FAN YANG KUO

MECANISMO DE POSICIONAMENTO DE CÂMERA DE VÍDEO

COM DOIS GRAUS DE LIBERDADE

Relatório apresentado à Escola Politécnica da Universidade de São Paulo para a conclusão das disciplinas PMC 580 e PMC 581 (Projetos Mecânicos I e II)

São Paulo

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Área de Concentração :
Engenharia Mecatrônica

Orientador :
Prof.Dr. Newton Maruyama

São Paulo

1997

Dedicatória

Aos Meus Pais que sempre me apoiaram nos momentos mais difíceis.

AGRADECIMENTOS

Ao amigo Antônio Fernando Maiorquim que nos ajudaram a solucionar diversas dúvidas durante o desenvolvimento do projeto.

Ao Prof.Dr. Júlio Adamovsky que sempre foi atencioso nas consultas e fornecendo diretrizes seguras.

A todos que direta ou indiretamenta colaboraram na execução deste trabalho.

SUMÁRIO

1 INTRODUÇÃO

Este relatório visa à apresentação das atividades desenvolvidas ao longo do ano de 1997 nas disciplinas PMC 580 (Projeto Mecânico I) e PMC 581 (Projeto Mecânico II), oferecidas pelo Departamento de Engenharia Mecânica da Escola Politécnica da Universidade de São Paulo. Visando o desenvolvimento pelos alunos participantes de um mecanismo de posicionamento de câmera de vídeo com dois graus de liberdade.

2 OBJETIVOS

Mecanismo em questão teve como motivação o projeto de ambiente integrado para o desenvolvimento de sistemas para desenvolvimento de sistemas para gestão, monitoração e controle de edifícios, executado pelo Departamento de Engenharia da Escola Politécnica da USP e coordenado pelo Prof.Dr. Paulo Miyagi.

Nesse ambiente integrado, as áreas principais do conhecimento técnico-científico onde este projeto será localizado são : especificação de controle para sistemas de eventos discretos, monitoração em sistemas sensoriais de arquitetura distribuída, sistemas de controle de acesso, sistemas multi-agentes, integração de sistemas e teoria de supervisórios. Dentro deste contexto, o mecanismo de posicionamento de câmera será útil para as atividades de monitoração e controle de acesso das instalações.

Ambiente a ser utilizado para a instalação desta infra-estrutura é o laboratório CIS (Centro de Integração de Sistemas), localizado no Departamento de Engenharia Mecânica, onde se encontram o hall de entrada, um auditório, uma sala de reuniões, sala de controle e planta piloto de detergentes. O croqui das instalações de laboratório CIS-Poli é apresentado na figura 1.

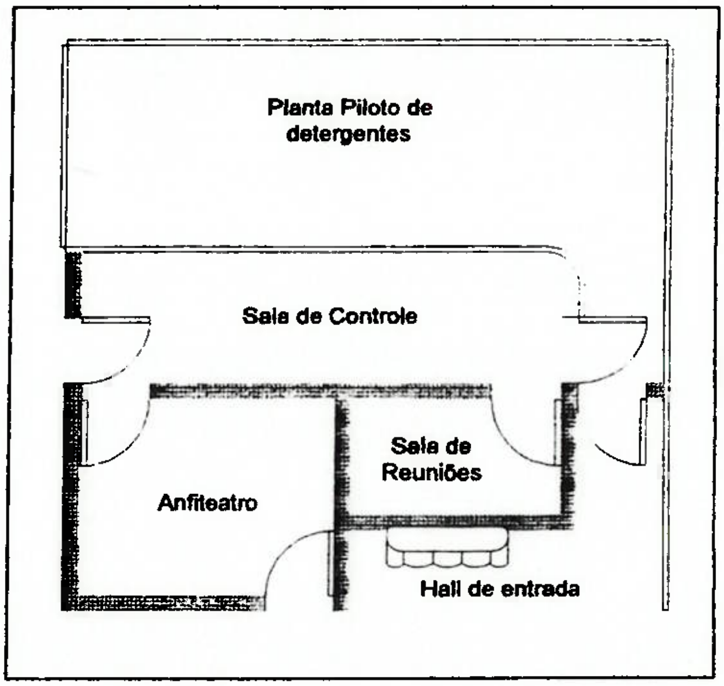


Fig 1 - Croqui do Laboratório CIS-POLI

No Laboratório serão instalados sensores e equipamentos destinados para o sistema de monitoração e controle de acesso e de intrusão dentro das salas. Estes dispositivos estarão ligados em microcomputadores que armazenarão os dados destes dispositivos, dados estes que poderão ser acessados posteriormente através de uma requisição remota.

As câmeras de vídeo serão ligadas nos microcomputadores através das placas de aquisição de imagens. Estas imagens serão utilizadas para a verificação da situação interna de um ambiente monitorado. O dispositivo alvo do projeto desenvolvido é o suporte em que as câmeras ficarão fixas e que deve possibilitar ao usuário, remotamente, a movimentaçõa angular dessas câmeras.

Os microcomputadores serão utilizados para o desenvolvimento de sistemas de software e na implementação dos servidores específicos e estarão interligados através de uma rede Ethernet com protocolo TCP/IP de tal forma a possibilitar o estabelecimento de conexão remota aos sistemas de monitoração e controle, permitindo a implantação de uma arquitetura cliente/servidor, onde o usuário (cliente) poderá solicitar ao servidor de imagem a movimentação e a respectiva monitoração de uma câmera situada no interior do ambiente.

A figura 2 mostra a arquitetura do sistema a ser implementado.

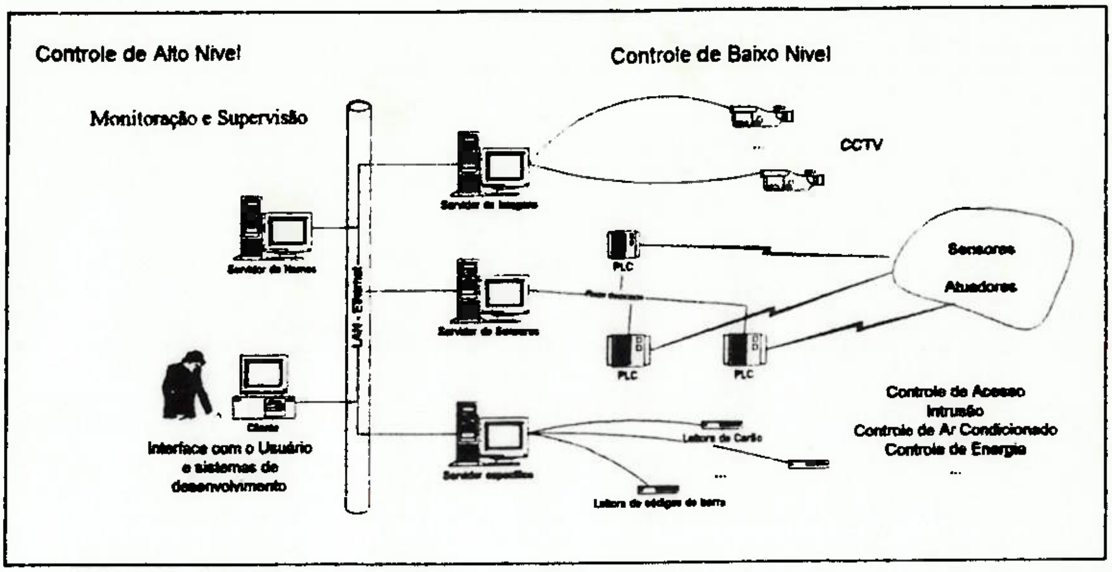


Figura 2 - Arquitetura do sistema

3 ESPECIFICAÇÕES TÉCNICAS E CONSTRUTIVAS

3.1. ESPECIFICAÇÕES TÉCNICAS

- Dentro dos objetivos propostos, há a necessidade de se construir um mecanismo com as seguintes características :
- Possibilite a movimentação angular com dois graus de liberdade;
- Possibilite a monitoração e controle realizados remotamente desta movimentação ;

- Não tenha as dimensões exageradas, pois se trata de equipamento de seguranção e como tal deve ter instalação discreta;
- Tenha a confiablidade de acordo com as expectativas referentes a um equipamento de segurança.

- Movimento com dois graus de liberdade, conforme figura 3 : ângulo de Pan (movimentação panorâmica) e Tilt (movimento de elevação).

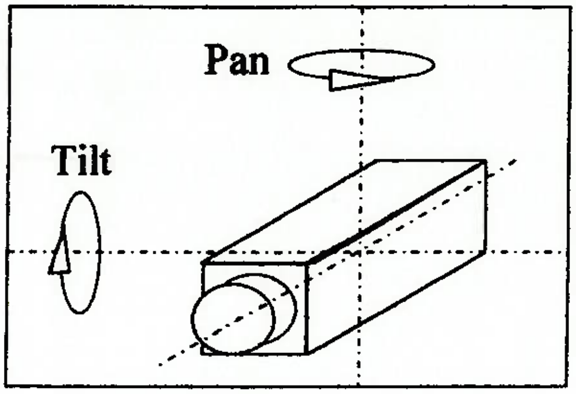


Fig. 3 - Definição dos ângulos de movimentação

Para o movimento, pode-se especificar os seguintes parâmetros :

	Campo de Rotação	Velocid. de Rotação
Pan (Panorâmico)	350 ¤	9 ¤ / seg
Tilt (Inclinação)	+/- 90 ¤	3 ¤ / seg

Estes valores foram definidos a partir de especificações de sistemas comerciais similares existentes, no entanto, pelo projeto, o campo de rotação pode ser amplificado.

