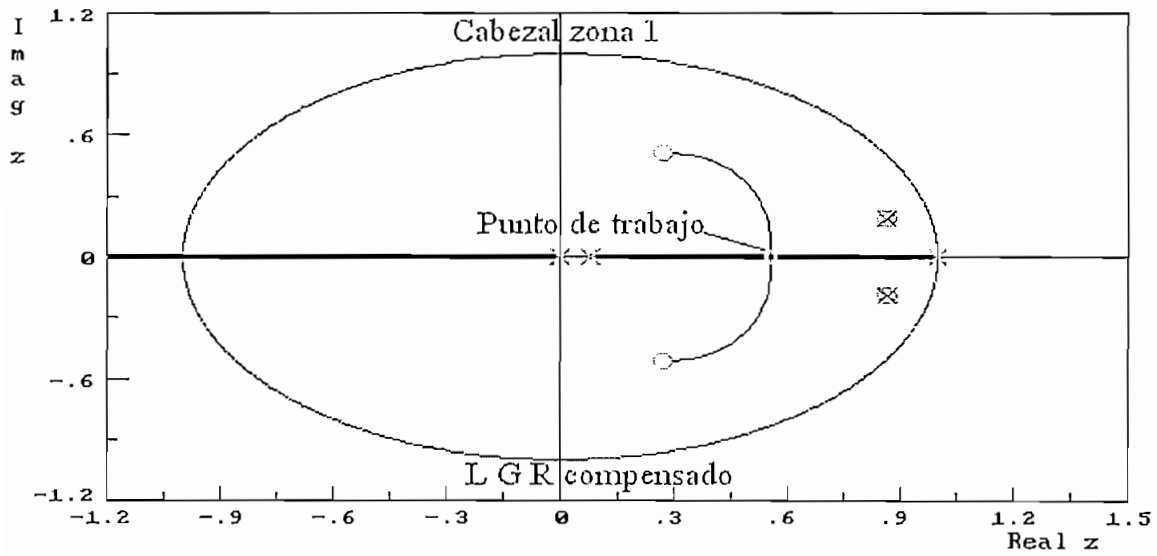


Figura B.4.4 Lugar geométrico de las raíces para el sistema compensado de la zona 1 del cabezal

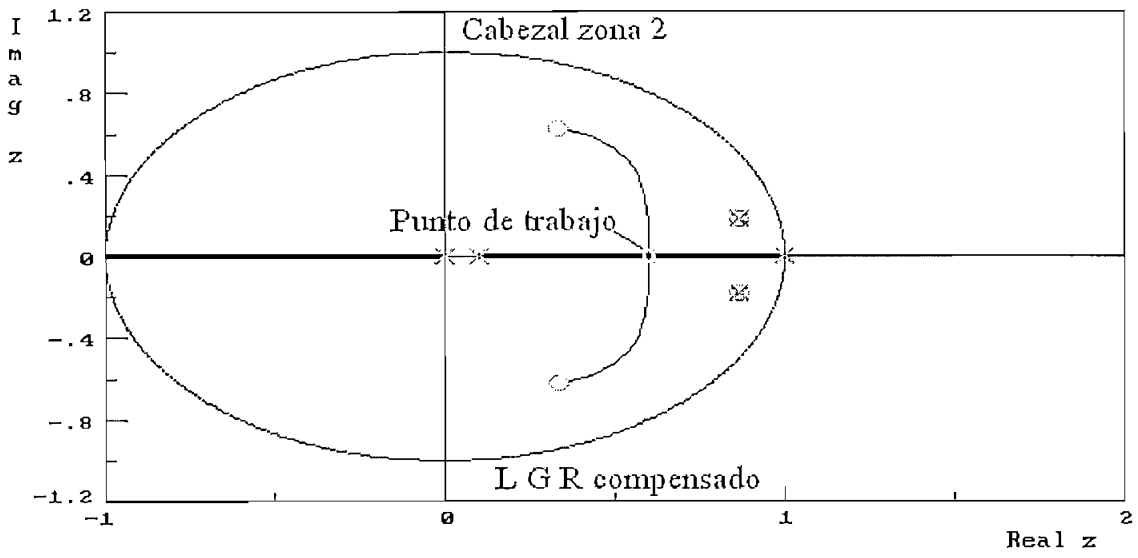


Figura B.4.5 Lugar geométrico de las raíces para el sistema compensado de la zona 2 del cabezal

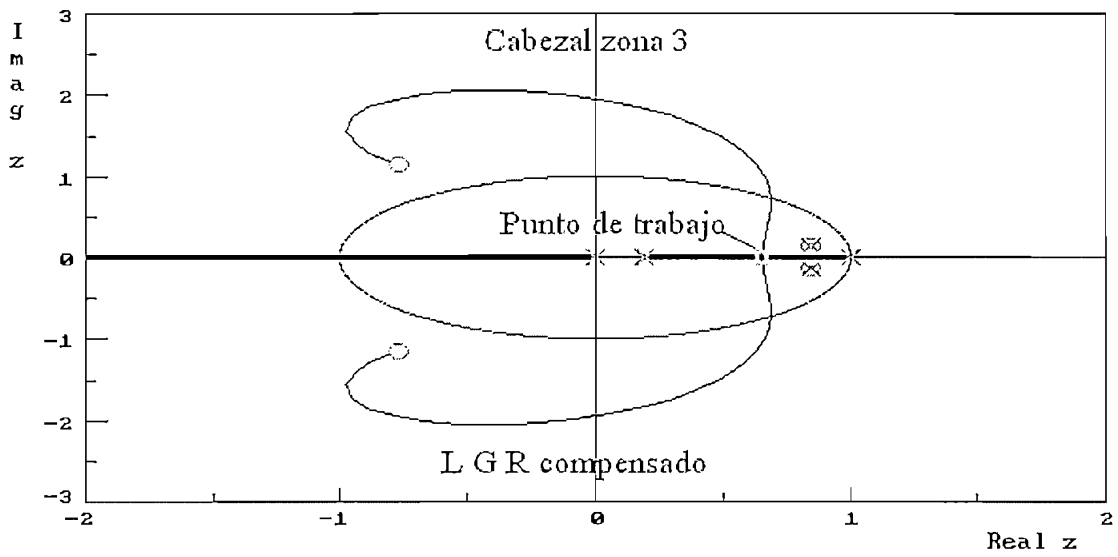


Figura B.4.6 Lugar geométrico de las raíces para el sistema compensado de la zona 3 del cabezal

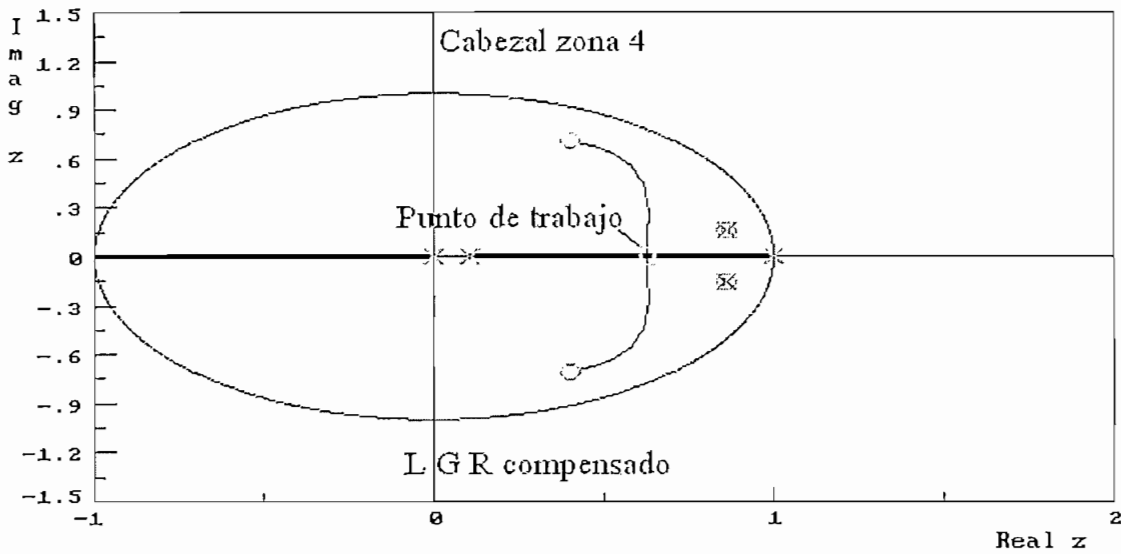


Figura B.4.7 Lugar geométrico de las raíces para el sistema compensado de la zona 4 del cabezal

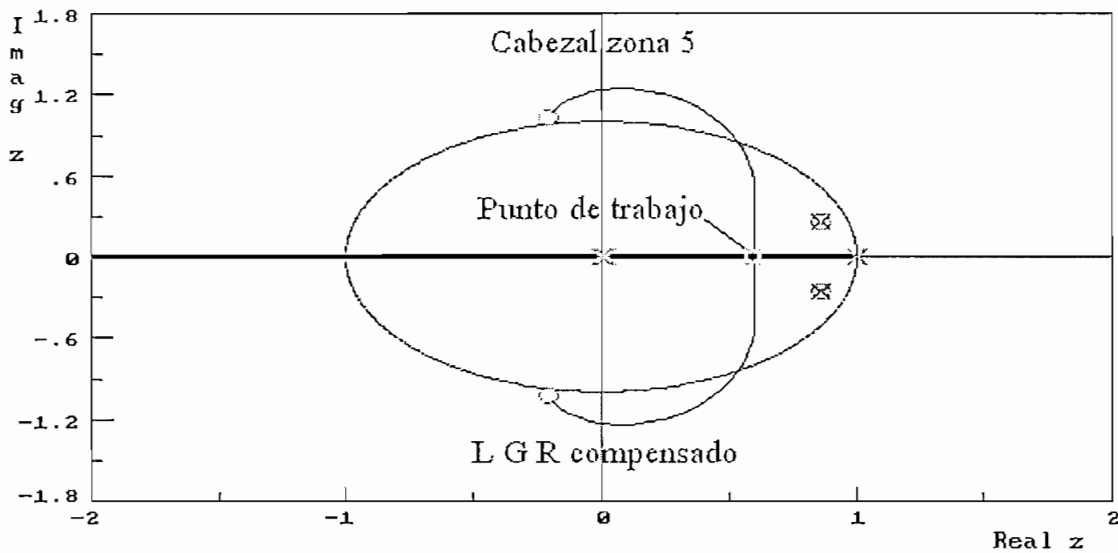


Figura B.4.8 Lugar geométrico de las raíces para el sistema compensado de la zona 5 del cabezal

Para determinar el valor de la constante K_1 se debe ubicar donde el índice de amortiguamiento es igual a uno del lugar geométrico de las raíces. Para obtener los valores de k_p , k_i , k_d se procede a resolver el sistema de ecuaciones (B4.4, B4.5, B4.6) y se obtiene los siguientes valores:

Zona de extrusión	Controlador PID
Túnel 2	$K_{\varepsilon=1} = 2,251$ $k_p = 1,56$; $k_i = 0,14$; $k_d = 3,98$
Túnel 3	$K_{\varepsilon=1} = 6,501$ $k_p = 3,11$; $k_i = 1,08$; $k_d = 12,59$
Túnel 4	$K_{\varepsilon=1} = 2,216$ $k_p = 0,76$; $k_i = 0,25$; $k_d = 4,64$
Cabezal 1	$K_{\varepsilon=1} = 8,889$ $k_p = 4,11$; $k_i = 1,18$; $k_d = 17,51$
Cabezal 2	$K_{\varepsilon=1} = 14,09$ $k_p = 6,58$; $k_i = 1,81$; $k_d = 27,72$
Cabezal 3	$K_{\varepsilon=1} = 8,731$ $k_p = 5,25$; $k_i = 0,92$; $k_d = 16,11$
Cabezal 4	$K_{\varepsilon=1} = 11,54$ $k_p = 6,13$; $k_i = 1,33$; $k_d = 22,048$
Cabezal 5	$K_{\varepsilon=1} = 5,288$ $k_p = 2,06$; $k_i = 1,13$; $k_d = 10,58$

Tabla B.4.2 Constantes del controlador digital para la máquina extrusora

Las figuras siguientes muestran las respuestas discretas del sistema compensado mediante el lugar geométrico de las raíces.

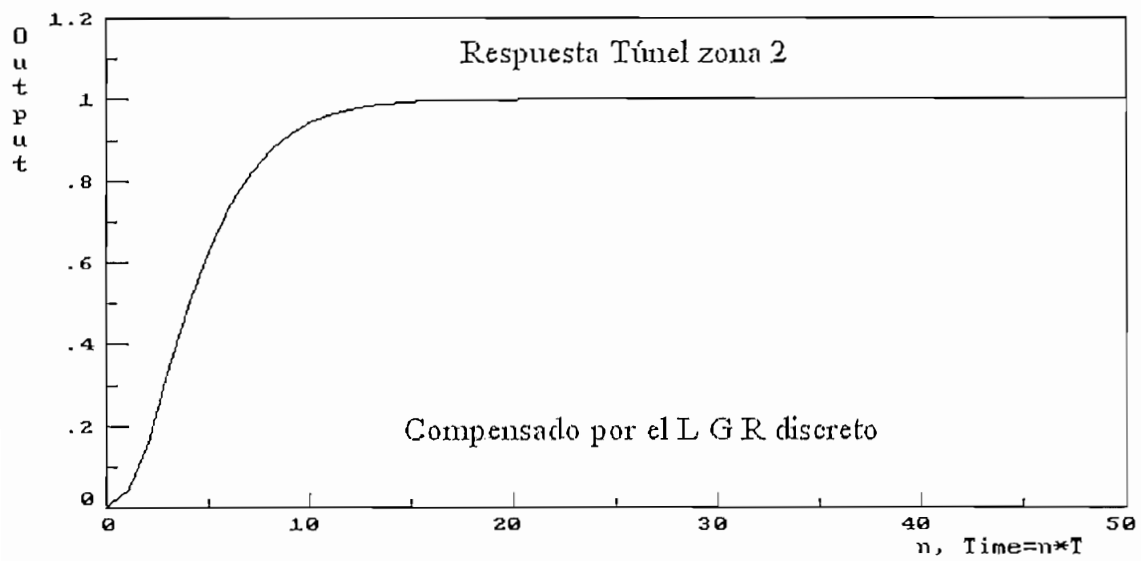


Figura B.4.9 Respuesta en el tiempo del lazo cerrado con control PID de la zona 2 del túnel

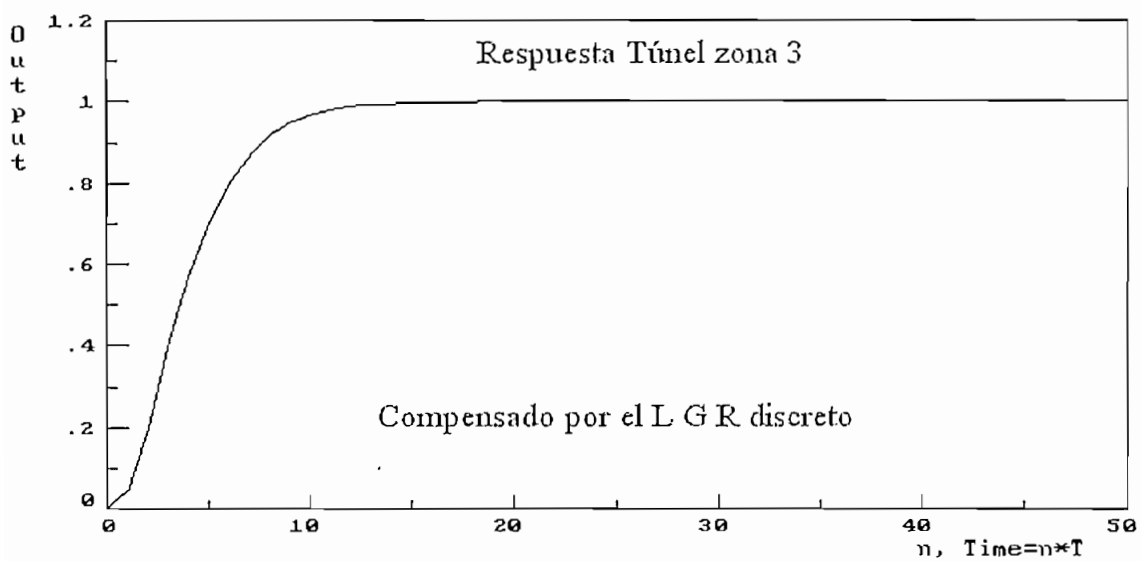


Figura B.4.10 Respuesta en el tiempo del lazo cerrado con control PID de la zona 3 del túnel

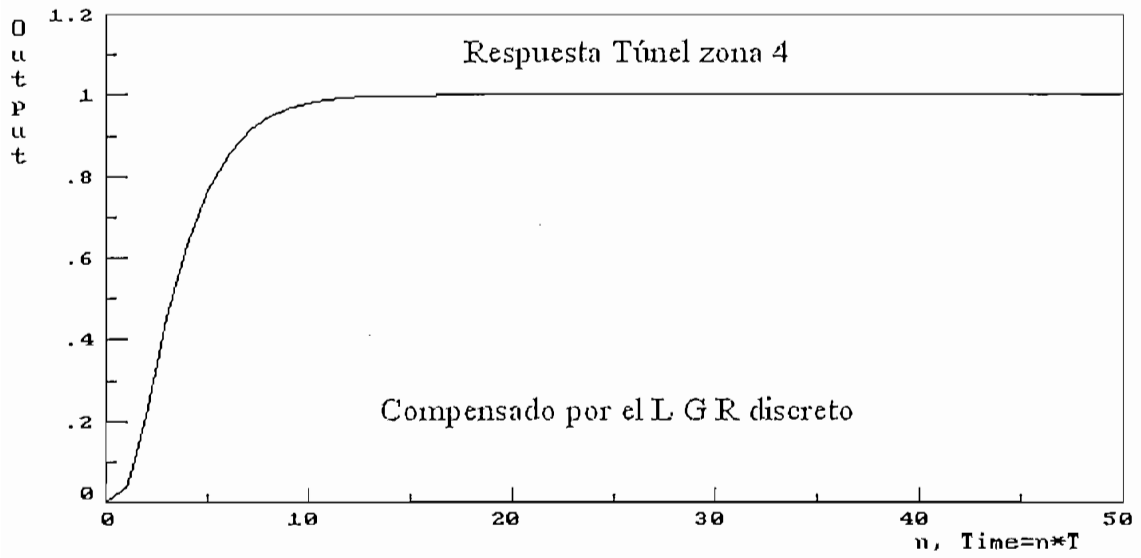


Figura B.4.11 Respuesta en el tiempo del lazo cerrado con control PID de la zona 4 del túnel

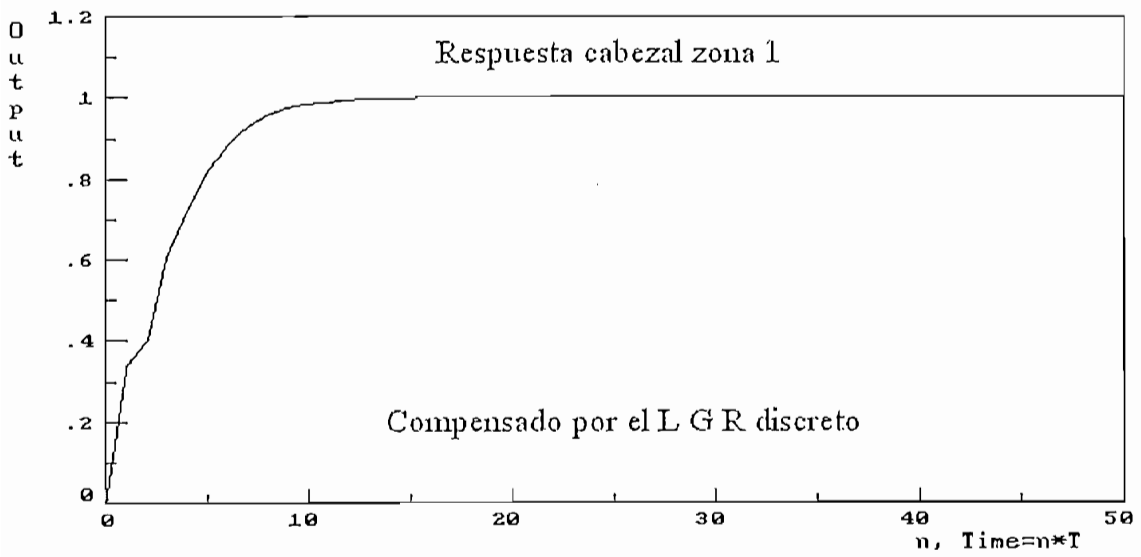


Figura B.4.12 Respuesta en el tiempo del lazo cerrado con control PID de la zona 1 del cabezal

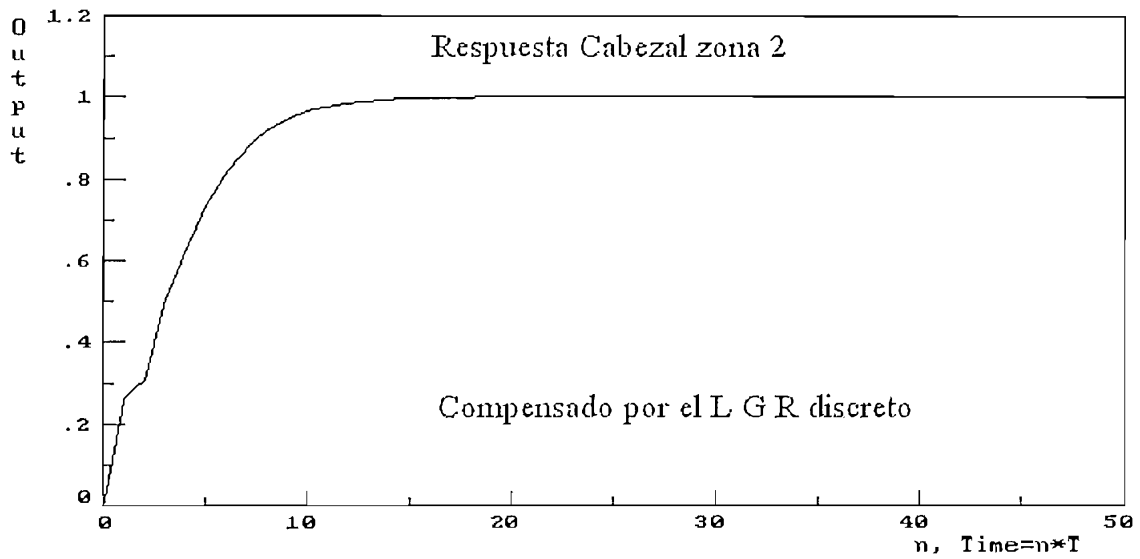


Figura B.4.13 Respuesta en el tiempo del lazo cerrado con control PID de la zona 2 del cabezal

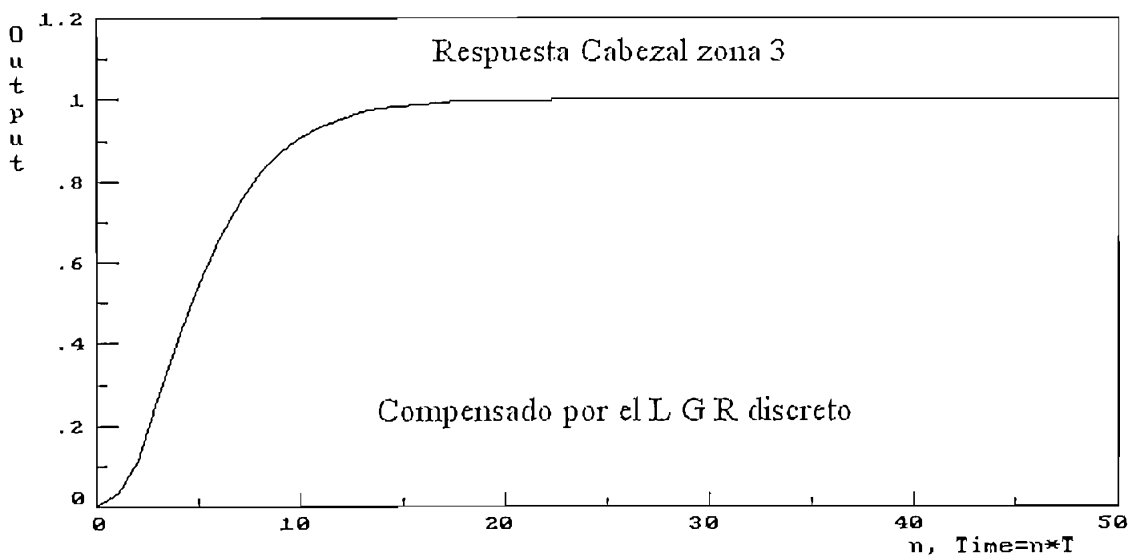


Figura B.4.14 Respuesta en el tiempo del lazo cerrado con control PID de la zona 3 del cabezal

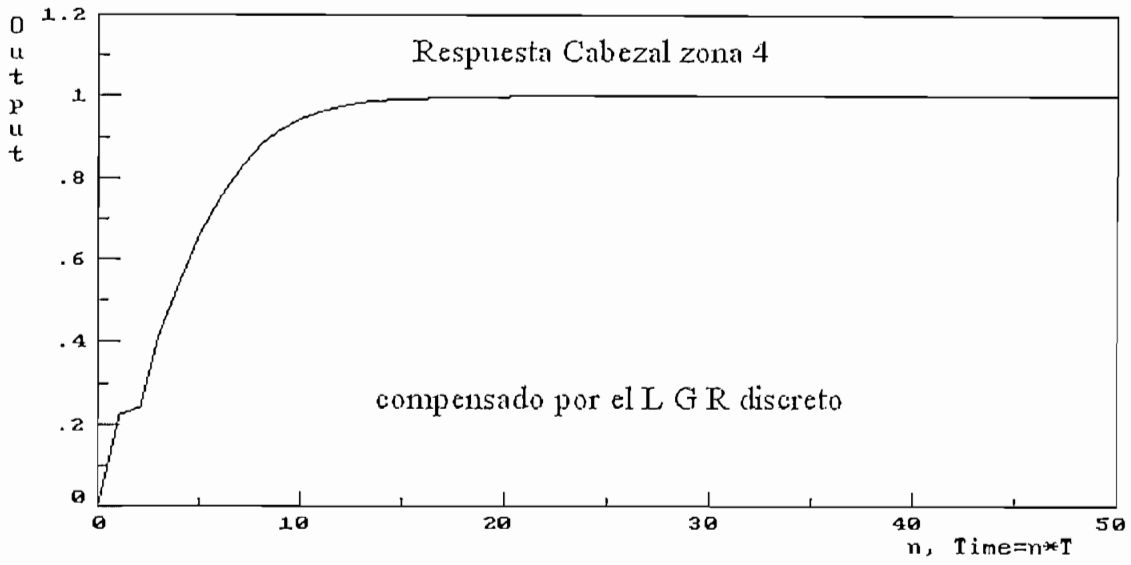


Figura B.4.15 Respuesta en el tiempo del lazo cerrado con control PID de la zona 4 del cabezal

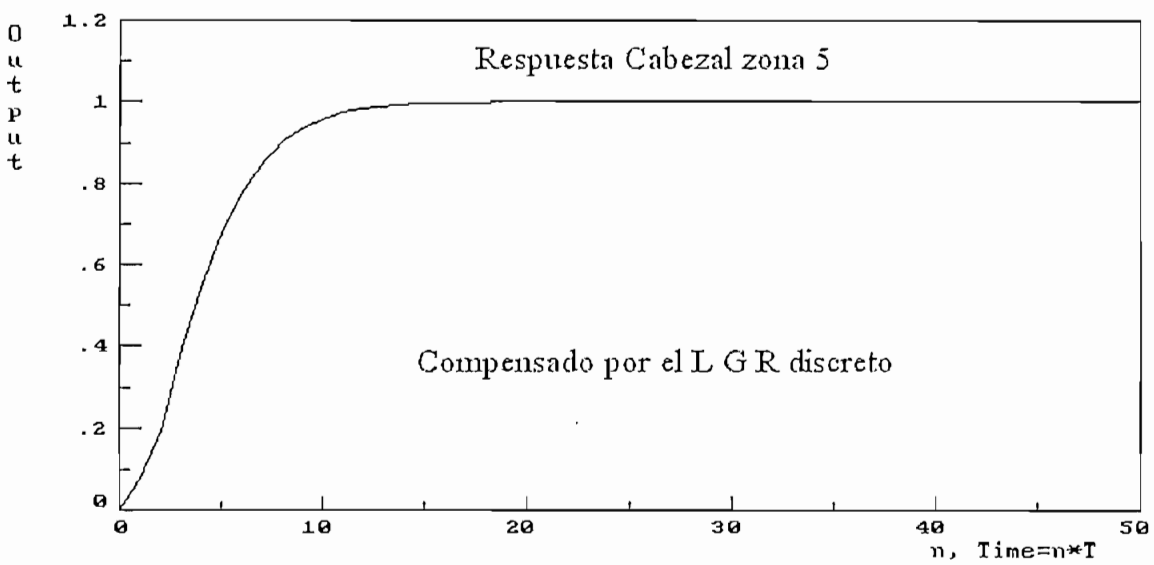


Figura B.4.16 Respuesta en el tiempo del lazo cerrado con control PID de la zona 5 del cabezal

De las figuras anteriores, se ve que presentan una respuesta en lazo cerrado del sistema compensado con G_{PID} a una entrada escalón, obteniéndose los datos listados a continuación:

Zona extrusora	k_p	k_i	k_d	M_p (%)	t_s (min)	E_p
T Z 1	1,63	0,43	5,42	0	10,18	0

B.5.- Diseño de la compensación por medio de un método de calibración.

Método de Ziegler-Nichols.

Los resultados sugeridos por Ziegler-Nichols se resumen en la tabla B.5.1

Tipo de control	Constante proporcional k_p	Tiempo integral T_I	Tiempo derivativo T_D
P	$0,5 * k_{cr}$	∞	0
PI	$0,45 * k_{cr}$	$\tau_o / 1,2$	0
PID	$0,6 * k_{cr}$	$0,5 * \tau_o$	$0,125 * \tau_o$

Tabla B.5.1 Valores de ajuste de los controladores P, PI, PID basadas en la ganancia crítica k_{cr} y el periodo crítico τ_o

B.5.1- Diseño del control Proporcional Integral Derivativo, PID

Para la compensación de la máquina extrusora, se utilizará el esquema clásico del controlador PID, cuya función de transferencia es:

$$C(s) = k_p \left(1 + \frac{1}{s.T_I} + s.T_D \right) \quad (B.5.1)$$

Donde: $k_p = k_p$

$$k_i = k_p / T_I$$

$$k_d = k_p * T_D$$

Al aplicar el método de Ziegler-Nichols, en la simulación de las zonas de la extrusora se tiene la figuras siguientes:

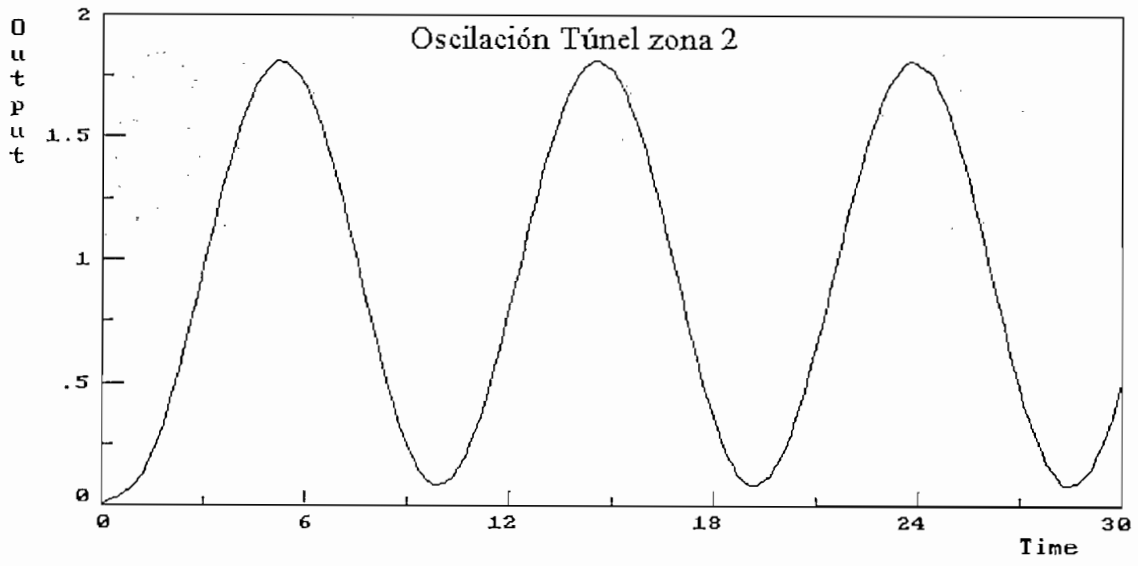


Figura B.5.1 Respuesta oscilatoria de la zona 2 del túnel en lazo cerrado cuando la ganancia K_p es crítica

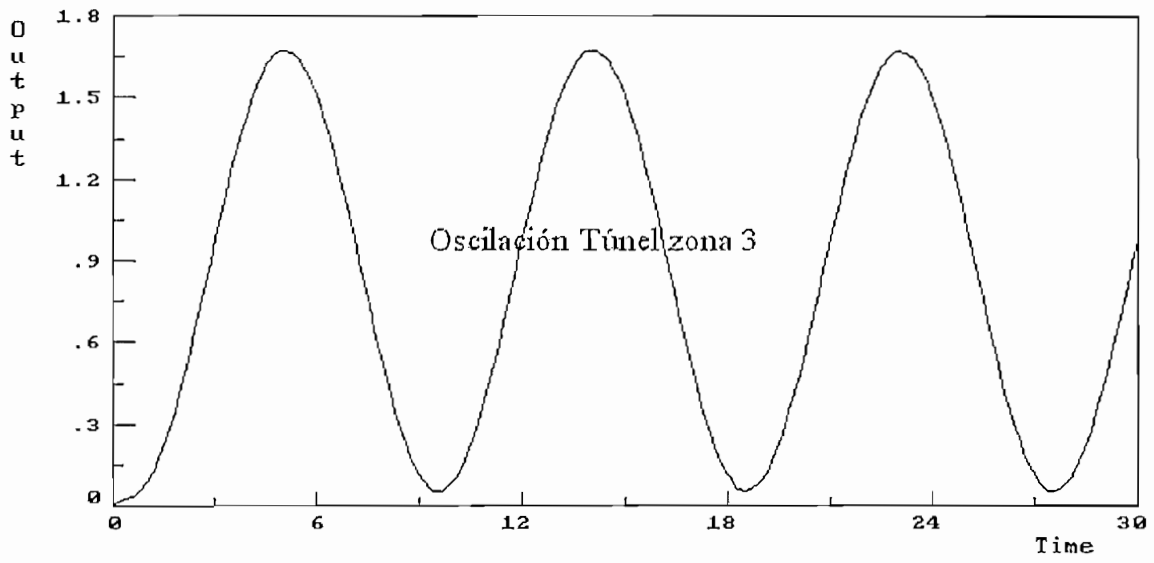


Figura B.5.2 Respuesta oscilatoria de la zona 3 del túnel en lazo cerrado cuando la ganancia K_p es crítica

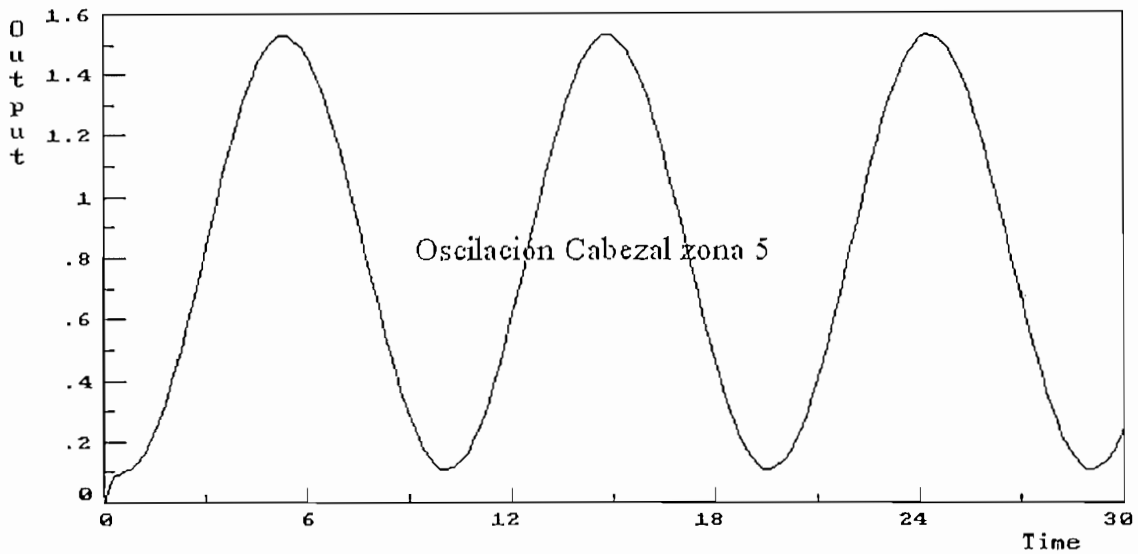


Figura B.5.5 Respuesta oscilatoria de la zona 5 del cabezal en lazo cerrado cuando la ganancia K_p es crítica

De las figuras B.5.1 a B.5.5 se obtiene el período de oscilación natural, τ_o en minutos, para encontrar los parámetros se utiliza la ganancia crítica k_{cr} de la tabla B.5.2

ZONA	K_{cr}	τ_o
TUNEL 2	13,40	9,3
TUNEL 3	31,82	9
TUNEL 4	19,35	10
CABEZAL 1		
CABEZAL 2		
CABEZAL 3	40,172	11
CABEZAL 4		
CABEZAL 5	24,15	9,5

Tabla B.5.2 Rango de ganancia según el LGR de las zonas de la máquina extrusora

Luego se aplica los valores de la tabla B.5.2 para ajustar los parámetros del controlador PID, y, reemplazando estos valores de los parámetros, en la expresión B.5.1, se obtiene el algoritmo del controlador PID clásico, así:

Zona de extrusión	Compensador
Túnel 2	$G_{C_{TZ2}} = 8,04 \left(1 + \frac{1}{4,64 s} + 1,16 s \right)$
Túnel 3	$G_{C_{TZ3}} = 19,10 \left(1 + \frac{1}{4,5 s} + 1,12 s \right)$

Túnel 4	$G_{C_{TZ4}} = 4,64 \left(1 + \frac{1}{5 s} + 1,25 s \right)$
Cabezal 3	$G_{C_{CZ3}} = 24,10 \left(1 + \frac{1}{5,5 s} + 1,37 s \right)$
Cabezal 5	$G_{C_{CZ5}} = 14,49 \left(1 + \frac{1}{4,75 s} + 1,18 s \right)$

Tabla B.5.3 Compensadores PID para las funciones de transferencia de la máquina extrusora

Despejando los valores de las constantes del controlador se tiene:

Zona de extrusión	Controlador PID
Túnel 2	$k_p = 8,04$; $k_i = 1,73$; $k_d = 9,32$
Túnel 3	$k_p = 19,10$; $k_i = 4,19$; $k_d = 21,49$
Túnel 4	$k_p = 4,64$; $k_i = 0,928$; $k_d = 5,8$
Cabezal 3	$k_p = 24,10$; $k_i = 4,38$; $k_d = 33,01$
Cabezal 5	$k_p = 14,49$; $k_i = 3,05$; $k_d = 17,20$

Tabla B.5.4 Constantes del controlador digital para la máquina extrusora

Las respuestas del sistema en lazo cerrado al ser perturbado por un cambio paso del set point, utilizando las ecuaciones de la tabla B.5.3 como función de compensación, se presenta a continuación.

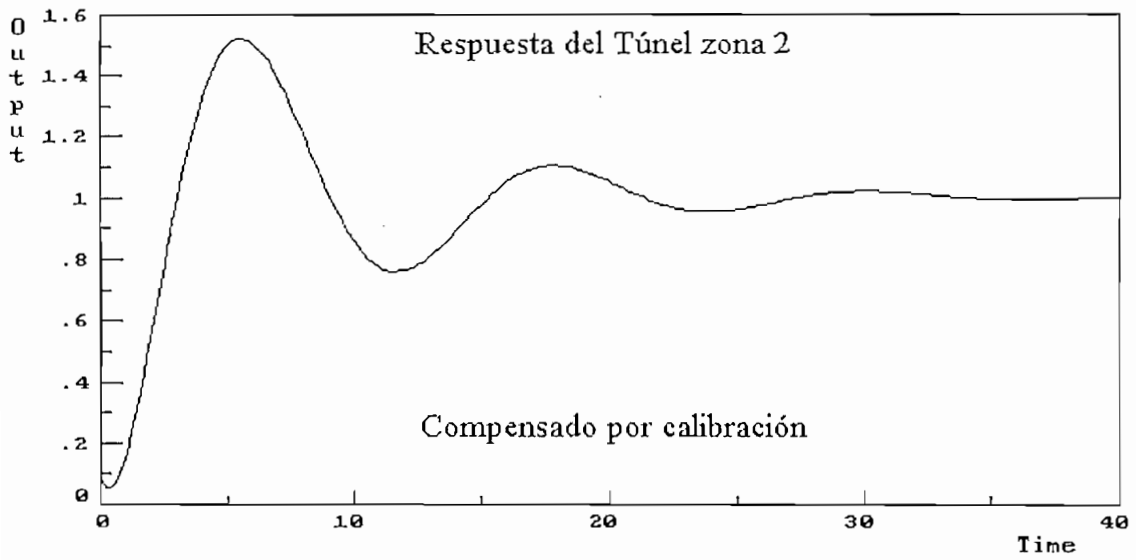


Figura B.5.6 Respuesta en lazo cerrado de la zona 2 del túnel de la extrusora, utilizando un control PID

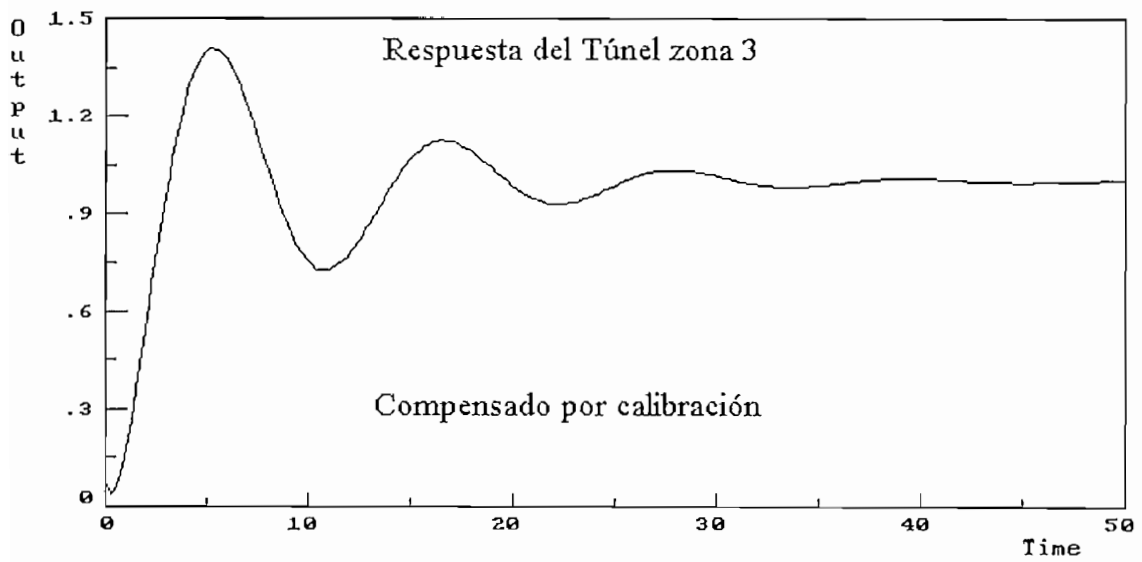


Figura B.5.7 Respuesta en lazo cerrado de la zona 3 del túnel de la extrusora, utilizando un control PID

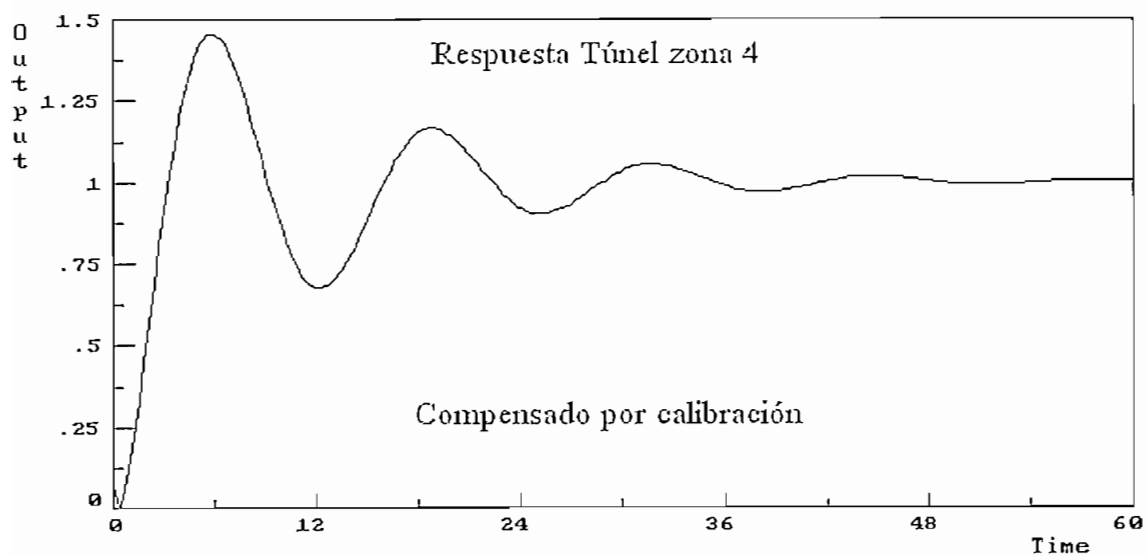


Figura B.5.8 Respuesta en lazo cerrado de la zona 4 del túnel de la extrusora, utilizando un control PID

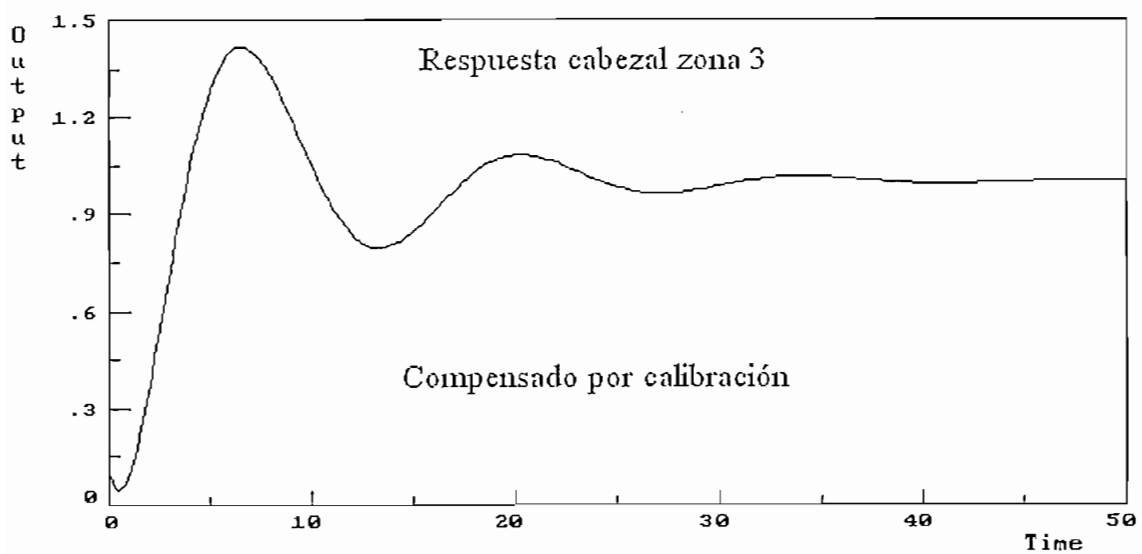


Figura B.5.9 Respuesta en lazo cerrado de la zona 3 del cabezal de la extrusora, utilizando un control PID

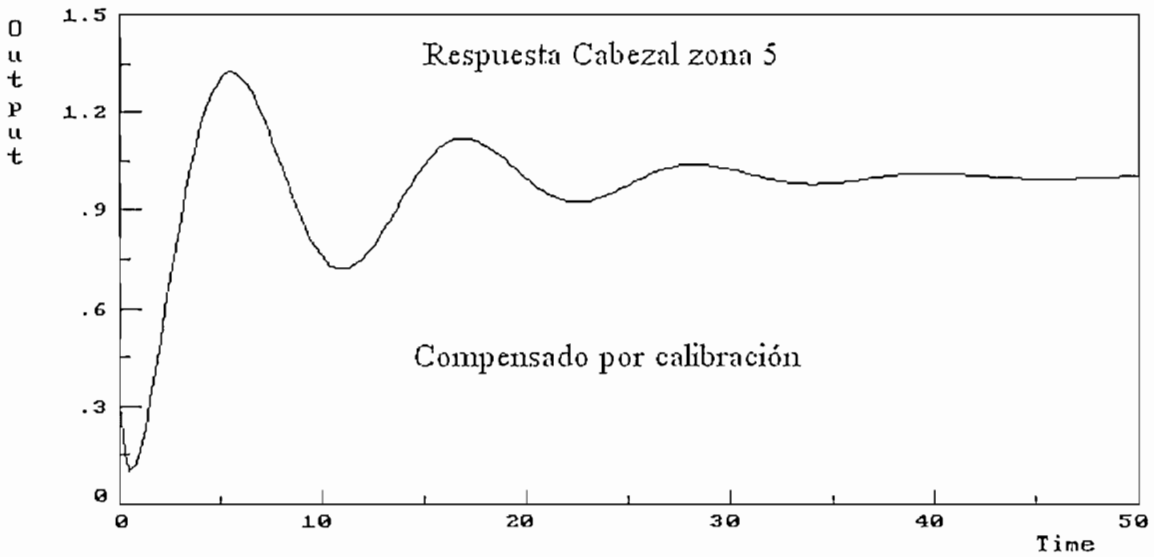


Figura B.5.10 Respuesta en lazo cerrado de la zona 5 del cabezal de la extrusora, utilizando un control PID

De las figuras B.5.6 a B.5.10 se observa las características de funcionamiento en estado transitorio y se tiene:

Zona extrusora	k_p	k_i	k_d	M_p (%)	t_s (min)	E_p
T Z 1	9,22	1,94	10,9	42,6	24,36	0
T Z 2	8,04	1,73	9,32	52,1	20,07	0
T Z 3	19,1	4,19	21,4	40,9	23,79	0
T Z 4	4,64	0,92	5,8	45,4	32,65	0
C Z 3	24,1	4,38	33,0	41,5	22,31	0
C Z 5	14,4	3,05	17,2	32,5	24,16	0

Tabla 4.4 Valores de constantes del PID y características obtenidas de las zonas de extrusión

B.5.2- Diseño del control Proporcional Integral Derivativo, PID discreto

Se utiliza el esquema clásico del controlador PID, cuya función de transferencia es:

$$C(s) = k_p \left(1 + \frac{1}{s.T_I} + s.T_D \right)$$

Discretizando la ecuación B.5.1 se obtiene:

$$G_{PID(z)} = k_p \left(1 + \frac{T}{2T_I} \frac{z+1}{z-1} + T_D \frac{z-1}{Tz} \right) \quad (\text{B.5.2})$$

Donde: $k_p = k_p$

$$k_i = k_p / T_I$$

$$k_d = k_p * T_D$$

Al aplicar el método de Ziegler-Nichols, en las zonas de la extrusora se tiene:

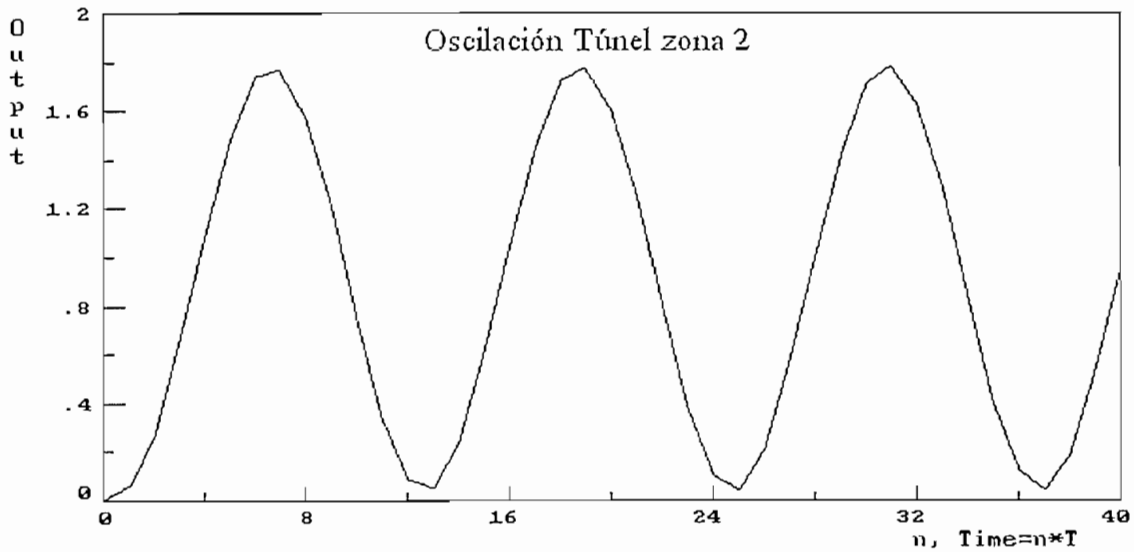


Figura B.5.11 Respuesta oscilatoria de la zona 2 del túnel en lazo cerrado cuando la ganancia K_p es crítica

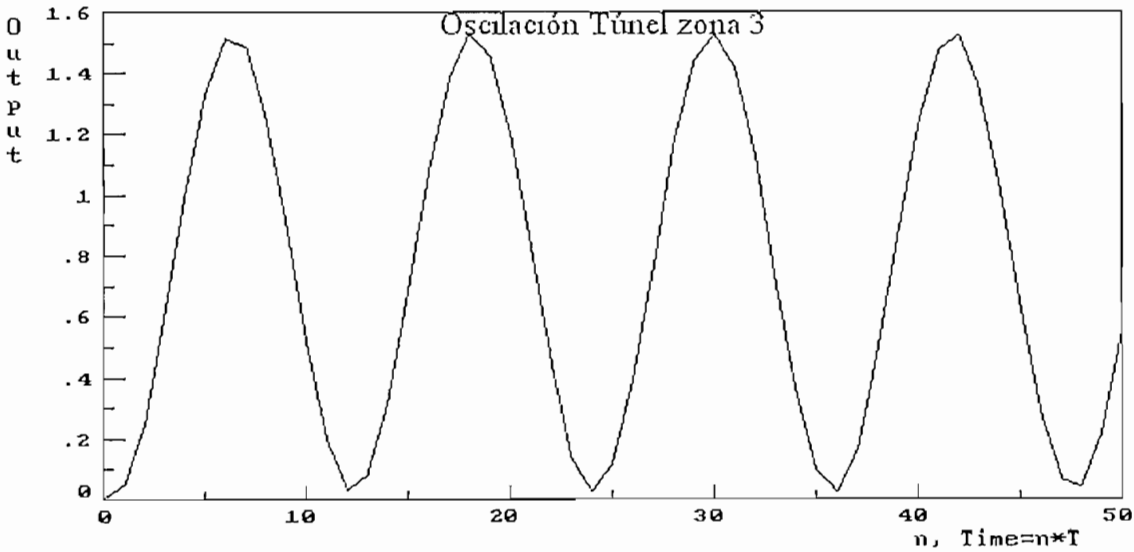


Figura B.5.12 Respuesta oscilatoria de la zona 3 del túnel en lazo cerrado cuando la ganancia K_p es crítica

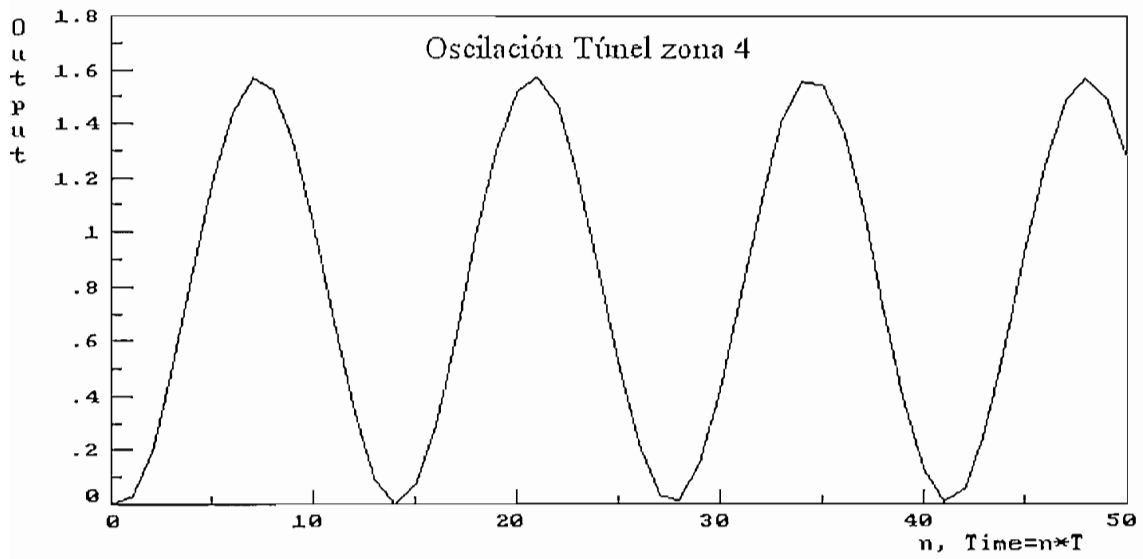


Figura B.5.13 Respuesta oscilatoria de la zona 4 del túnel en lazo cerrado cuando la ganancia K_p es critica

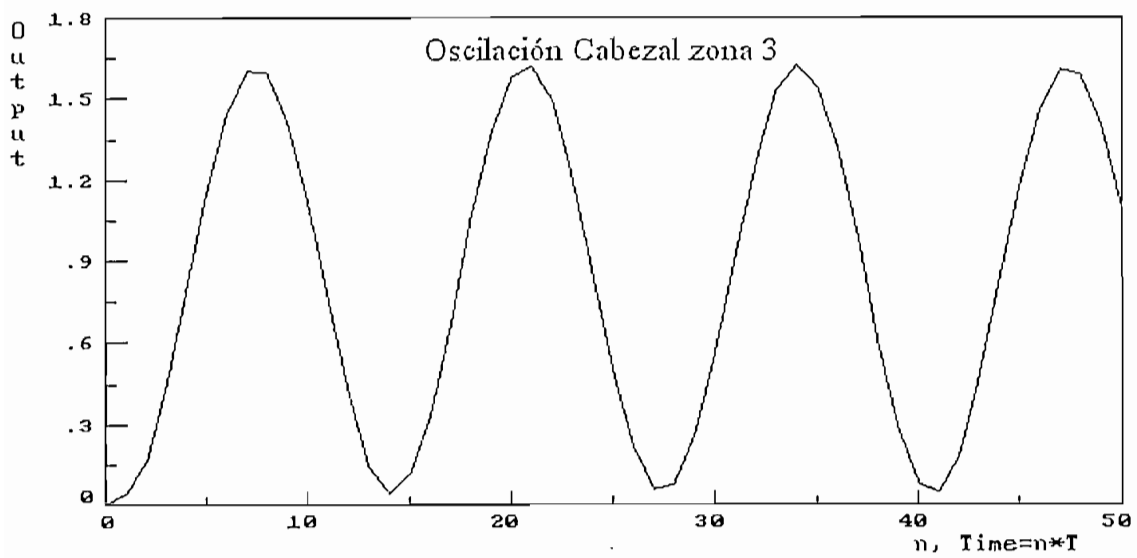


Figura B.5.14 Respuesta oscilatoria de la zona 3 del cabezal en lazo cerrado cuando la ganancia K_p es critica

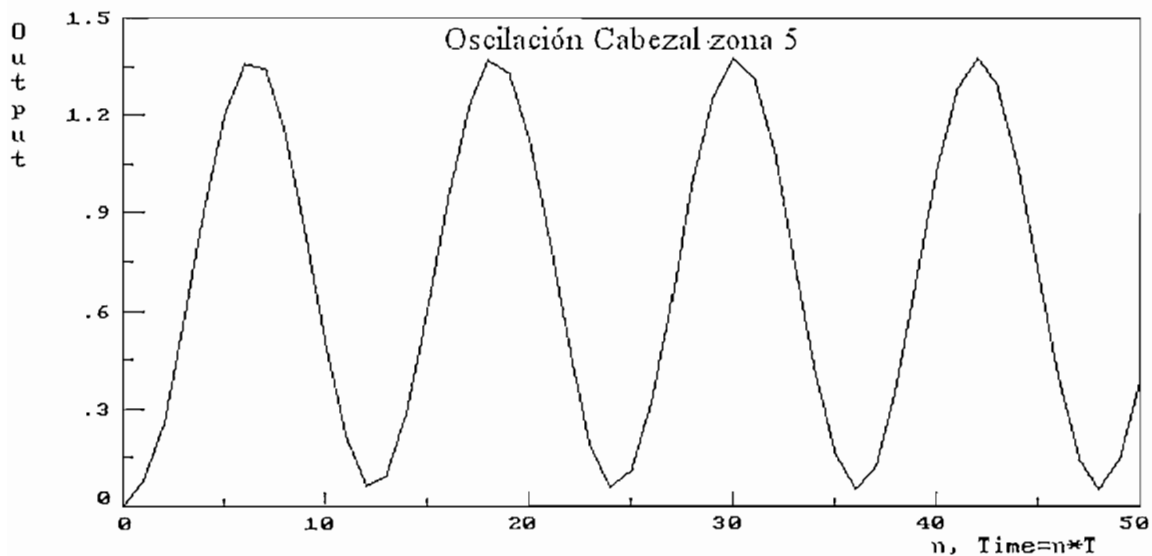


Figura B.5.15 Respuesta oscilatoria de la zona 5 del cabezal en lazo cerrado cuando la ganancia K_p es crítica

De las figuras B.5.11 a B.5.15 se obtiene el período de oscilación natural, τ_0 en minutos, para encontrar los parámetros se despeja la ganancia crítica k_{cr} .

ZONA	K_{cr}	τ_0
TUNEL 2	9,1	12
TUNEL 3	7,9	12
TUNEL 4	17,32	13
CABEZAL 1		
CABEZAL 2		
CABEZAL 3	26,65	13
CABEZAL 4		
CABEZAL 5	13,5	12

Tabla B.5.5 Rango de ganancia según el LGR de las zonas de la máquina extrusora

Luego se aplica los valores de la tabla B.5.1 para ajustar los parámetros del controlador PID, y, reemplazando estos valores de los parámetros, en la expresión B.5.2, se obtiene el algoritmo del controlador PID clásico, así se obtiene los siguientes resultados:

Zona de extrusión	Compensador
Túnel 2	$G_{c_{T22}} = 4,75 \left(1 + \frac{T}{2 * 6} \frac{z+1}{z-1} + 1,5 \frac{z-1}{T z} \right)$
Túnel 3	$G_{c_{T23}} = 10,39 \left(1 + \frac{T}{2 * 6} \frac{z+1}{z-1} + 1,5 \frac{z-1}{T z} \right)$
Túnel 4	$G_{c_{T24}} = 2,37 \left(1 + \frac{T}{2 * 6,5} \frac{z+1}{z-1} + 1,62 \frac{z-1}{T z} \right)$
Cabezal 3	$G_{c_{C23}} = 16 \left(1 + \frac{T}{2 * 6,5} \frac{z+1}{z-1} + 1,62 \frac{z-1}{T z} \right)$
Cabezal 5	$G_{c_{C25}} = 8,10 \left(1 + \frac{T}{2 * 6} \frac{z+1}{z-1} + 1,5 \frac{z-1}{T z} \right)$

Tabla B.5.6 Compensadores PID para las funciones de transferencia de la máquina extrusora

Despejando los valores de las constantes del controlador y asumiendo un valor del periodo de muestreo de 1, se tiene:

Zona de extrusión	Controlador PID
Túnel 2	$k_p = 4,75$; $k_i = 0,79$; $k_d = 7,12$
Túnel 3	$k_p = 10,39$; $k_i = 1,73$; $k_d = 15,59$
Túnel 4	$k_p = 2,37$; $k_i = 0,36$; $k_d = 3,85$
Cabezal 3	$k_p = 16$; $k_i = 2,46$; $k_d = 26$
Cabezal 5	$k_p = 8,10$; $k_i = 1,35$; $k_d = 12,15$

Tabla B.5.4 Constantes del controlador digital para la máquina extrusora

La respuesta del sistema en lazo cerrado al ser perturbado por un cambio paso del setpoint, utilizando las ecuaciones de la tabla B.5.4 como función de compensación, se presentan en las figuras B.5.16 a B.5.20 siguientes.

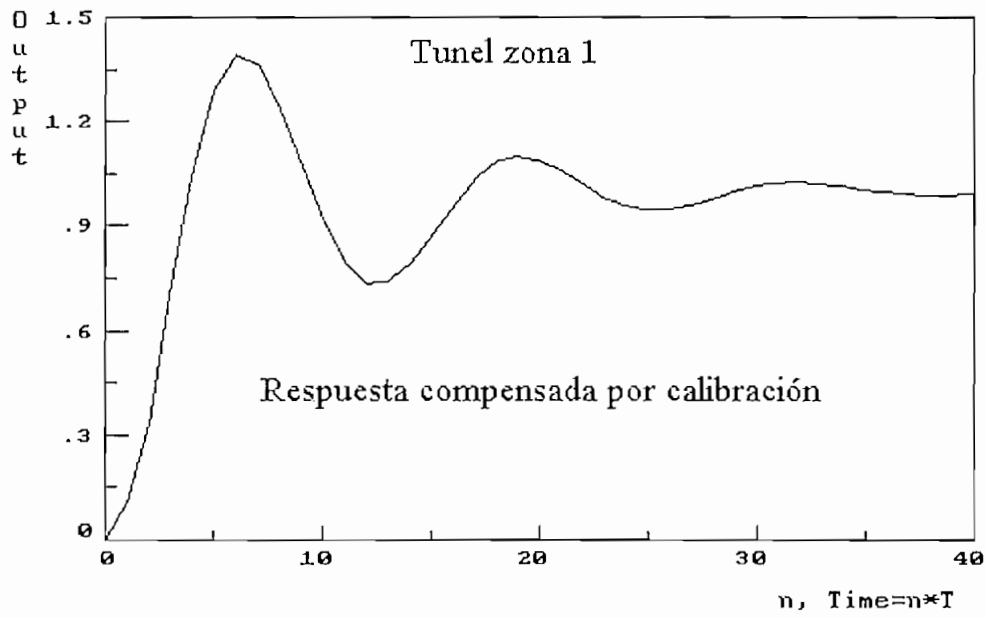


Figura B.5.16 Respuesta en lazo cerrado de la zona 2 del túnel de la extrusora, utilizando un control PID

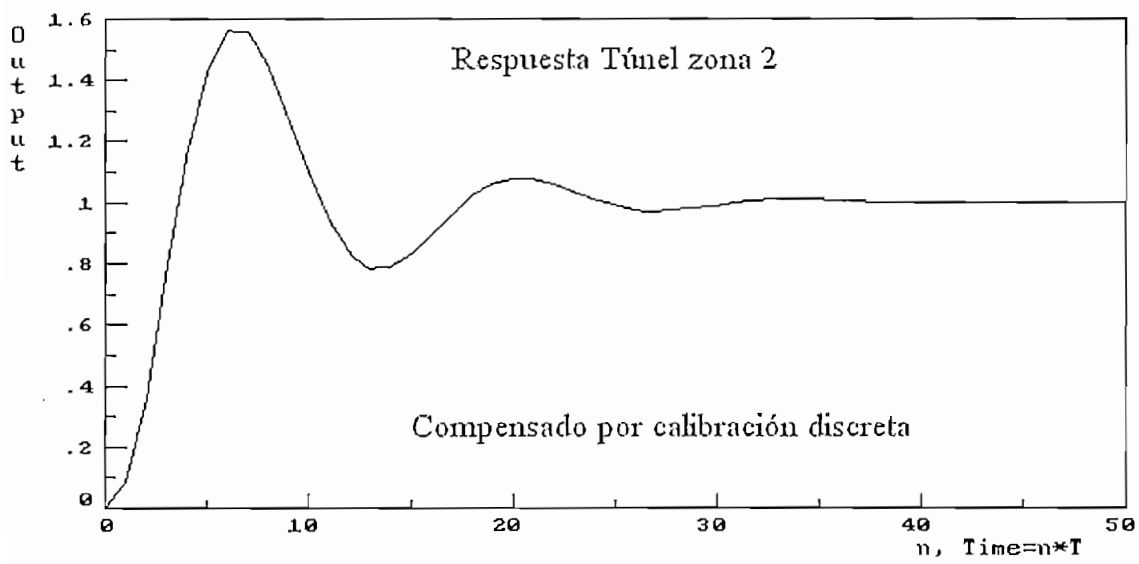


Figura B.5.17 Respuesta en lazo cerrado de la zona 3 del túnel de la extrusora, utilizando un control PID

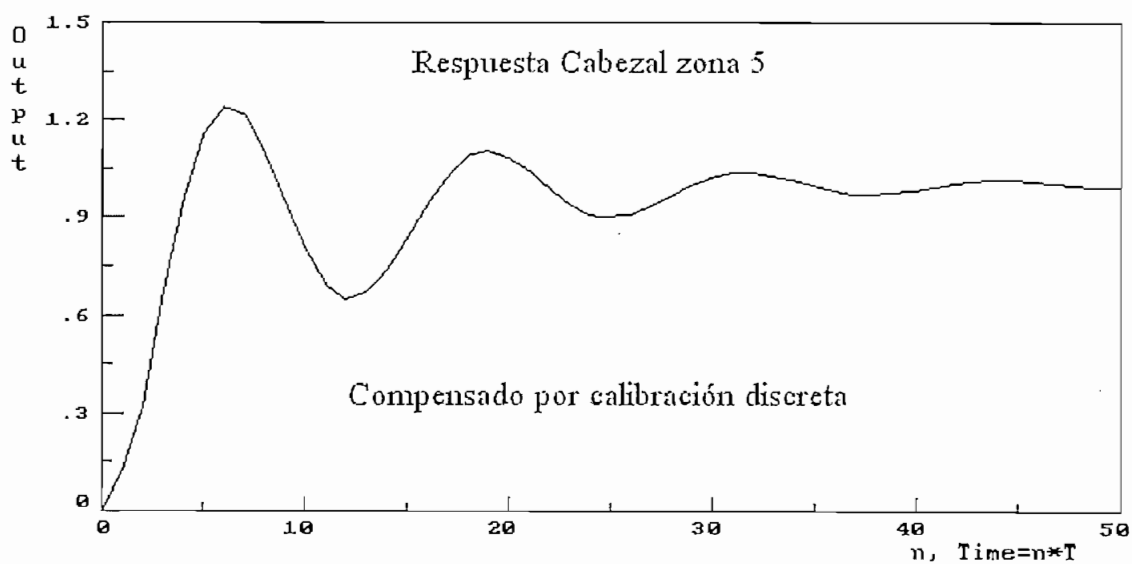


Figura B.5.20 Respuesta en lazo cerrado de la zona 5 del cabezal de la extrusora, utilizando un control PID

De las figuras B.5.16 a B.5.20 se observa las características de funcionamiento en estado transitorio y estable y se tiene:

Zona extrusora	k_p	k_i	k_d	M_p (%)	t_s (min)	E_p
TZ 1	5,46	0,91	8,19	38,720	26,72	0
TZ 2	4,75	0,79	7,12	55,8	22,3	0
TZ 3	10,39	1,73	15,59	35,34	26,85	0
TZ 4	2,37	0,36	3,85	39,85	33,24	0
CZ 3	16	2,46	26	43,8	24,25	0
CZ 5	8,10	1,35	12,15	24,06	27,5	0

Tabla 4.5 Valores de constantes del PID y características obtenidas de las zonas de extrusión

ANEXO C

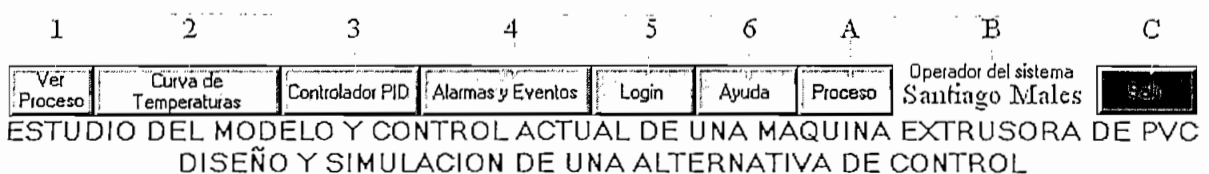


Figura. 1 VI Panel de control Simulación, modo Proceso

Este VI es el encargado de inicializar todo el controlador digital, tiene dos modos de operación, proceso y simulación, los mismo que pueden ser elegidos mediante el icono A de la figura 1. Cuando el icono esta activo en el modo *Proceso*, aparecen los iconos mostrados en la figura 1.

El funcionamiento de cada uno de estos iconos se describe a continuación:

Ver proceso, señalado con el numero 1, al ser este icono pulsado llama al VI *Presentación del*

Manual del usuario.

El software de monitoreo y control de esta tesis esta desarrollado en un ambiente Windows, que facilita la operación e interrelación entre el operador y el proceso de extrusión de pvc. Se describe el manejo de este software.

Software de control

El software de monitoreo y control empieza en un Instrumento virtual (VI) que se denomina *Panel de control Simulación*, el mismo que se ilustra en la figura 1.

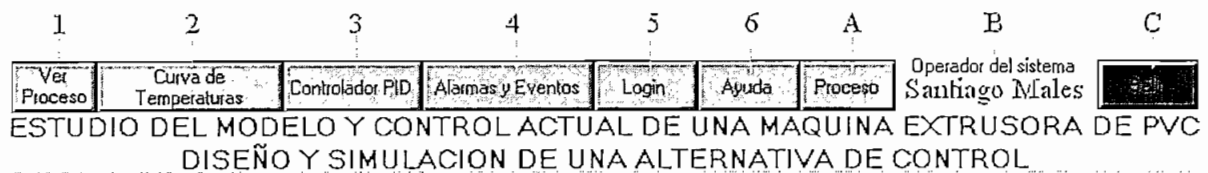


Figura. 1 VI Panel de control Simulación, modo Proceso

Este VI es el encargado de inicializar todo el controlador digital, tiene dos modos de operación, proceso y simulación, los mismo que pueden ser elegidos mediante el icono A de la figura 1. Cuando el icono esta activo en el modo *Proceso*, aparecen los iconos mostrados en la figura 1.

El funcionamiento de cada uno de estos iconos se describe a continuación:

Ver proceso, señalado con el numero 1, al ser este icono pulsado llama al VI *Presentación del proceso*, el cual muestra la pantalla que contiene la representación mímica de la máquina extrusora de pvc.

Curva de temperaturas, señalado con el número 2, al ser este icono pulsado llama al VI *Gráficas*, que muestra la curva de temperaturas del proceso de extrusión de pvc, el set point y la variable del proceso de la zona de trabajo elegida.

Controlador PID, señalado con el número 3, al ser este icono pulsado llama al VI *Controlador digital extrusor* que ilustra la pantalla del controlador digital donde se pueden setear todos los set point; parámetros k_p , k_i , k_d , limite; tipo de configuración y período de discretización del controlador digital; además se puede variar el error admisible el tipo de referencia del proceso de extrusión y el modo de trabajo sea este proceso real o simulación.

Este icono esta activo solo para usuarios autorizados.

Alarmas y eventos señalado con el número 4, al ser este icono pulsado llama al VI *Eventos extrusión* el cual despliega una pantalla de alarmas y eventos del proceso de extrusión en tiempo real

Login señalado con el número 5, al ser este icono pulsado llama una sub pantalla propia del software Bridge VIEW en la cual puede ingresar el nombre del operador y su clave de accesos, la misma que es proporcionada por el administrador del programa.

Ayuda, llama a una rutina de ayuda acerca del software.

Operador del sistema indica la persona que está operando el sistema previamente ingresado mediante el icono de Login, siempre y cuando tenga los accesos concedidos por el administrador del sistema.

Salir permite salir del programa siempre y cuando sea un usuario autorizado para ejecutar dicho icono, caso contrario no realizará ninguna acción en el programa.

Cuando el icono A esta activo en el modo *Simulación*, se tiene la pantalla mostrada en la figura 2



Figura 2 Opción del panel de control en modo simulación

El funcionamiento de los iconos mostrados en la figura 2 se los describe a continuación:

Respuesta del proceso, al ser ejecutado este icono llama al VI "*Función en el tiempo*", la misma que muestra en una pantalla las opciones para realizar un análisis de las funciones de transferencia de la máquina extrusora de pvc, ver la respuesta en el tiempo de la zona de extrusión al ir variando los parámetros, configuración y periodo de discretización del controlador digital.

De la misma forma permite ver la ubicación de los polos y ceros de la zona compensada.

Al ejecutarse el VI *Panel de control simulación* aparece la representación gráfica del proceso, y, sobre esta pantalla se muestran por defecto al activarse este VI, dos sub pantallas, las mismas que

son, “*Alarmas del proceso*” y “*logo*”, las cuales que siempre están activas y no se interponen a la presentación de otras ventanas cuando se esta ejecutando el programa.

A continuación se describe cada uno de los VI que integran este trabajo.

Alarmas del Proceso

Este VI esta siempre activo desde que se inicia el programa, la razón se debe a que como su nombre lo indica se trata de una pantalla que indica las alarmas que ocurren durante el proceso, pues en la práctica cuando se opera cualquier sistema de control, el operador siempre debe disponer de las alarmas, para evitar cualquier contrariedad al proceso normal de trabajo. La gráfica 5.10 ilustra la pantalla de presentación.

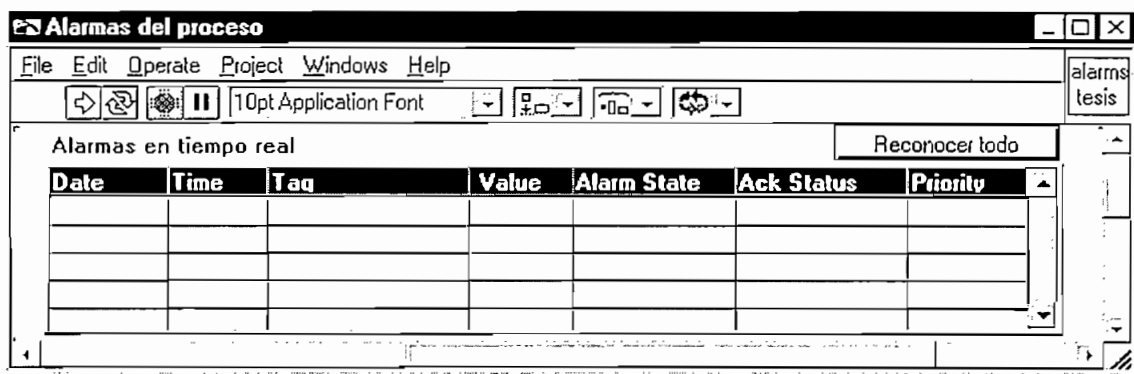


Figura 3 Gráfica de Alarmas del proceso

La pantalla mostrada en la figura 3 esta compuesta por dos elementos, una tabla donde se despliegan las alarmas en tiempo real y el icono *Reconocer todo* que permite reconocer las alarmas mostradas en la misma.

Logo

Este VI aparece siempre en la esquina superior derecha y muestra los mímicos que ilustran los sellos de la facultad de Ingeniería Eléctrica y La Escuela Politécnica Nacional respectivamente. También ilustra la información acerca del director y el autor de este trabajo.



Figura 4 Logo.vi

Presentación del proceso

Esta pantalla muestra los mímicos relativos a la máquina extrusora de PVC, y van a ayudar a la comprensión del proceso, la figura 5 muestra la pantalla de este VI:

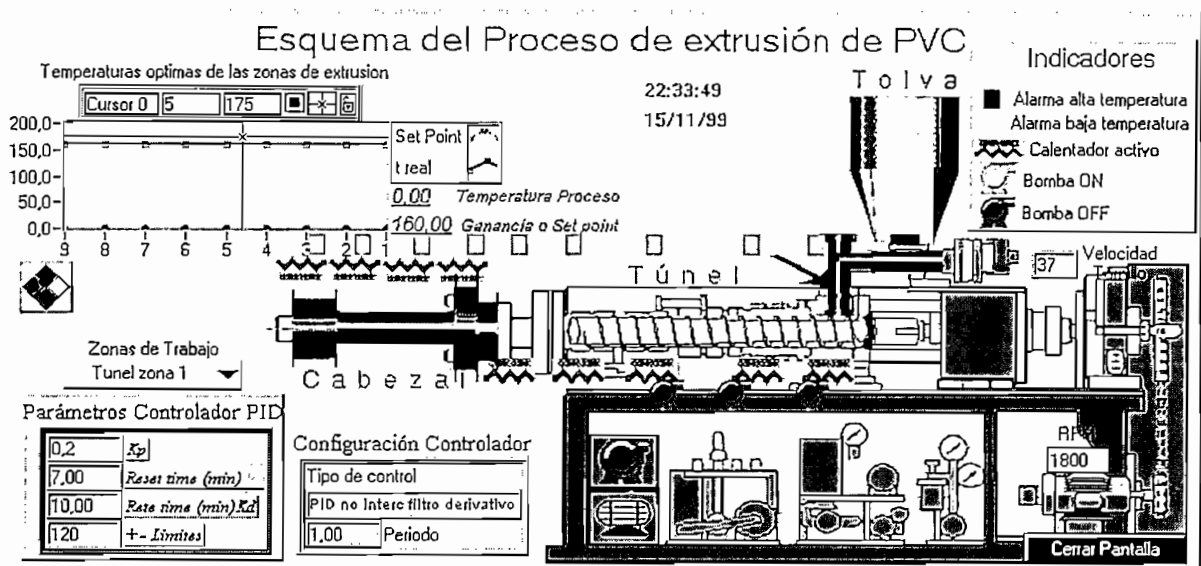


Figura. 5 Pantalla del VI Presentación del proceso

A continuación se describe cada uno de los componentes de esta pantalla

- *Temperaturas óptimas de las zonas de extrusión*, ubicado en la esquina superior izquierda muestra como varía el *Set point* y la *t real* (temperatura real) de las zonas de la extrusora; esto permite ilustrar de forma comprensible como varía la curva de temperaturas del proceso. Ubicando el cursor sobre cualquier punto de la curva, se van a leer los parámetros indicados.

- *Velocidad del tornillo*, este icono permite variar la velocidad del tornillo
- * *Control*, este icono permite comandar el encendido y apagado de la máquina extrusora desde el panel de operación
- * *Indicadores*, describe el significado de los iconos, el estado ON OFF cuando cambian de color

* Se añaden algunos gráficos adicionales para ilustrar el proceso

Gráficas

Este VI muestra de manera detallada la curva de temperaturas del proceso de extrusión, y cómo varia en tiempo real la *temperatura del proceso* y el *Set point* (figura 7). Tiene dos subpantallas, la una muestra, la curva de la temperatura del proceso de extrusión; y la otra el comportamiento de las temperaturas del Set point, y de la zona de trabajo del proceso, en tiempo real

Tiene el icono *Zona de trabajo*, el cual permite elegir la zona de extrusión y observar en una gráfica la evolución del proceso de la zona elegida, de una manera independiente.

Se puede desplazar en las gráficas con la ayuda de los cursores que poseen y ver el valor exacto de temperatura en el punto deseado.

Esta pantalla es solo para el monitoreo de temperaturas del proceso de extrusión de PVC.

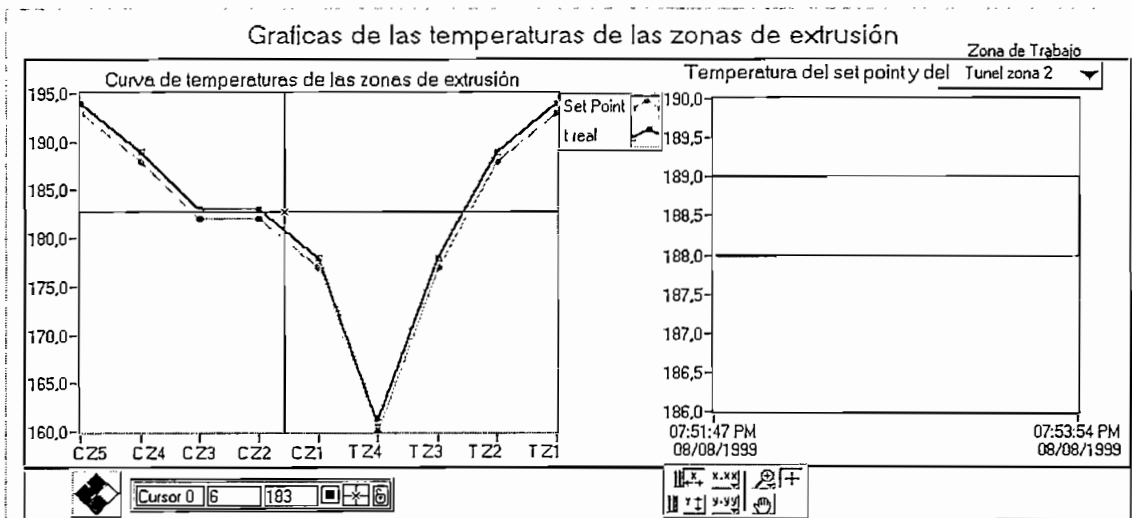


Figura 7 Pantalla de presentación de VI Gráficas

Controlador digital extrusor

Este VI mostrado en la figura 8 es el corazón de este trabajo, aquí se generan los valores de temperaturas del proceso en el caso de la simulación, o se podría analizar los datos que ingresaren por las respectivas tarjetas de acondicionamientos de señales (el análisis de datos con acondicionadores de señal, esta fuera del alcance de este trabajo). En este VI se pueda cambiar el *Set Point* del proceso e ingresar los valores de las zonas de trabajo (que para esta tesis se simulan).

Esta compuesta de mímicos donde se pueden cambiar todos los parámetros de *Controlador PID*, el tipo de controlador a utilizar, el periodo de discretización del controlador, los valores del error de la simulación.

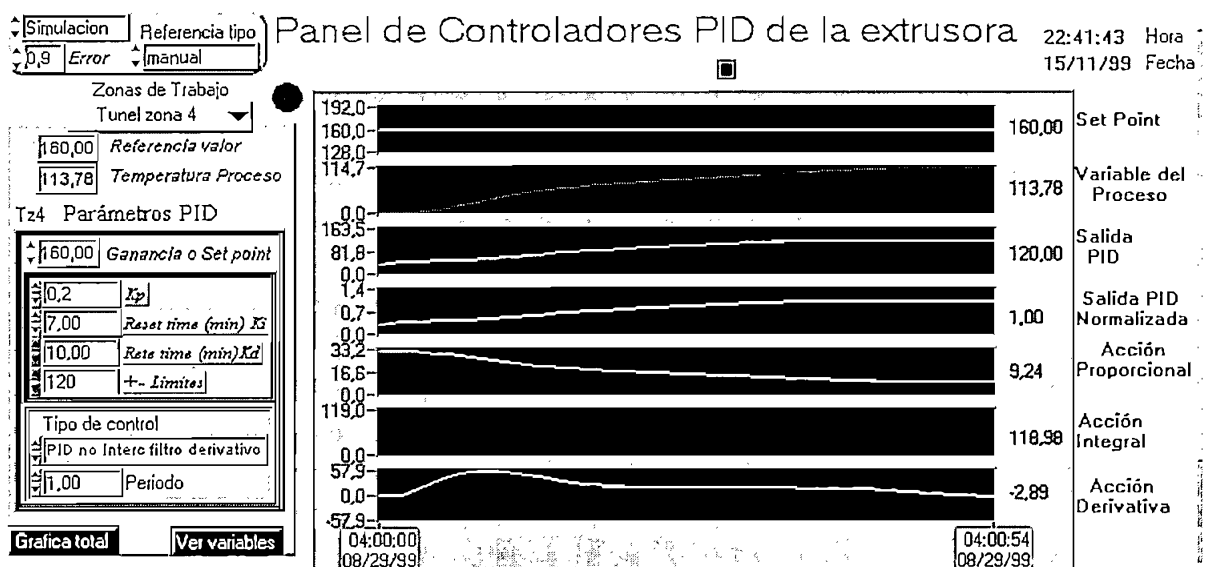


Figura 8.- Controlador PID extrusora.VI

A continuación se describe los componentes que integran este VI.

- *Simulación* o *Proceso Real* ubicado en la esquina superior izquierda, permite escoger entre los modos *Simulación* o *Proceso real*.

Al elegir el modo *Simulación* se dispone de un generador de señales que simula el ingreso de una referencia al controlador; para observar la respuesta del controlador se ingresan algunos tipos de señales, como onda sinusoidal, cuadrada, triangular, diente de sierra y randómica. Esto permite ver en tiempo real como reacciona el controlador digital a este tipo de señales, y

concluir como va a responder en el proceso de extrusión, ante los diversos cambios en la referencia.

Al elegir el modo *Proceso real* se podría analizar los datos que ingresaren por las respectivas tarjetas de acondicionamientos de señales (el análisis de datos con acondicionadores de señal, esta fuera del alcance de este trabajo) y observar como el controlador digital trabajaría en el proceso.

- **Error** ubicado en la esquina superior izquierda bajo al icono anterior, permite ingresar el valor del error admisible en el proceso, esto se lo realiza para generar eventos y alarmas del proceso de extrusión

Los eventos y alarmas generados durante el proceso de extrusión de pvc van ha ser mostrados en los VI de *alarmas*, y *eventos del proceso* si los valores sobrepasan los previamente fijados en el icono *Error*, esta interrelación con los VI antes mencionados se realiza mediante la interfaz HMI, propia del software Bridge VIEW la misma que utiliza los TAGS, que recogen las señales en el VI *Controlador digital extrusor*.

- **Referencia tipo** Ubicado en la esquina superior izquierda junto al selector *Simulación*. En este selector se puede elegir la referencia a ser usada en la simulación del proceso de extrusión, lo cual permite observar la respuesta simulada del controlador digital en lazo cerrado ante la referencia elegida.

El selector *Referencia tipo* tiene algunas señales, las mimas que son: onda senoidal, cuadrada, triangular, diente de sierra y randomica,

- **Zonas de trabajo** Ubicado en la parte izquierda bajo los iconos anteriores, permite elegir la zona de trabajo del proceso de extrusión, y, a su vez muestra los parámetros de temperatura del proceso, set point, parámetros del controlador, tipo de configuración del controlador digital y el periodo de discretización de la zona elegida de extrusión.
- **Referencia valor** Muestra el valor de la referencia que tiene la zona de trabajo elegida
- **Temperatura Proceso** Muestra el valor de la temperatura que tiene la zona de trabajo elegida
- **Ganancia o set point** Permite setear el valor de temperatura en la zona de trabajo elegida, a la que el proceso de extrusión en lazo cerrado debe llegar , mediante la acción del controlador digital.

- **Parámetros PID** Ubicado en la parte izquierda, permite setear los parámetros del controlador digital de la zona de trabajo elegida.

En este mímico se ingresan los valores de k_p , k_i o **Reset time**, k_d o **Rate time** , y el **limite** dentro del cual va ha trabajar el controlador digital.

k_p es la ganancia proporcional del controlador digital.

k_i o **Reset time** es la constante de integración del controlador digital.

k_d o **Rate time** es la constante derivativa del controlador digital.

limite es el valor al cual se limita la salida del controlador digital, para evitar su saturación del mismo.

- **Tipo de control** Ubicado en la parte inferior izquierda, permite elegir el tipo de configuración del controlador digital en la zona de trabajo elegida.

Este selector tiene algunas configuraciones para el controlador digital, las mismas que son:

Proporcional P

Proporcional Integral PI

Proporcional Derivativo PD

Proporcional Integral Derivativo PID clásico

PID interactuante.

PID no interactuante.

PID no interactuante con componente derivativa filtrada

En la opción *Periodo* se setea el periodo de discretización con el cual va a trabajar el controlador digital en la zona de extrusión elegida.

- **Gráfica total** Ubicado en la esquina inferior izquierda, es un icono de dos estados; permite observar la evolución del proceso y la respuesta del controlador digital en lazo cerrado en la zona de trabajo elegida. Sus estados son:

Gráfica total permite observar en la pantalla de gráficos la evolución del proceso del control de temperatura de la zona de trabajo elegida, muestra la evolución de:

Set point.

Variable de proceso.

Salida PID.

Salida PID normalizada.

Acción Proporcional.

Acción integral

Acción Derivativa.

Gráfica corta permite observar en la pantalla de gráficos la evolución del proceso del control de temperatura de la zona de trabajo elegida, solo del set point y la variable del proceso

- *Ver variables* Ubicado en la esquina inferior izquierda junto al icono anterior, permite observar las temperaturas y los set point de la mismas de todas las zonas de trabajo.
- En la parte central se tiene una pantalla que gráfica las señales del proceso, en esta se puede observar como varía en el tiempo los siguientes parámetros:

Set point, muestra el valor en la gráfica al cual esta seteado el controlador digital

Variable del proceso muestra el valor en la gráfica de la temperatura del proceso de extrusión en la zona de trabajo elegida

Salida PID muestra el valor en la gráfica de la salida del controlador digital.

Salida PID normalizada muestra el valor en la gráfica de la salida normalizada del controlador digital, esto permite tener un rango apropiado de valores, los mismos que van a los actuadores de la zona de trabajo elegida.

Acción proporcional muestra el valor en la gráfica de la acción proporcional en el controlador digital de la zona de trabajo elegida.

Acción integral muestra el valor en la gráfica de la acción integral en el controlador digital en la zona de trabajo elegida.