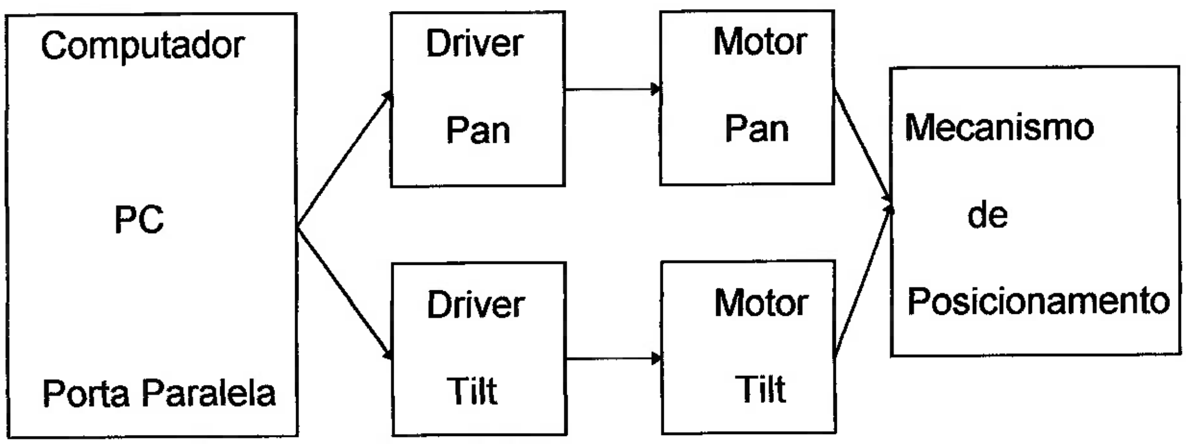
E a velocidade de movimentação depende dos clocks fornecidos aos drivers de motores de passos.

3.2. Especificações construtivas

- Pequeno volume ocupado, afim de possibilitar instalação discreta, conveniente a um equipamento desta natureza.
- Construção simples, porém robusta, de modo a suportar pequenos impactos provenientes do ambiente em que opera ou de atos de agressão contra o equipamento.
- Proteção dos cabos destinados à alimentação dos motores e os necessários aos comandos da câmera de vídeo.

4 SÍNTESE DA SOLUÇÃO ADOTADA

Esquema de Controle do Mecanismo de Posicionamento



4.1.Computador :

O computador utilizado para mandar sinais aos drivers dos motores foi um Pentium de 133 Mhz, 32 Mbytes de Ram.

O interface através da porta paralela do PC está descrito a seguir.

Foram necessários somente 4 sinais para comandar o driver para motor de passos :

- Clock para driver Pan
- Direção para diver Pan (Horário ou Anti-horário)
- Clock para driver Pan
- Direção para diver Pan (Horário ou Anti-horário)

Sabe-se que uma porta paralela para impressora possui um total de 12 saídas e 5 entradas digitais (PC - padrão IBM) e restantes 8 pinos são aterrados.

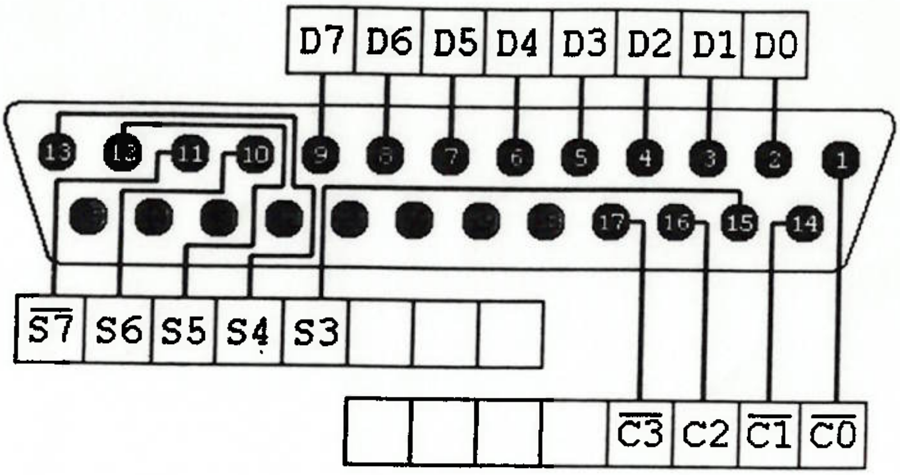


Fig 4 - Conector fêmea tipo D de 25 vias

Para o projeto, utilizaram-se :

D1 (cor vermelho) : clock do driver Pan

D2 (cor laranja) : direção do driver Pan

D3 (cor azul) : clock do driver Tilt

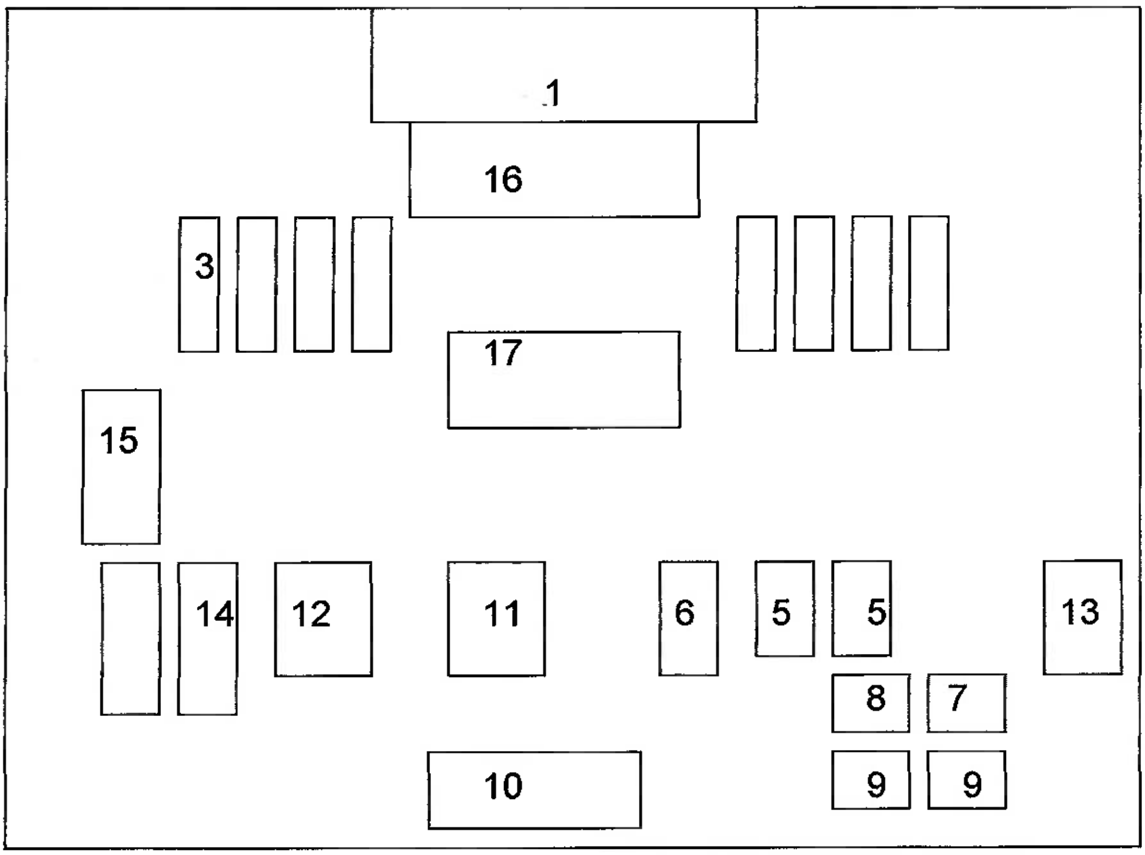
D4 (cor verde) : direção do dirver Tilt

A parte do software para mandar sinais pelas saídas paralelas foi feita em linguagem "C".

4.2. Driver para o motor de passo:

O projeto de driver foi baseado em circuitos integrados L297 e L298N da SGS-Thomson Microeletronics, que além do alto desempenho, caracterizam-se pela simplicidade, pois o PC envia apenas os sinais de clock (step) e sentido (horário e anti-horário).

A foto do circuito está a seguir e poderá esclarescer melhor a montagem do dirver.