Acción derivativa muestra el valor en la gráfica de la acción derivativa en el controlador digital de la zona de trabajo elegida.

Figura. 11 Pantalla del Históricos.

Login

Este pulsador llama a una ventana que permite tener la seguridad para el programa, así se garantiza que sólo los usuarios autorizados pueden y deban realizar cambios a los parámetros del controlador digital de este software, la designación de usuarios y sus niveles de accesos la realiza quien este encargado de administrar el programa.

La figura muestra esta pantalla donde se ingresan al nombre del usuario y su clave de accesos.

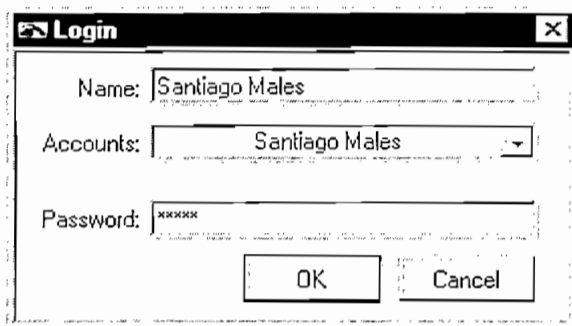


Figura. 12 Login

Ayuda

Este icono permite llamar a la ayuda del programa en el modo *Proceso*

En la pantalla de simulación se tiene los siguientes VI:

Función en el tiempo

Este VI (figura 13) muestra la respuesta en el tiempo y la ubicación de los polos y ceros de las funciones de transferencia de la máquina extrusora del proceso de extrusión las mismas que fueron obtenidas en el capítulo 3, así también se puede observar la repuesta del sistema compensado mediante el controlador digital.

Este VI es solo para análisis del sistema de control, ya que se puede medir el máximo sobre pico

En la pantalla de simulación se tiene los siguientes VI:

Función en el tiempo

Este VI (figura 13) muestra la respuesta en el tiempo y la ubicación de los polos y ceros de las funciones de transferencia de la máquina extrusora del proceso de extrusión las mismas que fueron obtenidas en el capítulo 3, así también se puede observar la repuesta del sistema compensado mediante el controlador digital.

Este VI es solo para análisis del sistema de control, ya que se puede medir el máximo sobre pico porcentual, el tiempo de respuesta y el error de posición de la función de transferencia ante la acción de una función paso unitaria en lazo cerrado.

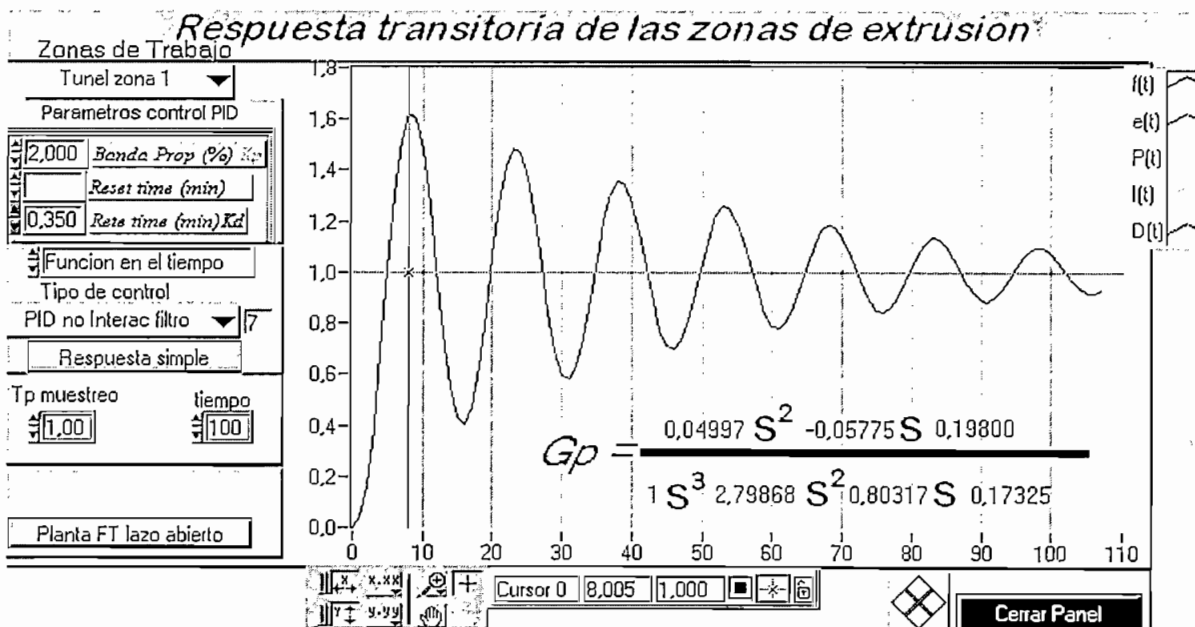


Figura 13 Función en el tiempo.vi

A continuación se describe los componentes que integran este VI.

- **Zona de trabajo** Ubicado en la parte superior izquierda, permite elegir la zona de trabajo del proceso de extrusión ha simular.
- **Parámetros PID** Ubicado en la parte izquierda, permite setear los parámetros del controlador digital de la zona de trabajo.

En este mímico se ingresan los valores de k_p , k_i o **Reset time**, k_d o **Rate time** , con los que ha simular el controlador digital.

k_p es la ganancia proporcional del controlador digital.

k_i o **Reset time** es la constante de integración del controlador digital.

k_d o **Rate time** es la constante derivativa del controlador digital.

- **Función en el tiempo** Ubicado en la parte media izquierda, es un icono de dos estados; permite observar la respuesta del sistema en el tiempo y la ubicación de los polos y ceros del controlador digital en lazo cerrado en la zona de trabajo elegida. Sus estados son:

Función en el tiempo permite observar en la pantalla de gráficos la respuesta del sistema compensado por el controlador digital. Con esta opción se determinan las características del lazo de extrusión ante una entrada unitaria y se miden lazo cerrado el máximo sobre pico porcentual, el tiempo de establecimiento y el error de posición de la función de transferencia, tanto compensada o no compensada.

Polos y ceros ubicación permite observar en la pantalla de gráficos la ubicación de los polos y ceros de la función de transferencia de la zona de extrusión, tanto compensada o no. La figura 5.24 muestra la pantalla con esta opción.

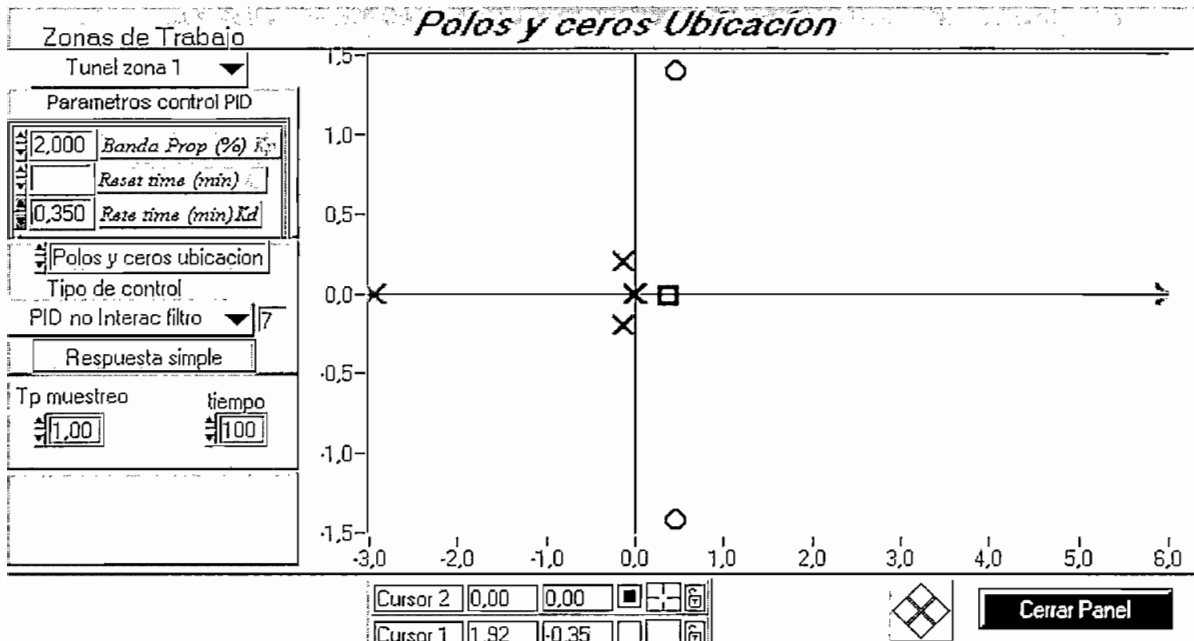


Figura. 14 Opción de polos y ceros

- *Tipo de control* Ubicado en la parte media izquierda, permite elegir el tipo de configuración del controlador digital en la zona de trabajo elegida.

Este selector tiene algunas configuraciones para el controlador digital, las mismas que son:

Proporcional P

Proporcional Integral PI

Proporcional Derivativo PD

Proporcional Integral Derivativo PID clásico

PID interactuante.

PID no interactuante.

PID no interactuante con componente derivativa filtrada

- *Periodo* setea el periodo de discretización con el cual va a trabajar el controlador digital en la zona de extrusión elegida
- *Tiempo* Este icono permite seleccionar el tiempo de simulación, el mismo esta mostrado en el eje las abscisas de la gráfica de respuesta en el tiempo.
- En el centro de la pantalla se tiene una gráfica donde van ha ir la respuesta en tiempo o la ubicación de polos y ceros de la función de transferencia y el controlador digital elegido.
- Cerrar Panel Ubicado en la parte inferior derecha, al ser ejecutado este icono permite salir del VI función en el tiempo.
- Se tiene además cursores que ayudan ha determinar la posición y el valor de la respuesta.

Todo este conjunto de iconos descritos conforman este VI.

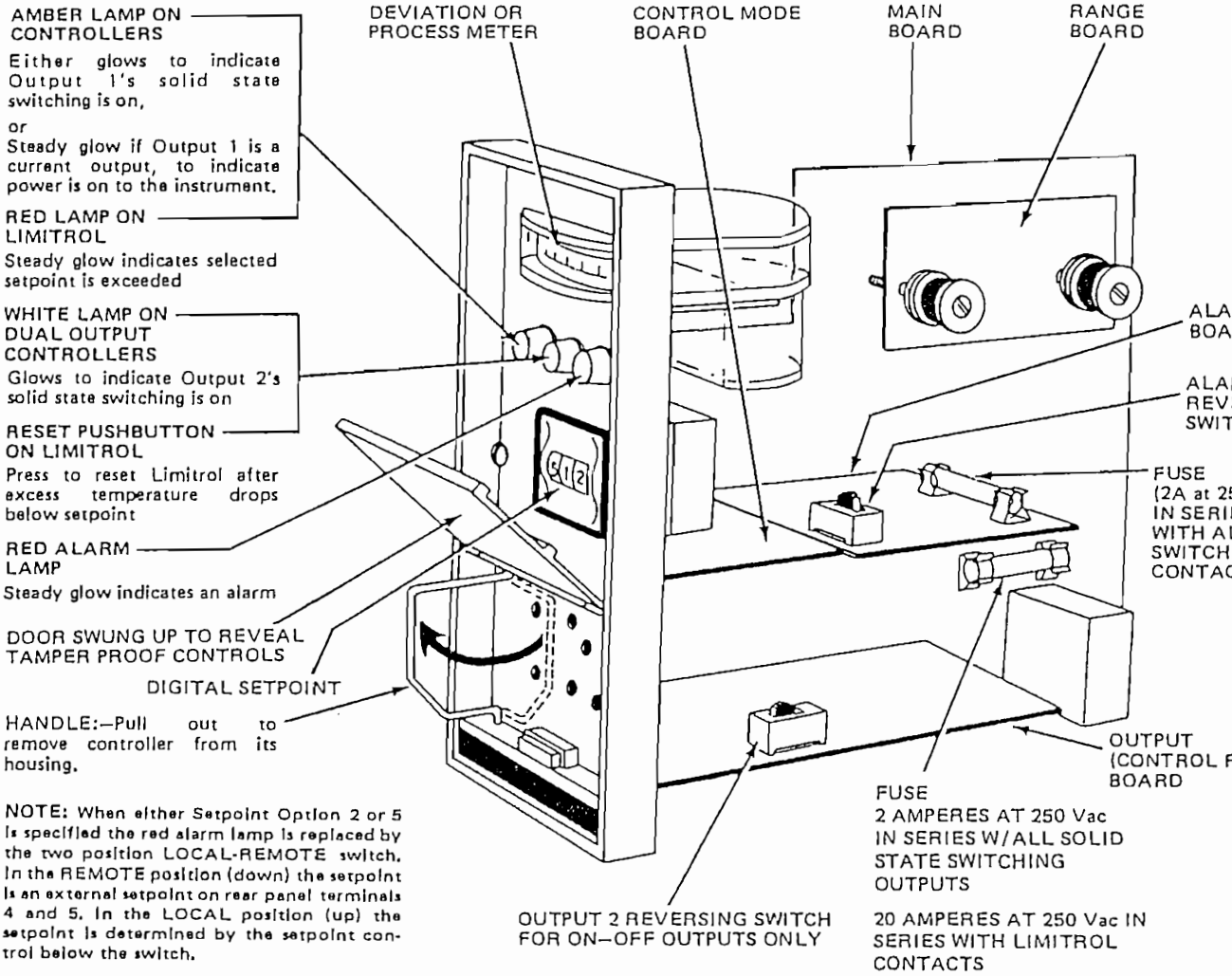
Ayuda

Los iconos de ayuda tanto en proceso como en simulación muestran las indicaciones de uso de este software.

ANEXO D



SERIES 520 — MODELS 521, 522, 523, AND 524
ANALOG AND DIGITAL SETPOINT CONTROLLERS



AMBER LAMP ON CONTROLLERS
Either glows to indicate Output 1's solid state switching is on, or Steady glow if Output 1 is a current output, to indicate power is on to the instrument.

RED LAMP ON LIMITROL
Steady glow indicates selected setpoint is exceeded

WHITE LAMP ON DUAL OUTPUT CONTROLLERS
Glows to indicate Output 2's solid state switching is on

RESET PUSHBUTTON ON LIMITROL
Press to reset Limitrol after excess temperature drops below setpoint

RED ALARM LAMP
Steady glow indicates an alarm

DOOR SWUNG UP TO REVEAL TAMPER PROOF CONTROLS

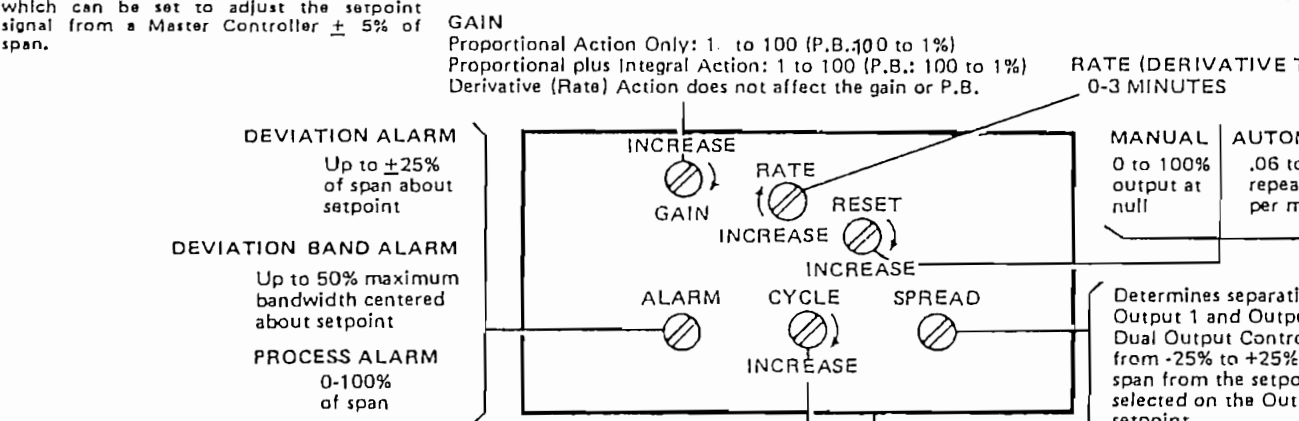
HANDLE:—Pull out to remove controller from its housing.

NOTE: When either Setpoint Option 2 or 5 is specified the red alarm lamp is replaced by the two position LOCAL-REMOTE switch. In the REMOTE position (down) the setpoint is an external setpoint on rear panel terminals 4 and 5. In the LOCAL position (up) the setpoint is determined by the setpoint control below the switch.

When Setpoint Option 7 is specified the Setpoint is omitted.

When Setpoint Option 8 is specified the Setpoint is replaced by a Trim Control which can be set to adjust the setpoint signal from a Master Controller $\pm 5\%$ of span.

Figure 2-1. Parts Description



COOLING LIMIT ADJUSTMENT (located in the hole marked SPREAD). Continuously adjustable to limit the percent ON time between 5 (CCW) and 100 (CW). This prevents excess cooling. Only on models 522H, 523H, 524H, 522J, 523J, 524J, 522K, 523K, and 524K.

Figure 2-2. Functions of Internal Front Panel Controls

WARNING
FUSE SIZE MUST NOT BE EXCEEDED. COPPER FOIL ON MAIN BOARD WILL BE DESTROYED AT HIGHER CURRENTS.

Determines separation of Output 1 and Output 2. Dual Output Control from -25% to +25% span from the setpoint selected on the Output setpoint. Output 2 is switch reversible. Only on models 522E, 523E, 524E, 522F, 523F, 524F, 522G, 523G, and 524G.

Storing Temperature

-40°F to +150°F.

Frequency Response Direct current to 0.7 Hz in the proportional action only controllers. Depends on setting of RESET control in Proportional plus Integral Action Controllers.

Line Voltage Stability 10% change in line voltage will not shift control by more than 0.1% of span.

Temperature Stability

4 microvolts per °F, maximum.

2 microvolts per °F, typical.

Sensitivity 0.00075% of span for 100% change in output.

Isolation Fully Isolated

Isolated Remote Setpoint Voltage (Optional) 1-5Vdc. Source should be free of transients and have an impedance less than 200 ohms. For operation of more than one controller from the same external source, a source resistance under 50 ohms is recommended. Input impedance is 1M ohms typical.

Isolated Trim Setpoint (Optional) Requires 1-5Vdc setpoint voltage from an external source. Source resistance up to 20 ohms. Trim control adjusts the instrument setpoint $\pm 5\%$ of span. Input impedance is 20k ohms.

Isolated Output Setpoint Voltage (Optional) 1-5Vdc proportional to instrument setpoint span. Short circuit has no effect on control action. Source resistance less than 10 ohms.

Maximum total output current of Process Signal Output option plus Output Setpoint Voltage option is 10mA dc.

Isolated Process Signal (Optional): 1-5Vdc on rear panel terminals. External short circuit has no effect on control action. Source resistance less than 10 ohms. Maximum total output current of Process Signal Output option plus Output Setpoint Voltage option is 10mA dc.

Power Consumption 7 VA.

Shipping Weight 4 pounds (no housing).

1.3 OPERATION

1.3.1 Front Panel Controls and Indicators

SETPOINT ADJUST Control for selecting the nominal setpoint temperature.

Amber Lamp Located on left side of upper front panel. Glows when the output switch is on.

Red Alarm Lamp (optional auxiliary alarm) Located on right side of upper front panel. Steady glow indicates an alarm.

ALARM control on Main Board (Optional) Potentiometer for selecting alarm trip point.

Deviation Alarm: 0 to 25% of span about setpoint.

Deviation Band Alarm: From + and -1.5% up to + and -25% (fully CW) of span. 50% maximum bandwidth.

Process Alarm: 0-100% (fully CW) of span.

GAIN control on the Main Board Single turn potentiometer for selecting gains of 10 (fully CCW) to 100 (fully CW) for Proportional Action Only Controllers; and from

1 (fully CCW) to 100 (fully CW) for Proportional plus Integral Action Controllers. At a setting of 1, the proportional bandwidth is 100% of span; at 10, 10% of span; and at 100, 1% of span. Derivative (Rate) Action does not affect the gain (proportional band).

Manual RESET control on Control Mode Board (Model 522B) Single turn potentiometer for selecting 0 (fully CCW) to 100% (fully CW) output at null with the GAIN pot set at 10 (fully CCW). Requires narrower adjustment range for higher gains.

Integral RESET control on Control Mode Board (Model 523B and 524B) Single turn dual potentiometer and switch for selecting .06 to 6 (fully CW) repeats per minute. When fully CCW, integral action is turned off.

CYCLE control on Output Board Single turn potentiometer for selecting a cycle time from 6 (fully CW) to 60 (fully CCW) seconds.

Derivative RATE control on Control Mode Board (Model 524B) Single turn potentiometer for selecting a Derivative Action time from 0 (fully CCW) to 3 (fully CW) minutes.

LOCAL-REMOTE Switch (Setpoint Option 2 or 5) When Setpoint Option 2 or 5 is specified the red alarm lamp is replaced by the two position LOCAL-REMOTE switch. In the REMOTE position (down) the setpoint is an external setpoint on rear panel terminals 4 and 5. In the LOCAL position (up) the setpoint is determined by the setpoint control below the switch.

TRIM control (Setpoint Option 8) Single turn potentiometer for decreasing a remote setpoint voltage -5% of span (fully CCW) to increasing the remote setpoint voltage +5% of span (fully CW). TRIM control is marked -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, and 5 in Percent of Span. When Setpoint Option 8 is specified the TRIM control replaces the front panel SETPOINT ADJUST control.

1.3.2 Preliminary Adjustments

It may be necessary to operate the process equipment to make preliminary adjustments on it and also, for example, to dry out furnace liner material. During any preliminary operation, turn the RESET control off. Set the GAIN control fully CCW. Now adjust the Setpoint control as desired.

Always make a permanent record of any final settings for a specific process so that if the controls are changed for any reason, the original settings can be duplicated. Upsets can be simulated by turning the Setpoint control to different settings with the degree of upset desired proportional to the change in setting. Allow enough time, when making adjustments, for the system to stabilize. Remember that optimum controller adjustments are those that produce satisfactory results in a stable system. Optimum adjustments are not necessarily the finest and most sensitive settings that can be obtained.

1.3.3 Model 522B Controller With Proportional Action Only

With Proportional Action Only, the output is a proportional correction signal for returning the process variable to the setpoint selected on the Setpoint control. The amount of amplification is selected by the operator on the GAIN control. At fully CW gain is 100 (maximum), the proportional bandwidth is minimum. At fully CCW gain is 10

(minimum), the controller proportional bandwidth is maximum. Set the GAIN control high enough to produce a stable process condition, but no higher. If there is excessive overshoot of the setpoint or more than minimum recovery time from a step change in the process variable, reduce the gain to obtain minimum recovery time. With Proportional Action Only there may be an offset (droop) of the measured variable from the setpoint selected on the Setpoint control.

The process should be stabilized (zero deviation) at the selected setpoint.

1. If offset is below zero deviation, turn the RESET control CW one mark and allow time for the process to stabilize. Continue CW rotation in this manner until the process stabilizes.
2. If offset is above zero deviation, turn the RESET control CCW one mark and allow time for the process to stabilize. Continue CCW rotation in this manner until the process stabilizes.

1.3.4 Model 523B Controller With Proportional Plus Integral Action

The following procedure gives initial settings that represent a compromise between close control of minor process upsets and good recovery from large upsets. Allow plenty of time for the process to stabilize after each adjustment. Proceed as follows:

1. Set the GAIN control at midpoint.
2. Turn the RESET control fully CCW to off.
3. Adjust the Setpoint Control to the desired operating setpoint.
4. Allow plenty of time for the controlled variable to stabilize.
5. For either of the two conditions (A or B) that follow, after each change in setting of the GAIN control, a simulated process upset should be caused by changing the Setpoint control about 5% (this is 50°F for a scale of 1000°F) of scale range. Such a simulated process upset will show any tendency to cycle. Changes in the setting of the Setpoint control should be made up and down alternately to remain near the operating setpoint selected in step 3.
 - A. If the process variable is stable, turn the GAIN control clockwise in steps of one division until instability is reached. After the process becomes unstable, turn the GAIN control counterclockwise one division.
 - B. If the process variable is unstable, turn the GAIN control counterclockwise until the process variable becomes stable.
6. After the completion of step 5, allow time for the process to settle down. Then turn the RESET control to midpoint, and observe the behavior of the process.
 - A. If the midpoint setting is the correct one, the offset read on the temperature scale of the front panel meter at the end of step 5 will disappear in about 2 to 5 minutes, without overshoot.
 - B. If the midpoint setting is too fast for the process, cycling will occur. If cycling occurs, turn the RESET control one division CCW. Wait for the process to settle down. If it does not again turn the RESET control one division CCW. Continue this procedure until the process settles down.

7. Introduce a step change of 5 to 10%. For best results, the step response should be observed on a recorder. With a recording very fine observations can be made to obtain closer to optimum settings. Taking a recording is almost mandatory for very critical processes, where both overshoots and settling times must be minimized. Fortunately, the majority of processes are not so critical and satisfactory results may be obtained without special equipment simply by observing the deviation.

- A. If more overshoot occurs than can be tolerated, decrease the setting of the GAIN control counterclockwise in steps of about one division. If more than two steps are required, it may be preferable to switch the RESET control to a slower setting (turn CCW) rather than to continue on to an unusually low gain.
- B. If there is no overshoot, the time required to reach the new equilibrium may be excessive, at any rate, it can be reduced by increasing the gain until a single, small overshoot occurs in response to a step change. Such a setting is usually preferred, as settling time is minimal. If more than three steps are required to obtain an overshoot, it may be preferable to turn the RESET control CW to a faster rate, then turn the GAIN control a few divisions CCW to achieve stability.

1.3.5 Model 524B Controller With Proportional Plus Integral Plus Derivative Action

First perform the procedure in paragraph 1.3.4.

Derivative time is continuously adjustable by the RATE control from 0 (fully CCW) to 3 (fully CW) minutes.

Derivative action occurs only when the input signal is changing. Should too much Derivative time be added to a process, it will cause instability similar to the instability caused by too much Integral action or too much gain action. Too little Derivative time will not provide enough correction for error. With the correct amount of Derivative time applied, large upsets tend to be anticipated. In general, a slow responding process requires very little if any Derivative time. The dial markings of the RATE control correspond to the time that the proportional action is advanced, or the lead time that proportional plus Derivative action has over proportional action alone.

1.3.6 Cycle Time

Cycle time is the time in seconds of one period of on and off. A stopwatch is required to accurately set cycle time. Look at the Amber lamp and take an average of the time it is on and off.

The CYCLE adjustment varies the switching rate from 6 (at CW) to 60 (at CCW) seconds per cycle. The faster cycle rates of the order of 10 seconds per cycle provide better control of loads with fast response times and little lag time. However, a relatively faster cycle time causes added wear on an external electromechanical contactor. A faster cycling rate of 0.6 (at CW) to 6 (at CCW) can be obtained by removing C3 from the Output Board. This faster cycling rate will enable optimum control of a process with a Barber-Colman solid state contactor.



INDUSTRIAL INSTRUMENTS DIVISION
ROCKFORD, ILLINOIS, U.S.A. 61101

2.1 After Unpacking

Check the contents of the shipping container against the packing slip. If the equipment is damaged in transit, report the extent of the damage to the carrier immediately.

2.2 Mounting

The ambient temperature should be within 40°F to 130°F. The series 520 can be mounted in any position.

After the cutout is made in the panel, proceed as follows to install one instrument. Completely unscrew the two driving screws for the mounting brackets and pull the mounting brackets completely out of their tracks in the case. Place the housing in the panel cut-out. Replace the mounting brackets. Tighten the mounting bracket screws until the brackets hold the housing snugly against the panel. **CAUTION:** — Do not over-tighten the mounting bracket screws — over-tightening screws could damage the panel.

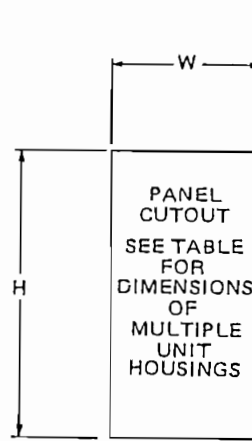
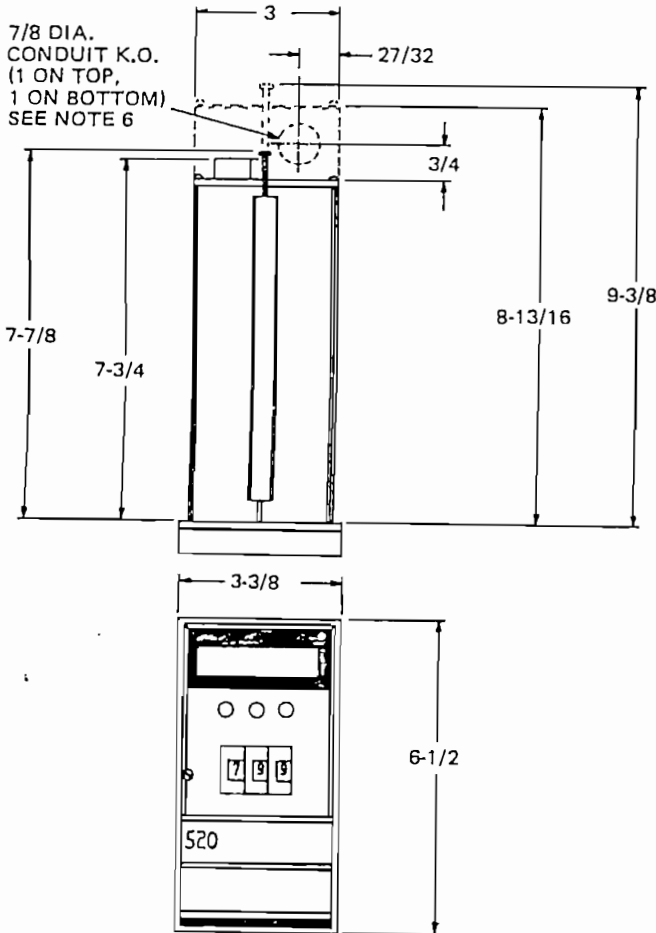
The captive screw on the left side of the panel in the middle is the fastener for the instrument. After the housing is mounted in the panel, push the controller firmly into its slot until the screw touches the threaded hole in back of it. Do not push instrument further but instead turn screw clockwise until instrument is pulled fully into its housing.

2.3 Power Wiring

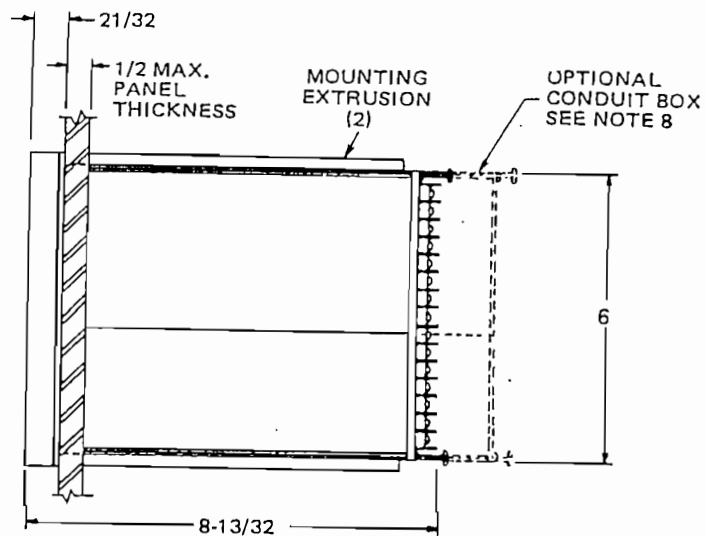
Input line voltage must be 120 or 240 Vac, $\pm 10\%$, at 60 Hz; or, 110 or 220 Vac, $\pm 10\%$, at 50 Hz; by terminal selection. Connect the line voltage to the terminal marked L2 and either the terminal marked 240V L1 or the terminal marked 120V L1. Connect panel ground to the GROUND terminal.

2.4 Input Wiring

The SIGNAL input terminals are marked TC (+ and -) and are for any Input Signal — observe polarity. For RTD sensors there is no polarity to observe. For three wire RTD's, connect the two WHITE wires of the RTD together.



- NOTE:
1. ALL DIMENSIONS IN INCHES.
 2. TOL. ALL DIM. $\pm 1/16$
 3. DIMENSIONS GUARANTEED ONLY IF THIS PRINT IS CERTIFIED.
 4. MIN. HORZ. SPACING CENTERS 3-7/16
 5. MIN. VERT. SPACING CENTERS 6-9/16
 6. APPLETON NO. 92T050 TWO PIECE STEEL CONDUIT CONNECTOR OR EQUIVALENT MUST BE USED FOR CONDUIT CONNECTIONS.
 7. FOR MOUNTING IN A 19" RELAY RACK 7" HIGH THE MAX. NO. OF UNITS WILL BE 1 ROW OF 5.
 8. CONDUIT BOX FITTED TO CASE AT FACTORY.



PANELMOUNT CUT OUT DIMENSIONS SHOWN AT LEFT

NUMBER OF UNITS WIDE W	1	2	3	4	5	6	7	8	9
	NUMBER OF UNITS HIGH H	3-1/8	6-9/16	10	13-7/16	16-7/8	20-5/16	23-3/4	27-3/16
1	6-1/8	1	2	3	4	5	6	7	8
2	12-11/16	2	4	6	8	10	12	14	16
TOTAL NUMBER OF UNITS									

Example 1: Single Panelmount cut out is 3-1/8" wide by 6-1/8" high.

Example 2: An array 9 wide by 2 high, cut out is 30-5/8" wide by 12-11/16" high.

Note: — Standard Relay Rack Panel Cut-Outs are made at the factory; and, the housings specified are shipped fastened to the panel.

Figure 2-3. Mounting Dimensions

2.5 Alarms

2.5.1 General

For safety purposes the Models 521L and 521T Limitrols are recommended.

These alarms are not recommended for safety purposes. Alarm boards in the Series 520 are shipped from the factory with the following wiring conditions:

1. Alarm light is on when alarm relay is de-energized.
2. Normally open alarm contact is connected to instrument alarm terminals.

2.5.2 ALARM Potentiometer and Alarm Reversal Switch

Either a Process, a Deviation, or a Deviation Band Alarm may have been specified. The alarm action is determined by the front panel ALARM pot and by a slideswitch located on the Alarm Board. Figure 2-1 shows the location of the switch.

Set the switch as follows.

Process Alarm: pull out to alarm* on decreasing signal,
push in to alarm* on increasing signal.

Deviation Alarm: pull out to alarm* on decreasing signal,
push in to alarm* on increasing signal.

Deviation Band Alarm: push in to alarm* inside the
bandwidth,
pull out to alarm* outside the
bandwidth,

*"to alarm" means that terminals 6 and 7 open.

Next, set the ALARM potentiometer.

The Process Alarm can be set to trip anywhere within the span of the instrument by means of the 20-turn ALARM potentiometer. Turn the ALARM pot clockwise to increase the alarm trip point.

The Deviation Alarm can be set to trip up to $\pm 25\%$ of span from setpoint by means of the single turn ALARM potentiometer. With the ALARM pot turned fully CCW the alarm will trip at a deviation of 25% of span below setpoint.

With the ALARM pot fully CW the alarm will trip at a deviation of 25% of span above the setpoint.

The Deviation Band Alarm can be set to trip up to plus and minus 25% of span (total of 50% of span) about setpoint. Turn the single turn ALARM pot clockwise for a wider deviation band.

2.5.3 Setting a Deviation Alarm Trip Point

2.5.3.1 With Millivolt Source Input

Proceed as follows:

1. Disconnect any input or output.
2. Turn power on to the Series 520.
3. Connect a d-c millivolt source (B-C Portable Potentiometer output) to the SIGNAL input terminals. Increase the millivolt input signal until it is above (below for a low deviation alarm) midscale and the difference between the signal and midscale is the desired deviation.
4. Adjust the setpoint to midscale.
5. Turn the ALARM potentiometer until the red alarm lamp lights.

2.5.3.2 With Process Input

Proceed as follows.

1. Allow the process to stabilize at the desired setpoint.
2. Quickly perform steps 3, 4 and 5 that follow.
3. Adjust the setpoint until it is below (above for a low deviation alarm) the desired setpoint mentioned in step 1, by the amount of the alarm deviation.
4. Turn the ALARM potentiometer until the red alarm lamp lights.
5. Quickly return setpoint to the value it had in step 1.

2.5.4 Setting A Deviation Band Alarm

With the Deviation Band Alarm option, when the ALARM potentiometer is fully CW, the bandwidth is 50% of span. When fully CCW, the bandwidth is about 2% of span.

2.5.4.1 With Millivolt Source Input

Proceed as follows.

1. Disconnect any input or output.
2. Turn power on to the Series 520.
3. Connect a d-c millivolt source (B-C Portable Potentiometer output) to the SIGNAL input terminals. Increase the millivolt input signal until it is above (or below) midscale and the difference between the signal and midscale is half the desired bandwidth.
4. Adjust the setpoint to midscale.
5. Turn ALARM potentiometer until red lamp lights.

2.5.4.2 With Process Input

Proceed as follows.

1. Allow the process to stabilize at the desired setpoint.
2. Quickly perform steps 3, 4, and 5 that follow.
3. Adjust the setpoint until it is above (or below) the desired setpoint mentioned in step 1, by the amount of half the bandwidth.
4. Turn the ALARM potentiometer until the red alarm lamp lights.
5. Quickly return setpoint to the value it had in step 1.

2.5.5 Setting A Process Alarm Trip Point

Proceed as follows.

1. Disconnect any input or output.
2. Turn power on to the Series 520.
3. Connect a d-c millivolt source to the SIGNAL input terminals. Adjust the millivolt input signal to the equivalent of the desired alarm temperature.
4. Turn the ALARM potentiometer until the red alarm lamp lights.

2.5.6 Re-connecting the Red Alarm Lamp to Indicate A Safe Condition

Do not make this wiring change for a safety related application. This wiring condition is suitable for such purposes as the following: Indicating that temperature is normal, furnace or extruder is ready to operate, extruder barrel temperature is at required temperature, zone temperature on furnace or extruder is at required temperature.

To make this wiring change refer to Figure 2-4 and proceed as follows. A black lead from the red alarm lamp is connected to terminal D on the Alarm Board. Disconnect the black lead from terminal D and connect it to the adjacent terminal E.

2.5.7 Re-connecting the Normally Open Alarm to Normally Closed

Do not make this wiring change for a safety related application. This wiring condition is suitable for such purposes as the following: programming and sequencing.

To make this wiring change refer to Figure 2-4 and proceed as follows. A gray wire from the printed circuit board connector number 11 is connected to terminal B. Disconnect the gray wire from terminal B and connect it to terminal A.

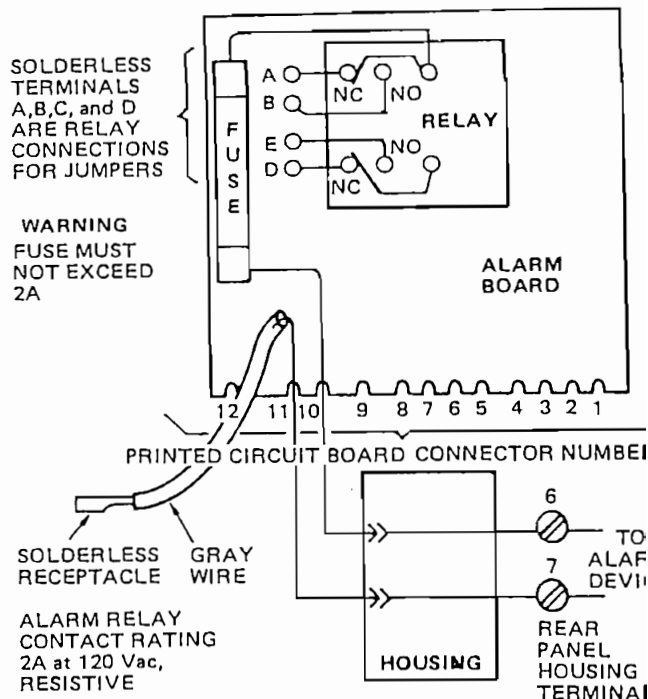


Figure 2-4. Alarm Wiring

2.6 Field Changing The Model 521A To Reverse The ON-OFF Output

---IMPORTANT---
INSTRUMENT MUST HAVE BEEN ORDERED WITH DOWN SCALE TCB (THERMOCOUPLE BREAK PROTECTION) IN ORDER TO MAKE THIS CHANGE.

The Model 521A is shipped with pin A connected to pin 6 by means of a jumper; and, with pin C connected to pin 7 by means of a jumper.

To reverse the ON-OFF output, make the jumper connections shown in Figure 2-5; that is, connect pin C to pin 6 and connect pin A to pin 7.

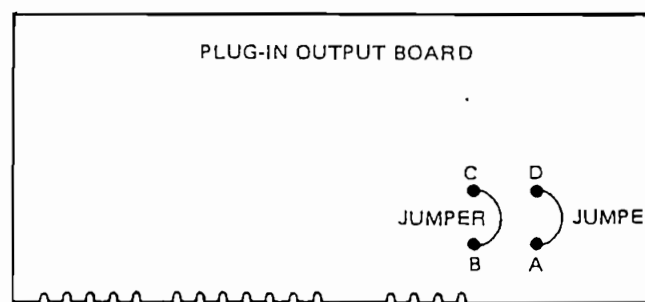


Figure 2-5. Jumpers

2.7 Field Changing the Output of the Models 521L and 521T from High Limit to Low Limit

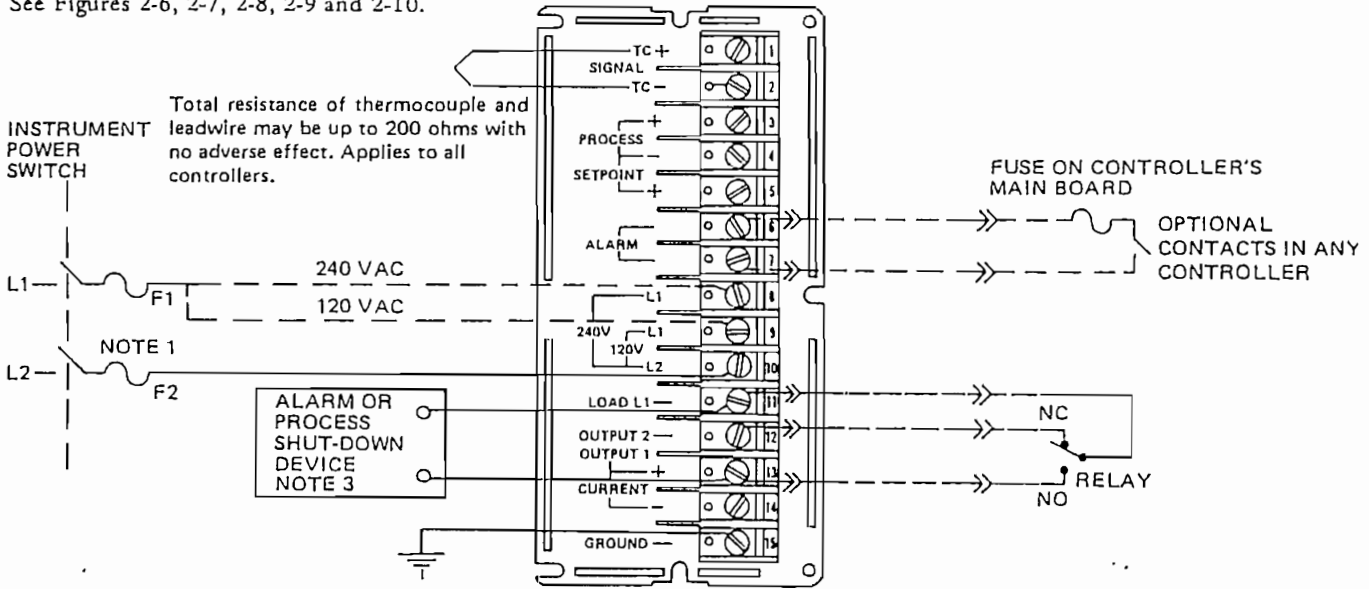
---IMPORTANT---
INSTRUMENT MUST HAVE BEEN ORDERED WITH DOWN SCALE TCB (THERMOCOUPLE BREAK PROTECTION) IN ORDER TO MAKE THIS CHANGE.

The Model 521L is shipped with pin A connected to pin 6 by means of a jumper; and, with pin C connected to pin 7 by means of a jumper. This is an "upscale" Limitrol.

To change to a "downscale" Limitrol make the jumper connections shown in Figure 2-5; that is, connect pin C to pin 6, and connect pin A to pin 7.

2.8 Output Wiring

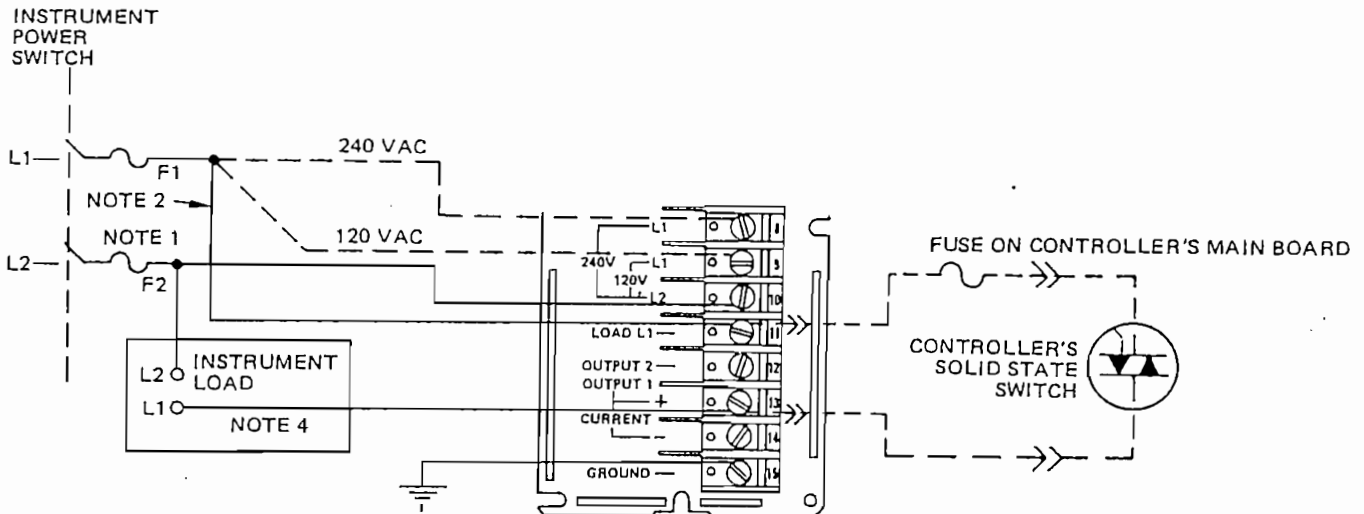
See Figures 2-6, 2-7, 2-8, 2-9 and 2-10.



Notes:

1. Instrument power switch and instrument fuses are included for illustrative purposes only. If the L2 line is a neutral or ground line, fuse F2 is not normally recommended. Consult local codes and appropriate wiring standards.
2. Limitrol Relay Contact Ratings: 5A at 120 or 240 Vac.
3. Power connections are made at the discretion of the installer.

Figure 2-6. Output Wiring, Limitrol (521L and 521T)

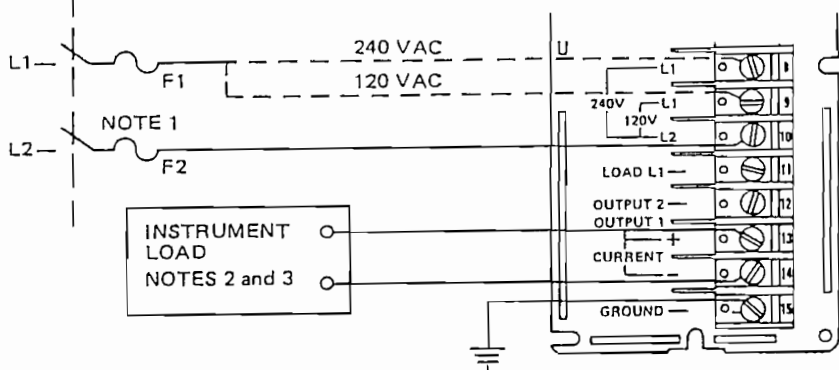


Notes:

1. Instrument power switch and instrument fuses are included for illustrative purposes only. If the L2 line is a neutral or ground line, fuse F2 is not normally recommended. Consult local codes and appropriate wiring standards.
2. Instrument load power, LOAD L1, may be obtained from a separate power source in phase with the instrument power supply. Instrument signal light will not operate unless Instrument L2 and instrument load L2 are connected as shown. Instrument signal light will not operate if LOAD L1 is powered by a separate source of less than 100 Vac rms.
3. Instrument load may be either a contactor coil, a Barber-Colman SOLID STATE CONTACTOR, or heater.
4. Rating of Solid State Switching Output: (both ON-OFF and Time-Proportioning): 1A continuous, 10A inrush, 30mA minimum. Any voltage from 24 Vac to 240 Vac can be switched but the voltage switched must be the same phase and have the same common line as the instrument power supply.

Figure 2-7. Output Wiring, Single Solid State Switching Output (521A, 522B, 523B and 524B)

**INSTRUMENT
POWER
SWITCH**



Notes:

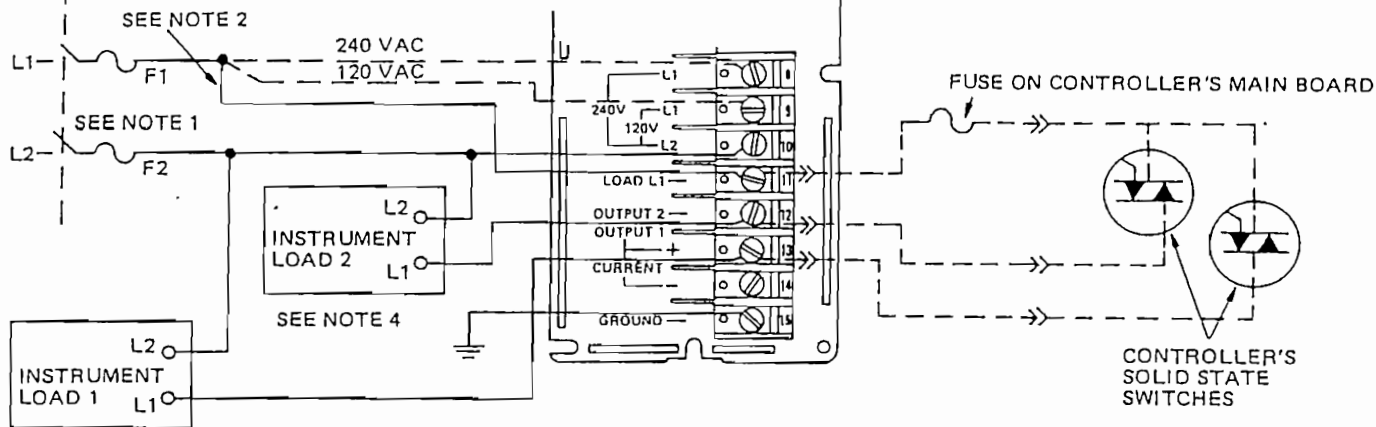
1. Instrument power switch and instrument fuses are included for illustrative purposes only. If the L2 line is a neutral or ground line, fuse F2 is not normally recommended. Consult local codes and appropriate wiring standards.
2. The constant current outputs of these controllers are short circuit proof. Either plus or minus may be grounded or remain floating.
3. Either the 2-12 mA or 4-20 mA output will drive the Model 656 Current-to-Position Converter for positioning a Barber-Colman Motor Operator or the Model PO2R Current-to-Pneumatic Transducer.

Either current output will drive Barber-Colman Power Controllers.

4. Current Output: either 2-12mA into 1.5k ohms or less; or 4-20 mA into 750 ohms or less.

Figure 2-8. Output Wiring, Single Current Output (522C, 523C, 524C, 522D, 523D, 524D, 522P, 523P, 524P, 522Q, 523Q and 524Q)

**INSTRUMENT
POWER
SWITCH**



Notes:

1. Instrument power switch and instrument fuses are included for illustrative purposes only. If the L2 line is a neutral or ground line, fuse F2 is not normally recommended. Consult local codes and appropriate wiring standards.
2. Instrument load power, LOAD L1, may be obtained from a separate power source in phase with the Instrument power supply. Instrument signal light will not operate unless Instrument L2 and Instrument load L2 are connected as shown. Instrument signal light will not operate if LOAD L1 is powered by a separate source of less than 100 Vac rms.

3. Instrument load may be either a contactor coil, a Barber-Colman SOLID STATE CONTACTOR, or heater.

4. Rating of Solid State Switching Output: (both ON-OFF and Time-Proportioning): 1A continuous, 20A Inrush, 30mA minimum. Any voltage from 24 Vac to 240 Vac can be switched but the voltage switched must be the same phase and have the same common line as the instrument power supply.

Figure 2-9. Output Wiring, Dual Solid State Switching Outputs (522E, 523E, 524E, 522H, 523H and 524H)

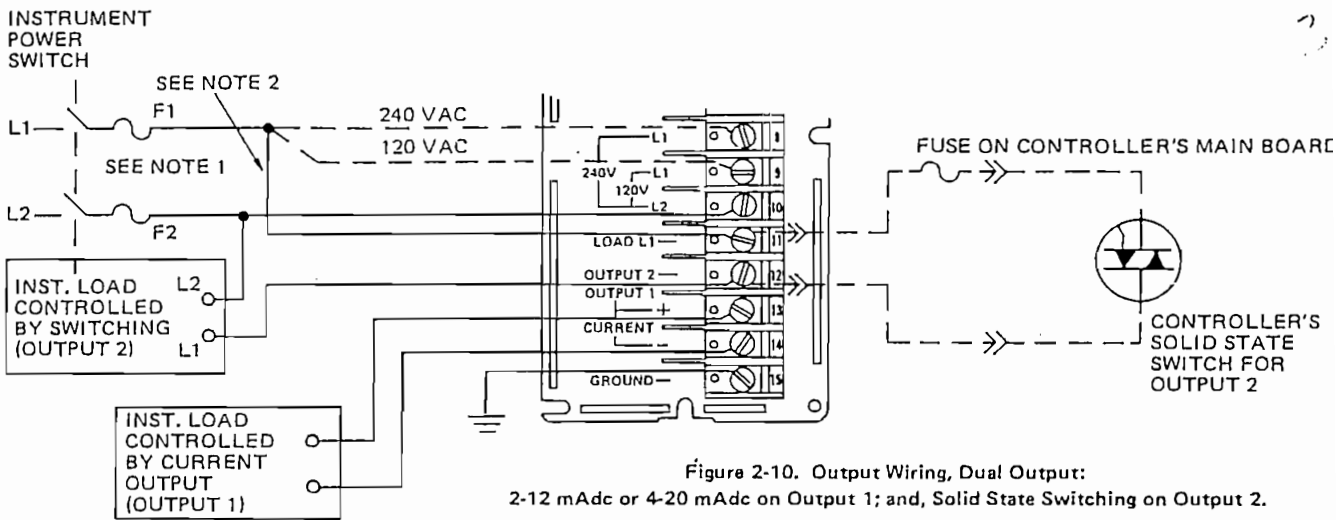


Figure 2-10. Output Wiring, Dual Output:
2-12 mAdc or 4-20 mAdc on Output 1; and, Solid State Switching on Output 2.
(522F, 523F, 524F, 522G, 523G, 524G, 522J, 523J, 524J, 522K, 523K, and 524K)

Notes:

1. Instrument power switch and instrument fuses are included for illustrative purposes only. If the L2 line is a neutral or ground line, fuse F2 is not normally recommended. Consult local codes and appropriate wiring standards.
2. OUTPUT 1: The constant current outputs of these controllers are short circuit proof. Either plus or minus may be grounded or remain floating.

Either the 2-12 mA or 4-20 mA output will drive the Model 656 Current-to-Position Converter for positioning a Barber-Colman Motor Operator or the Model P02R Current-to-Pneumatic Transducer.

Either current output will drive Barber-Colman Power Controllers.

Current Output: either 2-12mA into 1.5k ohms or less; or 4-20mA into 750 ohms or less.

3. OUTPUT 2: Instrument load power, LOAD L1, may be obtained from a separate power source in phase with the instrument power supply. Instrument signal light will not operate unless instrument L2 and instrument load L2 are connected as shown. Instrument signal light will not operate if LOAD L1 is powered by a separate source of less than 100 Vac rms.

Instrument load may be either a contactor coil, a Barber-Colman SOLID STATE CONTACTOR, or heater.

Rating of Solid State Switching Output: (both ON-OFF Time-Proportioning): 1A continuous, 20A inrush, 300VA minimum. Any voltage from 24 Vac to 240 Vac can be switched but the voltage switched must be the same phase and have same common line as the instrument power supply.

2.9 Setpoint Wiring — Isolated

2.9.1 Input Setpoint Wiring (Setpoint Options 2, 5, 7, and 8)

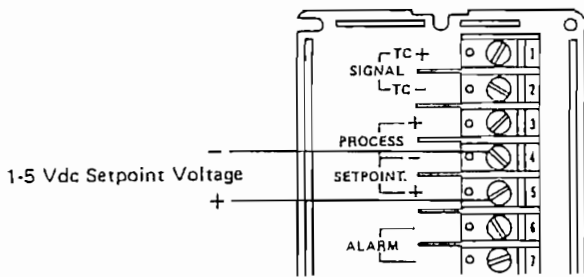


Figure 2-11. Setpoint Wiring

NOTES

1. Setpoint with Remote-Local Switch (Options 2 and 5).
Source should be free of transients and have an impedance less than 200 ohms. For operation of more than one controller from the same external source, a source resistance under 50 ohms is recommended. Typical input impedance of 1 meg ohm.
A REMOTE-LOCAL switch on the front panel allows the setpoint source to be either the front panel setpoint or the remote setpoint. For start-up or servicing the instrument may be switched to local setpoint operation. After start-up or servicing, control is returned to the remote setpoint.

2. No setpoint, requires remote setpoint voltage (Option 7)
Source should be free of transients and have an impedance less than 200 ohms. For operation of more than one controller from the same external source, a source resistance under 50 ohms is recommended.

3. Trim Setpoint (Option 8)
Requires 1-5 Vdc setpoint voltage from an external source. Source resistance up to 20 ohms. Trim control adjusts the setpoint.

A Trim Control, located in place of the Digital Setpoint, can be set to adjust the remote 1-5Vdc input setpoint signal $\pm 5\%$ span. The input setpoint signal is usually trimmed to allow correct for sensor differences or to select a desired temperature profile.

2.9.2 Output Setpoint Wiring (Setpoint Options 3 or 6)

NOTE:
1-5Vdc proportional to instrument setpoint span. Short circuit has no effect on control action. Source resistance less than 10 ohms. The Series 520 operates as a Master Controller which can transmit 1-5 Vdc output setpoint voltage to many multiple Slave Controllers.

Maximum total output current of Process Signal Output option is 10 mAdc. Output Setpoint Voltage option is 10 mAdc.

2.10 Process Signal Wiring — Isolated

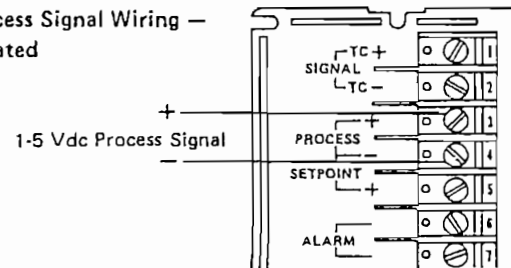


Figure 2-12. Process Signal Output Wiring (Setpoint Options 2, 3, 6, 7 and 8)

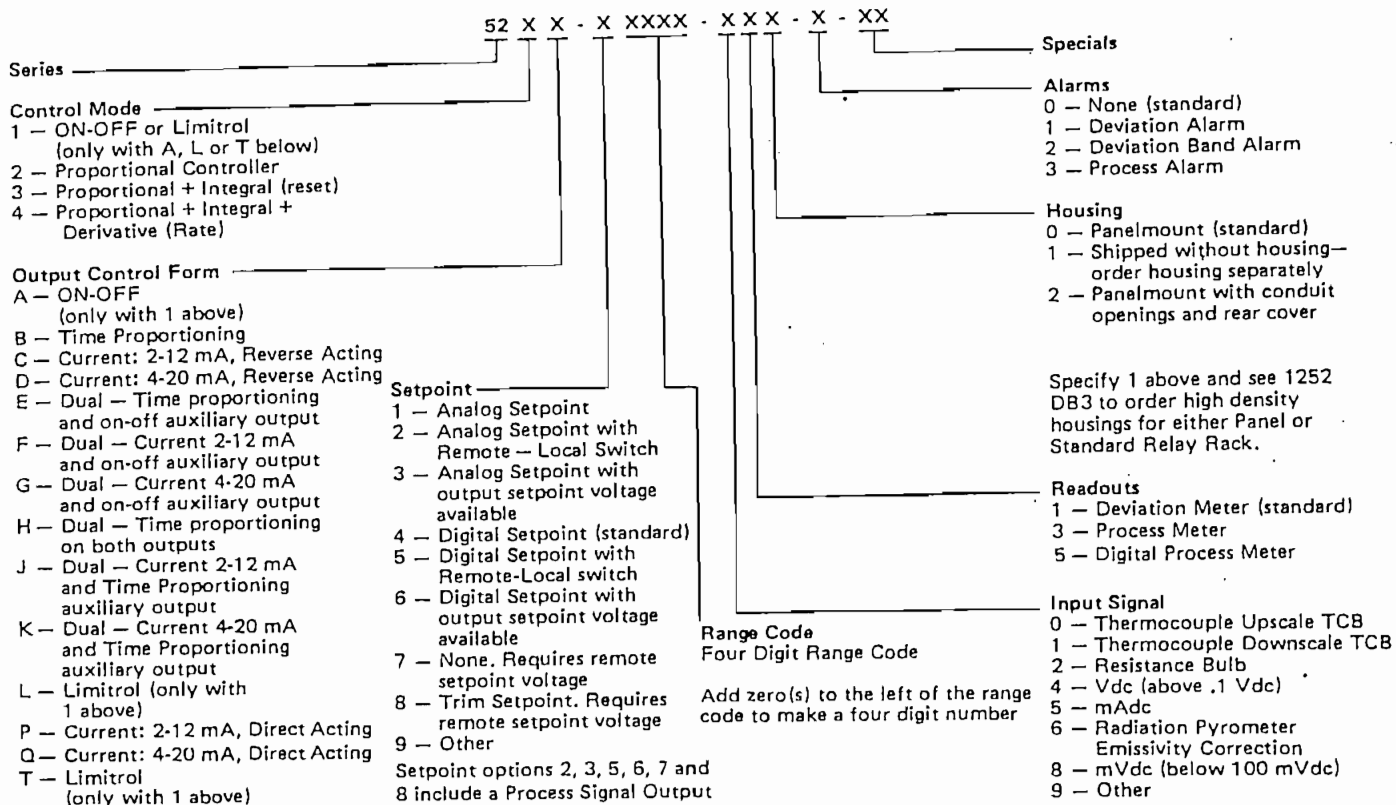
NOTE
External short circuit has no effect on control action. Source resistance less than 10 ohms.

Setpoint options 2, 3, 5, 6, 7, and 8 include Interface Signal Isolation. This means that the Process Signal and Setpoint Signal Outputs are isolated from the signal input terminals. There is also Input-Output Isolation.

Cooling Limit Adjustment on Output Control Forms H, J, and K. Continuously adjustable from 5 to 100% of time.

THIS MODEL NUMBER CODE EXPLAINS THE MODEL NUMBER STAMPED ON THE CONTROLLER

WRITE THE ENTIRE 15-DIGIT CODE WHEN ORDERING



All of the models include, as standard, indicator lights appropriate to the output form selected.

CALIBRATION CHARTS, DIGITAL SETPOINT ONLY

0 TO 799°F
DIGITAL RANGE CODE 0016

True Temp °F	Dial Setting or DPM Reading	Setpoint Voltage	Input mV
0	12	1.059	-0.89
50	57	1.286	0.51
100	104	1.520	1.94
150	152	1.759	3.41
200	200	2.003	4.91
250	250	2.250	6.42
300	299	2.499	7.95
350	349	2.749	9.48
400	400	3.000	11.02
450	450	3.252	12.57
500	500	3.503	14.11
550	550	3.754	15.65
600	600	4.005	17.19
650	650	4.255	18.72
700	700	4.505	20.25
750	750	4.755	21.78
799	799	5.000	23.29

0 TO 598°F
DIGITAL RANGE CODE 0015

True Temp °F	Dial Setting or DPM Reading	Setpoint Voltage	Input mV
0	10	1.069	-0.89
25	33	1.219	-0.20
50	56	1.373	0.51
75	79	1.528	1.22
100	103	1.686	1.94
125	127	1.846	2.67
150	151	2.007	3.41
175	175	2.170	4.16
200	200	2.333	4.91
225	224	2.498	5.66
250	249	2.664	6.42
275	274	2.830	7.18
300	299	2.997	7.95
325	324	3.165	8.71
350	349	3.333	9.48
375	375	3.501	10.25
400	400	3.669	11.02
425	425	3.838	11.79
450	450	4.006	12.57
475	475	4.175	13.34
500	501	4.343	14.11
525	526	4.511	14.88
550	551	4.679	15.65
575	576	4.847	16.42
598	599	5.000	17.12

200 TO 1190°F
DIGITAL RANGE CODE 0203

True Temp °F	Dial Setting or DPM Reading	Setpoint Voltage	Input mV
200	202	1.010	4.91
250	251	1.206	6.42
300	301	1.404	7.95
350	351	1.603	9.48
400	401	1.803	11.02
450	451	2.003	12.57
500	501	2.203	14.11
550	550	2.403	15.65
600	600	2.603	17.19
650	650	2.802	18.72
700	700	3.000	20.25
750	749	3.199	21.78
800	799	3.398	23.32
850	849	3.597	24.85
900	899	3.797	26.40
950	949	3.999	27.95
1000	1000	4.202	29.52
1050	1051	4.407	31.10
1100	1103	4.616	32.71
1150	1156	4.827	34.34
1190	1199	5.000	35.67

0 TO 1999°F
DIGITAL RANGE CODE 0030

True Temp °F	Dial Setting or DPM Reading	Setpoint Voltage	Input mV
0	13	1.027	-0.69
100	109	1.217	1.52
200	208	1.415	3.82
300	305	1.611	6.09
400	401	1.803	8.31
500	498	1.996	10.56
600	597	2.194	12.85
700	697	2.394	15.18
800	798	2.596	17.52
900	899	2.800	19.88
1000	1001	3.004	22.25
1100	1103	3.208	24.62
1200	1205	3.411	26.98
1300	1305	3.612	29.31
1400	1405	3.812	31.63
1500	1504	4.009	33.91
1600	1601	4.203	36.17
1700	1696	4.394	38.39
1800	1790	4.583	40.58
1900	1883	4.768	42.73
1999	1974	4.950	44.83

Barber-Colman Company
INDUSTRIAL INSTRUMENTS DIVISION

1300 Rock Street, Rockford, Illinois, U.S.A., 61101

4.2 Isolation Board Adjustments (All Setpoint Options Except 1 and 4)

This adjustment should be performed only if the Isolation Board A-11121-1 is plugged in and jumpers JA, JB, JC, JD, and JE on the Main Board have been clipped.

1. Place Fluke-meter leads on P6, Pin 7 and Pin 11. Adjust R13 on Isolation Board for +15 volts $\pm .1\%$.
2. Place Fluke-meter leads on P6, Pin 4 and Pin 11. Voltage should be -5.1 volts $\pm 5\%$ (4.845V to 5.355V). If it is not in this range diode D8 may be defective.
3. Place a clip-on jumper from P6, Pin 11 to Pin 14. Also, place a Fluke-meter from P6, Pin 1 to P6 Pin 5.
4. Observe the mV reading obtained with the input signal at mid-span. Vary the input signal from the PORTABLE POT, throughout the instrument process range (2V to 10V), and adjust R1 on the Isolation Board for minimum change over the full process span. The Isolation Board should track within .1% of the process span. Example: Process Range = 2V to 10V; Process Span = 8V = 8000 mV (.1% = 8 mV). Note: Tracking may not occur at 0 Vdc offset. Tracking above 40 mV offset may indicate a D1-D2 mismatch, or a bad isolation transformer.
5. Now, with the +15V isolated supply calibrated, and the isolator tracking adjusted with setpoint at medium scale, recalibrate the process output. Disconnect jumper installed in step 3 and adjust R8 on Main Board for 6V $\pm .1\%$.
6. Measure the deviation output of IC3A as follows: Connect the positive probe to Pin 1 of P5, and the negative probe to Pin 7 of P5. The precision voltmeter should read 0 Vdc $\pm .025$ Vdc. Adjust R8 for zero deviation. Do not make any other adjustment but this — move the SETPOINT ADJUST control to zero. Voltmeter should read -4 Vdc $\pm .08$ Vdc. Lastly, move the SETPOINT ADJUST control to full scale. Voltmeter should read +4 Vdc $\pm .08$ Vdc.
7. Next, go back to the Main Board Adjustments and do the Meter Span Adjustment.

Table 4-2. Isolation Board A-11121-1, Parts List

Symbol	Part Number	Description
CAPACITORS		
C1,2,3	39-400	10uF, 20%, 15 WVDC, Tantalum
C4	39-466	.0047uF, 10%, 50 WVDC, Polycarbonate
C5	39-163	100uF, +100-10%, 50 WVDC, Electrolytic
C6	39-076	250pF, 20%, 500 WVDC, Ceramic
C7	CYZR-803	.1uF, 20%, 40 WVDC, Monolithic Ceramic
DIODES		
D1,2	A-10057	60 PIV, $I_f = 100$ mA, Matched Threshold
D3	37-179	6.2V Zener, 5%, 400 mW
D4,5,6,7	EYZP-384	250 PIV, $I_f = 100$ mA, Silicon Diode
D8	37-162	5.1V Zener, 5%, 400 mW
INTEGRATED CIRCUITS		
IC1	31-1015	Dual 741 Minidip Op Amp
IC2	31-1002	709 Op Amp
IC3	31-1012	741C Op Amp Minidip
IC4	31-1010	723C Voltage Regulator
TRANSISTOR		
O1	EYZP-632	2N4124 NPN Silicon
RESISTORS		
Resistors are 10%, 1/4W, unless stated otherwise.		
R1	29-377	2k, 20%, 1/2W, Potentiometer
R2	E19-29-328	19.1k, .5%, 1/8W
R3	40-1950	22k
R4,6,7	40-1847	47k
R5	40-1845	29k
R8,9	CYZR-864-330	20k, 5%, 1/8W
R10	E19-35-943	2.7 ohms
R11	CYZR-861-218	1.5k, 1%, 1/8W
R12	CYZR-864-251	3.32k, .5%, 1/8W
R13	29-418	1k, 20%, 1/2W, Potentiometer
R14	CYZR-864-247	3.01k, .5%, 1/8W
TRANSFORMER		
T1	30-319-1	Modulator



Series 520 Troubleshooting Main Board and Range Boards, Changing Ranges

This Manual Section is only for Blue Boards.

5. TROUBLESHOOTING

5.1 General

All of the Controller, except the preamplifier stage of IC1, can be troubleshot with a VOM of 20,000 ohms/volt sensitivity. Do not attempt to make major repairs on the Main Board. Minor repairs such as replacing broken pins may be made. Recalibrate the Main Board if you replace any critical component on it.

When making repairs on printed circuit boards or soldering transistor or integrated circuit terminals, use a 35 watt or less soldering iron and 63/37 or 60/40 resin core solder.

Following is a list of instruments for field troubleshooting the Controller.

Oscilloscope with calibrated sweep or equivalent (required to check waveforms).

Accurate DC Voltmeter

Strip Chart Recorder

In any general troubleshooting procedure, always do paragraph 5.2 first.

5.2 Power Supply Board

Measure all voltage outputs. If any part is replaced the controller must be completely recalibrated.

5.3 Excessive Drift of Either Setpoint or Process Temperature

The drift may be due to thermocouple deterioration. Thermocouple deterioration is usually found in a periodic inspection program. To determine thermocouple deterioration place the test thermocouple as close to the thermocouple under test as possible. If the output of the thermocouple under test differs from what is acceptable by the user (outside his or the manufacturer's specifications) then the thermocouple is defective.

Inspect thermocouple to leadwire and leadwire to controller connections to be certain they are covered properly so that air drafts across them are not affecting temperature indications by causing temperature gradients.

Measure the line voltage. It must be within the specified range.

5.4 Preamplifier IC1 and Range Board

Troubleshooting the Preamplifier stage of IC1 and the Range Board to which it is connected, requires battery operated voltmeters with input impedances of 10M ohms or higher.

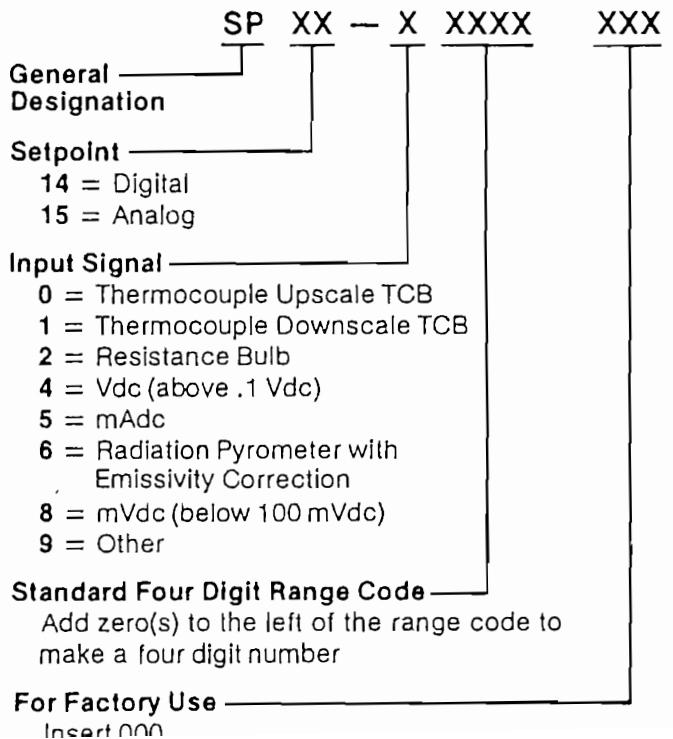
Battery operated test instruments with such an input impedance are the Hewlett-Packard Company Model 427A Multi-Function Meter and the John Fluke Manufacturing Company Model 871AB DC Differential Voltmeter. The remainder of the controller following the DC Amplifier may be troubleshot with a VOM with a 20,000 ohms/volt voltmeter or higher sensitivity.

5.5 Thermocouple Break Check

- 1. Disconnect any input (TC or dc millivolt source).
2. The Temperature Indicator should go full scale.
3. A milliammeter connected across the current output terminals should indicate zero.

5.6 Range Board Assemblies

Individual components on this assembly should not be replaced. When ordering a complete range board assembly, the following code must be written.



STANDARD RANGES FOR DIGITAL SETPOINTS AND FOR ANALOG SETPOINTS WITH SINGLE RANGE TEMPERATURE DIAL DIVISIONS

Thermocouple Ranges

Range	Code Number for Range and Thermocouple Type					Tungsten 5% Rhenium- Tungsten 26% Rhenium*
	J	K	R	S	B	
0-399°F	56					
0-499°F	306					
0-599°F	15					
0-799°F	16					
0-999°F	17	207				
0-1999°F		30	166	316		
0-2999°F			38	36	1814	
2000-3999°F						3382
200-799°F	751					
200-1199°F	203	2411				
500-1499°F	2980	3406				
1300-2299°F		3531				
0-399°C	22					
0-499°C	23					
0-599°C	24	110				
0-799°C		32				
0-999°C		33	276			
0-1999°C					3611	2552
200-1199°C		185	1597	3713		
500-1499°C			521	1395		3719

*No Symbol. Positive Wire is Hoskins Alloy 405. Negative Wire is Hoskins Alloy 426.

J—Iron Constantan K—Chromel Alumel R—Plat 13%
S—Plat 10% B—Plat 30% Rh/Plat 6% Rh

STANDARD RANGES FOR ANALOG SETPOINTS (°F AND °C) WITH DUAL RANGE TEMPERATURE DIAL DIVISIONS

The temperature range listed in column 1 is marked on the inner scale of the dial.

Thermocouple Ranges

Range	Code Number J
0-800°F	231
200-800°F	3644

RESISTANCE TEMPERATURE DETECTOR (RTD) RANGES

(100 ohm Resistance Bulb)

Range	Code Number For Range and Platinum RTD
0-100°F	3800*
0-599°F	3804
0-799°F	3805
200-799°F	3807
0-399°C	3810

*Digital Indicator reads 0 to 99.9

Range	Standard Millivolt Ranges- Uncompensated
0-9.99mV	381
0-49.9mV	1054
0-99.9mV	2892
-5 to 0 to +5mV	1324*

*Available only with Analog Setpoint

STANDARD RANGES FOR ANALOG SETPOINTS WITH SINGLE RANGE TEMPERATURE DIAL DIVISIONS

Cryogenic (Low Temperature) Ranges

Range	J	T	100 RTD PT*
-400°F to 0°F	—	—	3888
-300°F to +300°F	318	545	—
-100°F to +100°F	—	—	3816

* The RTD range cards are calibrated for the ranges specified and apply to a 100 ohm (at 0°C) platinum element with a temperature coefficient of .00391 ohm/ohm/°C. Consult factory for other ranges and for sensors with other temperature coefficients.

5.7 Changing Ranges

5.7.1 IDENTICAL RANGES

Changing range boards with identical ranges is very easy. Unplug the old range board and plug in the new range board. The new range board is factory calibrated and no calibration is required.

5.7.2 CHANGING FROM ONE SPAN TO ANOTHER WITHIN THE SAME KIND OF RANGE

For example, suppose a 0-399°F range board is replaced by a 0-599°F range board. The digital setpoint will still be effective but only up to 399°F. The setpoint must be modified. Also, the 6 Vdc Process Signal Adjustment and the 3 Vdc Setpoint Voltage Adjustment on the Main Board must be adjusted. Don't forget that any process meter should be replaced.

5.7.3 CHANGING BOTH SPANS AND KINDS OF RANGES

For example, suppose a 0-399°F range board is replaced by a 0-49.9 mV range board. The digital set-

point must be modified. The 6 Vdc Process Signal Adjustment and the 3 Vdc Setpoint Voltage Adjustment on the Main Board must be adjusted. Any process meter scale must be replaced.

5.8 Setpoint Switch Assemblies

Digits	Part Number	Digital Span
3	A-10342-100	0-X99
3	A-10342-200	200-X99
3	A-10342-300	500-X99
3	A-10342-400	1300-XX99
4	A-10343	0-9999

5.9 Modifying a 3-Digit Setpoint Assembly to Change its Range

To install the setpoint assembly, proceed as follows:

1. Hold modules and mounting cover together. Place one of the straps up from the bottom. Place second strap down with the short ends meeting the long ends. Short end should overlap on both sides and snap in place.
2. To set left most thumbwheel switch of the setpoint assembly (hundreds position) to minimum value of the required range, insert switch stop pin (part number 11-3413) into position 1. See example.
3. To set left most thumbwheel switch of the setpoint assembly (hundreds position) to the maximum value of the required range minus one, insert switch stop pin (part number 11-3413) into position 2. See example. Pins are not required for the ranges from 0 to 999.

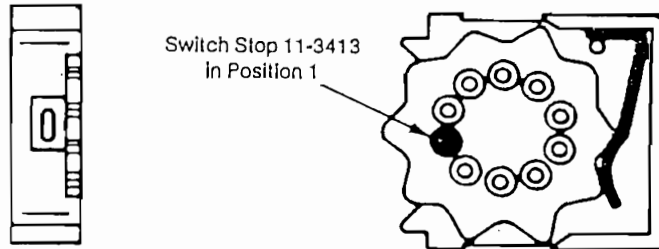
5.10 Modifying a 4-Digit Setpoint Assembly to Change its Range

To install the setpoint assembly, proceed as follows:

1. Hold modules and mounting together. Place one of the straps up from the bottom. Place second strap down with the short ends meeting the long ends. Short end should overlap on both sides and snap in place.
2. To set left most thumbwheel switch of the setpoint assembly (thousands position) to the minimum value of the required range, insert switch stop pin (part number 11-3413) into position 1. See example.
3. To set left most thumbwheel switch of the setpoint assembly (thousands position) to the maximum value of the required range minus one, insert switch stop pin (part number 11-3413) into position 2. See example.

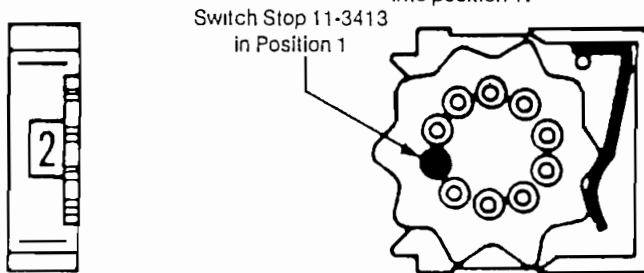
Example: 0 to 2999°F

Set left most thumbwheel switch to 0 and insert pin into position 1.

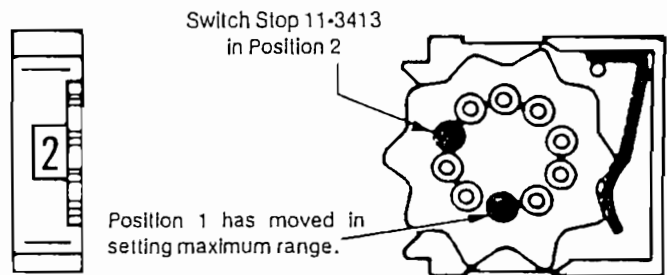


Example: 200 to 799°F

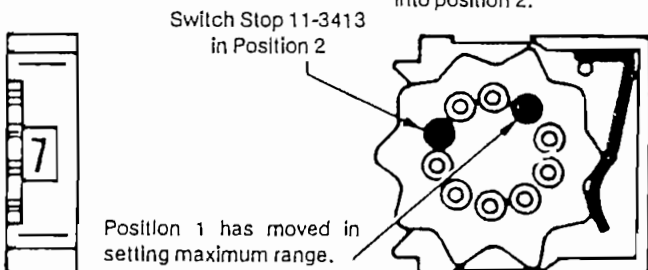
Set left most thumbwheel switch to 2 and insert pin into position 1.

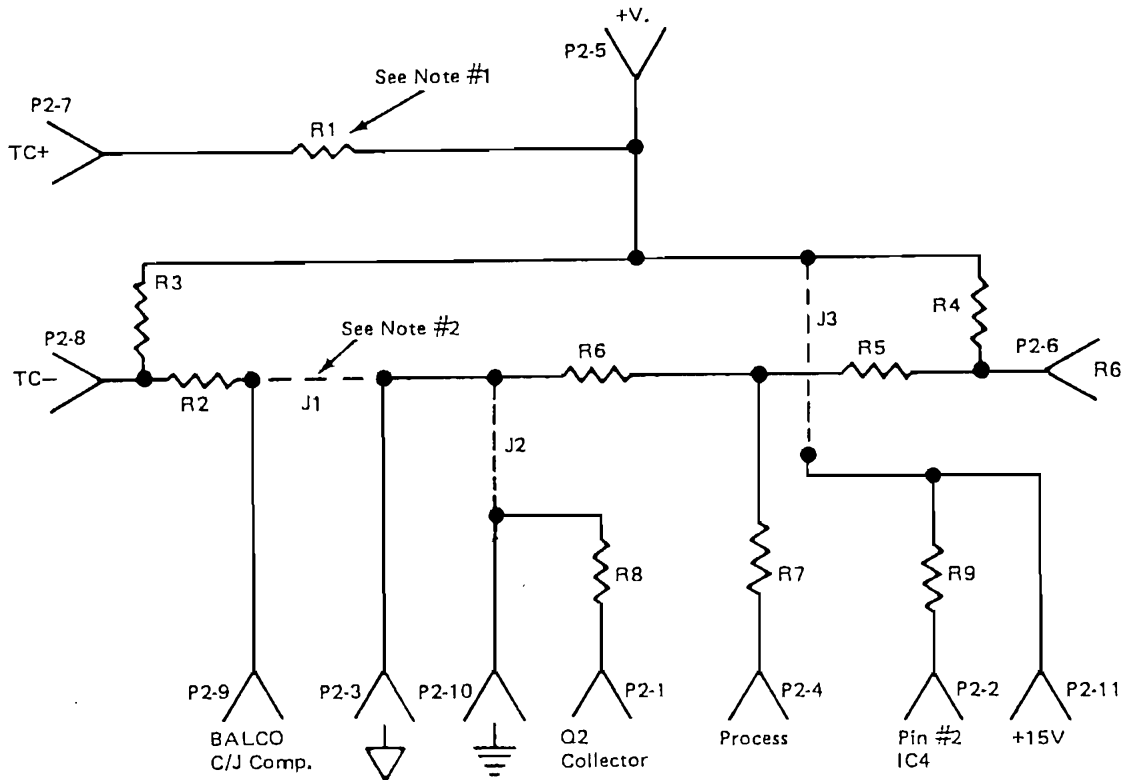


Set left most thumbwheel switch to 2 and insert pin into position 2.



Set left most thumbwheel switch to 7 and insert pin into position 2.

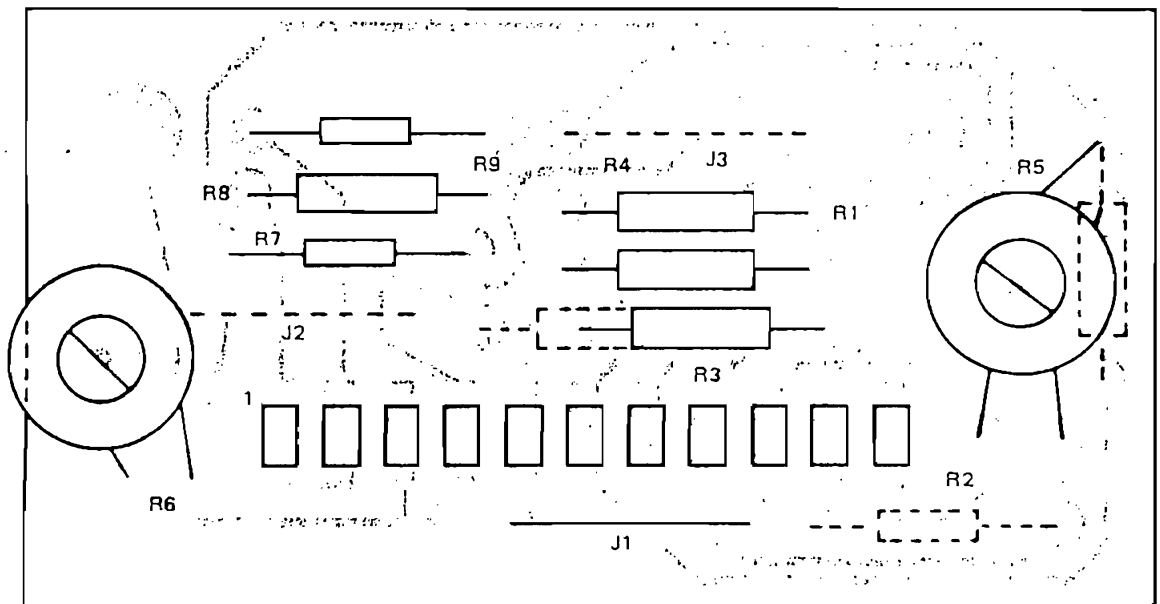




Notes

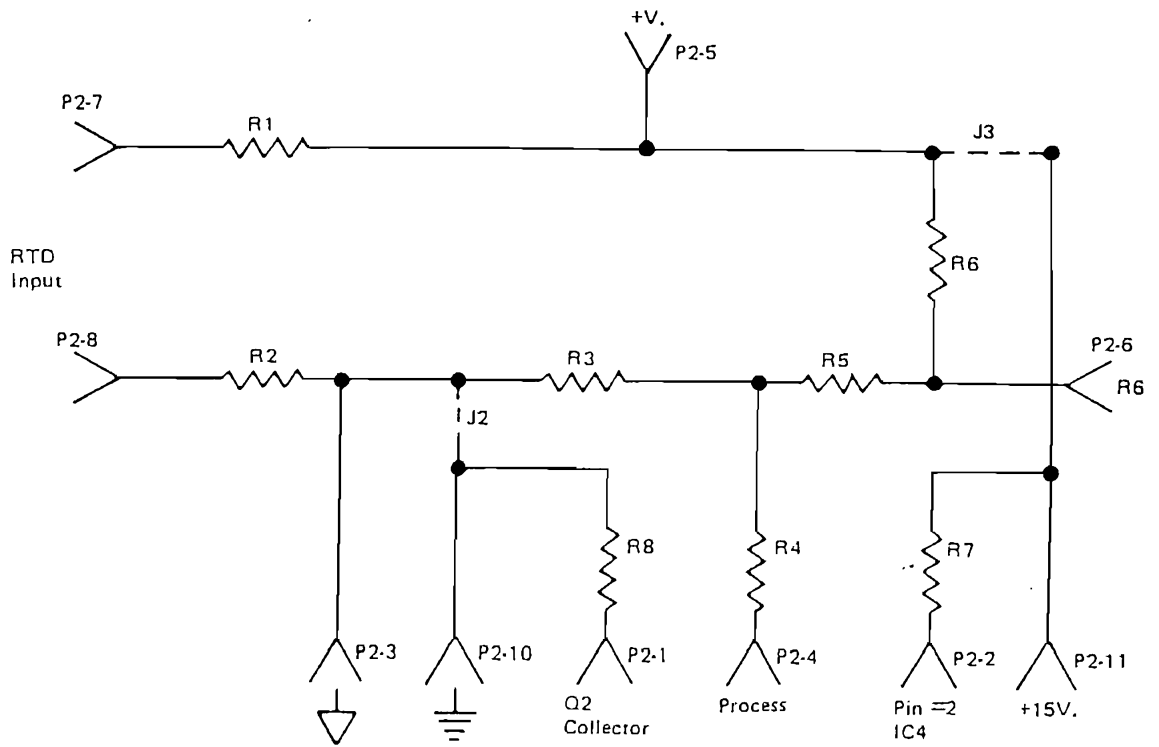
1. R1 is omitted for downscale TCB.
2. J1 is inserted for mV and Type B T/C ranges only.
3. J2 and J3 on SP05 and SP06.
4. R8 and R9 on Digital Setpoints.

R1 is the standard thermocouple break protection resistor. Resistors R2 and R5 set the required millivolt suppression to achieve the 2 to 10 Vdc process signal. R3 determines the current for the cold junction compensation by R2 on the Main Board. R6 and R7 are the preamplifier gain resistors. Resistors R8 and R9 are for span and suppression of the setpoint, respectively.