Legenda :

1. Cooler
2. Socket para ligar ao motor de passos
3. Diodo Zener (Semikron SK3GH04) - 8 unidades
4. Capacitor 470 μF
5. Capacitor 100 nF
6. Capacitor 3,3 nF
7. Resistência 1K
8. Resistência 2,2 K
9. Resistência 0,47 Ω (5W)
10. Fusível 1 A
11. Flip-Flop SN 7474
12. TL072
13. Conector para fonte
14. Diodo
15. Conector para fonte
16. Chip L298N SGS-Thomson
17. Chip L297 SGS-Thomson

Explicações mais detalhadas a respeito destes dois CIs :

O circuito integrado L297

Half / Full step

Horário/Anti-horário

Regulagem do chaveamento da intensidade de corrente

Outros componentes externos

Entrada de reajuste a zero e saída de ponto de referência

Entrada de habilitação

O circuito integrado controlador de motor de passo L297 gera quatro sinais para aplicação em motores de passo, controlados por microprocessadores, de duas fases bipolar e quatro fases unipolar. O motor pode ser acionado em meio passo, modo de onda normal e ligado ao circuito integrado pulsador PWM permite o chaveamento da corrente nas bobinas. Uma característica desse componente é que ele requer apenas os sinais de sincronismo, sentido e modo. A partir da geração desses sinais por um microprocessador o programa fica enormemente reduzido. Montado em encapsulamento plástico com 20 pinos, o L297 pode ser usado com o acionador de circuito de ponte monolítica assim como o L298N e L293E, ou com transistores discretos darlingtons.

O circuito integrado L298N

Opera com fonte de alimentação até 46 VDC

Opera com corrente até 4A

Baixa saturação de tensão

Proteção contra excesso de temperatura

Alta imunidade contra ruídos

O L298 é circuito integrado com encapsulamento de 15 pinos. Suporta altas tensões, altas correntes, opera com sinais TTL e proporciona cargas suficientes para acionar relés, solenóides, motoers de correntes contínua e motores de passo. Duas entradas são destinadas para habilitar ou desabilitar o dispositivo acionado pelo driver indepedente dos sinais de entrada. Os transistores de cada ponte são conectados a um sensor resitor que se encarrega de controlar o nível da corrente em cada fase. Uma fonte adicional de tensão é destinada para executar o trabalho lógico de baixa potência.

4.3.Motor de Passo:

Os motores utilizados foram adquiridos das impressoras matriciais em desuso.

O modelo dos motores é : 23LM-C004-04, da Minibea Co. LTD. (Astrosyn). Suas especificações técnicas estão a seguir :

Step Angle (passo) : 1,8 deg / passo

Holding Torque (Torque de Manutenção) : 0,5 Nm

Tensão Nominal (por fase) : 6V

Corrente Nominal (por fase) : 1,2 A

Resistência de Enrolamento (por fase) : 5 Ω

Indutância por Fase : 14 mH

Inércia do Rotor : 160 g.cm2

Peso do motor : 470 g

Para ambos movimentos foram utilizados os mesmos motores pois estavam com holding torque dentro da especificacão.

4.4. Mecanismo de Posicionamento :

A seguir estão as fotos dos mecanismos para a movimentação da câmera.

O relatório referente à fabricação das peças mecânicas e suas montagens está em outro volume, redigido por Fábio Yoshiyuki Massuda.

5 CONCLUSÃO

O protótipo funcionou com sucesso, tanto os drivers dos motores de passo quanto o mecanismo em si não apresentaram falhas.

6 REFERÊNCIAS BIBLIOGRÁFICAS

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Crowder, M. Richard; **Eletric Drives and Their Controls ;** Department of Eletrical Engineering; University of Southamton; Clarendon Press, Oxford, 1995.