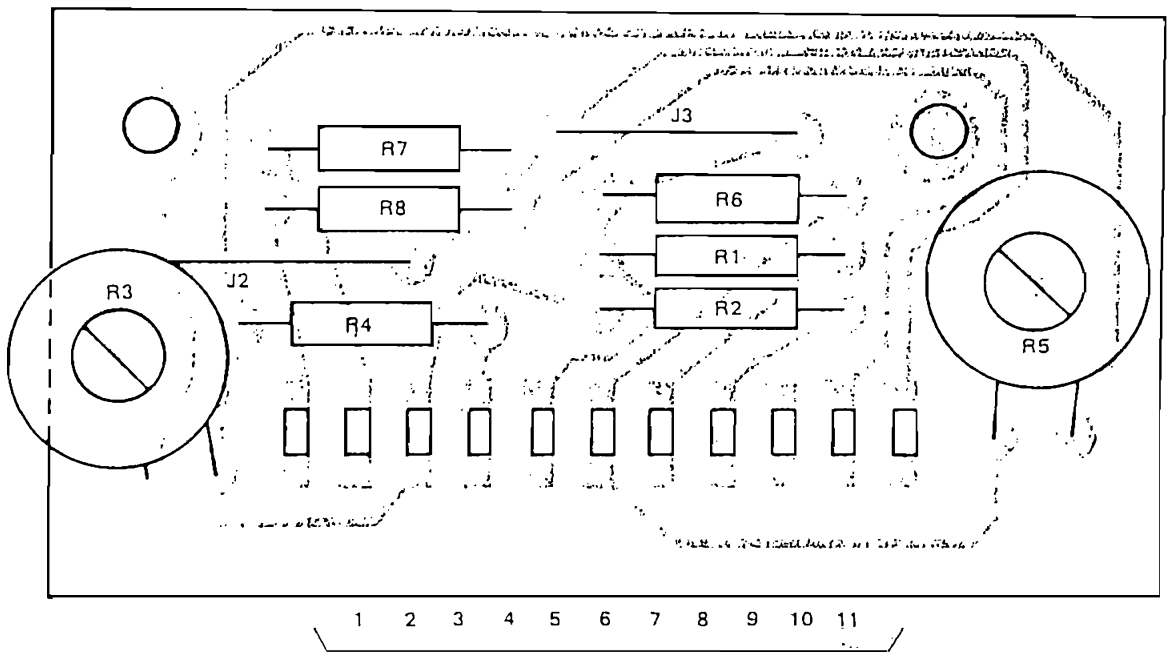
Board Connector Numbers—P2 Plugs Into Main Board

Figure 5-1. Thermocouple and Millivolt Range Board and Schematic



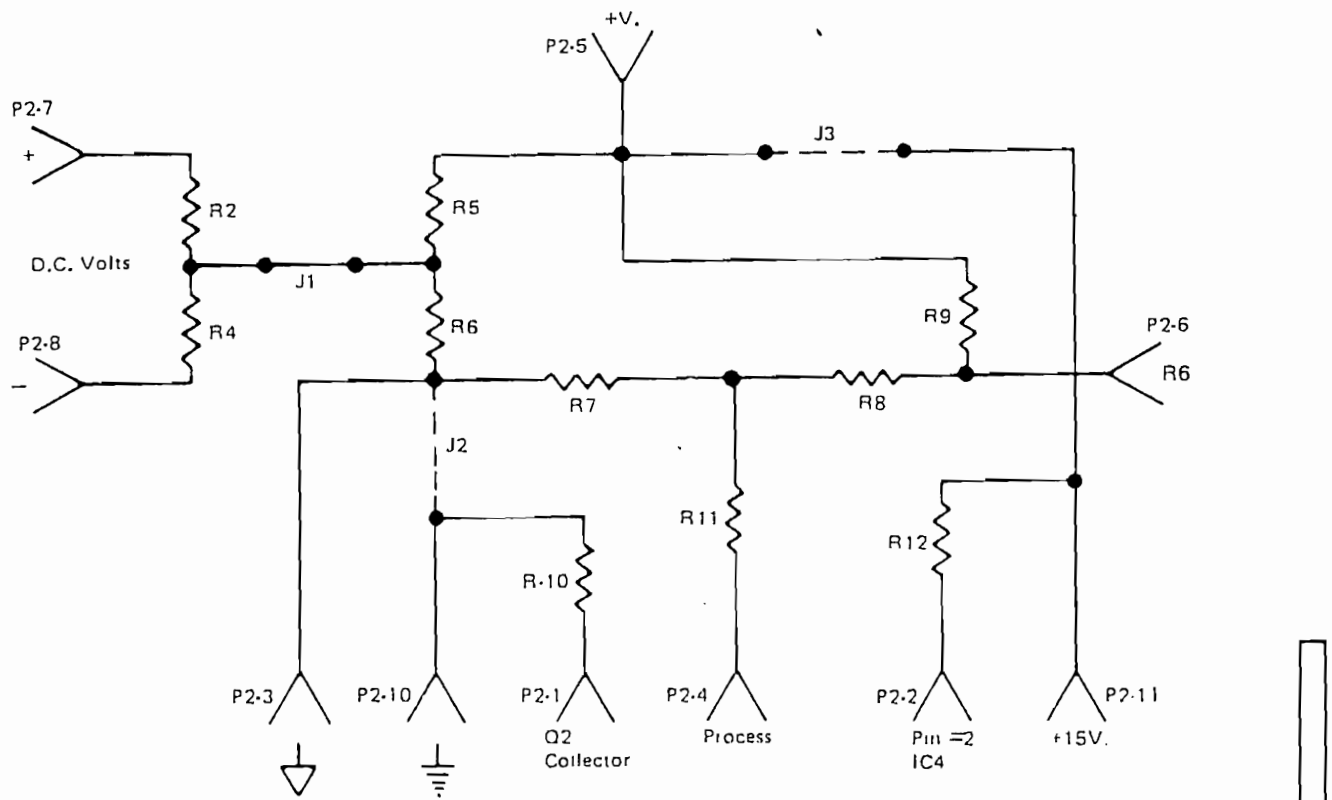
Notes

1. J2 and J3 on SPO5 and SPO6.
2. R8 and R7 on Digital Setpoints



Board Connector Numbers—P2 Plugs Into Main Board

Figure 5-2. Resistance Temperature Detector (RTD) Range Board and Schematic



Notes

1. J2 and J3 on SPO5 and SPO6.
2. R10 and R12 on Digital Setpoints

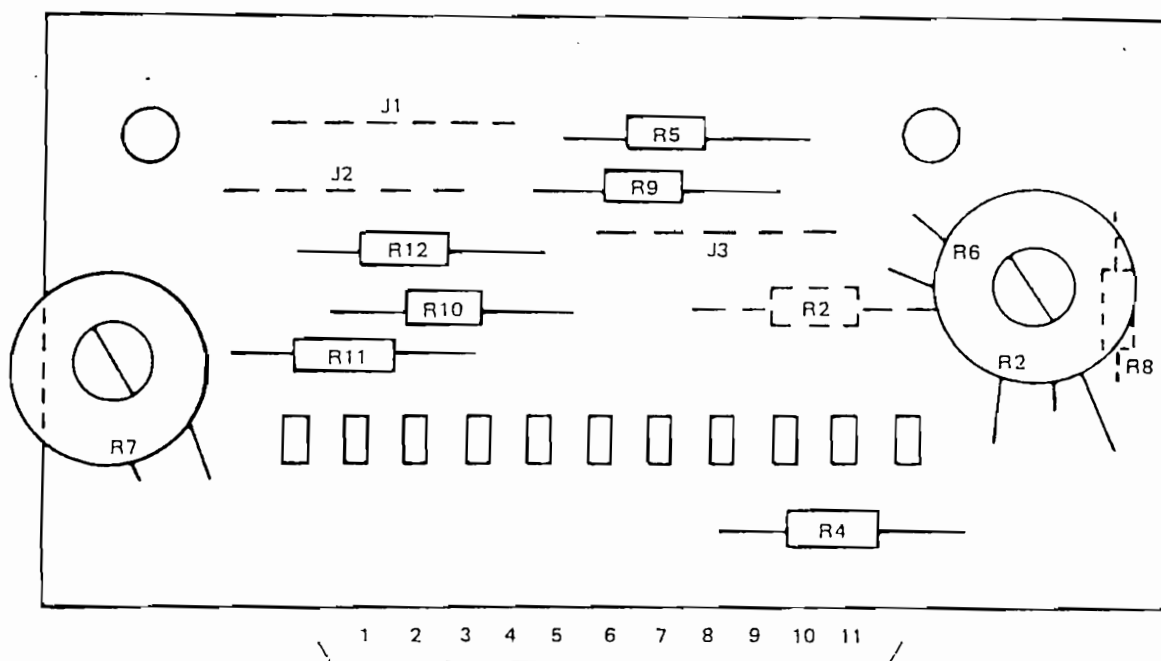
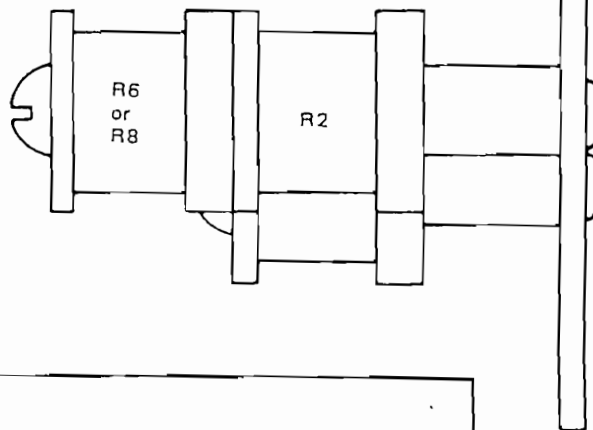
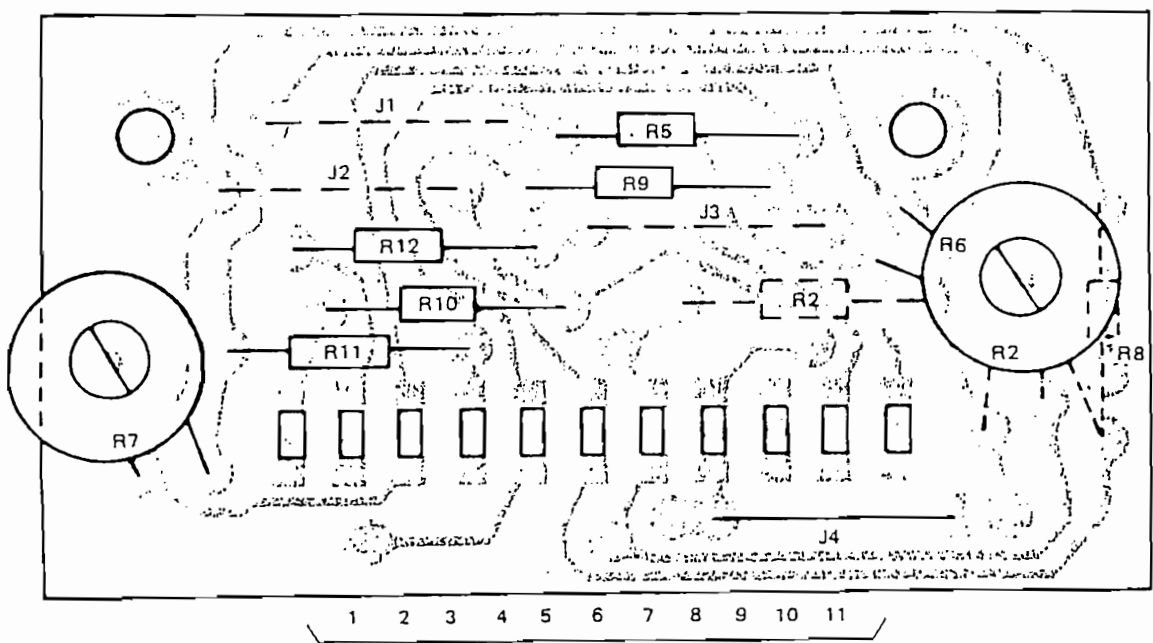
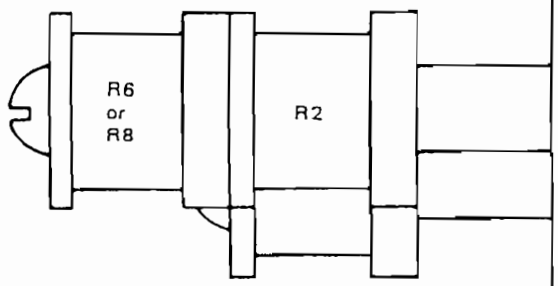
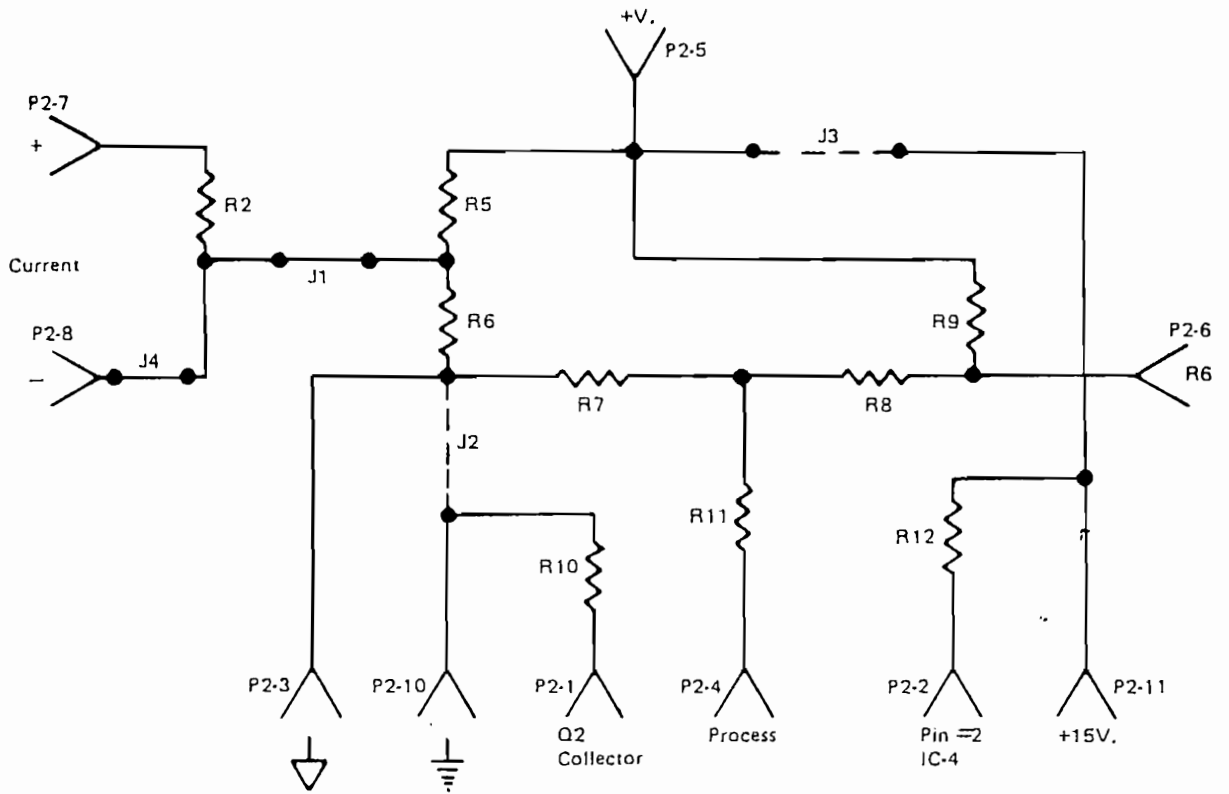
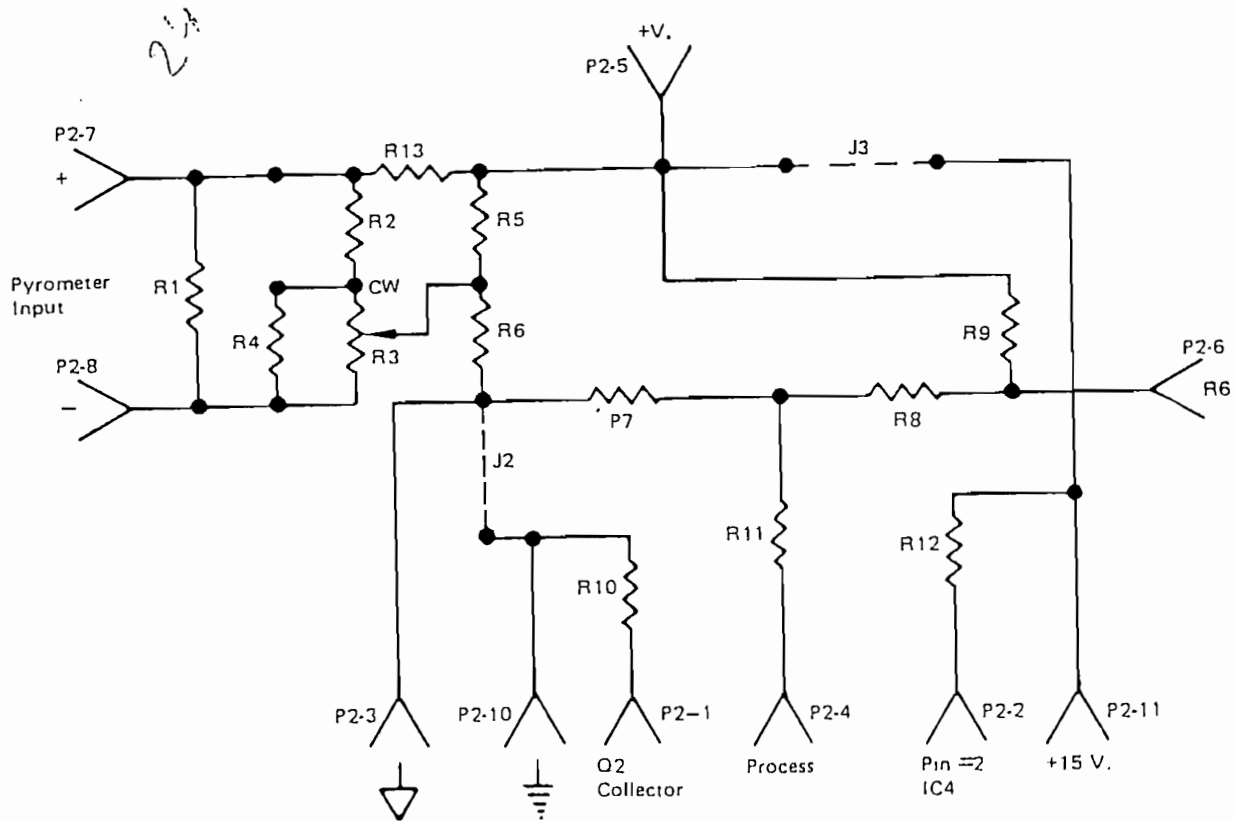


Figure 5-3. Voltage (both above and below .1 Vdc) Range Board and Schematic Board Connector Numbers—P2 Plugs Into Main Board

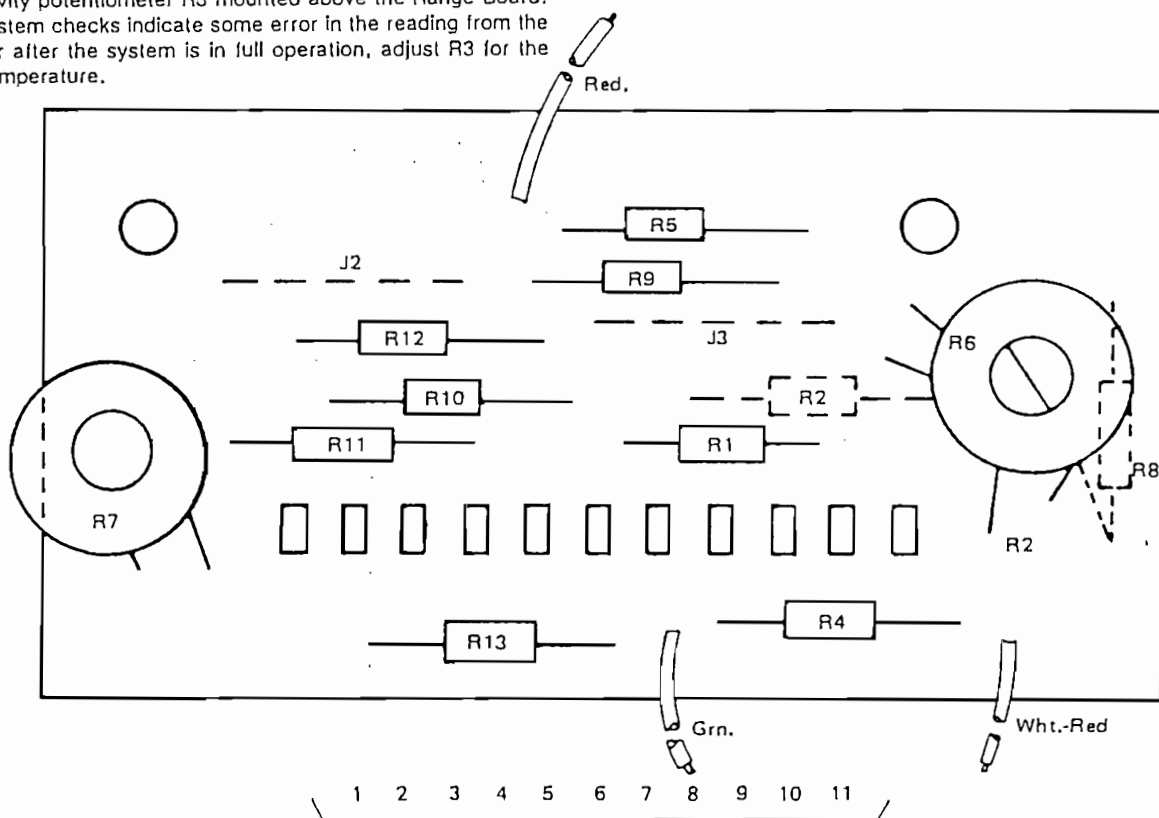


Board Connector Numbers—P2 Plugs Into Main Board

Figure 5-4. Current (mAdc) Range Board and Schematic



To Emissivity potentiometer R3 mounted above the Range Board. Should system checks indicate some error in the reading from the Pyrometer after the system is in full operation, adjust R3 for the correct temperature.



Board Connector Numbers—P2 Plugs Into Main Board

Figure 5-5. Radiation Pyrometer with Emissivity Correction Range Board and Schematic

Barber-Colman Company
INDUSTRIAL INSTRUMENTS DIVISION

1300 Rock Street, Rockford, Illinois, U.S.A., 61101



Service Information

SERIES 520 CIRCUIT DESCRIPTION AND SERVICE ALARM BOARD

This Manual Section is only for Blue Boards.

6. Alarms

6.1 GENERAL

Connections and adjustments for the Alarm Circuit are given in the Installation and Wiring Section for this manual. The alarm circuit is a simple voltage sensing circuit that drives a relay with an alarm contact rating of 2A at 120 Vac. The ALARM SET resistor R1 on the Main Board generates the reference voltage to which the process or deviation signal is compared at the input pins of IC1 on the alarm board. The ALARM SET resistor R1 is located at the upper left corner of the schematic of Figure 3-2.

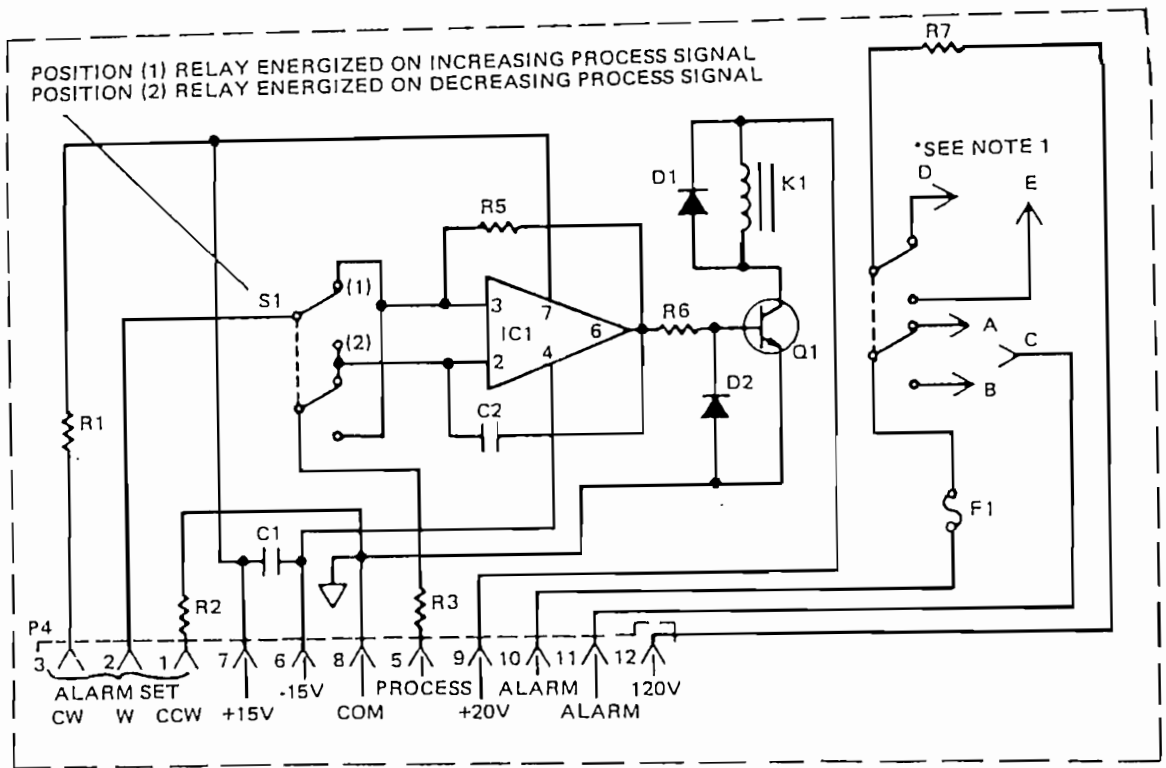
6.2 PROCESS AND DEVIATION ALARMS

The operation of both alarms is the same except for the input. The Process Signal input is on pin 5 on Figure 6-1. The Deviation Signal input is on pin 4 on Figure 6-2. If either the Deviation or Process Signal causes IC1 to turn on, the positive going output of IC1 turns on Q1, energizing K1. When K1 is energized, the front panel red alarm lamp goes off and remains off until IC1 turns off, deenergizing K1.

6.3 DEVIATION BAND ALARM

The Deviation Signal input is on pin 4 on Figure 6-3. IC1B and D1 form an "absolute value" circuit. The polarity of the "error" signal on the cathode of D1 always goes from 0 Vdc to a positive voltage with either a positive or a negative Deviation Signal on pin 4. The incoming Deviation Signal can swing to +4 Vdc or to -4 Vdc, depending on whether the process is above or below setpoint. The amplitude of the voltage on the cathode of D1 must always equal the amplitude of the voltage of the Deviation Signal. For example, if the Deviation Signal is either -4 Vdc or +4 Vdc, the voltage from the cathode of D1 to pin 8 (common) is +4 Vdc in both cases. The "error" voltage on the cathode of D1 is compared with the alarm trip point voltage set by the ALARM SET resistor R1 on the Main Board. If the "error" signal causes IC1 to turn on, the positive going output of IC1 turns on Q1, energizing K1. When K1 is energized, the front panel red lamp goes off and remains off until IC1 turns off.

25



*Note 1: One lead of Alarm Pilot Light connects to either point D or E. The other lead connects to pin 1 on the Main Board.

SOLDERLESS TERMINALS A, B, E, AND D ARE RELAY CONNECTIONS FOR JUMPERS

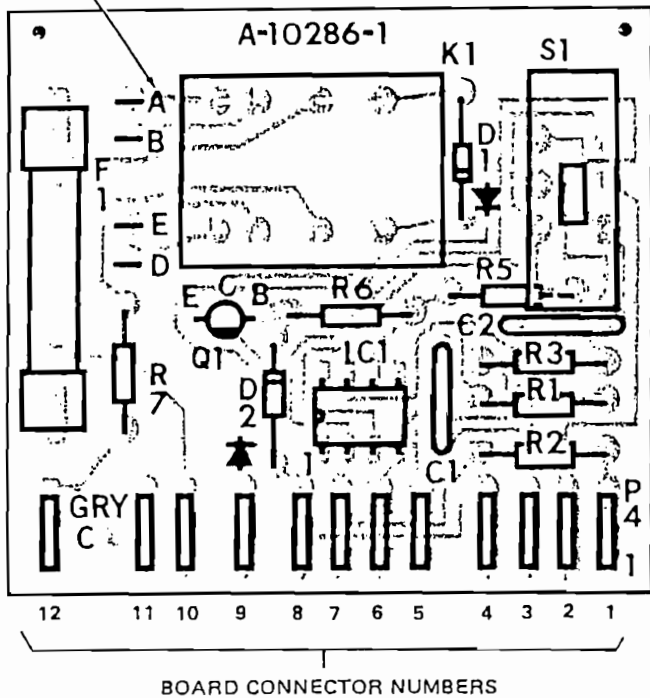
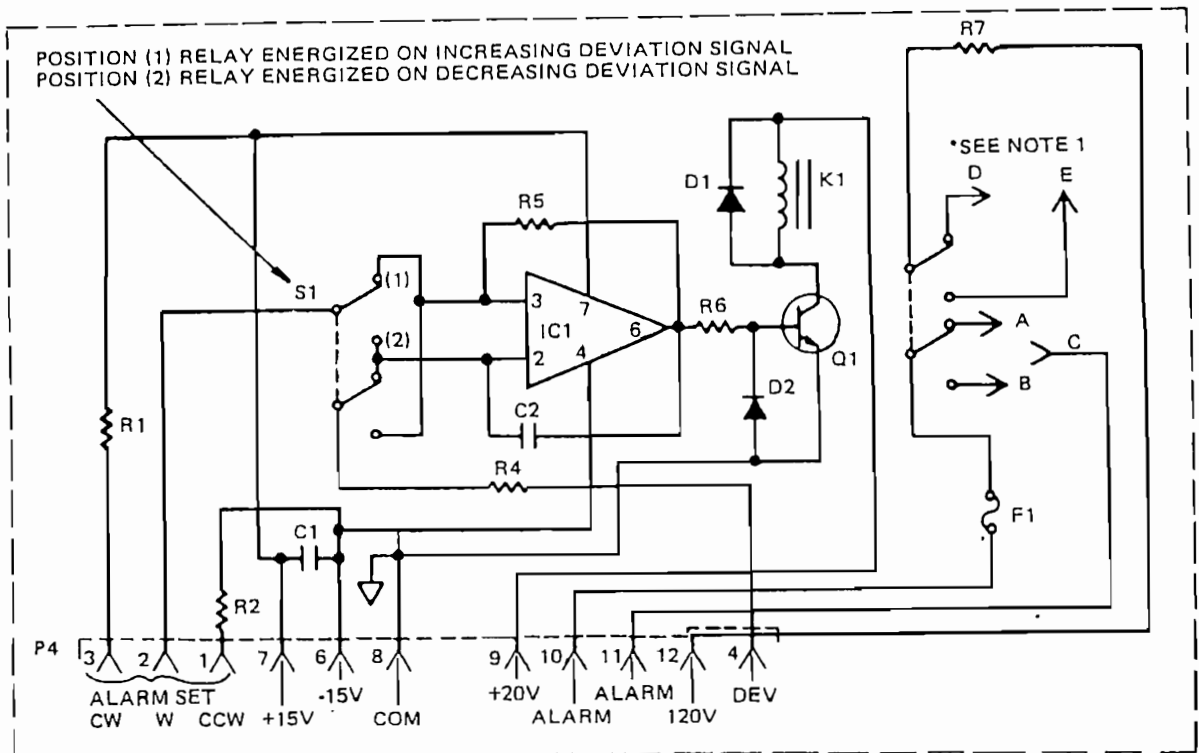


Figure 6-1. Process Alarm Board A-10286-1 and Schematic

Symbol	Part Number	Description
CAPACITORS		
C1,2	39-325	.05 uF 20% 100 WVDC
DIODES		
D1,2	EYZP-384	250PIV, I _T = 100 mA
FUSE		
F1	SYZE-206	2A, type AGC2
INTEGRATED CIRCUIT		
IC1	31-1012	741C Operational Amplifier
RELAY		
K1	38-205	DPDT, 20 Vdc, 12 mA
TRANSISTOR		
Q1	31-082	2N3416
RESISTORS		
Resistors are 10% tolerance, 1/4W, unless stated otherwise		
R1	CYZR-861-348	30.9k ohms 1%, 1/8W
R2	CYZR-861-310	12.4k ohms 1%, 1/8W
R3	CYZR-836-334	22k ohms
R5	40-1871	10M ohms
R6	40-1950	22k ohms
R7	40-1706	120k ohms 5%
SLIDE SWITCH		
S1	32-388	DPDT

Table 6-1. Process Alarm Board A-10286-1 Parts List



SOLDERLESS
 TERMINALS A, B, E,
 AND D ARE RELAY
 CONNECTIONS FOR
 JUMPERS

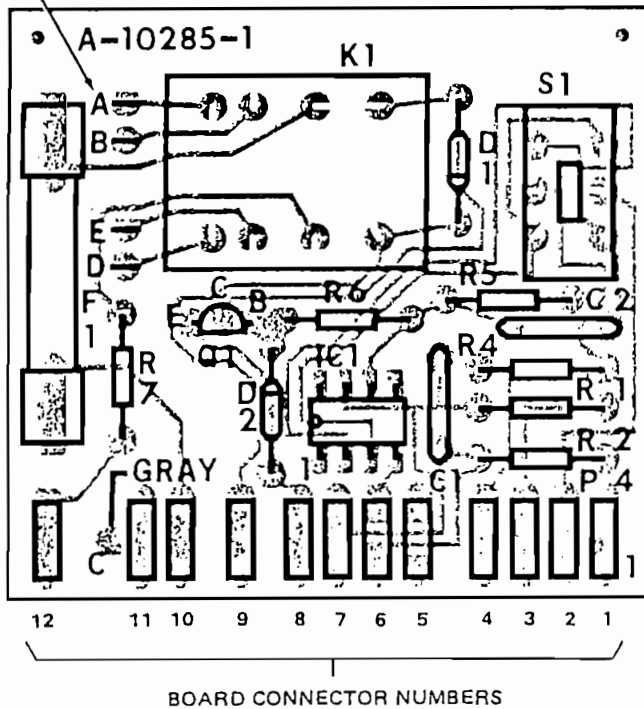


Figure 6-2. Deviation Alarm Board A-10285-1 and Schematic

Symbol	Part Number	Description
CAPACITORS		
C1,2	39-325	.05 uF 20% 100 WVDC
DIODES		
D1,2	EYZP-384	250 PIV, I _f = 100 mA
FUSE		
F1	SYZE-206	2A, type AGC2
INTEGRATED CIRCUIT		
IC1	31-1012	741C Operational Amplifier
RELAY		
K1	38-205	DPDT, 20 Vdc, 12 mA
TRANSISTOR		
Q1	31-082	2N3416
RESISTORS		
Resistors are 10% tolerance, 1/4W, unless stated otherwise		
R1	CYZR-861-307	11.5k ohms 1%, 1/8W
R2	CYZR-861-305	11.0k ohms 1%, 1/8W
R4	40-1552	8.2k ohms
R5	40-1808	2.7M ohms
R6	CYZR-481-160	22k ohms
R7	40-1706	120k ohms 5%
SLIDE SWITCH		
S1	32-388	DPDT

Table 6-2. Deviation Alarm Board A-10285-1 Parts List

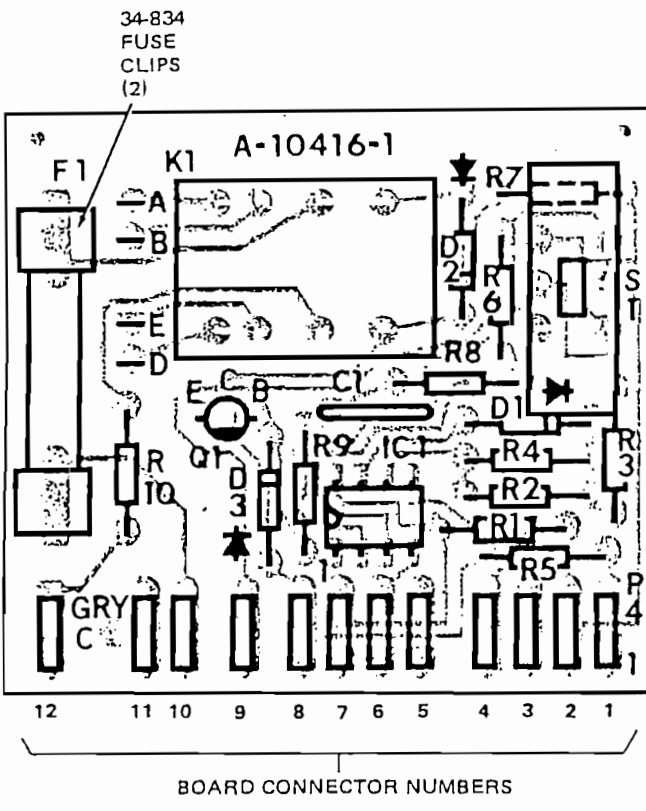
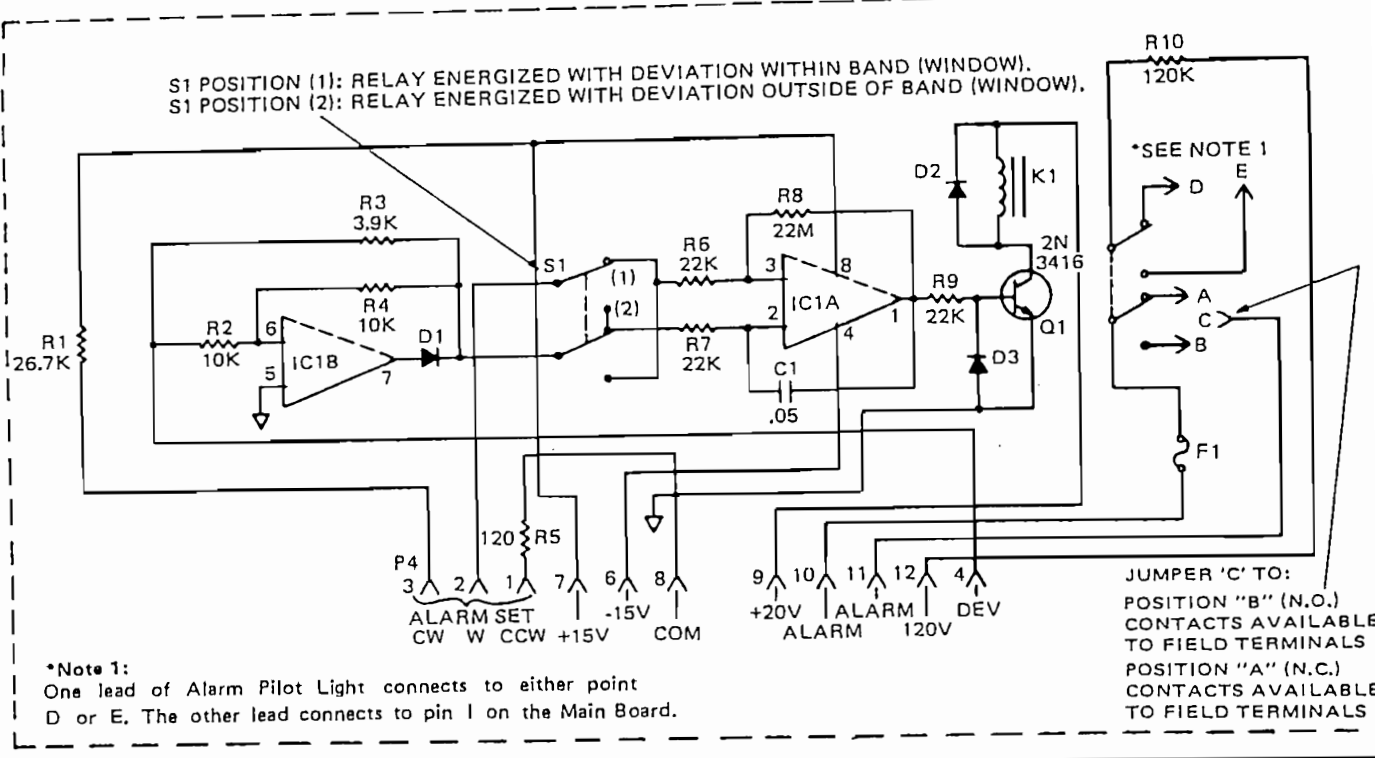


Figure 6-3. Deviation Band Alarm Board A-10416-1 and Schematic

Symbol	Part Number	Description
CAPACITOR		
C1	39-24	.05 uF 20%, 100 WVDC
DIODES		
D1,2,3	EYZP-384	250 PIV, I _f = 100 mA
FUSE		
F1	SYZE-206	2A, type AGC2
INTEGRATED CIRCUIT		
IC1	31-1015	Dual Minidip Operational Amp.
RELAY		
K1	38-205	DPDT, 20 Vdc, 12 mA
TRANSISTOR		
Q1	31-082	2N3416
RESISTORS		
Resistors are 10% tolerance, 1/4W, unless stated otherwise		
R1	CYZR-861-342	26.7k ohms 1%, 1/8W
R2,4	CYZR-861-301	10k ohms 1%, 1/8W
R3	40-1557	3.9k ohms
R5	40-1758	120 ohms
R6,7,9	CYZR-481-160	22k ohms
R8	40-1857	22M ohms
R10	40-1706	120k ohms 5%
SWITCH		
S1	32-388	DPDT, Slide Switch

Table 6-3. Deviation Band Alarm Board A-10416-1 Parts List

Barber-Colman Company
 INDUSTRIAL INSTRUMENTS DIVISION
 1300 Rock Street, Rockford, Illinois, U.S.A., 61101



Service Information

This Manual Section is only for Blue Boards.

520 Series Circuit Description And Service Control Mode Boards

7.1 Proportional plus Integral plus Derivative Board A-10514-1

7.1.1 CIRCUIT DESCRIPTION

See Figure 7-1. The Derivative (Rate) Circuit generates a correction signal that is a time derivative of the input signal to the Operational Amplifier (error signal). Since the correction signal is a derivative with respect to time, the Derivative circuit is operative only when the input signal is changing.

The bias of FET Q1A, Q1B and Q2A, Q2B is adjusted by resistor R3. The integral action is generated by R11 and C4. The range of reset rate is from .06 to 60 repeats per minute by R11. Field Effect Transistors Q1A, Q1B and Q2A, Q2B are connected in an emitter follower—current source configuration. Emitter follower Q2A has the high input impedance required for long integrating time constants. Emitter follower Q1A has the high impedance required for the long derivative times. Derivative time is adjusted from 0 to 3 minutes by R6. The derivative action is generated by R6, C2, and C3.

Reset Inhibition occurs when the demand signal (output of pin 6 of IC5 on the Main board) on pin 1 goes to the positive limits of the proportional band. The voltage at which inhibition occurs varies with the output control form board; and, on the dual output control forms H, J, and K, also with the GAIN RATIO setting. Part of the circuit which establishes the inhibition voltage is located on the output control form board.

For output control forms H, J, and K; with a GAIN RATIO setting of 4:1; inhibition occurs at 2.4 Vdc (for 1:1 it occurs at 6 Vdc). The inhibition voltage varies proportionally with GAIN RATIO settings so that inhibition occurs near the positive limit of the proportional band. When the limit voltage is exceeded, a transistor on the output board turns on, which turns on transistor Q3 and reduces the voltage across R11 and C4 to .6 Vdc.

For all other output control forms, a resistor on the output control form board establishes the correct inhibition voltage (+6 Vdc). When the limit voltage is exceeded, transistor Q3 turns on, reducing the voltage across R11 and C4 to .6 Vdc.

The effect of the inhibition circuit action is to clamp the Integral action to zero when the DEMAND signal exceeds the proportional band. This prevents excessive charge from accumulating on C4 during the time the controller is outside its proportional band. As the process signal again enters the proportional band, the output drops below 100% and normal circuit action is restored.

7.1.2 CALIBRATION OF FIELD EFFECT BIAS

Adjustments on the Main Board need not precede this adjustment.

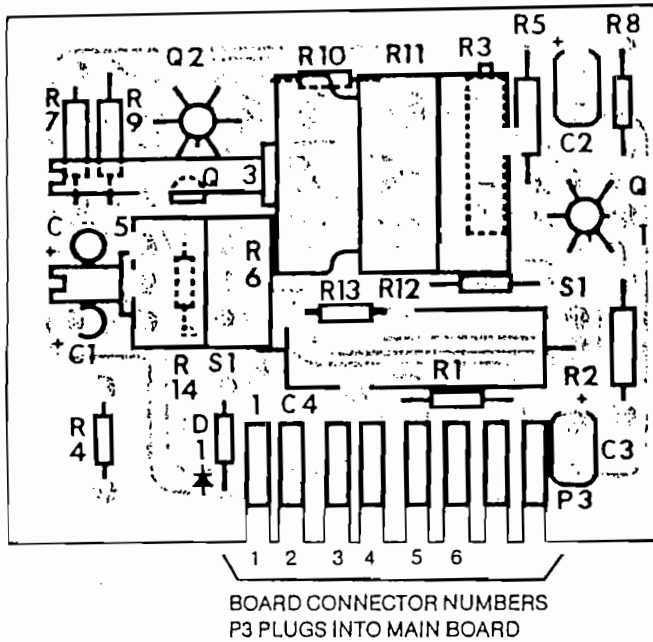
1. Remove the Output Control Form Board from P5.
2. Short pins 1, 2, and 7 of P5 on the Main Board.
3. Turn the front panel RESET control fully CCW to the off position.
4. Connect the precision digital voltmeter from the wiper of R3 to pin 7 of P5.
5. Adjust R3 until 0 Vdc \pm .0001 Vdc is obtained.
6. Remove the shorting jumpers from pins 1, 2 and 7 of P5. Replace the Output Control Form Board.
7. Allow power to remain on to the instrument and next perform any adjustments, if there are any, for the Output Section of this manual.

Table 7-1. Parts List, Proportional Plus Integral Plus Derivative Board A-10514-1

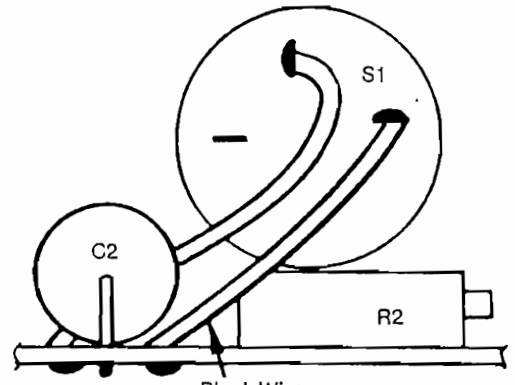
Symbol	Part Number	Description
CAPACITORS		
C1,5	39-442	4.7uF, 20%, 20 WVDC
C2,3	39-437	68uF, 20%, 15 WVDC
C4	E13-40	20uF, 20%, 50 WVDC
DIODE		
D1	EYZP-384	250 PIV, I _F = 100mA
TRANSISTORS		
Q1A,1B,- 2A,2B	31-157	2N3956, Factory selected dual FET
Q3	EYZP-623	2N4126

RESISTORS		
Resistors are 10% tolerance, 1/4W, unless stated otherwise		
R1	CYZR-481-300	220 ohms
R2	CYZR-862-201	1k ohms, 1%
R3	29-390	Variable, 1k ohms, 10%, 3/4W
R4,13	40-1847	47k ohms
R5,7,9	CYZR-862-218	1.5k ohms, 1%
R6	29-334	RATE pot, dual, 5M, 0.5M, 20%, 1/5W
R8,10,14	40-1314	100k ohms
R11	E19-121	RESET pot, dual 25M, 30%, 1/2W
R12	CYZR-481-120	470k, 5%

ROTARY SWITCH
SPDT, Part of R11



Order replacement boards by the assembly numbers prefixed by an A.



View of S1 Wiring

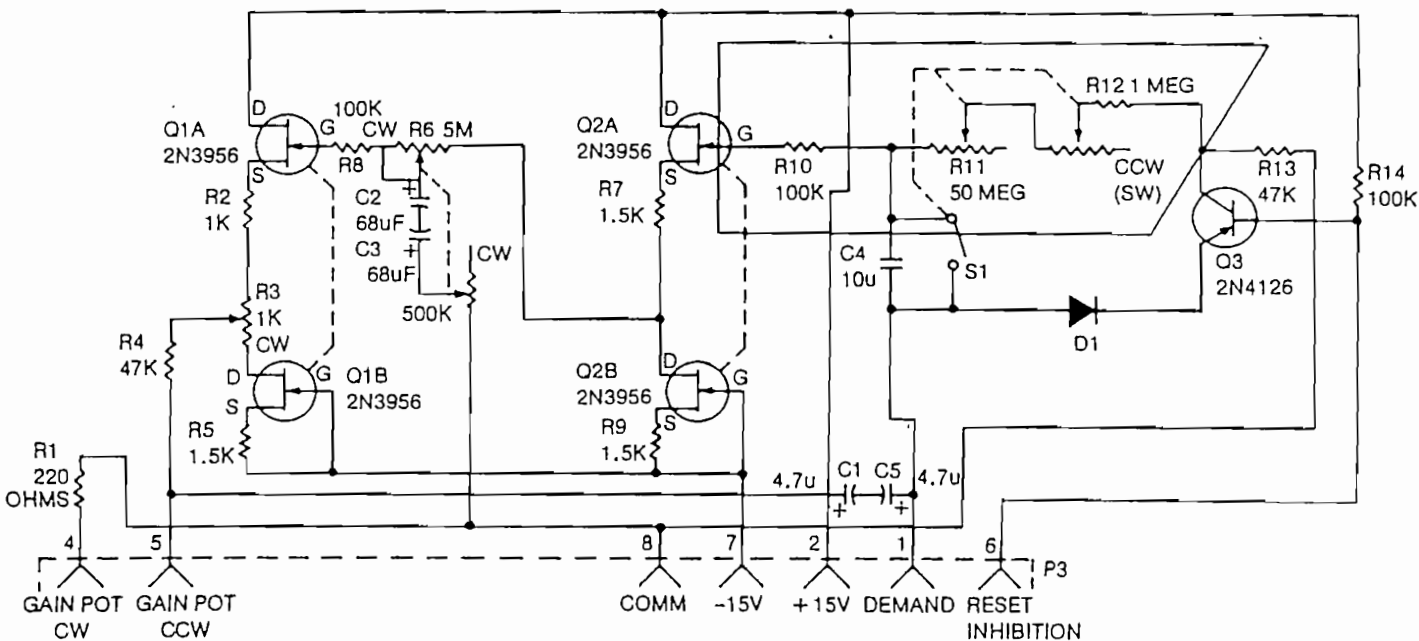


Figure 7-1. Proportional Plus Integral Plus Derivative Board A-10514-1 and Schematic

7.2 Proportional plus Integral Board A-10281-2

7.2.1 CIRCUIT DESCRIPTION

See Figure 7-2. The bias of FET Q1A and Q1B is adjusted by resistor R2. The integral action is generated by R6 and C2. The range of reset rate is from .06 to 6.0 repeats per minute. Field Effect Transistors Q1A and Q1B are connected in an emitter follower-current source configuration. The emitter follower has the high input impedance required for long integrating time constants. Reset Inhibition occurs when the demand signal (output of pin 6 of IC5 on the Main board) on pin 1 goes to the positive limits of the proportional band. The voltage at which inhibition occurs varies with the output control form board; and, on the dual output control forms H, J, and K, also with the GAIN RATIO setting. Part of the circuit which establishes the inhibition voltage is located on the output control form board. For single output controllers, inhibition occurs at +6 Vdc on pin 1 of P3. For Output Control Forms H, J, and K (4:1 ratio) inhibition occurs at 2.4 Vdc. When the limit voltage is exceeded, transistor Q2 turns on, reducing the voltage across R6 and C2 to .6 Vdc.

The effect of the inhibition circuit action is to clamp the Integral action to zero when the DEMAND signal exceeds the proportional band. This prevents excessive charge from accumulating on C2 during warm-up or on increase in setpoint. As the process signal again enters the proportional band, the output drops below 100% and normal circuit action is restored.

7.2.2 CALIBRATION OF FIELD EFFECT BIAS

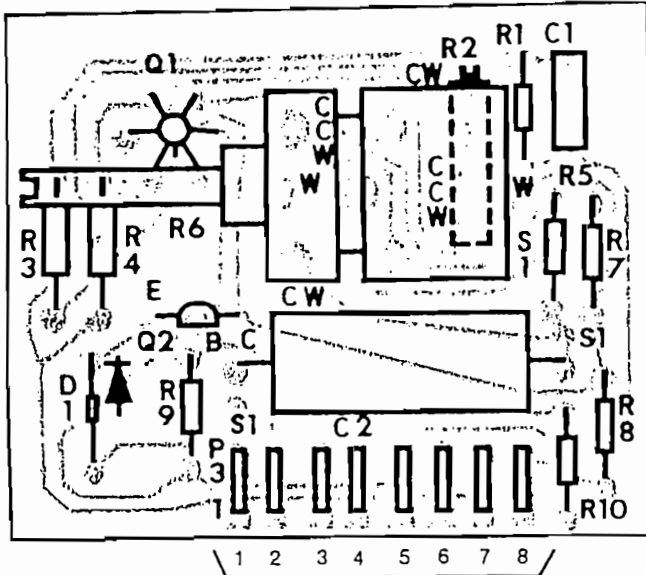
Adjustments on the Main Board need not precede this adjustment.

1. Remove the Output Control Form Board from P5.
2. Short pins 1, 2, and 7 of P5 on the Main Board.
3. Turn the front panel RESET control fully CCW to the off position.
4. Connect the precision digital voltmeter from the wiper of R2 to pin 7 of P5.
5. Adjust R2 until 0 Vdc \pm .0001 Vdc is obtained.
6. Remove the shorting jumpers from pins 1, 2, and 7 of P5. Replace the Output Control Form Board.
7. Allow power to remain on to the instrument and next perform any adjustments, if there are any, for the Output Section of this manual.

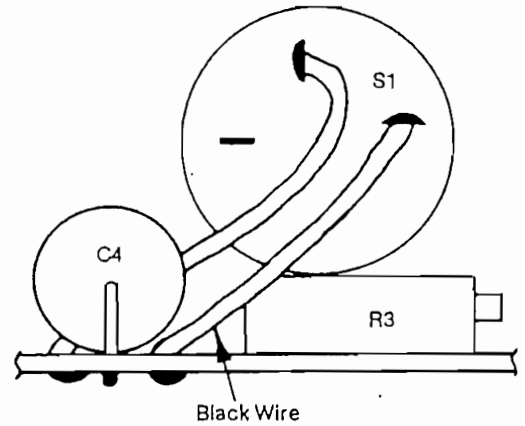
Table 7-2. Parts List, Proportional plus Integral Board A-10281-2

Resistors are 10% tolerance, 1/4W unless stated otherwise.

Symbol	Part Number	Description		
		CAPACITORS		
C1	CYZR-803	.1uF, 20%, 250 WVDC	R1,8	40-1847
C2	E13-40	20uF, 20%, 50 WVDC	R2	29-376
		DIODE	R3	CYZR-862-209
D1	EYZP-384	250 PIV, $I_f = 100mA$	R4	CYZR-862-218
		TRANSISTORS	R5,9	40-1314
Q1A,B	31-157	2N3956, Factory Selected dual FET	R6	E19-121
Q2	EYZP-623	2N4126	R7	CYZR-481-120
			R10	CYZR-481-300
			S1	ROTARY SWITCH SPDT, Part of R6



BOARD CONNECTOR NUMBERS P3 PLUGS INTO MAIN BOARD



View of S1 Wiring

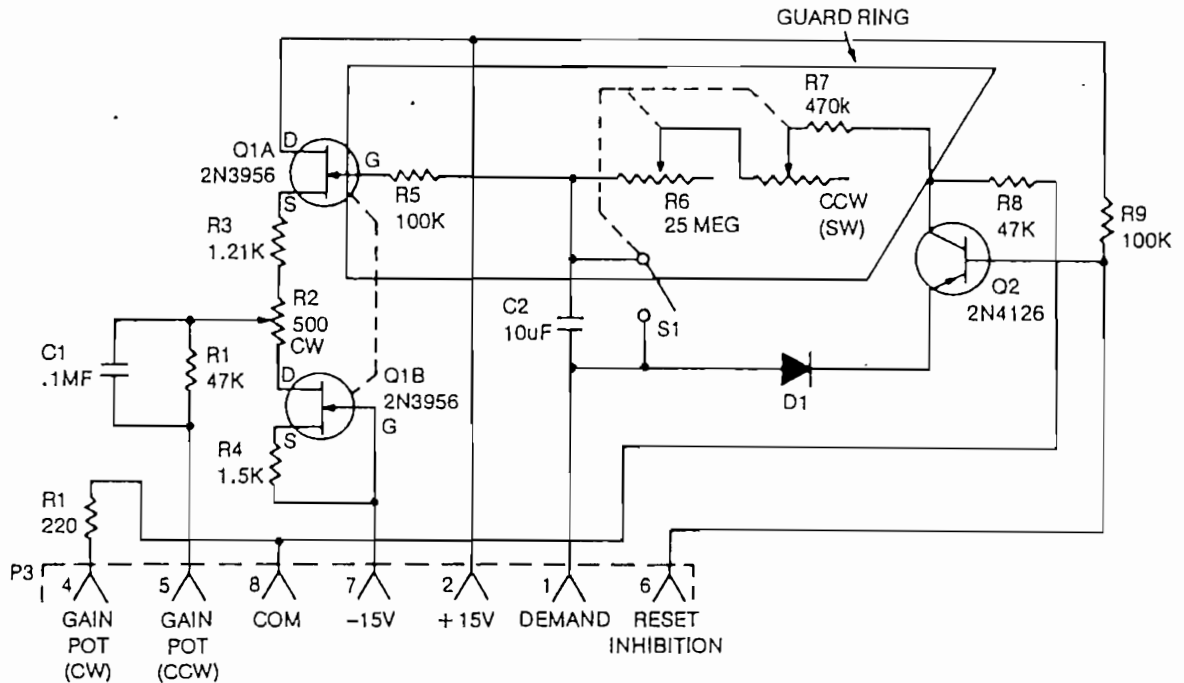


Figure 7-2. Proportional Plus Integral Board A-10281-2 and Schematic

7.3 Proportional Plus Manual Reset Board A-10280 Circuit Description

See Figure 7-3. The front panel manual RESET resistor drives the output control form board from full off to full on when the controller is at zero deviation. Resistors R1 and R4 on this board and R23 on the Main Board determine the gain of the controller.

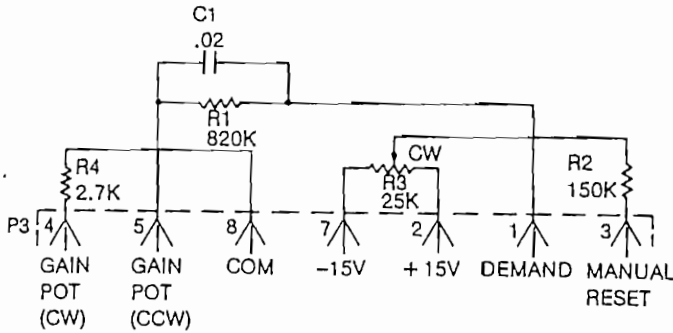
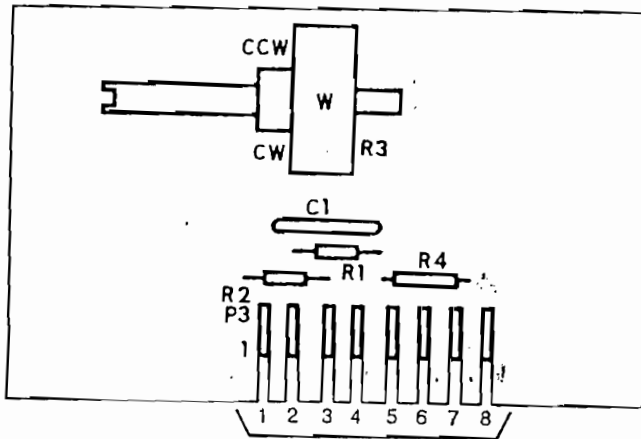


Figure 7-3. Proportional plus Manual Reset Board A-10280 and Schematic



Board Connector Numbers P3 Plugs Into Main Board

Order replacement boards by the assembly numbers prefixed by an A.

Table 7-3. Parts List, Proportional Plus Manual Reset Board A-10280

Symbol	Part Number	Description
CAPACITORS		
C1	39-416	.02uF, GMV, 600 WVDC
RESISTORS		
Resistors are 10% tolerance, 1/4W, unless stated otherwise.		
R1	CYZR-836-489	820k ohms
R2	40-1913	150k ohms
R3	29-371	RESET pot, 25k ohms, 30%, 1/2W
R4	CYZR-836-243	2.7k ohms



MODELS 522B, 523B, and 524B

8. OUTPUT BOARD CIRCUIT DESCRIPTION and SERVICE

This is the last section of Service Manual 1252 IN22.

This Manual Section is only for Blue Boards.

8.1 GENERAL

The circuit description, calibration and troubleshooting follows in paragraphs 8.2, 8.3, and 8.4.

8.2 CIRCUIT DESCRIPTION

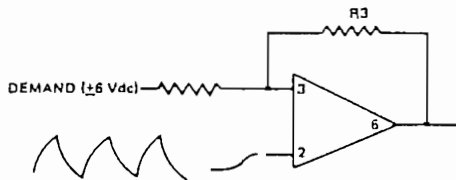


Figure 8-1. Triangular Waveform

See Figures 8-1 and 8-2. The demand signal on pin 2 of P5 is compared with a voltage with a triangular waveform. This waveform is generated by C1, C3, R4, and R5, and appears between terminal 2 of IC1 and the -15 Vdc on pin 5 of P5. When the Demand Signal on pin 3 of IC1 exceeds the maximum amplitude of the waveform the output of IC1 on pin 6 approaches the potential of the +15Vdc supply, causing Q1 to turn on, and allowing the gate signal to turn Q2 on. The rating of Q2 is 1A continuous, 20A inrush, 30mA minimum. When the Demand Signal is less than the minimum amplitude of the waveform (the condition calling for no power to the load), the potential on pin 6 of IC1 approaches -15 Vdc, causing Q1 and Q2 to turn off.

Fuse F1 on the Main Board is in series with Triac Q2. The fuse is rated 2A at 250 Vac. Fuse size must not be exceeded. The copper foil on the Main Board will be destroyed at higher currents.

8.3 CALIBRATION

8.3.1 General

The front panel CYCLE control is the only adjustment on this output board.

8.3.2 Obtaining a Faster Cycling Time

Potentiometer R4 is set to obtain a cycle time from 6 to 60 seconds nominal. This adjustment of cycle time can be changed to 0.6 to 6 seconds by either removing capacitor C3 or clipping one lead of C3. The faster cycling rate will enable optimum control of a solid state contactor.

8.4 TROUBLESHOOTING

For an overall inspection of this board, proceed as follows:

1. Connect a load to the output terminals that requires a current of 50 mAdc or more. The front panel Amber

lamp will not turn off unless the load has this minimum current.

2. Connect a dc millivolt source to controller rear panel input terminals 1 and 2. Be certain the polarity of the connections is correct. Adjust source for equivalent of midscale temperature.
3. Turn power on to the controller.
4. Turn the GAIN control fully CCW.
5. Now perform either a, b, or c, depending upon the model.
 - a. Model 522 – Short pins 1 and 7 of P5 on the Main Board. Connect a VOM between pins 2 and 7 of P5 on the Main Board. Adjust the front panel RESET control until the VOM reads 0 Vdc. Remove the short from pins 1 and 7 of P5. Disconnect the VOM. Proceed to step 6.
 - b. Model 523 – Turn the front panel RESET control fully CCW to the off position. Proceed to step 6.
 - c. Model 524 – Turn the front panel RESET control fully CCW to the off position. Turn the front panel RATE control fully CCW to the off position. Proceed to step 6
6. Turn the SETPOINT ADJUST control to midspan.
7. The front panel Amber lamp should be on 50% of the time.
8. Turn the SETPOINT ADJUST control to full scale.
9. The Amber lamp should be on more than 90% of the time and should glow steadily.
10. Turn the SETPOINT ADJUST control to minimum scale.
11. The Amber lamp should be dark more than 90% of the time.
12. If the correct indication is not obtained in steps 7 through 11, connect the VOM between pins 2 and 7 of P5. If both the following indications are correct, the output board is defective. Turn the SETPOINT ADJUST control to full scale:– the VOM should indicate 6Vdc. Turn the SETPOINT ADJUST control to minimum scale:– the VOM should indicate -6Vdc.

Do not depend on fuse F1 on the Main Board to protect Triac Q2, the primary purpose of the fuse is to protect the copper foil on the Main Board.

24

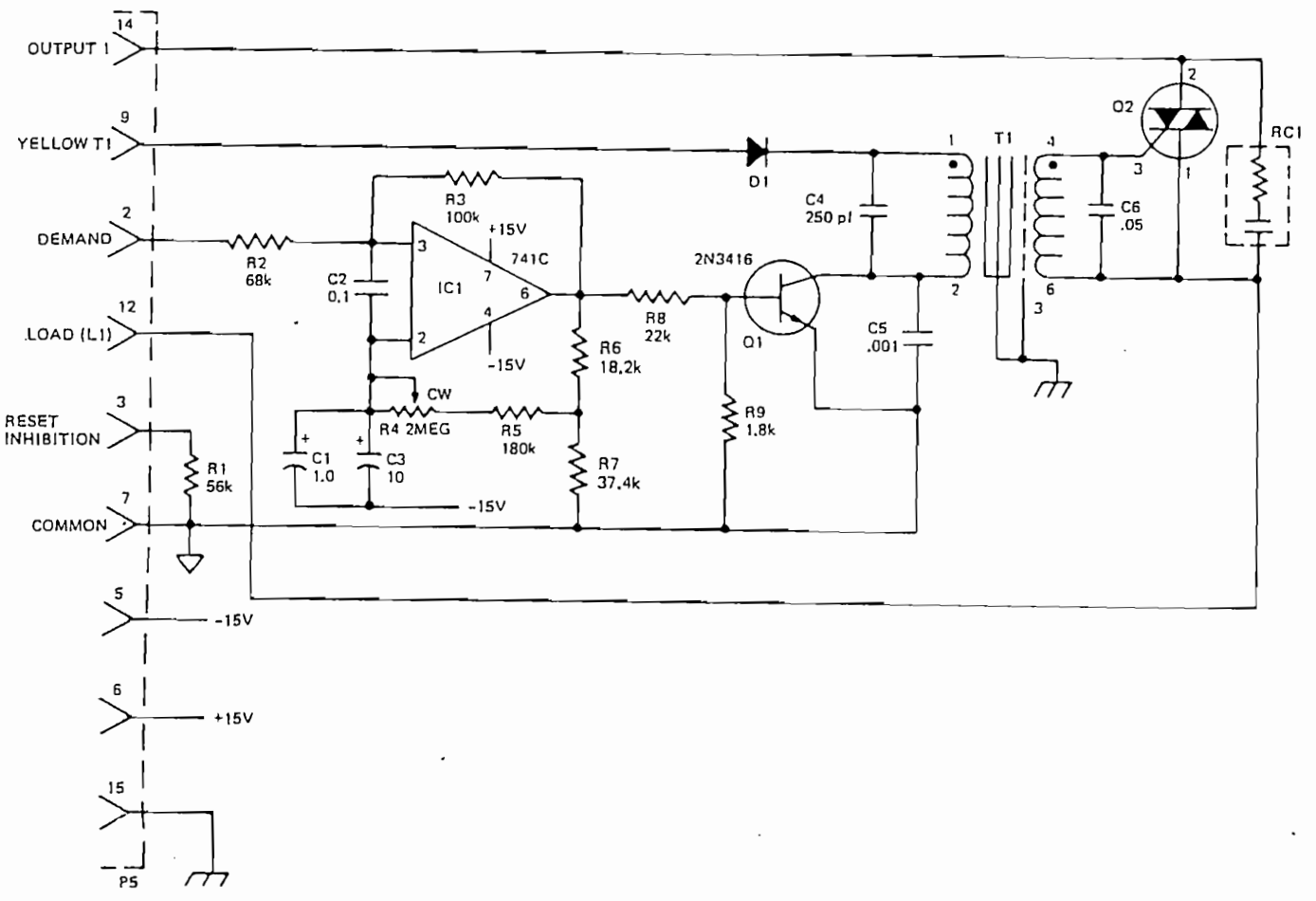
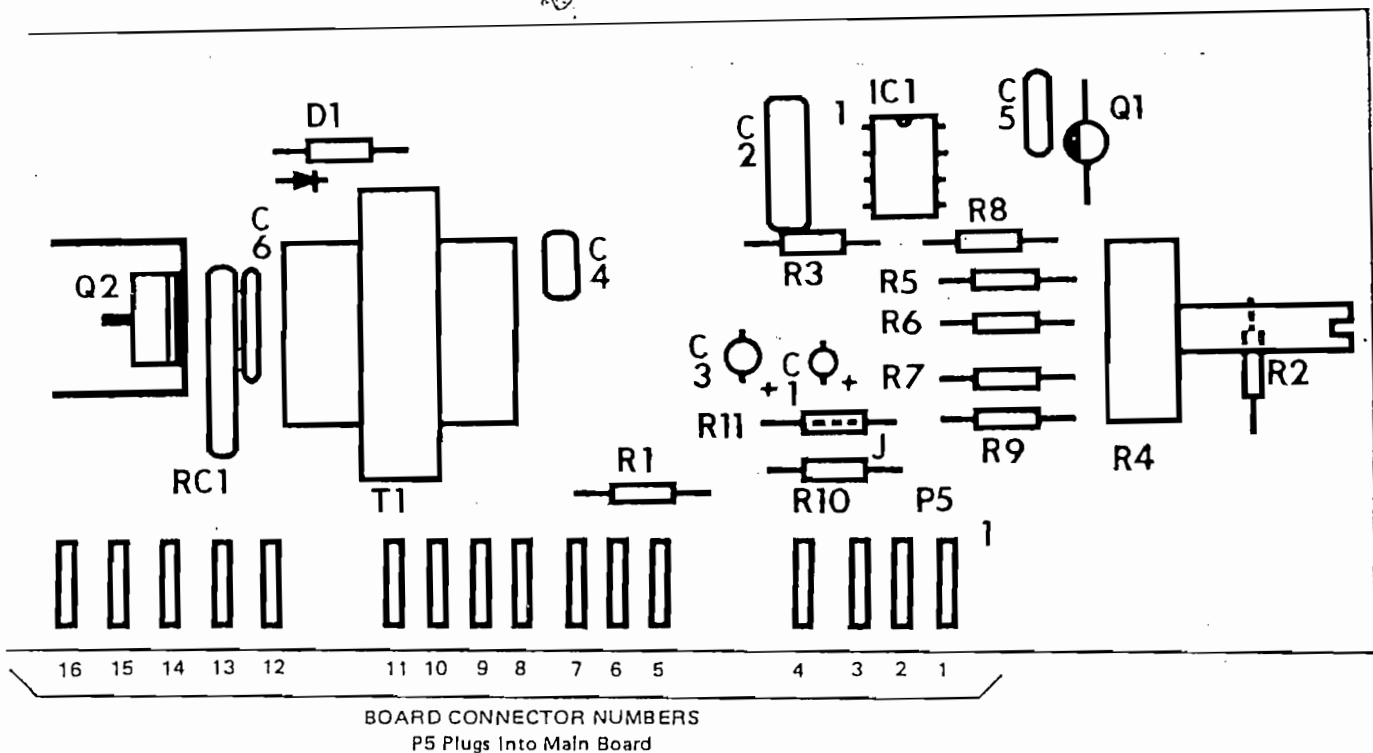


Figure 8-2. Single Time-Proportioning Solid State Switching Output Board A-10282-2 and Schematic

Table 8.1. Parts List, Single Time-Proportioning Solid State Switching Output Board A-10282-2

Symbol	Part Number	Description
CAPACITORS		
C1	39-382	1 μ F 20%, 35 WVDC
C2	CYZR-803	.1 μ F 20%, 250 WVDC
C3	39-431	10 μ F 10%, 25 WVDC
C4	39-076	250 ρ F 20%, 500 WVDC
C5	39-063	.001 μ F, GMV, 600 WVDC
C6	39-325	.05 μ F 20%, 100 WVDC
DIODE		
D1	EYZP-384	250 PIV, $I_f = 100$ mA
INTEGRATED CIRCUIT		
IC1	31-1012	741C Operational Amplifier
TRANSISTORS		
Q1	31-082	2N3416
Q2	31-155	Triac, Factory Selected. Either RCA 40669 or GE SC 146D
RESISTORS		
Resistors are 10% tolerance, 1/4W, unless otherwise stated		
R1	CYZR-481-200	56k ohms
R2	40-1568	68k ohms
R3	40-1314	100k ohms
R4	29-373	Cycle pot, 2M ohms 30%, 1/5W
R5	40-1917	180k ohms
R6	CYZR-862-326	18.2k ohms, 1%
R7	CYZR-862-356	37.4k ohms, 1%
R8	40-1950	22k ohms
R9	40-1842	1.8k ohms
RC1	50-1196	Suppressor
TRANSFORMER		
T1	30-323	Pulse

ANEXO E

Power Switching Devices

Mercury Displacement Relays

Extensive testing has proven Watlow mercury displacement relays will handle years of continuous cycles without risk of failure. The relay's silent operation, complete protection against hostile environments and total reliability of operation makes it the one switching device you can install and forget.

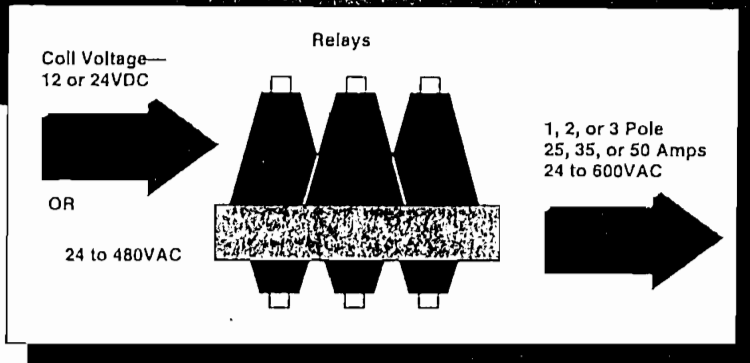
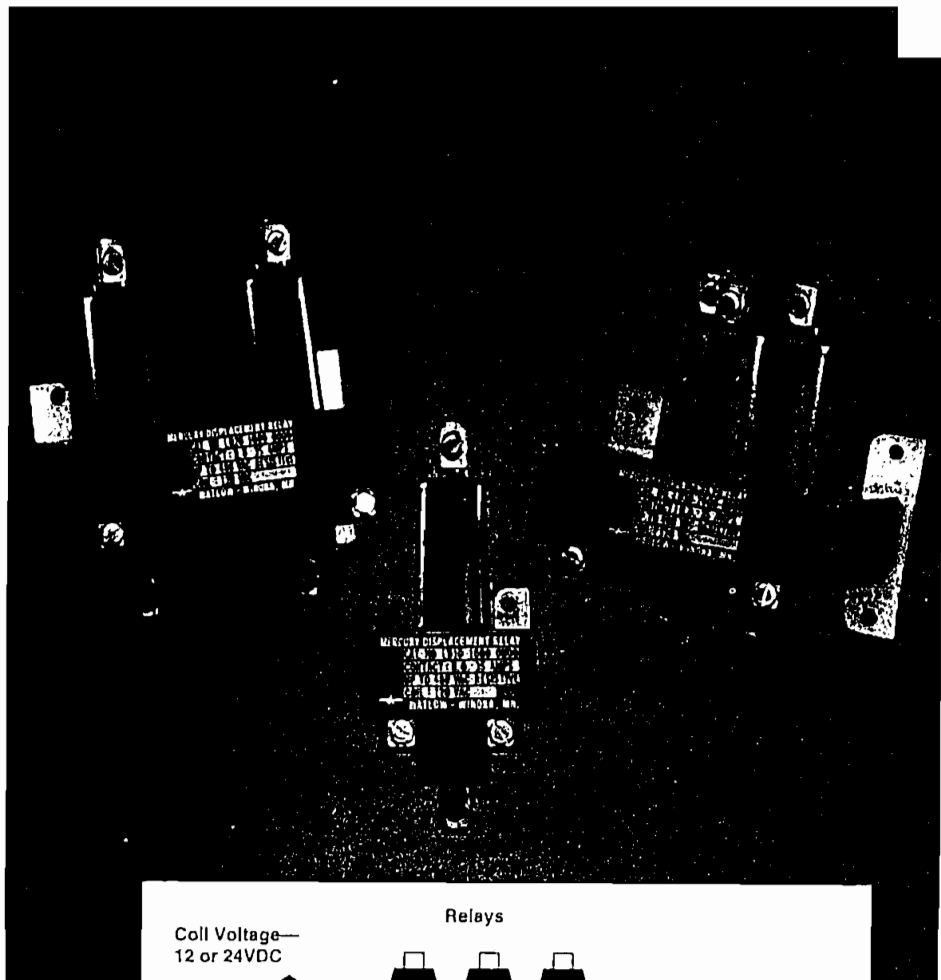
The MDR's basic mode of operation makes it superior to other electro-mechanical switches and solid state devices. For example, arcing, a frequent cause of short life with contacts, is rare for a MDR and doesn't harm it. The liquid creates a fresh, new contact surface for each cycle. The MDR is also superior since it opens the circuit completely and allows no leakage of current.

Performance Capabilities

- Coil voltages up to 480VAC on 1, 2, or 3 pole versions
- Voltages up to 600VAC on contacts
- Current ratings
 KD Series: 25 amps
 LD Series: 35 amps
 MD Series: 50 amps

Features

- **MDRs outperform and outlast** other switches on all types of resistive loads.
- **MDRs provide safer operation** than solid state devices since failure normally breaks the circuit.
- **A wide range of sizes and ratings** of MDRs are available to suit many diverse applications.
- **Low contact resistance** makes MDRs ideal for sensitive low voltage applications.
- **Teflon® guide rings** protect the plunger and its housing from cylinder wear.



- **Molded plastic case** seals all components in the proper position and protects against corrosive atmospheres
- **Ultra-pure inert gas**, used to fill the MDR after assembly, virtually eliminates arcing for extended relay life.

Applications

- Plastic injection molding
- Wave soldering

Power Switching Devices

Mercury Displacement Relays

Applications and Technical Data

Specifications

Operation

- A mercury displacement relay makes contact from one power electrode to a pool of mercury which, in turn, contacts the electrode. Like a solenoid, a field coil

activates the switch, opening or closing the circuit. But unlike a solenoid, the coil does not move contact points. It activates a plunger that raises or lowers the level of mercury to make or break connection with the inbound electrode.

Power Switching

- 1, 2, or 3 pole
- (KD) 25 Amp
- (LD) 35 Amp
- (MD) 50 Amp
- Voltage: 600VAC maximum
- Frequency: 50/60Hz
- Load type: resistive only
- Pull-in time: 75msec typical
- Drop-out time: 75msec typical

- Cycling frequency: 30/minute maximum
- Contact type: normally open.
- Contact resistance typical: (KD and LD) 0.003Ω, (MD) 0.002Ω
- Terminal type: (KD) Binding head screw, #8 AWG (LD) Pressure terminal, #6 AWG (LD) 10in (254mm) lead, #12 AWG stranded (MD) Pressure terminal, #2 AWG

Field Coil

- Voltage, current and power at 60Hz typical.

- Coil voltage tolerance: - 20%, +10%
- Terminals: screw clamp
- Maximum wire size: #12 AWG

1 Pole			2 Pole		3 Pole	
Voltage	Current	Power	Current	Power	Current	Power
120VAC	55mA	6.6VA	105mA	12.6VA	190mA	22.8VA
240VAC	28mA	6.7VA	53mA	12.7VA	98mA	23.5VA
480VAC	17mA	8.2VA	27mA	13.0VA	47mA	22.6VA
24VAC	250mA	6.0VA	470mA	11.3VA	940mA	22.6VA
208VAC	33mA	6.9VA	59mA	12.3VA	110mA	22.9VA
12VDC	225mA	2.7W	500mA	6.0W	950mA	11.4W
24VDC	130mA	3.1W	235mA	5.6W	460mA	11.0W

Agency Approval

(KD and LD)

- UL 508 File # E73741
- UL Tested 100,000 cycles for commercial cooking appliances, File # E73741
- CSA certified, File LR44426

(MD)

- UL 508, File # E73741
- CSA certified, File LR44426

Power Switching Devices

RETENA S.A.
 REPRESENTACION TECNICA
 MONTEDONDEGOS S. R.L.

Mercury Displacement Relays 1 Pole Wiring Example

Applications and Technical Data

Continued

Mounting Orientation

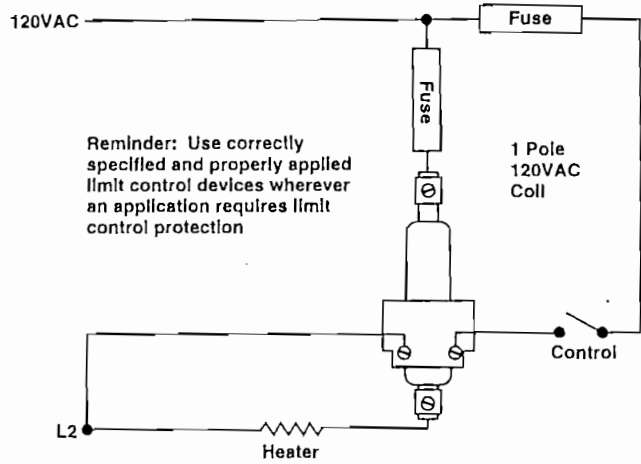
- Vertical

Operating Environment

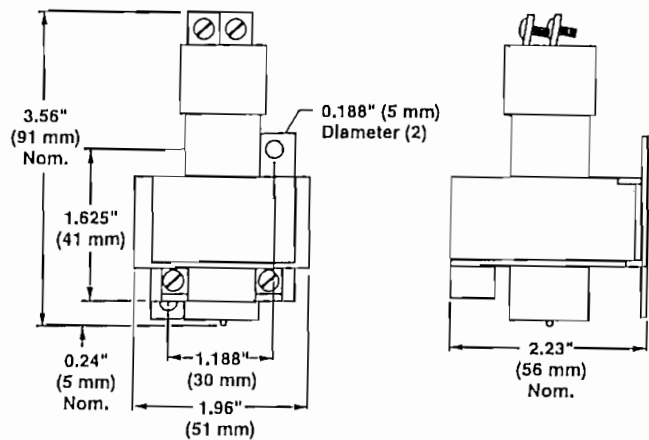
- -30 to 106°F/-30 to 41°C
- 0 to 100% RH

Weight

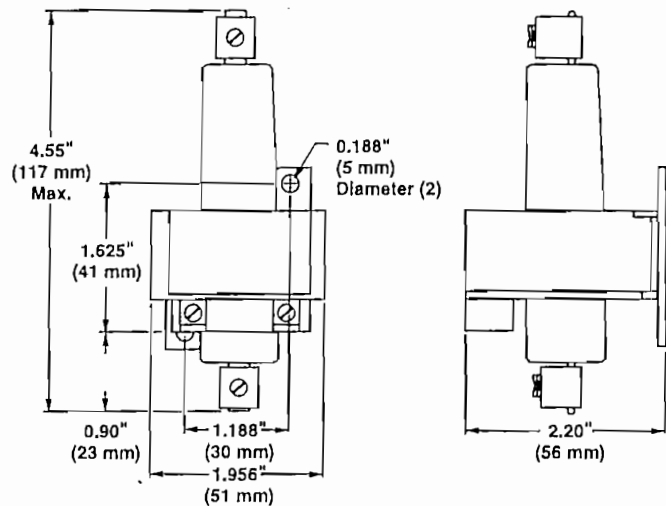
- 1 pole: 0.7 lb (0.32 kg)
- 2 pole: 1.3 lb (0.59 kg)
- 3 pole: 1.8 lb (0.82 kg)



1 Pole KD



1 Pole LD

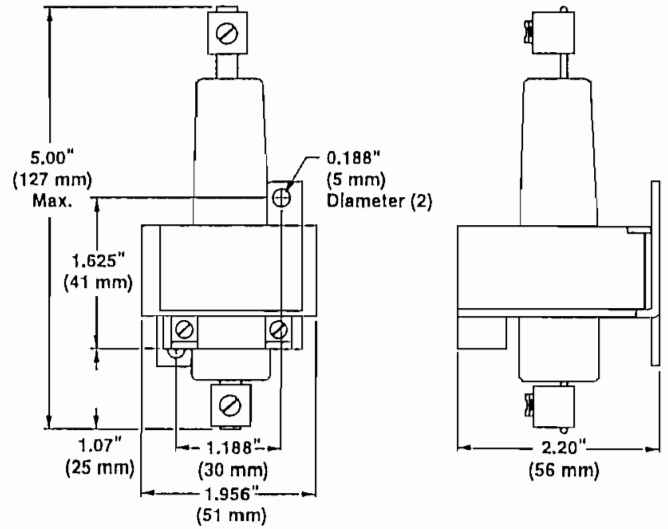


Power Switching Devices

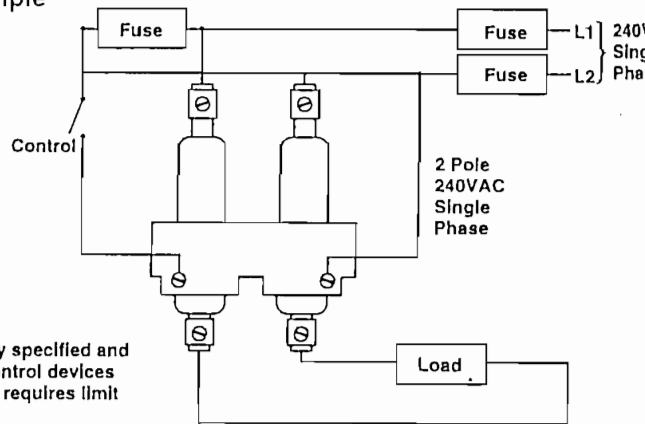
Mercury Displacement Relays

Applications and Technical Data
Continued

1 Pole MD

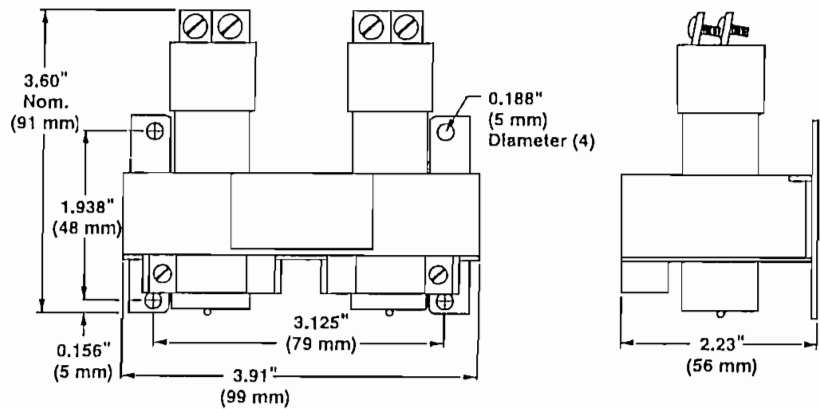


2 Pole Wiring Example



Reminder: Use correctly specified and properly applied limit control devices wherever an application requires limit control protection

2 Pole KD

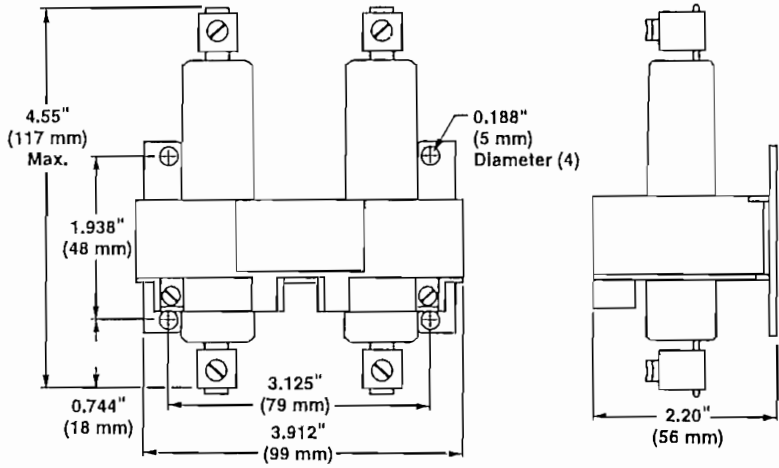


Power Switching Devices

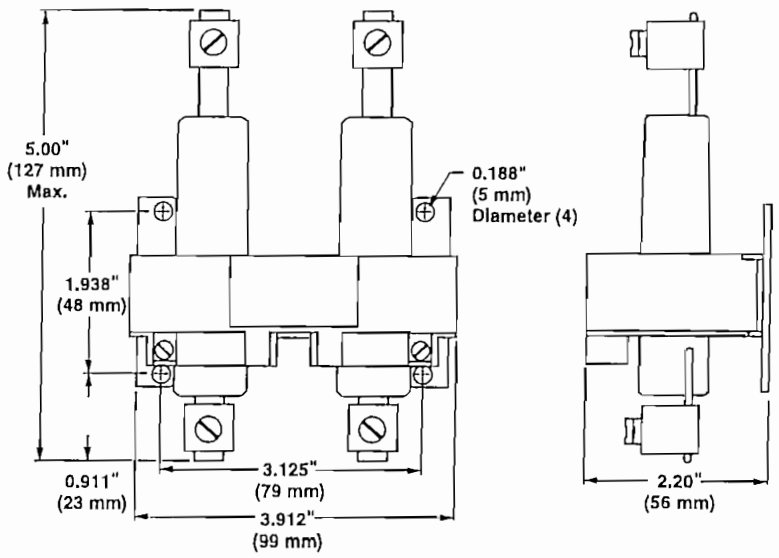
Mercury Displacement Relays

Applications and Technical Data
Continued

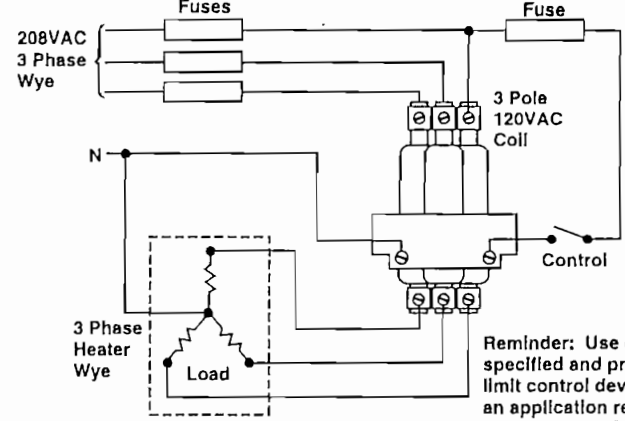
2 Pole LD



2 Pole MD



3 Pole Wiring Example



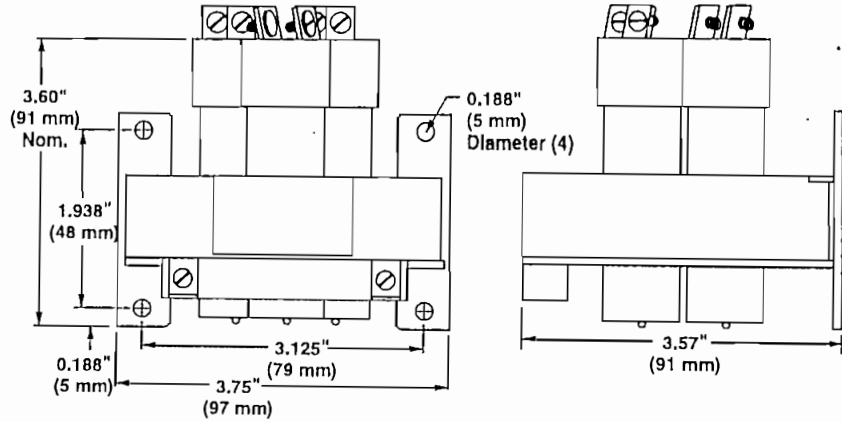
Reminder: Use correctly specified and properly applied limit control devices wherever an application requires limit control protection

Controls

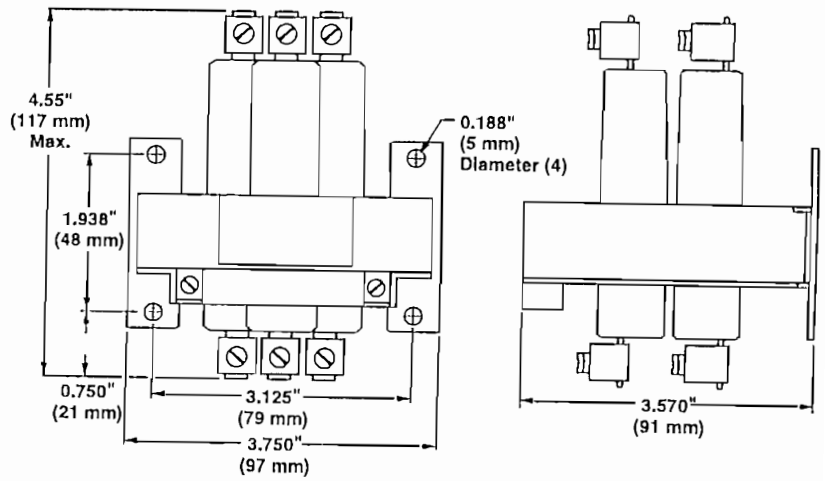
Power Switching Devices

Mercury Displacement Relays 3 Pole KD

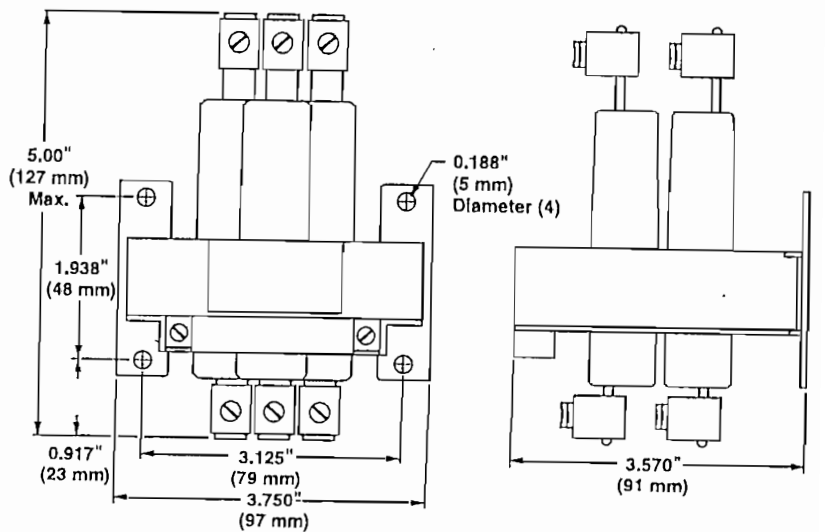
Applications and Technical Data
Continued



3 Pole LD



3 Pole MD



Power Switching Devices

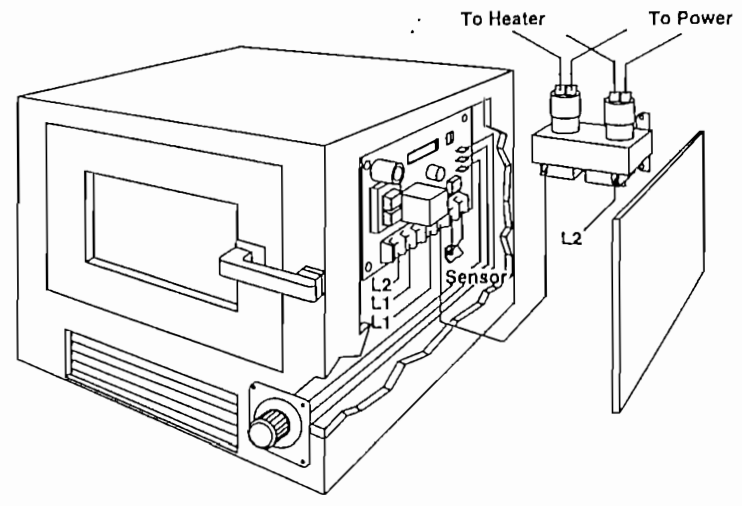
Mercury Displacement Relays

Applications and
 Technical Data

Continued

Application Sketch

The Watlow Series 80 controls auto-
 lave temperature; the MDR handles
 power switching.



F.O.B.: Winona, Minnesota

Ordering Information

To order, complete the model
 number on the right with the
 information below:

_____ - 0 0 0 - U 0 0

Category and Details

Series

- KD10 = 25A, 600VAC 1 pole, N.O.
- KD20 = 25A, 600VAC 2 pole, N.O.
- KD30 = 25A, 600VAC 3 pole, N.O.
- LD10 = 35A, 600VAC 1 pole, N.O.
- LD20 = 35A, 600VAC 2 pole, N.O.
- LD30 = 35A, 600VAC 3 pole, N.O.
- MD10 = 50A, 600VAC 1 pole, N.O.
- MD20 = 50A, 600VAC 2 pole, N.O.
- MD30 = 50A, 600VAC 3 pole, N.O.