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ANEXOS

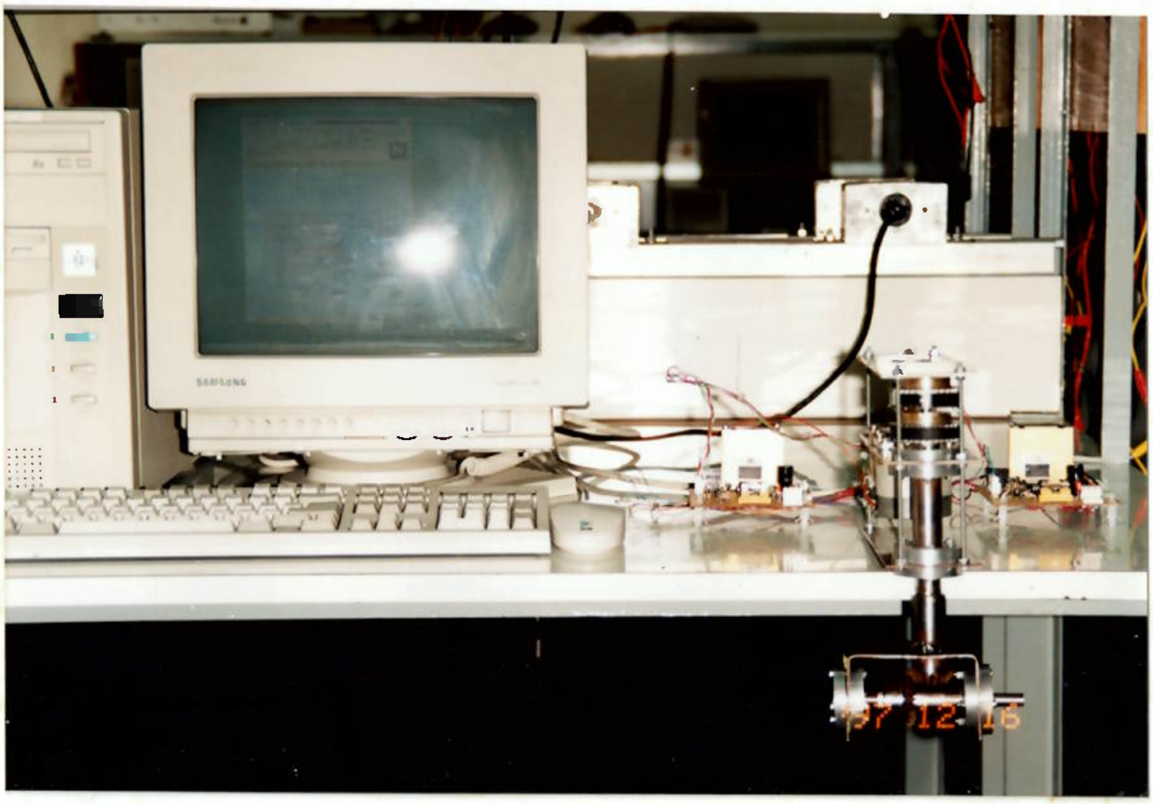


Foto 1 - O conjunto do Sistema

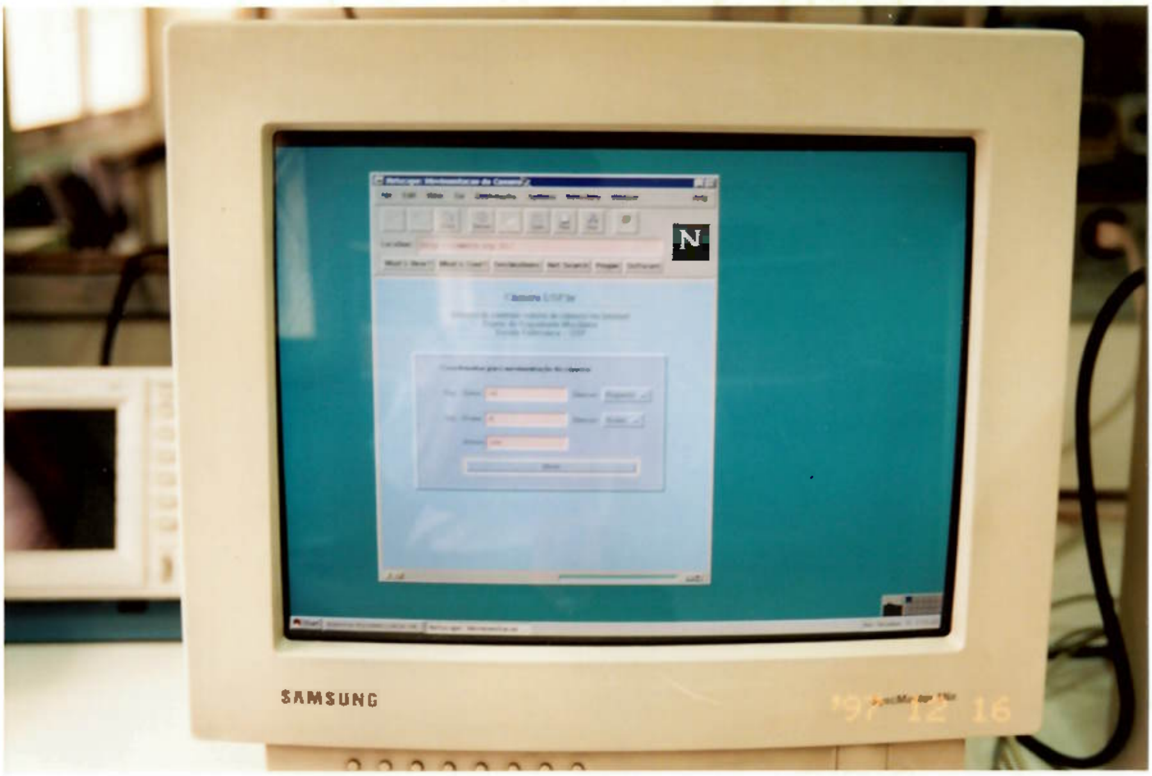


Foto 2 - Tela de Interface para acionamento do mecanismo

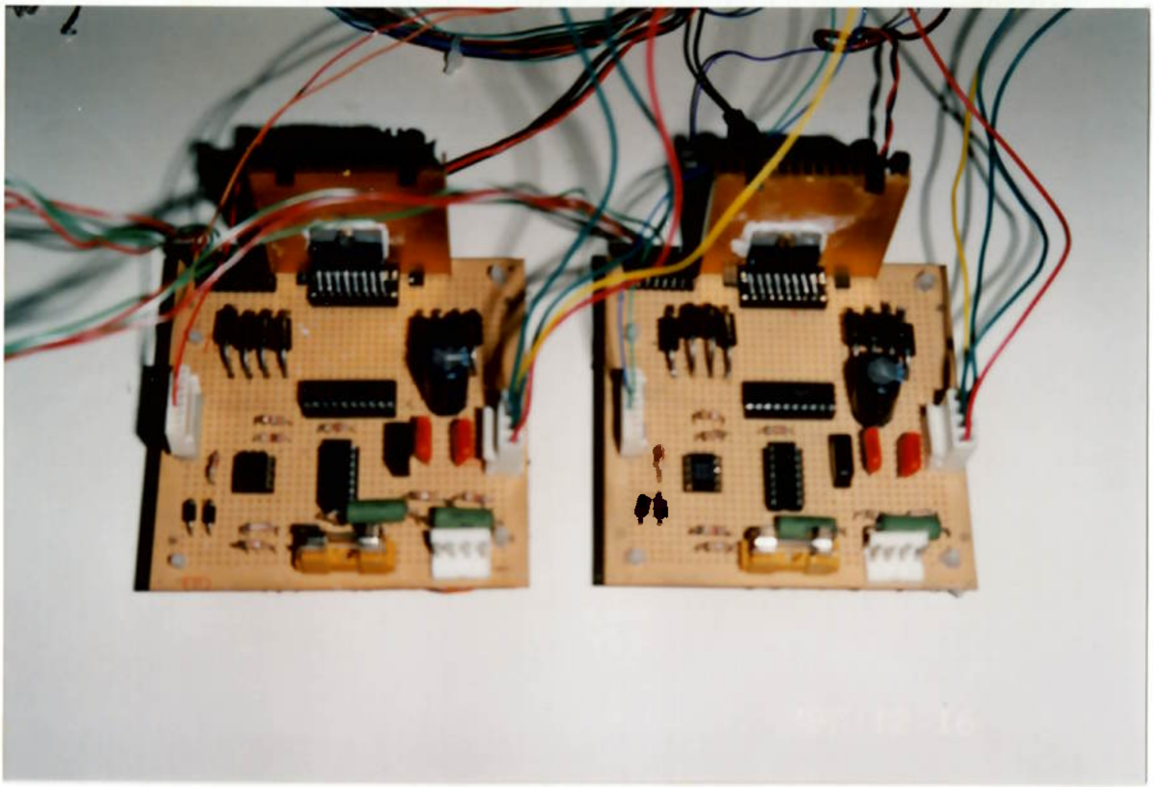


Foto 3 - Drivers Pan e Tilt

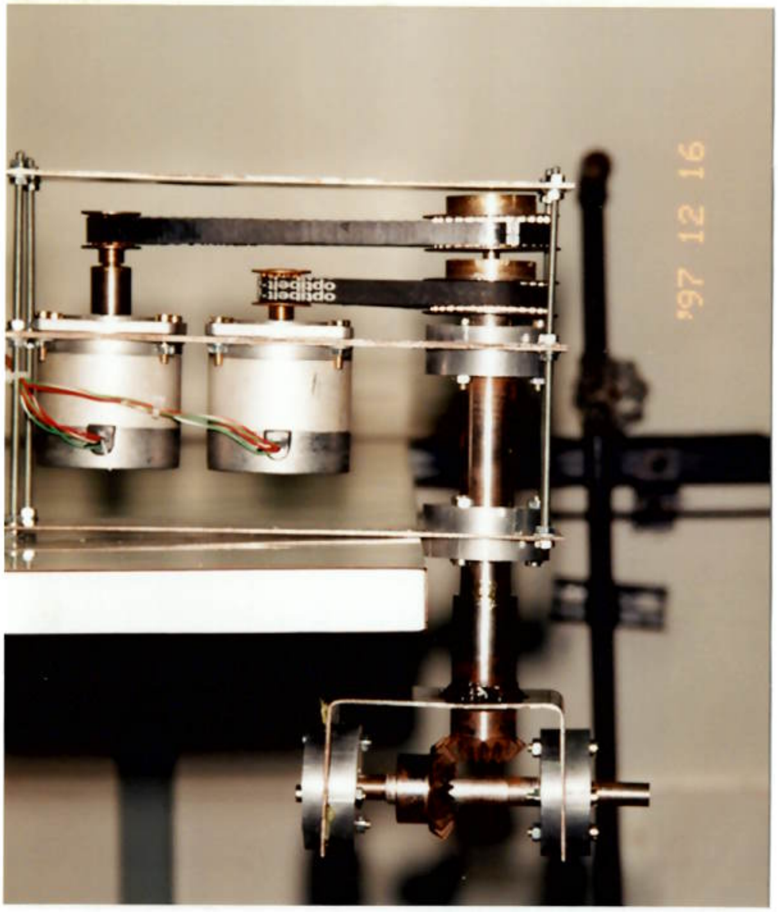


Foto 4 - Mecanismo de Posicionamento

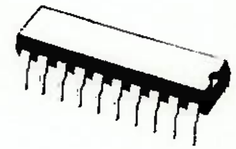
SGS-THOMSON MICROELECTRONICS

L297
L297A

STEPPER MOTOR CONTROLLERS

- NORMAL/WAWE DRIVE
- HALF/FULL STEP MODES
- CLOCKWISE/ANTICLOCKWISE DIRECTION
- SWITCHMODE LOAD CURRENT REGULATION
- PROGRAMMABLE LOAD CURRENT
- FEW EXTERNAL COMPONENTS
- RESET INPUT & HOME OUTPUT
- ENABLE INPUT
- STEP-PULSE DOUBLER (L297A only)

The L297 Stepper Motor Controller IC generates four phase drive signals for two phase bipolar and four phase unipolar step motors in microcomputer-controlled applications. The motor can be driven in half step, normal and wawe drive modes and on-chip PWM chopper circuits permit switch-mode control of the current in the windings. A feature of this device is that it requires only clock, direction and mode input signals. Since the phase are generated internally the burden on the microprocessor, and the programmer, is greatly reduced. Mounted in a 20-pin plastic package, the L297 can be used with monolithic bridge drives such as the L298N or L293E, or with discrete transistors and darlingtons. The L297A also includes a clock pulse doubler.



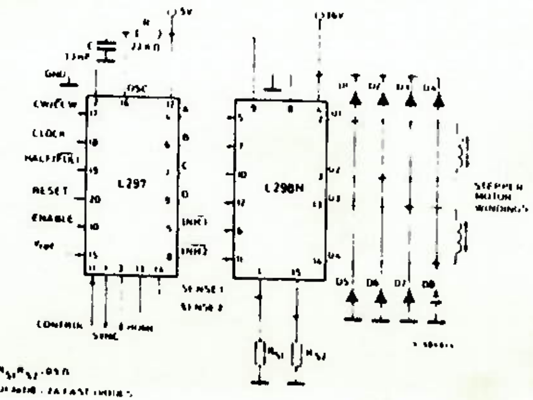
DIP-20 Plastic
(0.25)

ORDER CODES : L297 – L297A

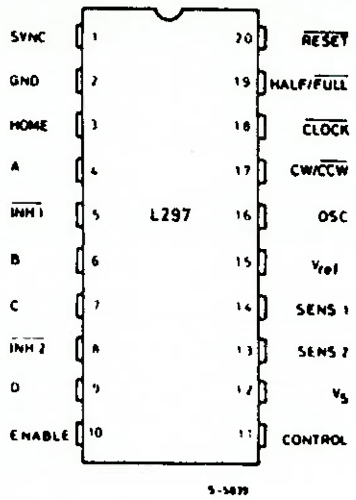
ABSOLUTE MAXIMUM RATINGS

V_s	Supply voltage	10	V
V_i	Input signals	7	V
P_{tot}	Total power dissipation (T_{amb} = 70 C)	1	W
T_{stg}, T_j	Storage and junction temperature	– 40 to + 150	C