Coil Voltage

- 1 = 120VAC
- 2 = 240VAC
- 3 = 480VAC
- 4 = 24VAC
- 5 = 208VAC
- 6 = 24VDC
- 7 = 12VDC
- 8 = 277VAC

Power Connections

- 0 = (LD & MD) Pressure terminal
- 1 = (LD) Pigtail leads, 10" long
- 4 = (KD) Binding head screws

UL and CSA Listed

600VAC power switching

Power Switching Devices

Mercury Displacement Relays

Ordering Information

Continued

Amps	Poles	Coil Voltage	Terminals	Agency	Approx. Net Wt. lbs (kg)	Code No.
25	1	120VAC	Screw	UL/CSA	0.7(0.32)	KD10-1000-4U00
25	1	240VAC	Screw	UL/CSA	0.7(0.32)	KD10-2000-4U00
25	2	120VAC	Screw	UL/CSA	1.3(0.59)	KD20-1000-4U00
25	2	240VAC	Screw	UL/CSA	1.3(0.59)	KD20-2000-4U00
25	3	120VAC	Screw	UL/CSA	1.8(0.82)	KD30-1000-4U00
25	3	240VAC	Screw	UL/CSA	1.8(0.82)	KD30-2000-4U00
35	1	120VAC	Pressure	UL/CSA	0.7(0.32)	LD10-1000-0U00
35	1	240VAC	Pressure	UL/CSA	0.7(0.32)	LD10-2000-0U00
35	2	120VAC	Pressure	UL/CSA	1.3(0.59)	LD20-1000-0U00
35	2	240VAC	Pressure	UL/CSA	1.3(0.59)	LD20-2000-0U00
35	3	120VAC	Pressure	UL/CSA	1.8(0.82)	LD30-1000-0U00
35	3	240VAC	Pressure	UL/CSA	1.8(0.82)	LD30-2000-0U00
50	1	120VAC	Pressure	UL/CSA	0.7(0.32)	MD10-1000-0U00
50	1	240VAC	Pressure	UL/CSA	0.7(0.32)	MD10-2000-0U00
50	2	120VAC	Pressure	UL/CSA	1.3(0.59)	MD20-1000-0U00
50	2	240VAC	Pressure	UL/CSA	1.3(0.59)	MD20-2000-0U00
50	3	120VAC	Pressure	UL/CSA	1.8(0.82)	MD30-1000-0U00
50	3	240VAC	Pressure	UL/CSA	1.8(0.82)	MD30-2000-0U00

Description	Part No.
Enclosure, control or 1 or 2 pole MDR	Z100-0361-0000
Enclosure, 3 pole MDR	Z100-0362-0000
Enclosure, 3 pole MDR & Relay Master	Z100-0561-0000

Availability

Stock: Same day shipment

All other combinations available in ten working days or less.

ANEXO F

INTRODUCTION

With a concern towards oversimplification, it can be said that your multi-screw extruder is a positive displacement pump for the controlled transport of material through a die. This is achieved with a barrel and screws to transport, mix and compress the material, heating and cooling systems to control the heat needed for processing, a drive train to power the screws, and instruments to record the process and inform us of possible problems.

BARREL AND SCREWS

The barrel assembly mounted on this machine has a meshing, dual, conical - taper bore. The combination of barrel taper and screw flight pitch enables us to achieve proper compression of PVC resin. The large outside diameter of the screws in the intake area offers good intake of material and a large surface for heat transfer into the material. The stock moves into compression zone next. At this point, the material should be semi-fluxed and will act as a seal for the vacuum being applied at the next zone. Because of the need for a seal, it is important that the screws be quite full in this area. The next zone is a decompression zone where vacuum is applied in order to prevent gaseous inclusions in the finished product. The last zone is the metering zone where the

material is slightly recompressed and metered out to the die. Due to the taper of the barrel, there is less surface area in the metering zone, therefore, less heat input and better control of stock temperature. The taper of the screws also reduces the screw surface area compared to extruders of similar output rates. Thrust force due to melt pressure therefore reduced considerably.

The screws each have a hollow core through which heat transfer fluid is pumped. This allows for transfer of any unwanted frictional heat from the metering zone back to the intake zone. This screw core cooling system as well as the four heat zones on the barrel are independently controlled by precision instruments with heaterbands and heat exchangers for accurate stabilization of operating temperatures.

The barrel assembly pivots to enable easy removal of the screws. Re-alignment of the barrel with the drive shafts is accomplished by a pin in the rear and guide blocks in the front.

HEATING AND COOLING SYSTEMS

Heat is applied to the four barrel zones by means of electrical heat bands and heat is removed by circulating oil through coils wound around the barrel at zones 2, 3 and 4. This oil is circulated by a pump unit with heat exchanger located in the base of the extruder on the left side to the front. The screw core cooling/heating is done with a floor mounted unit.

DRIVE TRAIN

The drive train starts with an infinitely variable speed, constant torque drive motor coupled to a speed reducer and then into a two shaft distribution gear drive. Since the drive shafts are on the same centerline as the tapered screws, it is possible to use large gears for torque transfer and large bearings to take up the axial force (back pressure) generated in the operation of the extruder.

MONITORING SYSTEMS

In order to achieve consistent quality of product, the speed and load of the drive train is measured as well as the axial load on the thrust bearings. The amount of vacuum applied to the material for de-gassing can be regulated and is measured by a gauge. The speed of the starve feeder screw is also shown on an RPM meter. The load being drawn by each heaterband is shown on an amp meter and controlled by a pyrometer unit. Problems with the cooling system, feeder system, venting system, torque overload, back pressure overload are both visually and audibly signaled to the operator by an alarm system built into the control cabinet.

TECHNICAL SPECIFICATIONS1. SCREWS:

Number of screws	2
Diameter front/rear	2.16/4.33 in. 55 - 110 mm
Length relative to front diameter	19D
Direction of rotation	Counter Rotating
Speed R.P.M.	7 to 36
Maximum torque per screw	2188 ft. lbs., 302 kpm
Total torque	4376 ft. lbs., 604 kpm

2. DRIVE, S.C.R. CONTROLLED D.C.:

Motor rating	30 H.P. - <u>22 kw</u>
Motor speed maximum	1750 RPM
Control range	1:5
Total gear reduction	1:48.6

3. PERMISSIBLE AXIAL LOAD/SCREW IN. LBS.:

Continuous - maximum	34,000 lbs., 15,400 kp
Short term - maximum	42,500 lbs., 19,300 kp
Thrust bearing maximum rated load	98,000 lbs., 44,500 kp
Thrust bearing life at - 21,000 lbs.	
Continuous load at 36 R.P.M.	75,000 hrs.
Back pressure measurement device	Electric

4. BARREL HEATING:
- | | |
|---------------------------|---------------------------------|
| Number of heating zones | 4 |
| Heating capacity | 18.7 KW |
| Temperature control range | 100° - 450° F.
38° - 232° C. |
5. BARREL AND RELATED COOLING:
- | | |
|------------------------------|---------------------|
| Type of cooling media | Heat transfer fluid |
| Number of cooling zones | 3 |
| Type of screw cooling media | Heat transfer fluid |
| Heat exchanger cooling media | Water |
| Number of cooling circuits | 3 |
6. ELECTRICAL REQUIREMENTS:
- | | |
|---------|------------------------|
| Motor | 460V, 3 PH, 60 Hz., 80 |
| Heaters | 230V, 3 PH, 60 Hz., 75 |
7. AIR AND WATER REQUIREMENTS:
- | | |
|---------------------------|---------------------------------------|
| Minimum air pressure | 40 PSI (2.8 kp/cm ²) |
| Air Inlet | 1/2 in. |
| Average water consumption | 3-1/2 Gal./Min. (0.8 M ³) |
| Water inlet | 1/2 in. |
| Drain connections | 1-1/4 in. and 1/2 in. |

is formed which is a combination of PVC and nonferrous metals along with most other materials used in the construction of DC motors. This combination of airborne PVC and water (atmospheric moisture) in pipe manufacturing plants makes re-occurring motor failure a major problem. To remedy this situation, certain steps must be taken to assure an acceptable clean air supply for proper ventilation.

At this time, no particle size, quantity or concentration of PVC has been established that will cause harm or failure

EXTRUDER DC IR
VENTILATION SPECIFICATION
AND REQUIREMENT

When PVC dust or powder is combined with water, hydrochloric acid is formed which is extremely corrosive. It attacks both ferrous and nonferrous metals along with most other materials used in the construction of DC motors. This combination of airborne PVC and water (atmospheric moisture) in pipe manufacturing plants makes re-occurring motor failure a major problem. To remedy this situation, certain steps must be taken to assure an acceptable clean air supply for proper ventilation.

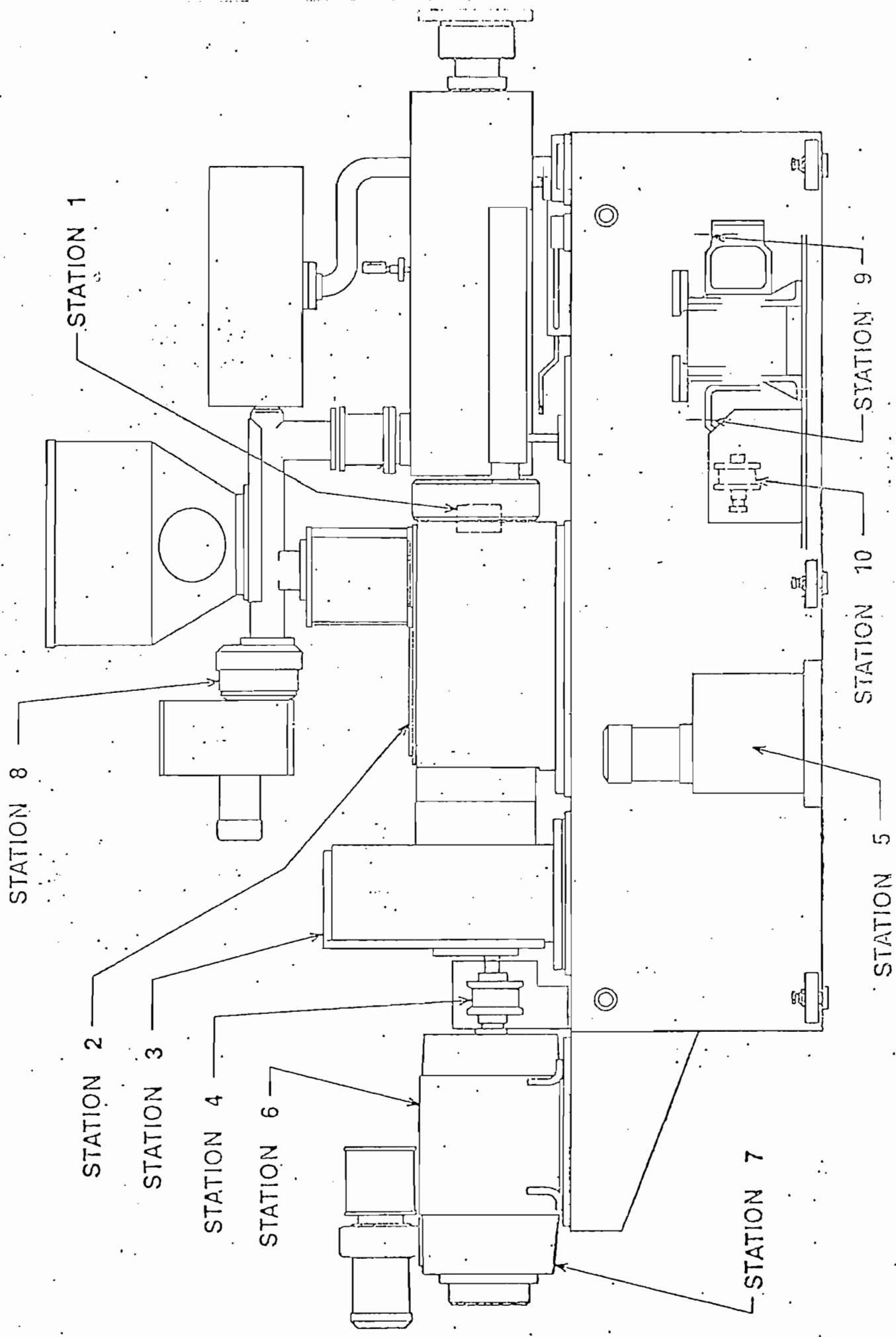
At this time, no particle size, quantity or concentration of PVC dust or powder has been established that will cause harm or failure to the motor. In essence, no in-house filtration system can be recommended or approved unless positively proved that the system will remove all contamination.

DC motor manufacturers recommend a separate ventilation system free of PVC dust or powder. Normal or average air (free of PVC dust or powder) can be piped in to ventilate these motors. Normal dirt, dust and small airborne particles will pass through and not cause injury. Filters supplied with motors, or equivalent must still be used.

Below is a chart showing the minimum air requirements and suggested air duct size for proper motor ventilation to extruder drive motors according to the horsepower rating.

MOTOR RATING	AIR VOLUME REQUIRED	MAX. VACUUM ALLOWED IN SUPPLY DUCT (I.W.=IN. WATER)	SUPPLY DUCT DATA		
			0 - 30 FT. RUN	30 - 60 FT. RUN	OVER 60 RUN
25 HP	270 CFM	.54 I.W.	6 In. Dia.	8 In. Dia.	Force Air System
30 HP	270 CFM	.86 I.W.	6 In. Dia.	8 In. Dia.	"
40 HP @ 1750 RPM	420 CFM	.82 I.W.	6 In. Dia.	8 In. Dia.	"
40&50 HP @ 2500 RPM	385 CFM	1.04 I.W.	6 In. Dia.	8 In. Dia.	"
60 HP @ 2500 RPM	600 CFM	1.66 I.W.	6 In. Dia.	8 In. Dia.	"
50 HP @ 1750 RPM	600 CFM	1.66 I.W.	6 In. Dia.	8 In. Dia.	"

NOTE: Blower filter supplied with the motor, or an equivalent filter, must be used with the above suggested venting systems.



STATION 8

STATION 1

STATION 2

STATION 3

STATION 4

STATION 6

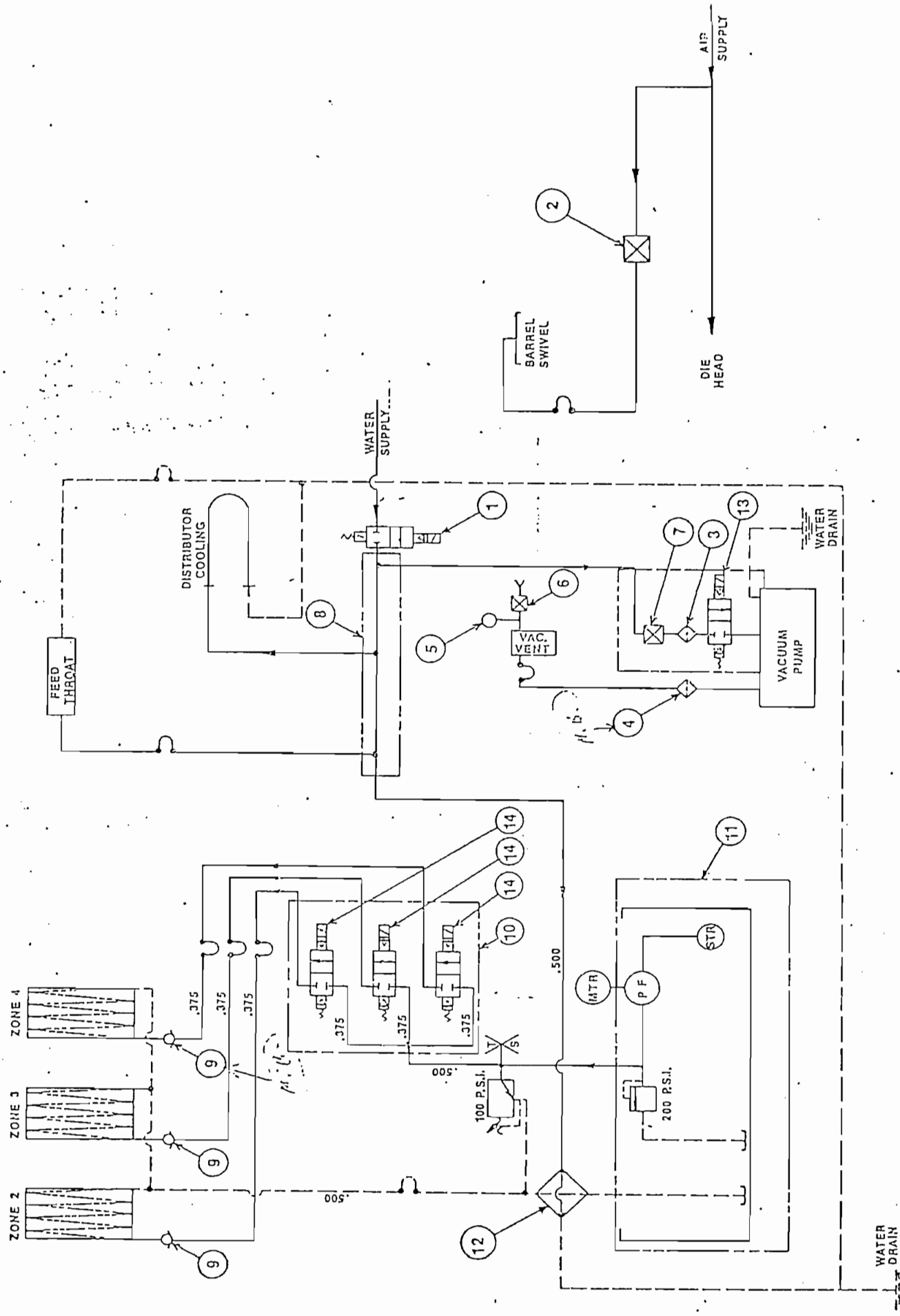
STATION 7

STATION 5

STATION 10

STATION 9

COOLING & AIR CIRCUIT DIAGRAM



This specification covers a dual purpose Premium Grade rust and oxidation inhibited petroleum fluid intended for service as a hydraulic oil and general purpose lubricant. These requirements exceed ASLE standard H-315.

CHEMICAL AND PHYSICAL PROPERTIES:

CAUTION
When P-57 is specified for use in a hydraulic system, do not use an anti-wear hydraulic oil.

A.P.I. Gravity (at 60°F)	(ASTM D 287)	27 to 30
Viscosity System (SUS at 100°F)	(ASTM D 2422)	No. 700
(Centistokes at 100°F)	(ASTM D 2161)	630 to 770
	(ASTM D 445)	135-165
Viscosity Index	(ASTM D 2270)	90 Min.
Color	(ASTM D 1500)	5.0 Max.
Flash (O.C.)	(ASTM D 92)	430°F. Min.
Fire (O.C.)	(ASTM D 92)	475°F. Min.
Neutralization No. (mg. KOH per gm. oil)	(ASTM D 664)	0.2 Max.
Rust Test	(ASTM D 665 Proc. "A")	Pass
Thermal Stability Test*		
Results after Test		
Precipitate or Sludge		100 mg./100 ml. Max.
Neutralization No.	(ASTM D 664)	0.15 Max. Increase
Viscosity Change	(ASTM D 2161)	5% Max. Change
Condition of Steel Rod		
Visual		No Discoloration
Deposit (per 200 ml.)		3.5 mg. Max.
Metal Removed (per 200 ml.)		1.0 mg. Max.
Condition of Copper Rod	(ASTM D 130 Color Class)	
Visual		2 Max.
Metal Removed (per 200 ml.)		10.0 mg. Max.

*See Test Procedure "A" in Chapter 10.

FIELD TEST REQUIREMENTS:

This lubricant must have all of the general qualities and properties required to insure its satisfactory performance as a machine tool lubricant and hydraulic medium. It is recommended to be changed at a semi-annual frequency (or after 1000 hours of operation) and to be used under conditions consistent with good machine tool practice.

CINCINNATI
MILACRON

Heavy Hydraulic Oil
and Lubricant

CM Spec.

P-57

1974

The approved products under Spec. P-57 (1974) are suitable for use in all Cincinnati Milacron machine tools requiring this viscosity hydraulic oil. CAUTION. Oil products that were formerly approved under Spec. P-57 will not necessarily meet the requirements for use in NC machine tool hydraulic systems.

APPROVED PRODUCTS LIST

The following is a list of approved lubricants that meet the minimum requirements of this specification. No inference should be made that all products are of the same quality.

SUPPLIER	PRODUCT NAME
Amoco Oil Co. (Standard Oil Co. Division of American Oil Co.)	American Industrial Oil No. 75
Atlantic Richfield Co.	Duro 600
BP Trading Ltd. and its Affiliated Companies	BP Energol TH-200HB
Chevron Oil Co.	Chevron OC Turbine Oil 24
Exxon Co. USA Esso Affiliated Companies	Nuto 76 Teresso 80
Getty Oil Co.	Veedol Aturbrio 71
Gulf Oil Canada Ltd.	Gulf Harmony 77
Gulf Oil Corp. and Subsidiaries	Gulf Harmony 76
Mobil Oil Corp.	Mobil D.T.E. Oil Extra Heavy
Petrofina Group	Fina Cirkan 51
Shell Oil Co.	Turbo 69
Standard Oil Co. (Ohio)/ Boron Oil Co. BP Oil Corp.	Factovis 80 Factovis 80 BP Energol HL-C150
Sun Oil Co.	Sunvis 975
Union Oil Co.	Union Unax RX 700

This specification covers a Premium Grade heavy-medium bodied nonlead E.P. type lubricant. This lubricant is for use in worm gear drives and in other applications where high load and shock load conditions exist. The additive(s) used must be a nonlead type, noncorrosive material and blended with a well refined high viscosity index dewaxed lubricating oil stock. These requirements meet or exceed ASLE E.P. gear lubricant G-1000 standard.

CHEMICAL AND PHYSICAL PROPERTIES:

A.P.I. Gravity (60°F)	(ASTM D-287)	22 Min.
Viscosity System	(ASTM D-2422)	1000
(SUS @ 100°F)	(ASTM D-2161)	900-1100
(Centistokes @ 100°F)	(ASTM D-445)	198-242
Viscosity Index	(ASTM D-2270)	85 Min.
Flash (O.C.)	(ASTM D-92)	380° F Min.
Pour Point	(ASTM D-97)	10° F Max.
Timken E.P. Test Lbs.	(ASTM D-2782)	45 Min.
Rust	(ASTM D-665 Proc. "A")	Pass
Thermal Stability Test*		
Results After Heat Test		
Viscosity	(ASTM D-2161)	5% Max. Increase
Precipitate or Sludge		None
Condition of Steel Rod		No Deposit or Discoloration
Condition of Copper Rod	(ASTM D-130 Color Class)	2 Max.

*See Test Procedure "B" in Chapter 10

FIELD TEST REQUIREMENTS:

This lubricant must have all of the general qualities and properties to insure its satisfactory performance as a machine tool worm gear lubricant. It is recommended to be changed at a semiannual frequency and to be used under conditions consistent with good machine tool practice.

GENERAL
MILITATION

Heavy-Medium
EP Gear Lubricant

CIA Spec.

P-74

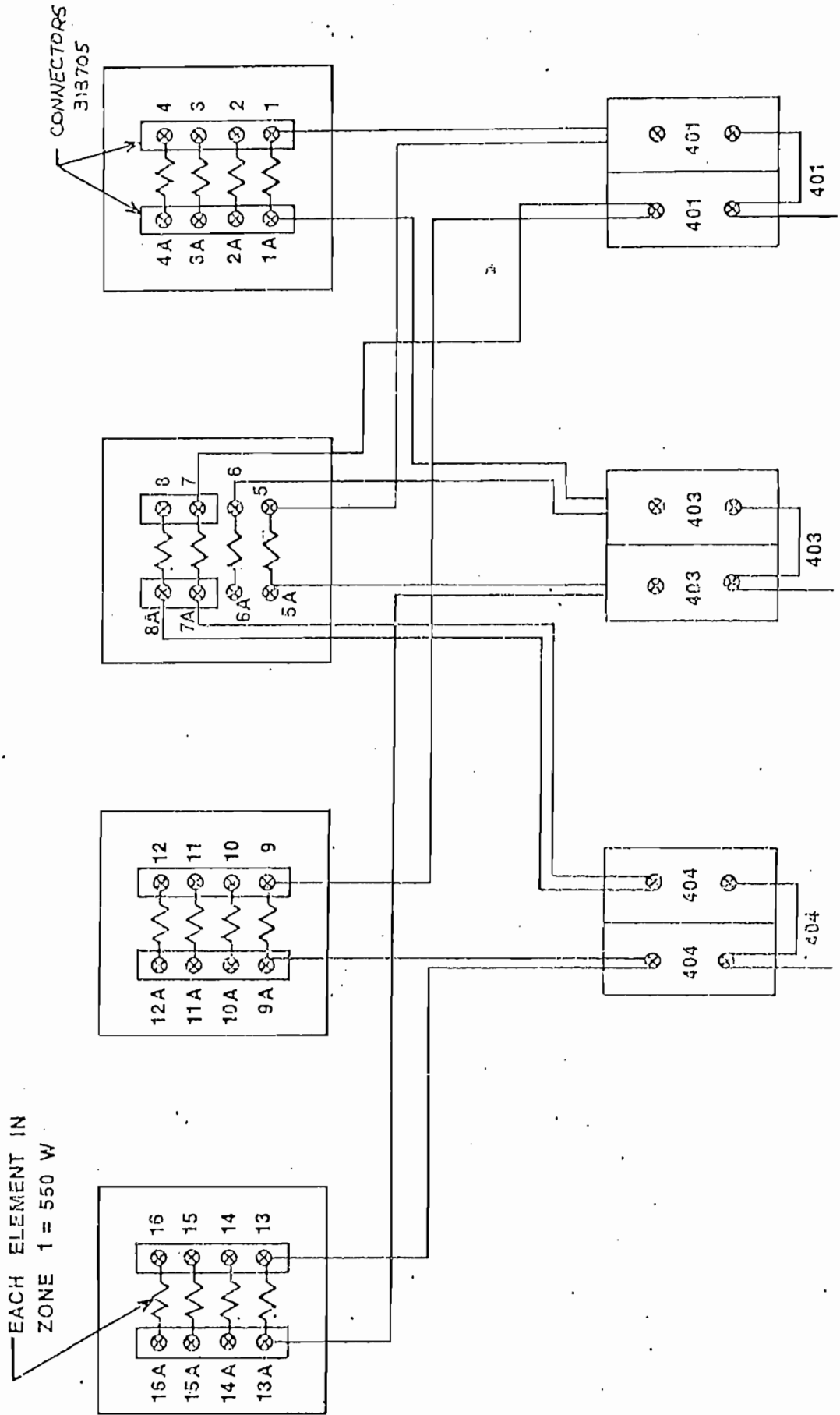
1974

APPROVED PRODUCTS LIST

The following is a list of approved lubricants that meet the minimum requirements of this specification. No inference should be made that all products are of the same quality.

SUPPLIER	PRODUCT NAME
Chevron Oil Co.	Chevron NL Gear Compound 220
Exxon Co. U.S.A.	Spartan EP 220
Gulf Oil Corp. & Subsidiaries	E.P. Lubricant S-100
Mobil Oil Corp.	Mobilgear 630
Shell Oil Co.	Omala 72
Standard Oil Co. (Ohio)	Gearep 90
Sun Oil Co.	Sunep 70
Texaco Inc.	Meropa 220