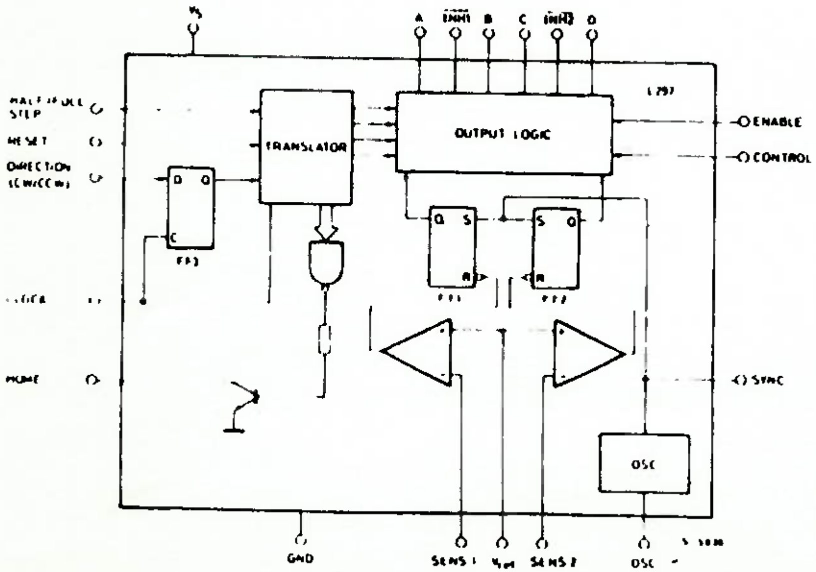
TWO PHASE BIPOLAR STEPPER MOTOR CONTROL CIRCUIT



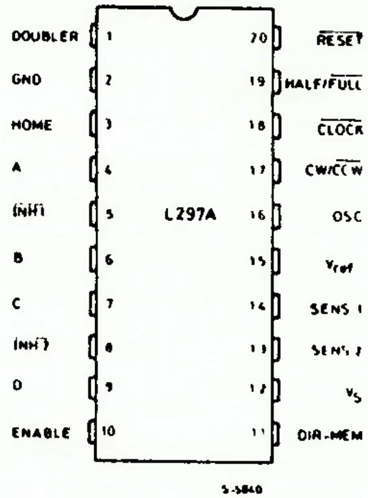
PIN CONNECTION (L297)



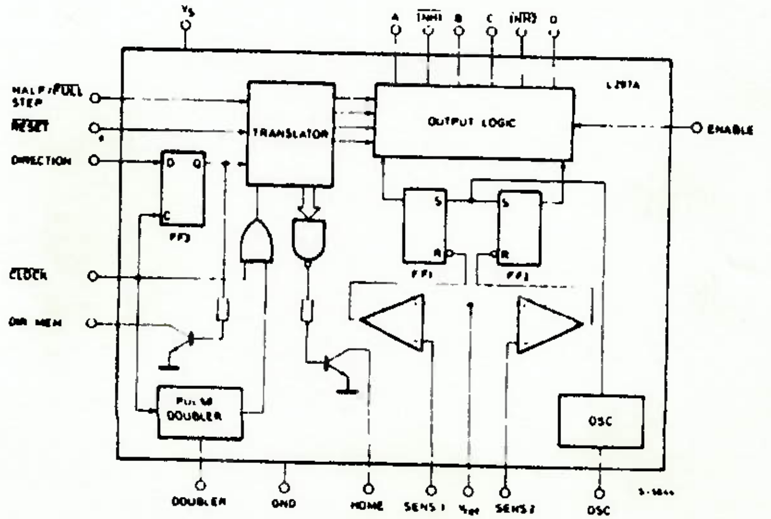
BLOCK DIAGRAM (L297)



PIN CONNECTION (L297A)



BLOCK DIAGRAM (L297A)



THERMAL DATA

$R_{th\,j\text{-}amb}$	Thermal resistance junction ambient	max	80	°C/W

PIN FUNCTIONS – L297

N	NAME	FUNCTION
1	SYNC	Output of the on-chip chopper oscillator. The SYNC connections of all L297s to be synchronized are connected together and the oscillator components are omitted on all but one. If an external clock source is used it is injected at this terminal.
2	GND	Ground connection.
3	HOME	Open collector output that indicates when the L297 is in its initial state (ABCD = 0101). The transistor is open when this signal is active.
4	A	Motor phase A drive signal for power stage.
5	INH1	Active low inhibit control for driver stages of A and B phases. When a bipolar bridge is used this signal can be used to ensure fast decay of load current when a winding is de-energized. Also used by chopper to regulate load current if CONTROL input is low.
6	B	Motor phase B drive signal for power stage.
7	C	Motor phase C drive signal for power stage.
8	INH2	Active low inhibit control for drive stages of C and D phases. Same functions as INH1.
9	D	Motor phase D drive signal for power stage.
10	ENABLE	Chip enable input. When low (inactive) INH1, INH2, A, B, C and D are brought low.
11	CONTROL	Control input that defines action of chopper. When low chopper acts on INH1 and INH2, when high chopper acts on phase lines ABCD.
12	V_s	5V supply input.
13	$SENS_2$	Input for load current sense voltage from power stages of phases C and D.
14	$SENS_1$	Input for load current sense voltage from power stages of phases A and B.
15	V_{ref}	Reference voltage for chopper circuit. A voltage applied to this pin determines the peak load current.
16	OSC	An RC network (R to V_{CC}, C to ground) connected to this terminal determines the chopper rate. This terminal is connected to ground on all but one device in synchronized multi - L297 configurations. f ≈ 1/0.69 RC, R > 10kΩ
17	CW/CCW	Clockwise/counterclockwise direction control input. Physical direction of motor rotation also depends on connection of windings. Synchronized internally therefore direction can be changed at any time.
18	CLOCK	Step clock. An active low pulse on this input advances the motor one increment. The step occurs on the rising edge of this signal.

PIN FUNCTIONS – L297 (continued)

N°	NAME	FUNCTION
19	HALF/FULL	Half/full step select input. When high selects half step operation, when low selects full step operation. One phase on full step mode is obtained by selecting FULL when the L297's translator is at an even-numbered state. Two phase on full step mode is set by selecting FULL when the translator is at an odd numbered position. (The home position is designate state 1).
20	RESET	Reset input. An active low pulse on this input restores the translator to the home position (state 1, ABCD = 0101).

PIN FUNCTIONS – L297A

Pin function of the L297A are identical to those of the L297 except for pins 1 and 11.

N	NAME	FUNCTIONS
1	DOUBLER	An RC network connected to this pin determines the delay between an input clock pulse and the corresponding ghost pulse.
11	DIR MEM	Direction Memory. Inverted output of the direction flip flop. Open collector output.

CIRCUIT OPERATION

The L297(A) is intended for use with a dual bridge driver, quad darlington array or discrete power devices in step motor driving applications. It receives step clock, direction and mode signals from the systems controller (usually a microcomputer chip) and generates control signals for the power stage.

The principal functions are a translator, which generates the motor phase sequences, and a dual PWM chopper circuit which regulates the current in the motor windings. The translator generates three different sequences, selected by the HALF/FULL input. These are normal (two phases energised), wave drive (one phase energised) and half step (alternately one phase energised/two phases energised). Two inhibit signals are also generated by the L297 in half step and wave drive modes. These signals, which connect directly to the L298's enable inputs, are intended to speed current decay when a winding is de-energised. When the L297 is used to drive a unipolar motor the chopper acts on these lines.

An input called CONTROL determines whether the chopper will act on the phase lines ABCD or the inhibit lines INH1 and INH2. When the phase lines are chopped the non active phase line of each pair (AB or CD) is activated (rather than interrupting the line then active). In L297 + L298 configurations this technique reduces dissipation in the load current sense resistors.

A common on-chip oscillator drives the dual chopper. It supplies pulses at the chopper rate which set the two flip-flops FF1 and FF2. When the current in a winding reaches the programmed peak value the voltage across the sense resistor (connected to one of the sense inputs $SENS_1$ or $SENS_2$) equals V_{ref} and the corresponding comparator resets its flip flop, interrupting the drive current until the next oscillator pulse arrives. The peak current for both windings is programmed by a voltage divider on the V_{ref} input.

Ground noise problems in multiple configurations can be avoided by synchronising the chopper oscillators. This is done by connecting all the SYNC pins together, mounting the oscillator RC network on one device only and grounding the OSC pin on all other devices.

The L297A includes a pulse doubler on the step clock line which is intended to simplify the implementation of multiple stepping. A ghost pulse is generated automatically after each input pulse, delayed by the time 0.75 R_d C_d.

The RC network should be dimensioned to place the ghost pulse roughly halfway between clock pulses. If pin 1 (DOUBLER) is grounded the doubler function is disabled.

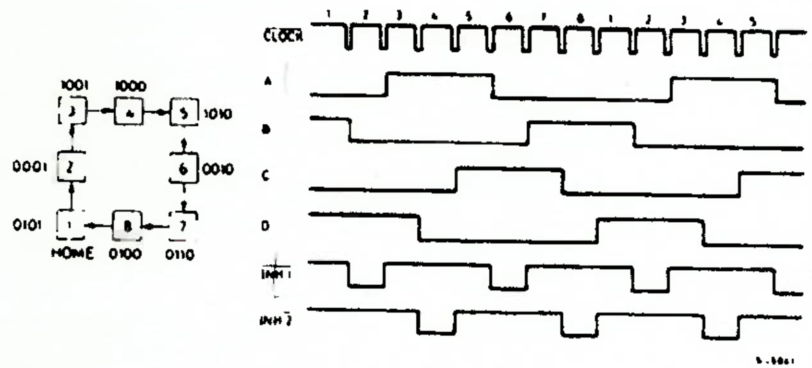
MOTOR DRIVING PHASE SEQUENCES

The L297's translator generates phase sequences for normal drive, wave drive and half step modes. The state sequences and output waveforms for these three modes are shown below. In all cases the translator advances on the low to high transition of CLOCK.