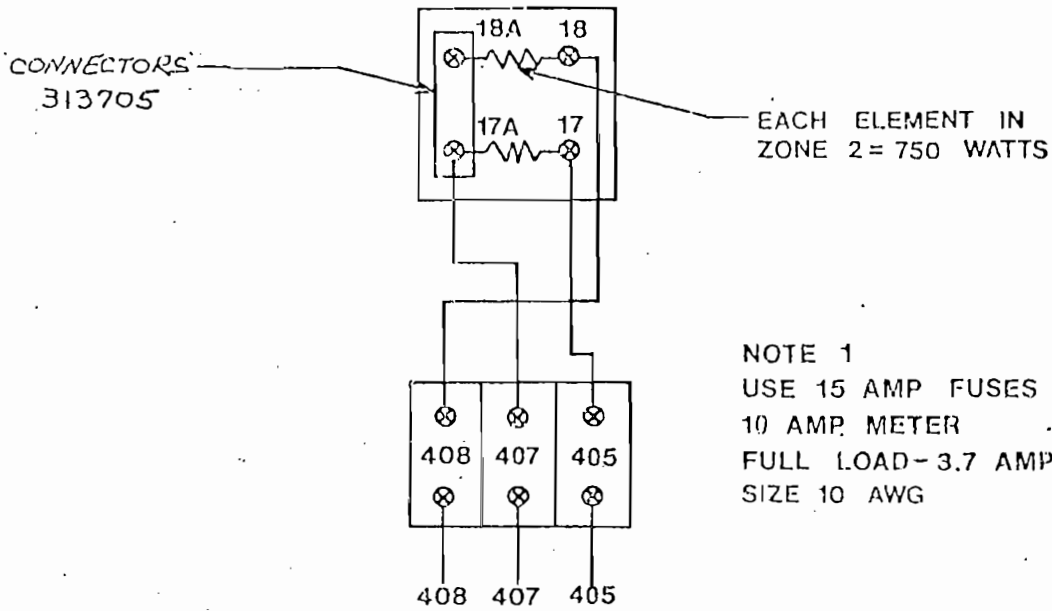
ZONE 1



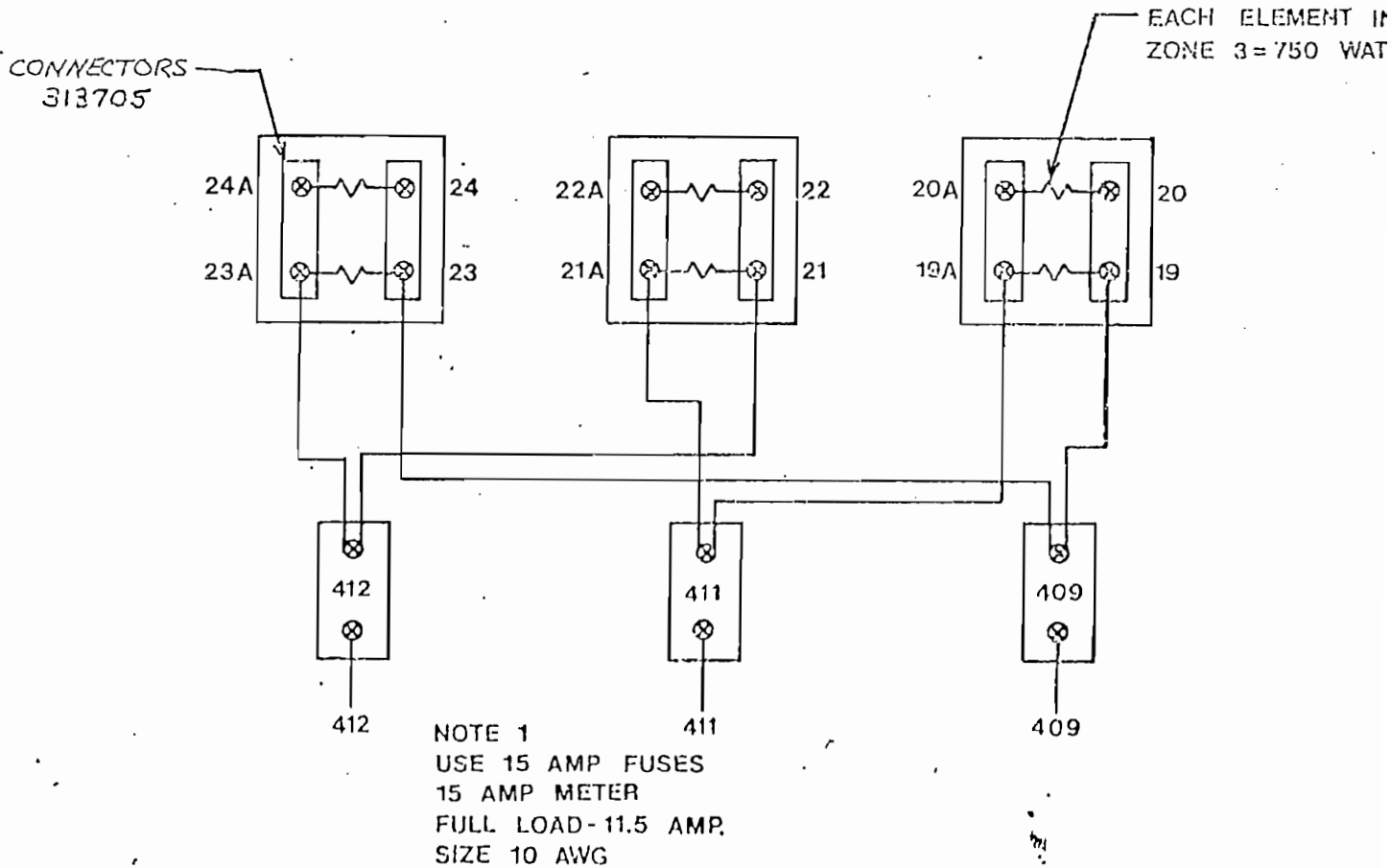
EACH ELEMENT IN
ZONE 1 = 550 W

NOTE 1
USE 30 AMP FUSES OR C.B.
30 AMP METER
FULL LOAD - 22 AMP.
SIZE 10 AWG

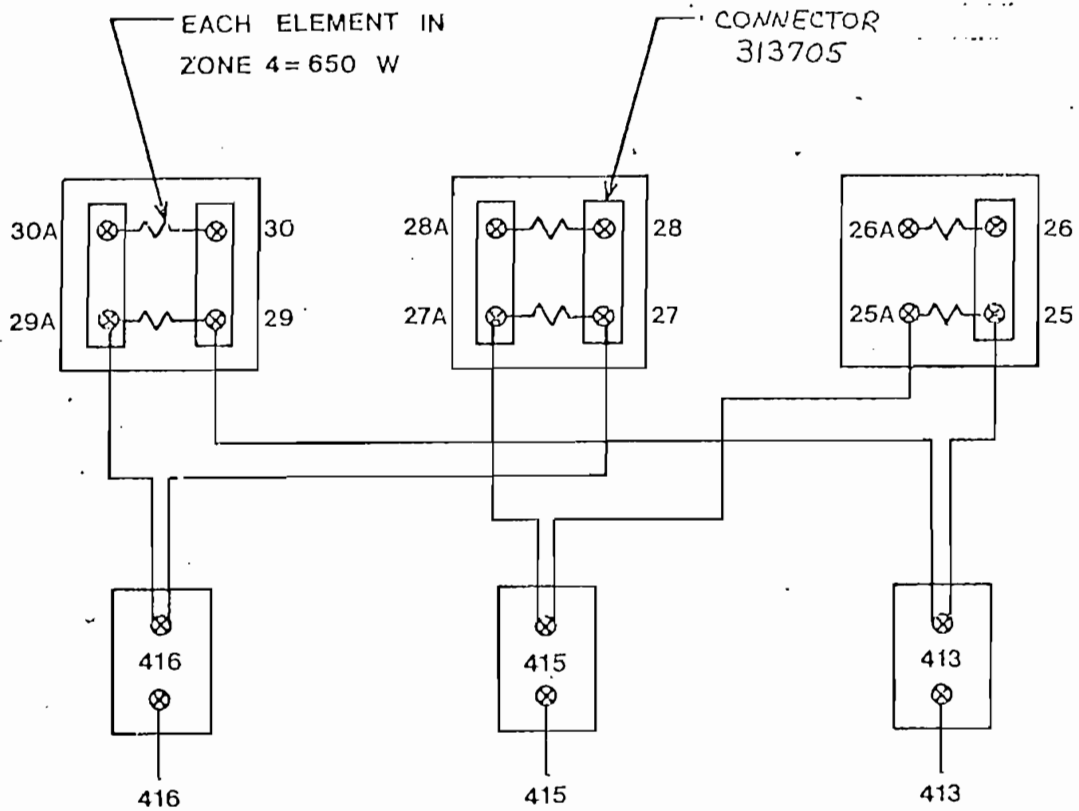
ZONE 2



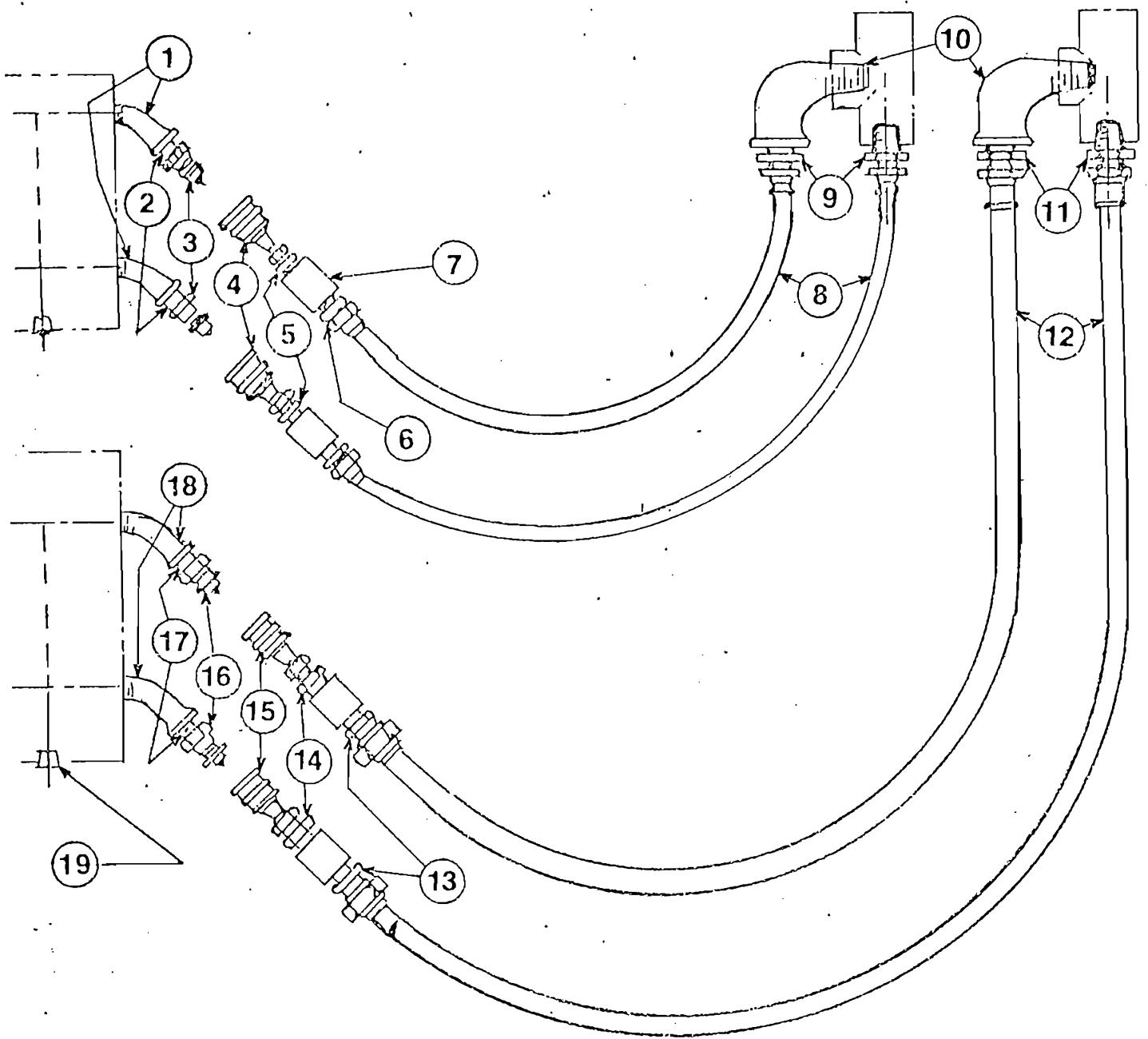
ZONE 3



ZONE 4

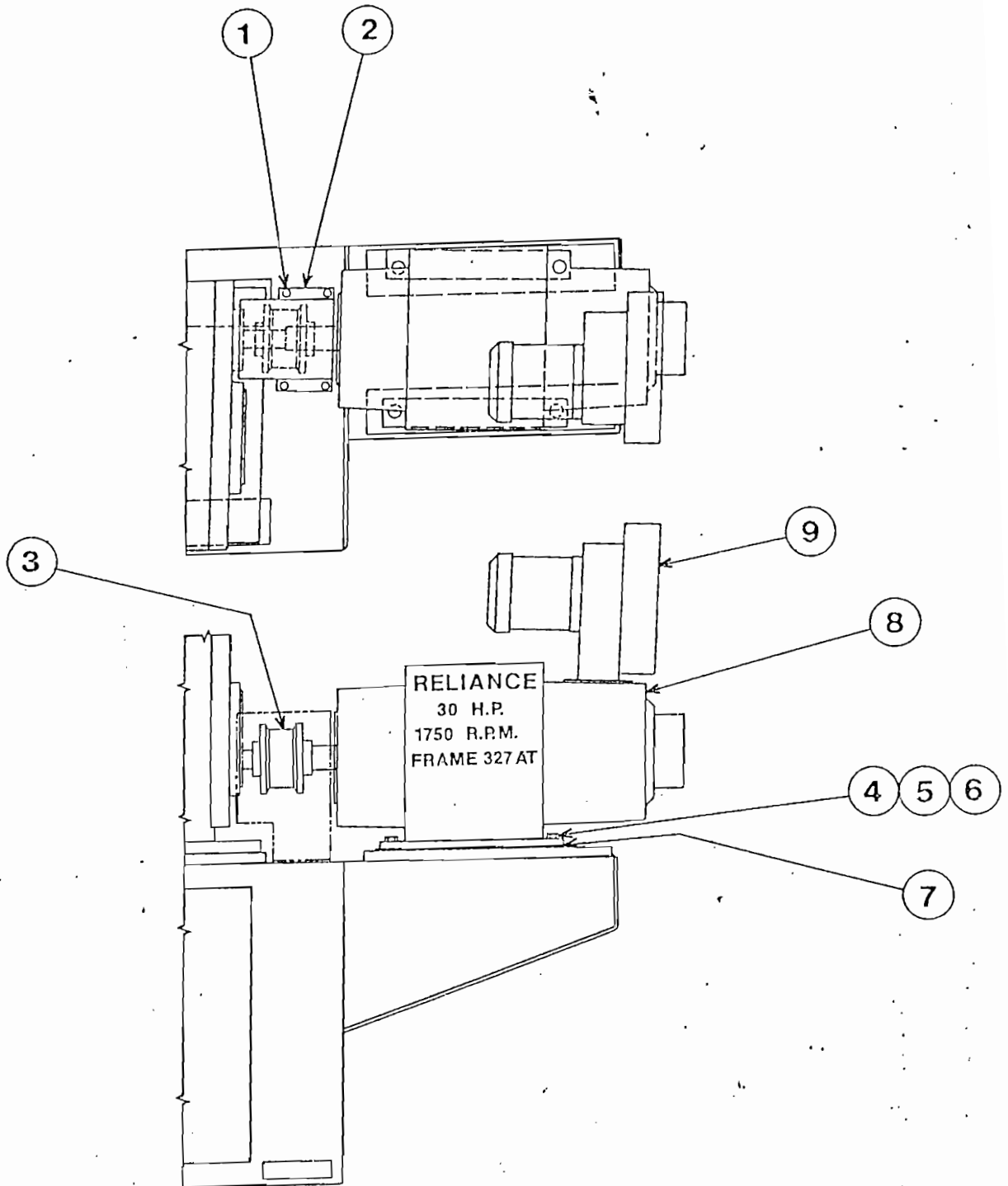


NOTE 1
USE 15 AMP FUSES OR C.B.
15 AMP METER
FULL LOAD-9.9
SIZE 10 AWG

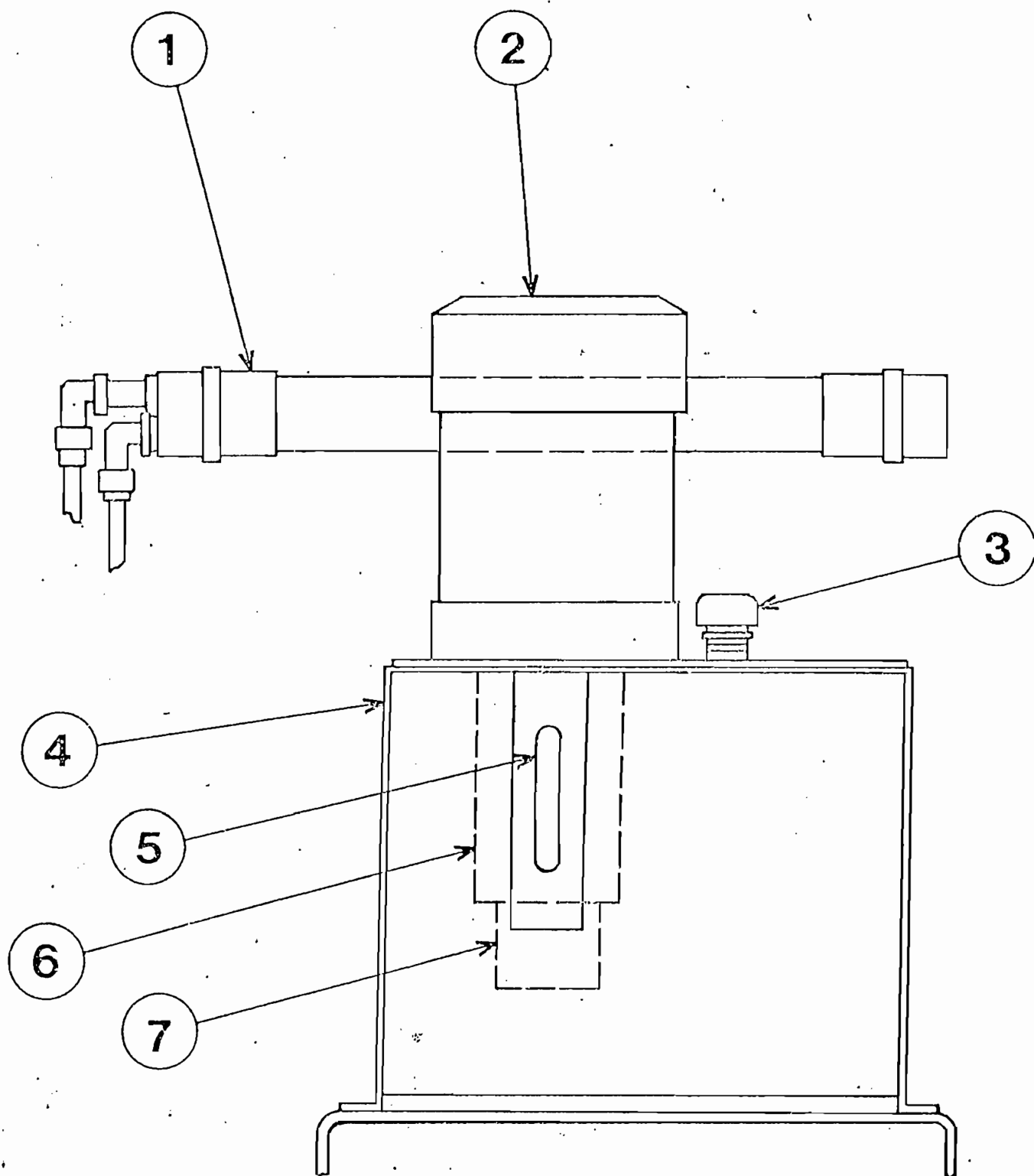


STERELCO PIPING

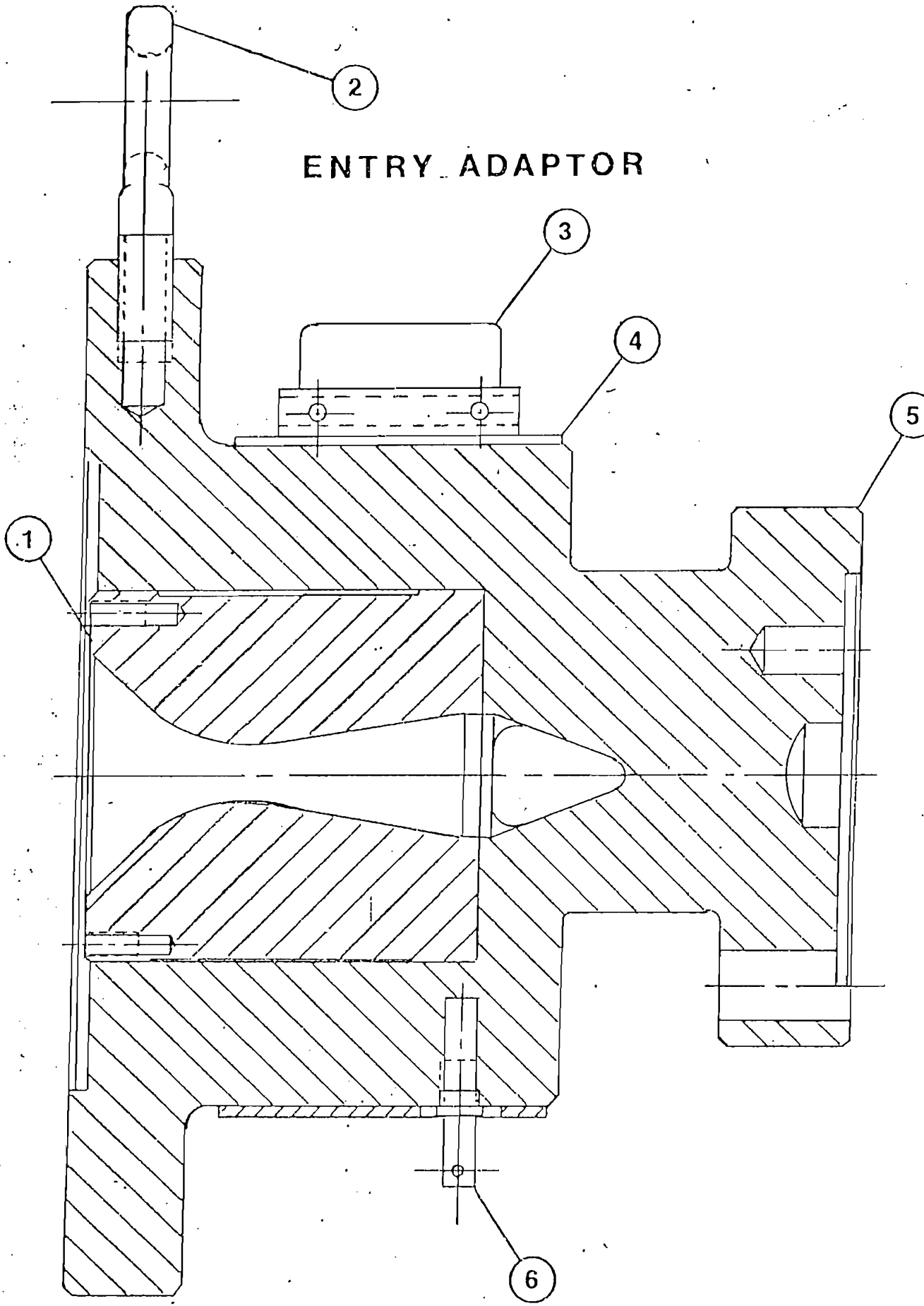
MOTOR DRIVE



BARREL COOLING UNIT

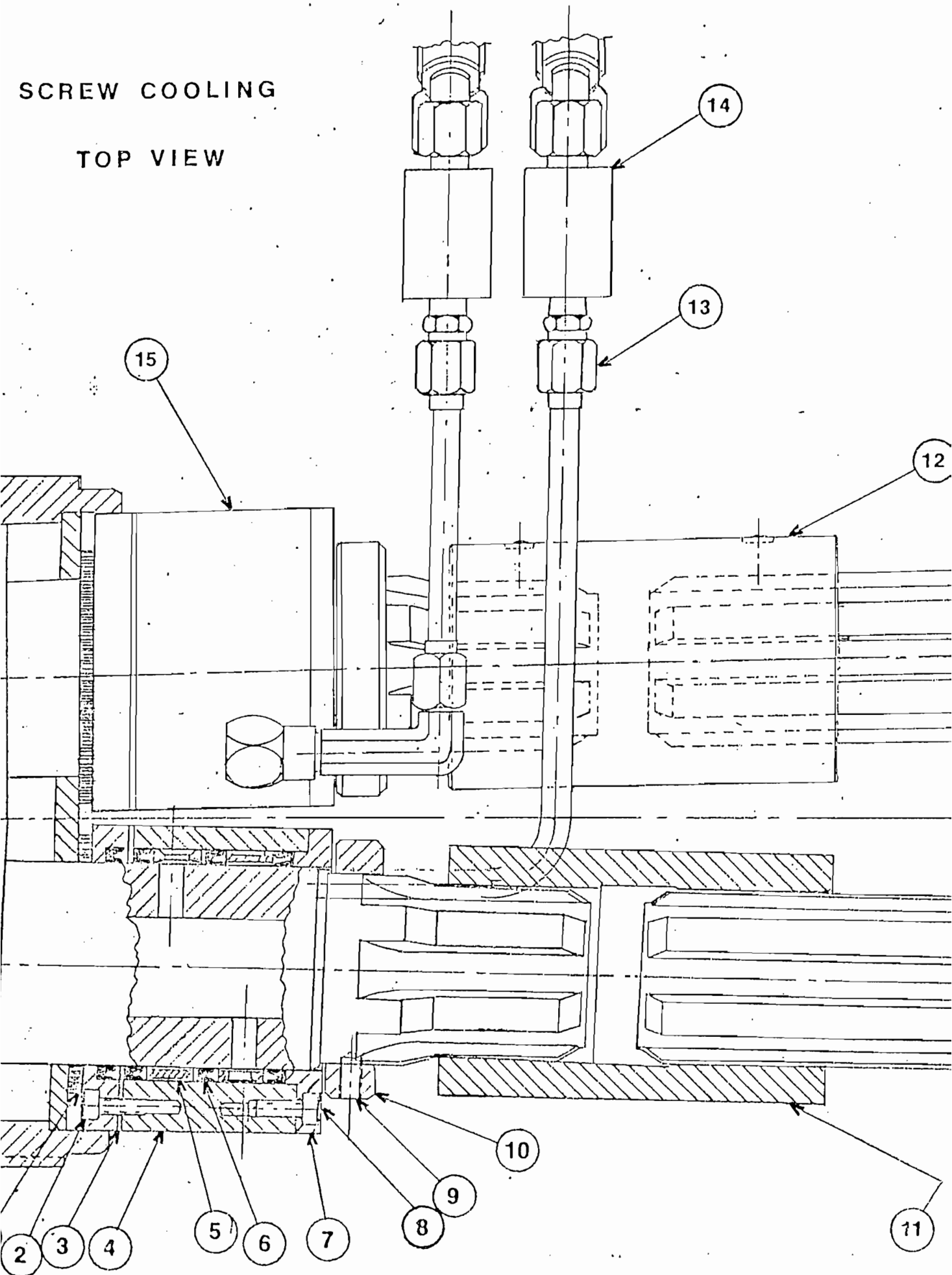


ENTRY ADAPTOR

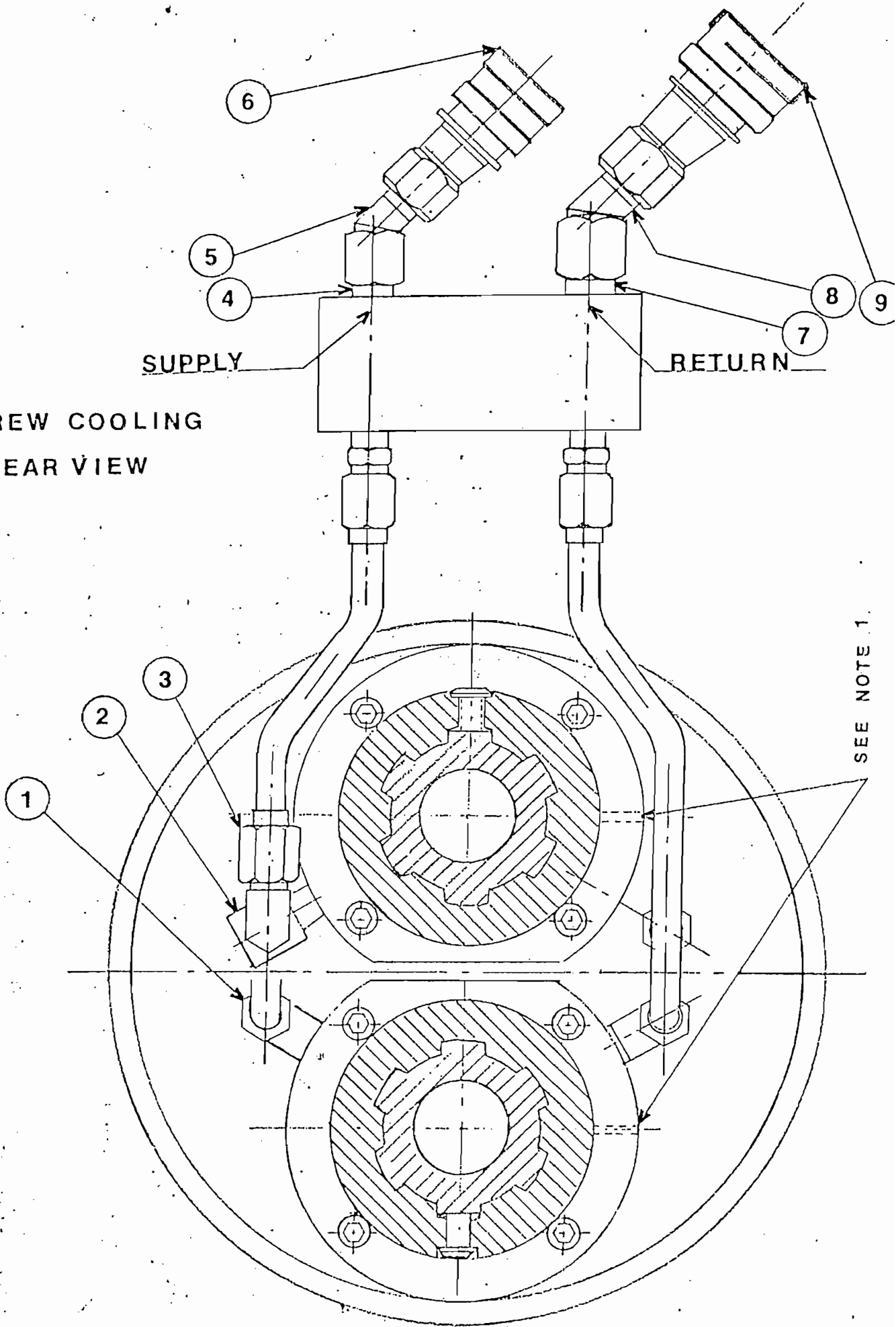


SCREW COOLING

TOP VIEW



SCREW COOLING
REAR VIEW



SEE NOTE 1.

ANEXO G

Temperature Data Logging with SCXI-MS100

Introduction

This application note describes how the SCXI-MS100 Temperature Measurement System can easily and accurately perform in a variety of temperature measurement applications.

Application

An environmental testing laboratory wishes to improve the usefulness of their thermal tests by collecting and analyzing more temperature data from the device under test (DUT) and by automating the tests with a PC that logs the data to hard disk for data analysis and report generation. The test chamber is instrumented with 32 thermocouples mounted throughout the chamber and directly on the DUT.

Solution Summary

The 32 thermocouple signals are conditioned and acquired by the SCXI-MS100 Temperature Measurement System. The SCXI-MS100, shown in Figure 1, includes all the hardware and software needed to measure and log up to 32 thermocouple or voltage inputs. The SCXI-MS100 combines shielded, low-noise SCXI signal conditioning hardware, an accurate 16-bit plug-in data acquisition (DAQ) board, and extremely easy-to-use data logging software (VirtualBench-Logger) to form a complete, ready-to-run temperature measurement system with logging, retrieving, and playback functionality.

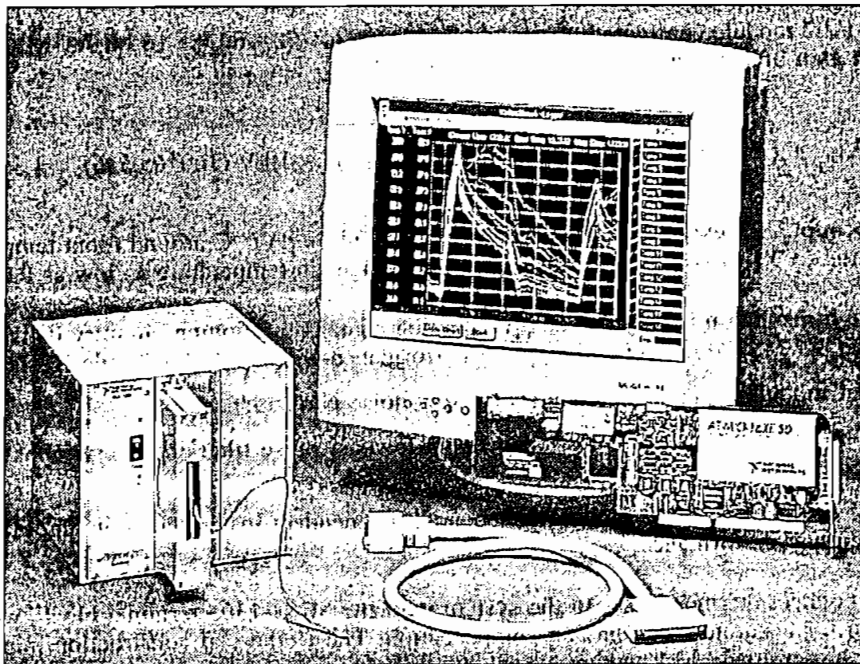


Figure 1. SCXI-MS100 Includes Signal Conditioning Hardware, Data Acquisition Board, and Logging Software for Windows.

Product and company names are trademarks or trade names of their respective companies.

Because the system is based on the modular SCXI platform, it can easily be expanded for more inputs or outputs simply by adding in additional SCXI modules with those capabilities. For example, the SCXI system could easily be expanded to add more inputs, such as additional thermocouple or pressure signals, or outputs to control the temperature of the chamber.

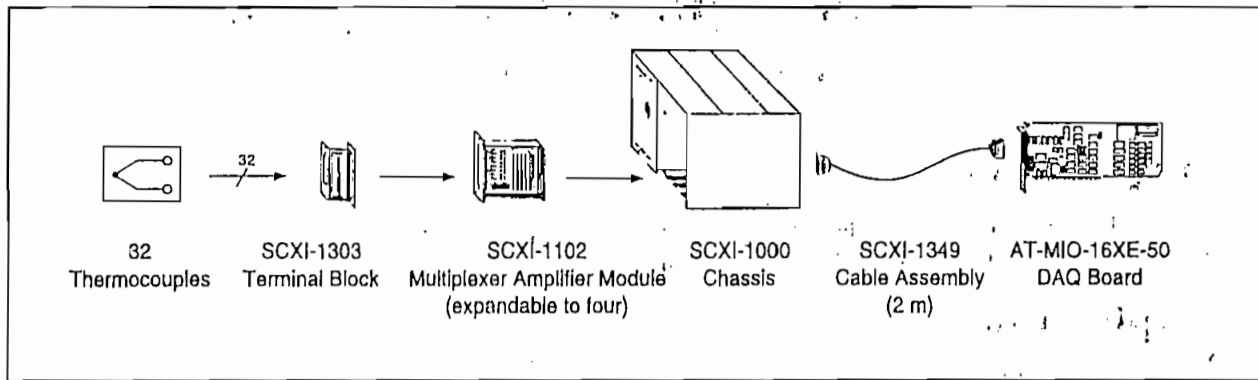


Figure 2. SCXI-MS100 Consists of the DAQ board, SCXI Signal Conditioning Module, Terminal Block, Chassis, and Cable

Selecting the Proper Measurement System

Thermocouples, with very low voltage levels and cold-junction compensation requirements, require specialized, high-quality signal conditioning hardware for reliable and accurate measurements. SCXI is a popular signal conditioning platform with a variety of input and output modules. In particular, the SCXI-1102 is a signal conditioning module for thermocouples and low-bandwidth voltage inputs. The SCXI-1102 module is the basis of the SCXI-MS100 system, which also includes the AT-MIO-16XE-50 plug-in board, which digitizes the amplified and conditioned voltages from the SCXI-1102.

With the SCXI-1102 module configured for an amplifier gain of 100, and the 16-bit AT-MIO-16XE-50 configured for a gain of 1, the measurement resolution of the system will be:

$$V_{\text{bit}} = (\text{ADC input range}) / (\text{amplifier gain} * 2^{16}) = 10 \text{ V} / (100 * 65,536) = 1.5 \mu\text{V/bit}$$

A type J thermocouple, for example, has a sensitivity of about 50 $\mu\text{V}/^\circ\text{C}$ around room temperature. In this case, therefore, the SCXI-MS100 will be able to sense changes in temperature as low as 0.03 $^\circ\text{C}$.

However, this high resolution is only useful if the analog signal conditioning circuitry delivers accurate, low-noise data. The SCXI-MS100 delivers this type of performance with the following design features:

- fully shielded modules, chassis, and cables for low-noise performance
- SCXI-1102 amplifier module includes independent lowpass noise filters on every input channel for maximum rejection of 50/60 Hz noise
- each channel of the SCXI-1102 module includes an independent instrumentation amplifier with low-drift and high-accuracy performance

In addition, you connect thermocouples to the system with the SCXI-1303 terminal block, which features an isothermal design for accurate cold-junction compensation. The isothermal construction minimizes temperature gradients within the terminal block, which contribute directly to measurement error.

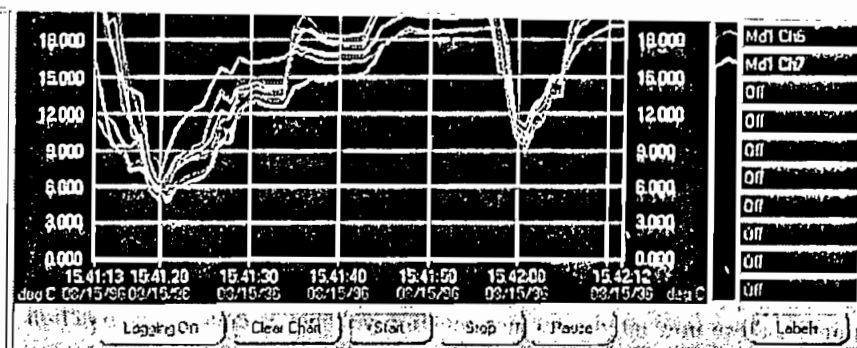


Figure 3. VirtualBench-Logger software, included with the SCXI-MS100 system, turns your PC into an automated data recorder.

Options for More Capabilities

Because the SCXI-MS100 is based on the modular SCXI platform, it is very easy to modify or enhance the

Ready-to-Run Software

The SCXI-MS100 system also includes VirtualBench-Logger, a Windows-based application program that acquires, scales, and logs data to the PC hard disk. You do not need to perform any programming—simply configure the software and start logging data. With an intuitive graphical user interface, VirtualBench-Logger displays data trends simultaneously as data are logged to disk. VirtualBench-Logger can also retrieve and replay previously logged data (Figure 3).

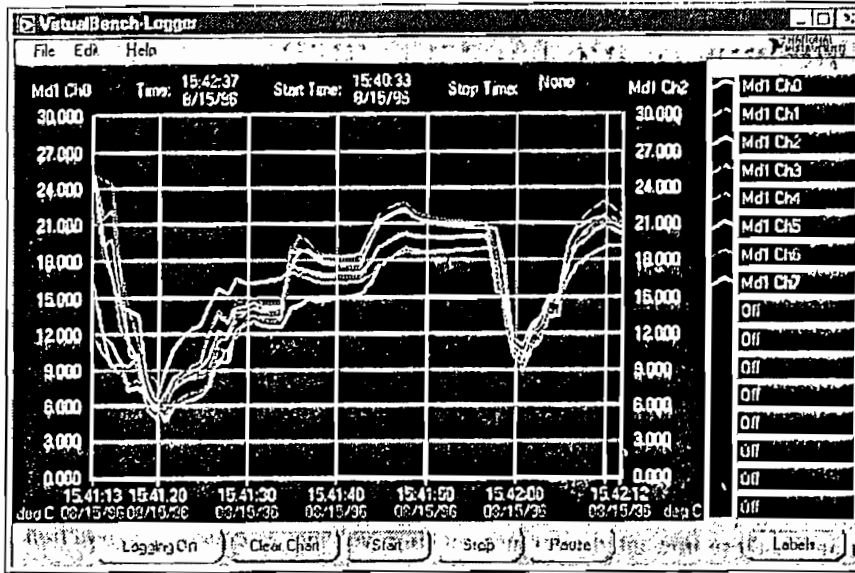


Figure 3. VirtualBench-Logger software, included with the SCXI-MS100 system, turns your PC into an automated data recorder.

Options for More Capabilities

Because the SCXI-MS100 is based on the modular SCXI platform, it is very easy to modify or enhance the SCXI-MS100 to address a wider range of applications. Some of the more popular requirements are briefly described below.

More Thermocouple Inputs—You can expand the SCXI-MS100 to a maximum of 128 inputs with the addition of three SCXI-MS100 32-Channel Expansion Kits. Each expansion kit includes a single SCXI-1102 module and SCXI-1303 terminal block. The SCXI chassis included with the SCXI-MS100 is a four-slot chassis that can house up to four SCXI modules. For even larger systems, you can replace the SCXI-1000 four-slot chassis with an SCXI-1001 12-slot chassis for up to 384 inputs.

Customized Software—If you require more flexibility, such as specialized data processing or acquisition modes, you can use the SCXI-MS100 hardware with data acquisition programming software, such as LabVIEW or LabWindows/CVI. All National Instruments application software works with the NI-DAQ driver software that controls the SCXI-MS100 system under Windows NT/95/3.x.

Additional Input and/or Output Types—If you require additional I/O channels, such as waveform captures, analog outputs, digital I/O, or relays, you can simply add the appropriate module to the SCXI-1000 chassis, which holds a total of four modules. See the National Instruments catalog for a complete listing of SCXI input and output modules.

Remote Data Logging—The SCXI-MS100 includes a 2 m cable to connect the SCXI chassis to the PC plug-in board. Similar cables are available in lengths up to 10 m. For applications that require a longer distance between the SCXI system and the PC, there are SCXI products with RS-485 serial port coupling for long-

Measuring Temperature with RTDs – A Tutorial

Introduction

A resistance-temperature detector (RTD) is a temperature sensing device whose resistance increases with temperature. An RTD consists of a wire coil or deposited film of pure metal. RTDs can be made of different metals and have different resistances, but the most popular RTD is platinum and has a nominal resistance of 100 Ω at 0° C.

RTDs are known for their excellent accuracy over a wide temperature range. Some RTDs have accuracies as high as 0.01 Ω (0.026° C) at 0° C. RTDs are also extremely stable devices. Common industrial RTDs drift less than 0.1° C/year, and some models are stable to within 0.0025° C/year.

RTDs can be difficult to measure because they have relatively low resistance (100 Ω) that changes only slightly with temperature (less than 0.4 Ω /°C). To accurately measure these small changes in resistance, you may need to use special configurations that minimize errors from lead wire resistance.

Because an RTD is a passive resistive device, you must pass a current through the device to produce a measurable voltage. This current causes the RTD to internally heat, which appears as an error. Self heating is typically specified as the amount of power that will raise the RTD temperature by 1° C, or 1 mW/°C. You can minimize self heating by using the smallest possible excitation current. The amount of self heating also depends heavily on the medium in which the RTD is immersed. An RTD can self heat up to 100 times higher in still air than in moving water.

The Relationship of Resistance and Temperature in RTDs

Compared to other temperature devices, the output of an RTD is relatively linear with respect to temperature. The temperature coefficient, called alpha (α), differs between RTD curves. Although various manufacturers may specify alpha differently, alpha is most commonly defined as the change in RTD resistance from 0 to 100° C, divided by the resistance at 0° C, divided by 100° C:

$$\alpha(\Omega/\Omega/^{\circ}\text{C}) = (R_{100} - R_0)/(R_0 * 100^{\circ}\text{C})$$

where R_{100} is the resistance of the RTD at 100° C, and R_0 is the resistance of the RTD at 0° C.

For example, a 100 Ω platinum RTD with $\alpha = 0.003911$ will measure 139.11 Ω at 100° C. Figure 1 displays a typical resistance-temperature curve for a 100 Ω platinum RTD.

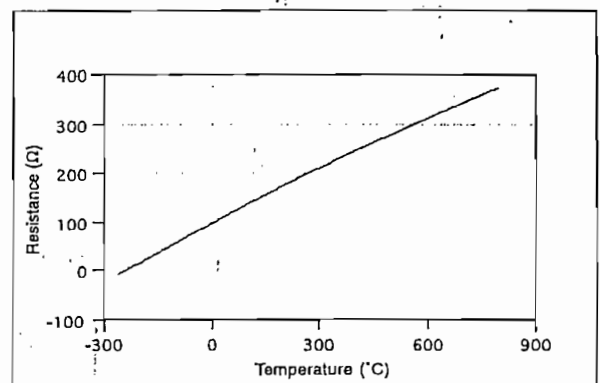


Figure 1. Resistance-Temperature Curve for a 100 Ω Platinum RTD, $\alpha = 0.00385$

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To reduce costs, you may instead want to use a three-wire RTD. By using the three-wire RTD in a Wheatstone configuration with a current source, as shown in Figure 4a, you can compensate for the lead resistances. Notice that, in this bridge configuration, the effects of R_{L1} and R_{L3} cancel each other out because they are located in opposite arms of the bridge. Lead resistance R_{L2} does not add significant error because little current flows through it.

Alternatively, you can use a current excitation source and connect the three-wire RTD as shown in Figure 4b. In this configuration, the resistance of only one lead, R_{L1} , adds error to the measurement.

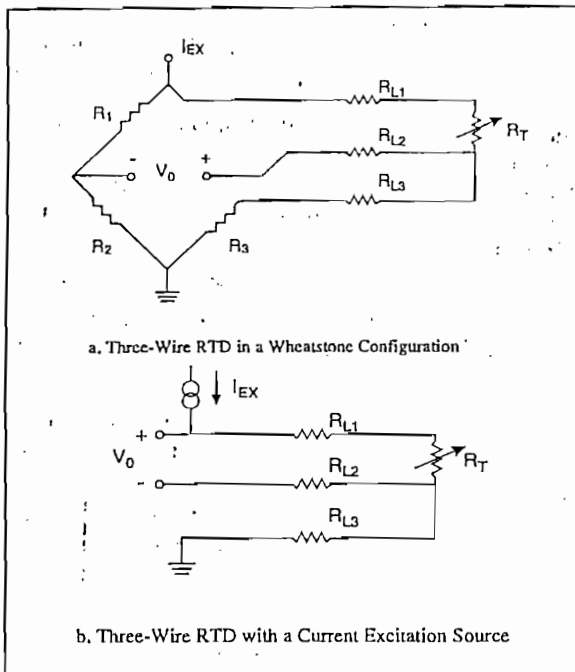


Figure 4. Three-Wire RTD Measurement with a Wheatstone Bridge and a Current Source

RTD Measurements with SCXI

Signal conditioning is generally required to interface an RTD to a measurement device such as a plug-in data acquisition (DAQ) board. Signal conditioning produces current excitation for the RTD, amplifies the output signal, and filters the signal to remove unwanted noise. You can also use signal conditioning to electrically isolate the RTD and the monitored system from the DAQ system and the host computer.

Signal Conditioning eXtensions for Instrumentation (SCXI) is a signal conditioning front end you can use with plug-in DAQ boards, or as a complete, external DAQ system. SCXI modules condition signals from a variety of signal sources, such as RTDs, thermistors, and thermocouples, and pass the conditioned signal to the plug-in DAQ board. The plug-in board can then acquire the signals directly into PC memory.

The SCXI product line has a variety of analog and digital signal conditioning modules for various types of signals. The SCXI-1121 and SCXI-1122 are well suited for RTDs.

The SCXI-1121 is an isolated amplifier and multiplexer module with four isolated input channels. Each of the four channels has a jumper-selectable gain amplifier (gains from 1 to 2,000) and a lowpass filter (4 Hz or 10 kHz). The SCXI-1121 also has four channels of isolated voltage or current excitation. You can configure each channel independently to produce a constant 0.15 mA, 0.45 mA, 3.333 V, or 10.0 V source.

The SCXI-1122 is a 16-channel isolated multiplexer module with a programmable amplifier (gains from 0.01 to 2,000) and a single 1.0 mA current excitation source.

Example—Monitoring 16 RTDs with the SCXI-1121

For this example, assume that you want to use 16 100 Ω four-wire RTDs to monitor the efficiency of a production process. You can monitor all 16 RTDs with four SCXI-1121 modules installed in a four-slot SCXI-1000 chassis. The modules and chassis are connected to a plug-in PC DAQ board that acquires the analog signals from all four modules and stores the digitized readings into PC memory.

The plug-in board in this example is the AT-MIO-16F-5, which is a 12-bit, 200 kHz multifunction I/O board for IBM PC AT and compatible computers. The AT-MIO-16F-5 board is used in the example because of its accuracy, high scan rate, and self-calibration capability. You can also use similar multifunction I/O boards for the Macintosh and PS/2 platforms with the SCXI system. The SCXI chassis is connected to the AT-MIO-16F-5 with the SCXI-1345 shielded cable assembly, which is available in lengths up to 10 m. The RTDs are wired into SCXI-1320 terminal blocks, which have convenient screw terminals with strain relief. Figure 5 is a diagram of the system.

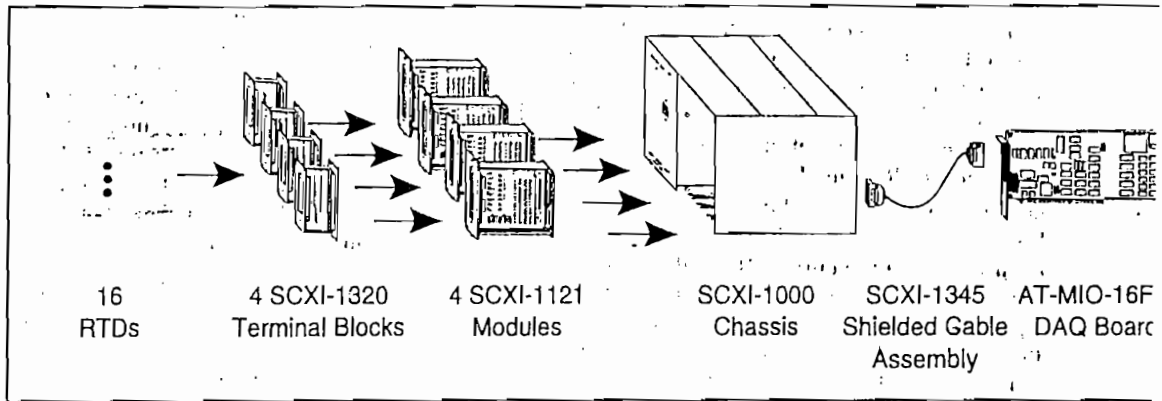


Figure 5. SCXI System for Monitoring 16 RTDs

An IBM PC/XT/AT or compatible computer controls the temperature monitoring system. Therefore, application software choices for controlling the system include National Instruments' LabWindows® for DOS or LabVIEW® for Windows. Alternatively, you can use a general-purpose programming language such as C, BASIC, or Pascal in DOS or Windows and control the DAQ hardware with the NI-DAQ® driver software that is included with all National Instruments plug-in DAQ boards.

Configuring an SCXI System for RTD Measurement

First, configure the SCXI-1121 modules for the RTD measurements. Configuring includes setting the excitation mode, gain, and bandwidth for each input channel of the SCXI-1121. Follow these steps to configure your SCXI-1121 modules:

1. Set the Excitation mode. Because you are using four-wire RTDs, configure each channel for constant current excitation. You can configure the current source for 0.15 mA or 0.45 mA. The lower current setting minimizes the RTD self-heating effect.
2. Set the gain. Determine what gain to apply to your RTD signal. Be careful to choose the gain so that the output of the SCXI-1121 does not exceed the ± 5 V input range of the AT-MIO-16F-5, but produces the optimum resolution. For example, suppose you will operate your 100 Ω RTD at a temperature up to 300° C. At this temperature, the RTD resistance increases to about 220 Ω . With a 0.15 mA current source, the voltage output at 300° C will be 220 Ω * 0.15 mA = 33 mV. Setting the gain of the SCXI-1121 to 100 will generate a

maximum voltage output of 3.3 V, which is within the ± 5 V input range of the plug-in

3. Set the bandwidth. The SCXI-1121 has configurable filters on each channel. You can set each filter for a cutoff frequency of 4 Hz or 10 kHz. The 4 Hz filter is particularly useful for rejecting 60 Hz noise from power lines and lighting.

Table 2 summarizes a typical SCXI-1121 configuration for measuring RTDs.

Table 2. Typical Configuration for an SCXI-1121 Used with RTDs

SCXI-1121 Parameter	Typical Setting for a 100 Ω Four-Wire RTD
Channel gain	100
Bandwidth	4 Hz
Excitation mode	Current
Excitation level	0.15 mA
Bridge completion	Disabled

Note: These settings are configured on a per-channel basis.

Connecting the RTDs to the SCXI-1121

Connect the RTDs to the SCXI-1121 modules through the SCXI-1320 shielded terminal block. Alternately, you can use the SCXI-1321 or SCXI-1328 blocks, which have special capabilities for gauges and thermocouples, respectively, or the SCXI-1330 connector and shell. Figure 6 shows the wire connections used to correctly wire a four-wire RTD to channel 0 of an SCXI-1320.

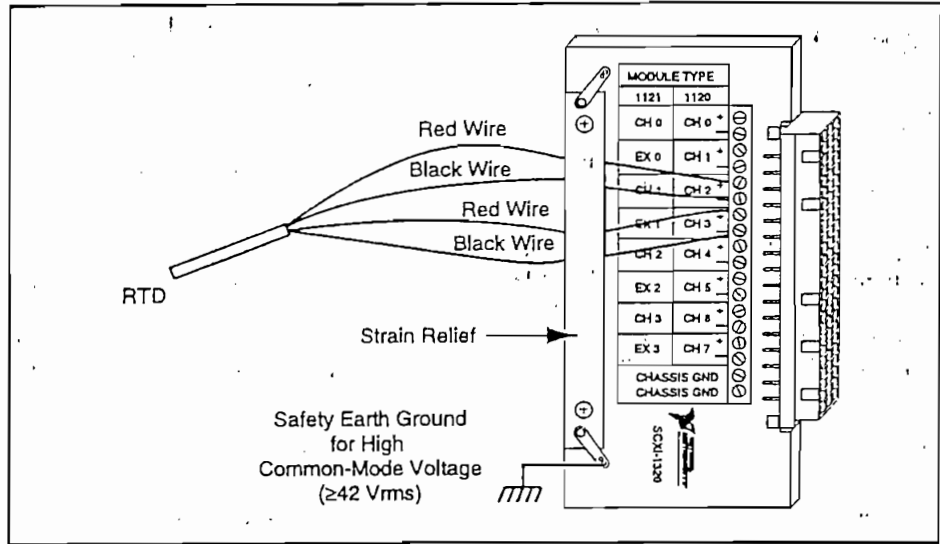


Figure 6. Connecting a Four-Wire Platinum RTD to Channel 1 of the SCXI-1320

Figure 7 contains wiring diagrams for connecting two-wire, three-wire, and four-wire RTDs to the SCXI-1121 module.

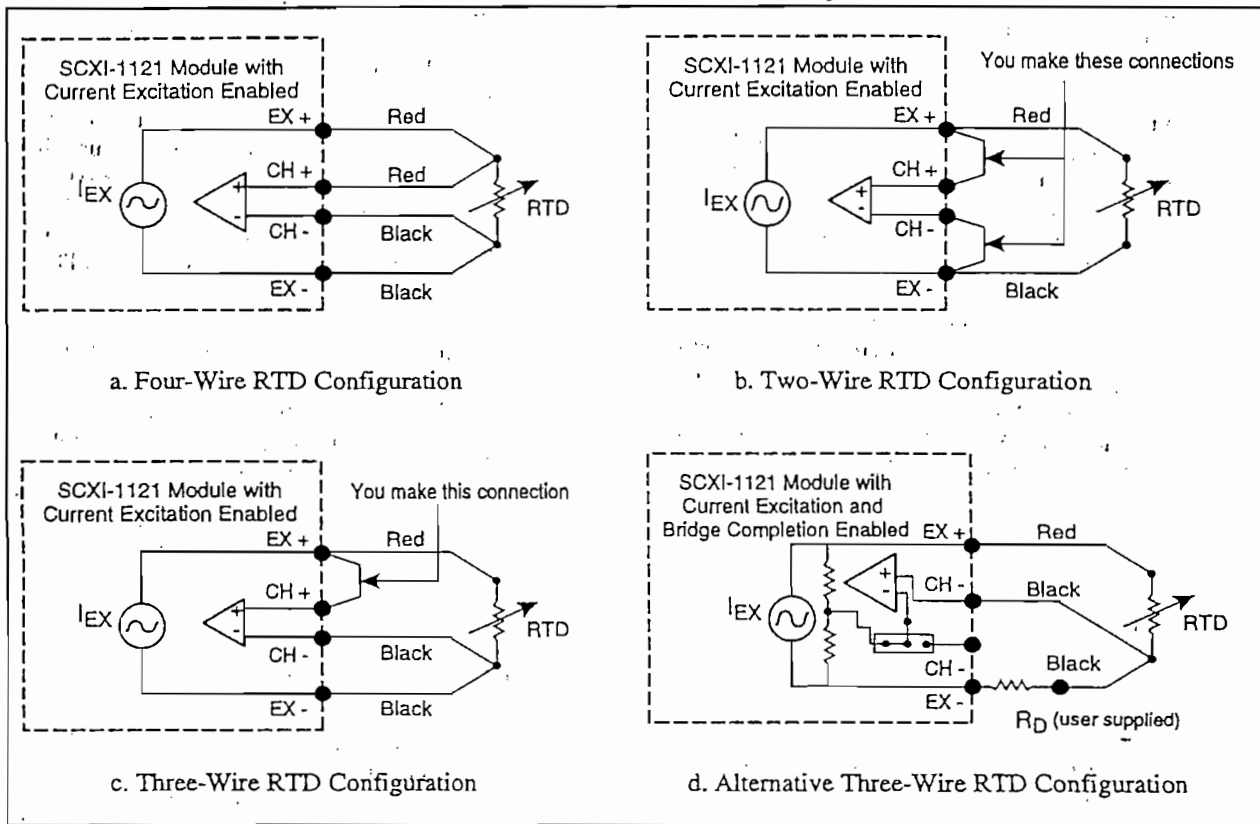


Figure 7. Wiring Diagrams for Two-Wire, Three-Wire, and Four-Wire Configurations

Measuring RTD Temperature

After you have configured and installed the plug-in DAQ board and SCXI-1121 modules and have correctly wired the RTDs to the SCXI terminal block, you can measure the temperature your RTDs sense.

You can use LabVIEW, LabWindows, or NI-DAQ software to easily monitor the voltages that the RTDs generate. The following software programming sequences are typical for taking an RTD measurement using each software package.

LabVIEW

Use this programming sequence with LabVIEW:

1. Configure the software driver to reflect the SCXI hardware settings. With LabVIEW for Windows, use the WDAQCONF . EXE utility. With LabVIEW for Macintosh, use the NI-DAQ Utilities, which are in the Control Panels folder. This step informs the software of which hardware is being used and how the modules are configured, including which gain value to use when scaling the data.
2. Measure the voltage from the RTD channel. You can use high-level VIs such as AI Sample Channel and AI Sample Channels, which are in the Easy I/O palette of the DAQ menu, to measure the voltage from one or more of the SCXI channels.
3. Scale the voltage measurement to a temperature reading. LabVIEW has a virtual instrument (VI) that uses the Callendar-Van Dusen equation to scale your voltage reading to a temperature reading. This VI, RTD Convert, is in the DAQ Utilities palette of the DAQ menu.

LabWindows

Use this programming sequence with LabWindows for DOS:

1. Configure the software driver, using the DAQCONF . EXE utility, to reflect the SCXI hardware settings. This step informs the software of which hardware is being used and how the modules are configured.
2. Measure the voltage from the RTD channel. For single-point voltage measurements, use the function sequence SCXI_Load_Config, SCXI_Single_Chan_Setup, AI_Read, and

AI_VScale. The AI_VScale function returns the voltage measured on the RTD channel.

3. Scale the voltage measurement to a temperature reading. LabWindows has conversion functions that use the Callendar-Van Dusen equation to scale your voltage reading to a temperature reading. These functions, RTD_Convert for single-point conversions and RTD_Buf_Convert for multiple conversions, are part of the Transducer Conversions instrument driver (convert . fp).

NI-DAQ

Use this programming sequence with NI-DAQ:

1. Configure the software driver to reflect the SCXI hardware settings. With NI-DAQ for Windows, use the WDAQCONF . EXE utility. With NI-DAQ for DOS, use the DAQCONF . EXE utility. If you are using NI-DAQ for Macintosh, configure the driver with the NI-DAQ Utilities, which are in the Control Panels folder. This step informs the software of which hardware is being used and how the modules are configured.
2. Measure the voltage from the RTD channel. For single-point voltage measurements, use the function sequence SCXI_Load_Config, SCXI_Single_Chan_Setup, AI_Read, and AI_VScale. The AI_VScale function returns the voltage measured on the RTD channel.
3. Scale the voltage measurement to a temperature reading. NI-DAQ has source code files that implement the Callendar-Van Dusen formula to scale your voltage reading to a temperature reading. These files are called RTD . c, RTD . pas, and RTD . bas for the C, Pascal, and BASIC programming languages.

Low-Cost RTD Measurements

The RTD application example in this application note uses the SCXI-1121 isolation amplifier. The SCXI-1121 module has four isolated and independently configurable excitation channels for each of the four isolated input channels. If channel-to-channel isolation is not important, you can configure a less expensive system by using the SCXI-1122, which includes one current excitation

source to power multiple RTDs., as shown in Figure 8.

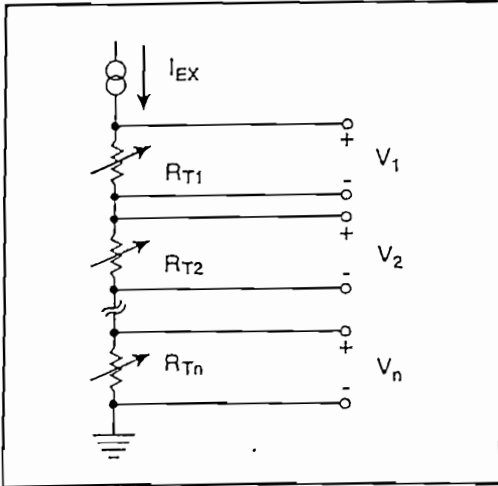


Figure 8. RTD Measurement with SCXI-1122

You can also use the current excitation channels of the SCXI 1121 module to power multiple RTDs connected to additional SCXI-1120 eight-channel isolation amplifier modules. A single SCXI-1121 excitation channel can drive a constant current supply through a load of up to 10 k Ω . If each RTD resistance will be limited to 250 Ω , for example, a single SCXI-1121 excitation channel can power up to 40 RTDs in a serial configuration.

For simpler, low-channel count RTD applications that do not require the flexibility and expandability of SCXI, the SC-2042-RTD signal conditioning accessory delivers a very cost-effective solution. The SC-2042-RTD is an 8-channel signal conditioning board that cables directly to a plug-in DAQ board or PCMCIA card. The SC-2042 includes eight independent constant current sources to power eight RTDs with screw terminals for 4-wire connections. The SC-2042-RTD operates with a variety of DAQ devices in differential mode, including MIO Series and E Series boards, DAQCard-1200, DAQPad-1200, and the Lab-PC+.

Conclusion

RTDs are versatile temperature sensors that have high accuracy over a wide range of temperatures. Because RTDs are low-resistance devices, you must be careful when wiring and measuring RTDs to avoid errors caused by lead resistance. Signal conditioning such as current excitation and amplification is required to make RTD measurements with DAQ equipment. A National Instruments SCXI signal conditioning system has configurable current excitation, amplification, filtering, and electrical isolation for your RTD applications. With the SCXI system, you can condition multiple RTD signals and pass the multiplexed signal to a PC plug-in DAQ board.

ANEXO H

Welcome To BridgeVIEW

BridgeVIEW adds real-time process monitoring, historical trending, alarm and event reporting, online configuration and PLC connectivity to a premiere graphical development environment.

BridgeVIEW makes use of an intuitive graphical user interface combined with a powerful graphical programming language, G, that enables you to perform data acquisition and analysis, create an operator interface or Human Machine Interface (HMI), and develop advanced supervisory control applications. BridgeVIEW provides the following features for the development of your Industrial Automation applications.

- Graphical Human-machine interface (HMI)
- Easy-to-use, fill in the blank configuration utilities
- Graphical programming tools
- Real-Time Database (RTDB)
- Historical data collection and trending (Citadel)
- Alarm and event reporting and logging
- Security
- Connectivity to PLC and industrial device networks
- OPC Server Support

Required System Configuration

What Is BridgeVIEW?

How Does BridgeVIEW Work?

What Is the BridgeVIEW System Architecture?

Where Should I Start?

Required System Configuration

BridgeVIEW is distributed on a CD-ROM that includes the complete BridgeVIEW 2.0 release.

The Windows 95/NT version of BridgeVIEW 1.1 runs on any system that supports Windows 95 or Windows NT 4.0. You should have a minimum of 24 MB of RAM for this version to run effectively. We recommend 32 MB of RAM and at least 30 MB of swap space available on your system.

Note The standard BridgeVIEW installation requires approximately 110 MB of disk space. A full installation requires approximately 150 MB. If you plan to install the NI-DAQ Server as well, an additional 30 MB is required.

What Is BridgeVIEW?

BridgeVIEW is a software package specifically targeted at industrial automation applications. BridgeVIEW provides configurable solutions for common HMI and SCADA functions while leveraging the flexibility of graphical programming. BridgeVIEW is built around the G programming language, created by National Instruments Corporation.