Clockwise rotation is indicated; for anticlockwise rotation the sequences are simply reversed. RESET restores the translator to state 1, where ABCD = 0101.

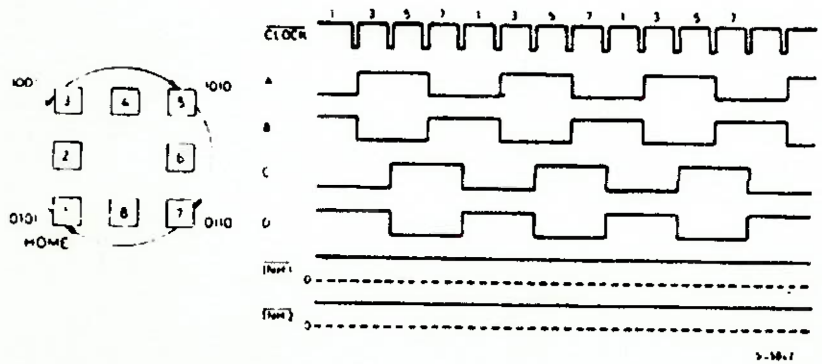
HALF STEP MODE

Half step mode is selected by a high level on the HALF/FULL input.



NORMAL DRIVE MODE

Normal drive mode (also called "two-phase-on" drive) is selected by a low level on the HALF/FULL input when the translator is at an odd numbered state (1, 3, 5 or 7). In this mode the INH1 and INH2 outputs remain high throughout.

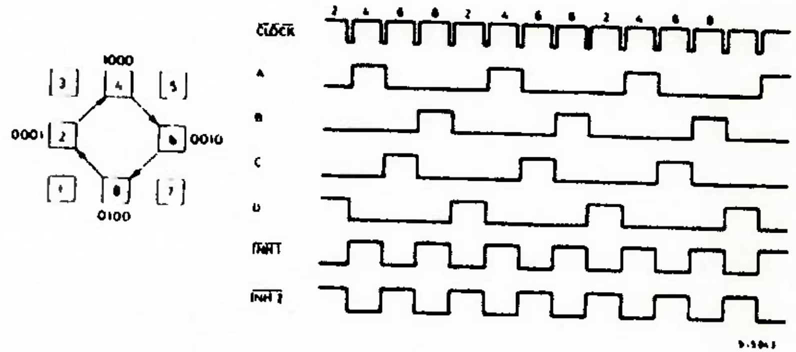


SGS-THOMSON MICROELECTRONICS

MOTOR DRIVING PHASE SEQUENCES (continued)

WAVE DRIVE MODE

Wave drive mode (also called "one phase on" drive) is selected by a low level on the HALF/FULL input when the translator is at an even numbered state (2, 4, 6 or 8).



ELECTRICAL CHARACTERISTICS (Refer to the block diagram T_{amb} = 25 °C, V_s = 5V unless otherwise specified)

	Parameter	Test conditions		Min.	Typ.	Max.	Unit
V_s	Supply voltage (pin 12)			4.75		7	V
I_s	Quiescent supply current (pin 12)	Outputs floating			50	80	mA
V_i	Input voltage (pin 11, 17, 18, 19, 20)		Low			0.8	V
			High	2		V_s	V
I_i	Input current (pin 11, 17, 18, 19, 20)		V_i = L			-100	µA
			V_i = H			10	µA
V_{en}	Enable input voltage (pin 10)		Low			1.5	V
			High	2		V_s	V
I_{en}	Enable input current (pin 10)		V_{en} = L			-100	µA
			V_{en} = H			10	µA
V_o	Phase output voltage (pins 4, 6, 7, 9)	I_o = 10mA	V_{OL}			0.4	V
		I_o = 5mA	V_{OH}	3.9			V
V_{inh}	Inhibit output voltage (pins 5, 8)	I_o = 10mA	$V_{inh\ L}$			0.4	V
		I_o = 5mA	$V_{inh\ H}$	3.9			V
V_{SYNC}	Sync Output Voltage	I_o = 5mA	$V_{SYNC\ H}$	3.3			V
		I_o = 5mA	$V_{SYNC\ L}$			0.8	V

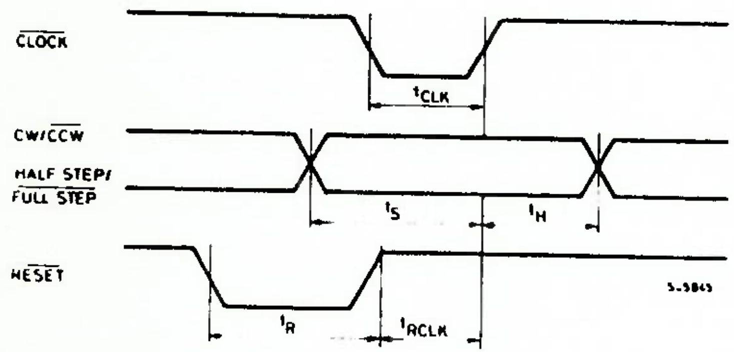
SGS-THOMSON MICROELECTRONICS

ELECTRICAL CHARACTERISTICS (continued)

	Parameter	Test conditions	Min.	Typ.	Max.	Unit
I_{leak}	Leakage current (pin 3, 11*)	V_{CE} = 7 V			1	μA
V_{sat}	Saturation voltage (pins 3, 11*)	I = 5 mA			0.4	V
V_{off}	Comparators offset voltage (pins 13, 14, 15)	V_{ref} = 1 V			5	mV
I_o	Comparator bias current (pins 13, 14, 15)		–100		10	μA
V_{ref}	Input reference voltage (pin 15)		0		3	V
t_{CLK}	Clock time		0.5			μs
t_S	Set up time		1			μs
t_H	Hold time		4			μs
t_R	Reset time		1			μs
t_{RCLK}	Reset to clock delay		1			μs

* L297A only

Figure 1.



APPLICATION INFORMATION

TWO PHASE BIPOLAR STEPPER MOTOR CONTROL CIRCUIT

This circuit drives bipolar stepper motors with winding currents up to 2A. The diodes are fast 2A types.

Figure 2.

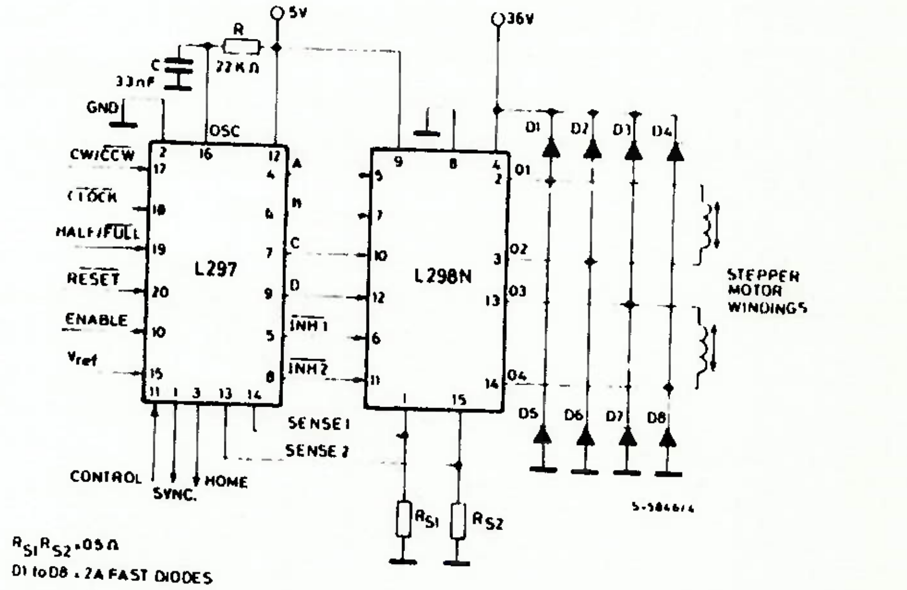


Figure 3 Synchronising L297s

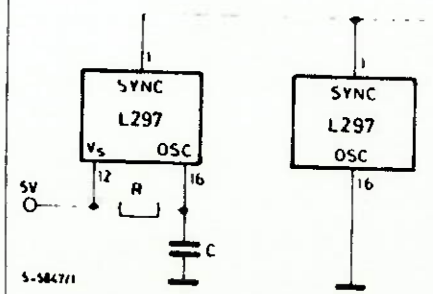
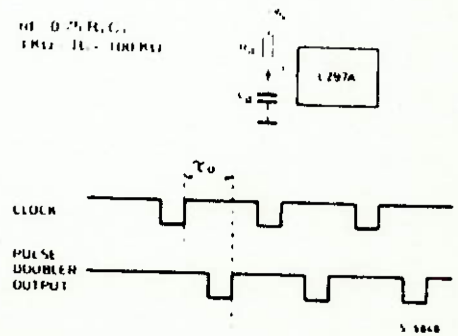


Figure 4 Pulse doubler (L297A)



SGS-THOMSON
MICROELECTRONICS

L298N

DUAL FULL-BRIDGE DRIVER

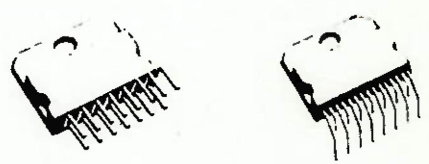
PRELIMINARY DATA

- OPERATING SUPPLY VOLTAGE UP TO 46 V
- TOTAL DC CURRENT UP TO 4 A
- LOW SATURATION VOLTAGE
- OVERTEMPERATURE PROTECTION
- LOGICAL "0" INPUT VOLTAGE UP TO 1.5 V (HIGH NOISE IMMUNITY)

DESCRIPTION

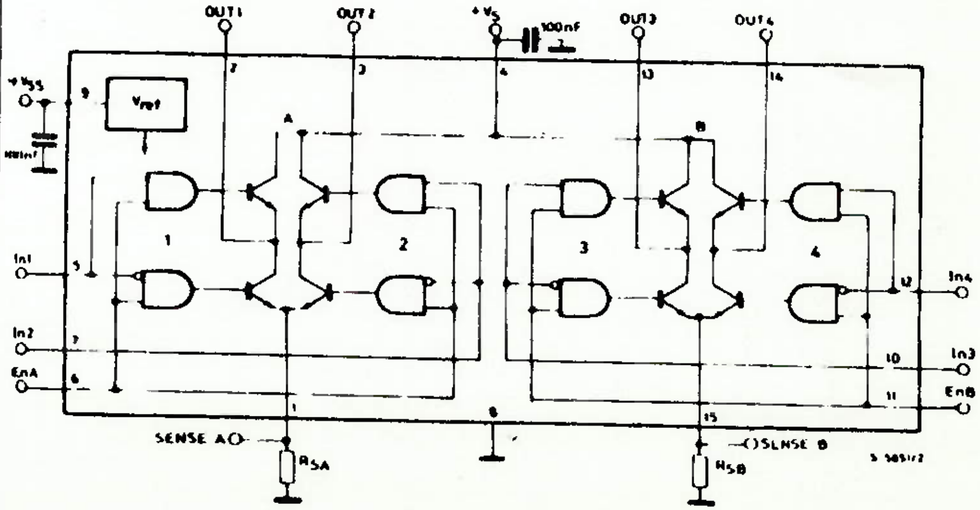
The L298N is an integrated monolithic circuit in a 15-lead Multiwatt™ package. It is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. Two enable inputs are provided to enable or disable the device independently of the input signals. The emitters of the lower transistors of each bridge are connected together and the corresponding external terminal can be used for the connection of an external sensing resistor. An additional supply input is provided so that the logic works at a lower voltage.

Multiwatt
(15 lead)



ORDER CODES : L298N
L298HN

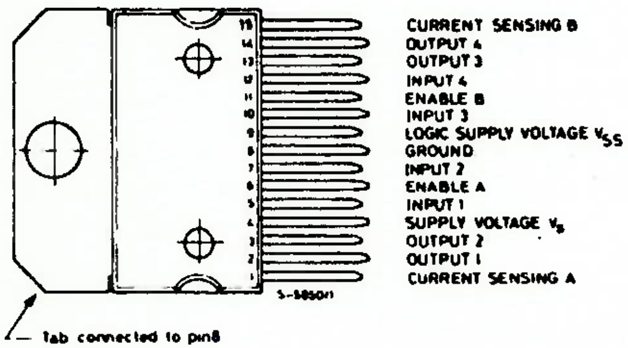
BLOCK DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Test Conditions	Unit
V_S	Power Supply	50	V
V_{SS}	Logic Supply Voltage	7	V
V_I, V_{en}	Input and Enable Voltage	0.3 to 7	V
I_O	Peak Output Current (each channel)		
	Non Repetitive (t = 100 µs)	3	A
	Repetitive (80 % on – 20 % off ; t_{on} = 10 ms)	2.5	A
	DC Operation	2	A
V_{sens}	Sensing Voltage	– 1 to 2.3	V
P_{tot}	Total Power Dissipation (T_{case} = 75 °C)	25	W
T_{stg}, T_j	Storage and Junction Temperature	– 40 to 150	°C

PIN CONNECTION (top view)



THERMAL DATA

$R_{th\ j\text{-}case}$	Thermal Resistance Junction case	Max	3	°C/W
$R_{th\ j\text{-}amb}$	Thermal Resistance Junction ambient	Max	35	°C/W

PIN FUNCTIONS (refer to the block diagram)

N	Name	Function
1 ; 15	Sense A ; Sense B	Between this pin and ground is connected the sense resistor to control the current of the load
2 ; 3	Out 1 ; Out 2	Outputs of the Bridge A ; the current that flows through the load connected between these two pins is monitored at pin 1
4	V_S	Supply Voltage for the Power Output Stages. A non inductive 100 nF capacitor must be connected between this pin and ground
5 ; 7	Input 1 ; Input 2	TTL Compatible Inputs of the Bridge A
6 ; 11	Enable A ; Enable B	TTL Compatible Enable Input : the L state disables the bridge A (enable A) and/or the bridge B (enable B)
8	GND	Ground
9	V_{SS}	Supply Voltage for the Logic Bloks. A 100 nF capacitor must be connected between this pin and ground
10 ; 12	Input 3 ; Input 4	TTL Compatible Inputs of the Bridge B
13 ; 14	Out 3 ; Out 4	Outputs of the Bridge B. The current that flows through the load connected between these two pins is monitored at pin 15

ELECTRICAL CHARACTERISTICS (V_S = 42 V ; V_{SS} = 5 V, T_j = 25 °C ; unless otherwise specified)

Symbol	Parameter	Test Conditions		Min.	Typ.	Max.	Unit
V_S	Supply Voltage (pin 4)	Operative Condition		V_{IH} + 2.5		46	V
V_{SS}	Logic Supply Voltage (pin 9)			4.5	5	7	V
I_S	Quiescent Supply Current (pin 4)	V_{en} = H; I_L = 0	V_i = L		13	22	
			V_i = H		50	70	mA
		V_{en} = L	V_i = X			4	
I_{SS}	Quiescent Current from V_{SS} (pin 9)	V_{en} = H; I_L = 0	V_i = L		24	36	
			V_i = H		7	12	mA
		V_{en} = L	V_i = X			6	
V_{iL}	Input Low Voltage (pins 5,7,10,12)			– 0.3		1.5	
V_{iH}	Input High Voltage (pins 5,7,10,12)			2.3		V_{SS}	V
I_{iL}	Low Voltage Input Current (pins 5,7,10,12)	V_i = L				– 10	
I_{iH}	High Voltage Input Current (pins 5,7,10,12)	V_i = H ≤ V_{SS} – 0.6 V			30	100	µA
V_{en} = L	Enable Low Voltage (pins 6,11)			– 0.3		1.5	
V_{en} = H	Enable High Voltage (pins 6,11)			2.3		V_{SS}	V
I_{en} = L	Low Voltage Enable Current (pins 6,11)	V_{en} = L				– 10	
I_{en} = H	High Voltage Enable Current (pins 6,11)	V_{en} = H ≤ V_{SS} – 0.6 V			30	100	µA
$V_{CEsat(H)}$	Source Saturation Voltage	I_L = 1 A			1.35	1.7	
		I_L = 2 A			2	2.7	V

ELECTRICAL CHARACTERISTICS (continued)

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
$V_{CEsat(L)}$	Sink Saturation Voltage	$I_L = 1$ A		0.85	1.6	V
		$I_L = 2$ A		1	2.3	
V_{CEsat}	Total Drop	$I_L = 1$ A [5]			3.2	V
		$I_L = 2$ A [5]			4.9	
V_{sens}	Sensing Voltage (pins 1, 15)		–1 [1]		2	V
$T_1(V_i)$	Source Current Turn off Delay	0.5 V_i to 0.9 I_L [2] [4]		1.5		µs
$T_2(V_i)$	Source Current Fall Time	0.9 I_L to 0.1 I_L [2] [4]		0.2		µs
$T_3(V_i)$	Source Current Turn on Delay	0.5 V_i to 0.1 I_L [2] [4]		2		µs
$T_4(V_i)$	Source Current Rise Time	0.1 I_L to 0.9 I_L [2] [4]		0.7		µs
$T_5(V_i)$	Sink Current Turn off Delay	0.5 V_i to 0.9 I_L [3] [4]		0.7		µs
$T_6(V_i)$	Sink Current Fall Time	0.9 I_L to 0.1 I_L [3] [4]		0.25		µs
$T_7(V_i)$	Sink Current Turn on Delay	0.5 V_i to 0.9 I_L [3] [4]		1.6		µs
$T_8(V_i)$	Sink Current Rise Time	0.1 I_L to 0.9 I_L [3] [4]		0.2		µs
$f_c(V_i)$	Commutation Frequency	$I_L = 2$ A		25	40	KHz
$T_1(V_{en})$	Source Current Turn off Delay	0.5 V_{en} to 0.9 I_L [2] [4]		3		µs
$T_2(V_{en})$	Source Current Fall Time	0.9 I_L to 0.1 I_L [2] [4]		1		µs
$T_3(V_{en})$	Source Current Turn on Delay	0.5 V_{en} to 0.1 I_L [2] [4]		0.3		µs
$T_4(V_{en})$	Source Current Rise Time	0.1 I_L to 0.9 I_L [2] [4]		0.4		µs
$T_5(V_{en})$	Sink Current Turn off Delay	0.5 V_{en} to 0.9 I_L [3] [4]		2.2		µs
$T_6(V_{en})$	Sink Current Fall Time	0.9 I_L to 0.1 I_L [3] [4]		0.35		µs
$T_7(V_{en})$	Sink Current Turn on Delay	0.5 V_{en} to 0.1 I_L [3] [4]		0.25		µs
$T_8(V_{en})$	Sink Current Rise Time	0.1 I_L to 0.9 I_L [3] [4]		0.1		µs
$f_c(V_{en})$	Commutation Frequency	$I_L = 2$ A		1		KHz

1) Sensing voltage can be –1 V for t ≤ 50 µsec; in steady state V_{sens} min ≥ – 0.5 V
2) See fig. 2
3) See fig. 4
4) The load must be a pure resistor
5) PIN 1 and PIN 15 connected to GND

Figure 1 : Typical Saturation Voltage vs. Output Current

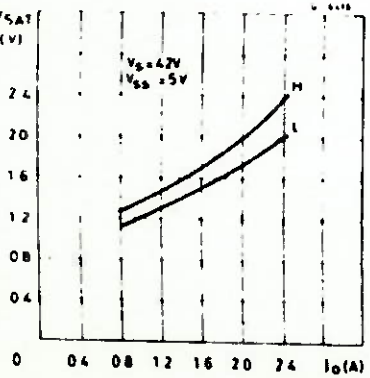
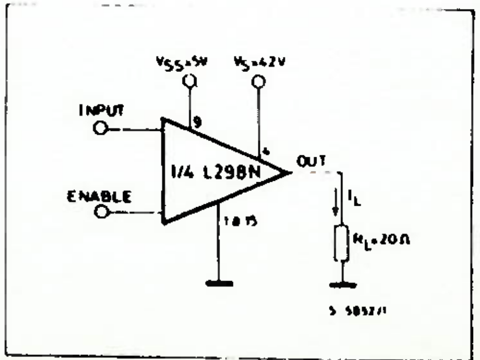


Figure 2 : Switching Times Test Circuits



Note : For INPUT Switching set EN = H
For ENABLE Switching set IN = H

Figure 3 : Source Current Delay Times vs. Input or Enable Switching.

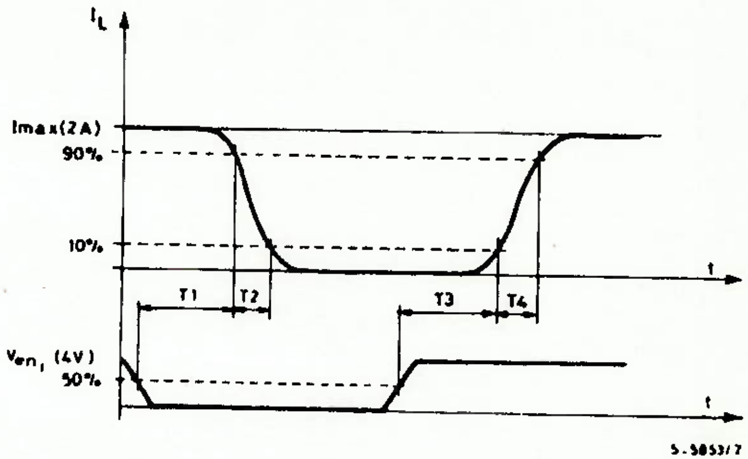
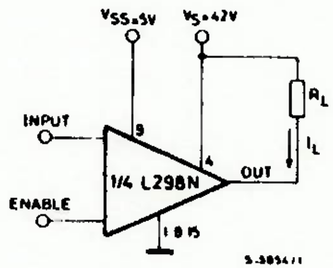


Figure 4 : Switching Times Test Circuits



Note : For INPUT Switching set EN = H
For ENABLE Switching set IN = L

Figure 5 : Sink Current Delay Times vs. Input 0 V Enable Switching.

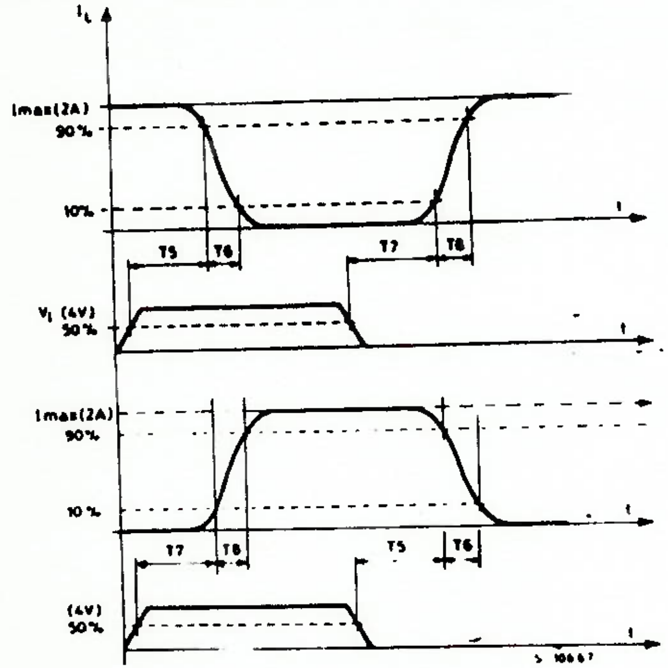
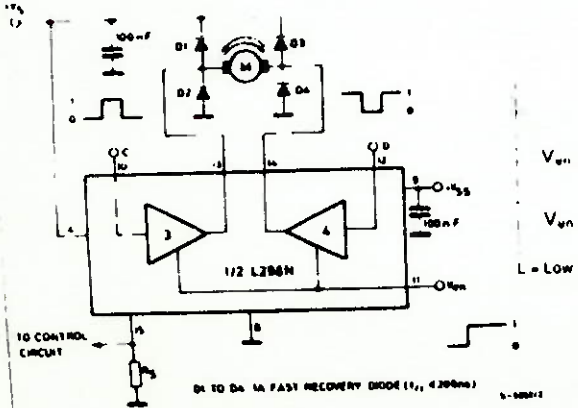


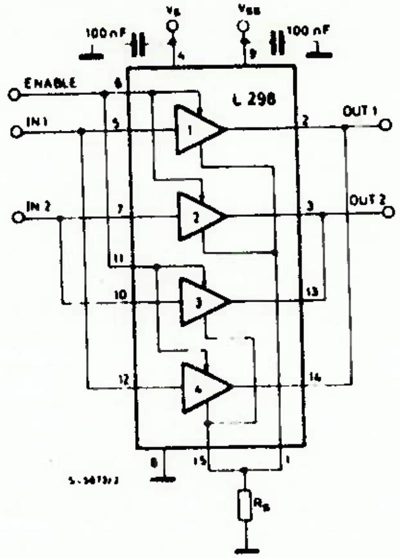
Figure 6 : Bidirectional DC Motor Control



	Inputs	Function
V_{en} = H	C = H ; D = L	Turn Right
	C = L ; D = H	Turn Left
	C = D	Fast Motor Stop
V_{en} = L	C = X ; D = C	Free Running Motor Stop

L = Low H = High X = Don't care

Figure 7 : For higher currents, outputs can be paralleled. Take care to parallel channel 1 with channel 4 and channel 2 with channel 3



APPLICATION INFORMATION (Refer to the block diagram)

1.1. POWER OUTPUT STAGE

The L298N integrates two power output stages (A ; B). The power output stage is a bridge configuration and its outputs can drive an inductive load in common or differenzial mode, depending on the state of the inputs. The current that flows through the load comes out from the bridge at the sense output : an external resistor (R_{SA} ; R_{SB}.) allows to detect the intensity of this current.

1.2. INPUT STAGE

Each bridge is driven by means of four gates the input of which are In1 ; In2 ; EnA and In3 ; In4 ; EnB. The In inputs set the bridge state when The En input is high ; a low state of the En input inhibits the bridge. All the inputs are TTL compatible.

2. SUGGESTIONS

A non inductive capacitor, usually of 100 nF, must be foreseen between both Vs and Vss, to ground, as near as possible to pin 8 (GND). When the large capacitor of the power supply is too far from the IC, a second smaller one must be foreseen near the L298N.

The sense resistor, not of a wire wound type, must be grounded near the negative pole of Vs that must be near the GND pin of the I.C.

Each input must be connected to the source of the driving signals by means of a very short path.

Turn-On and Turn-Off : Before to Turn-ON the Supply Voltage and before to Turn it OFF, the Enable input must be driven to the Low state.

3. APPLICATIONS

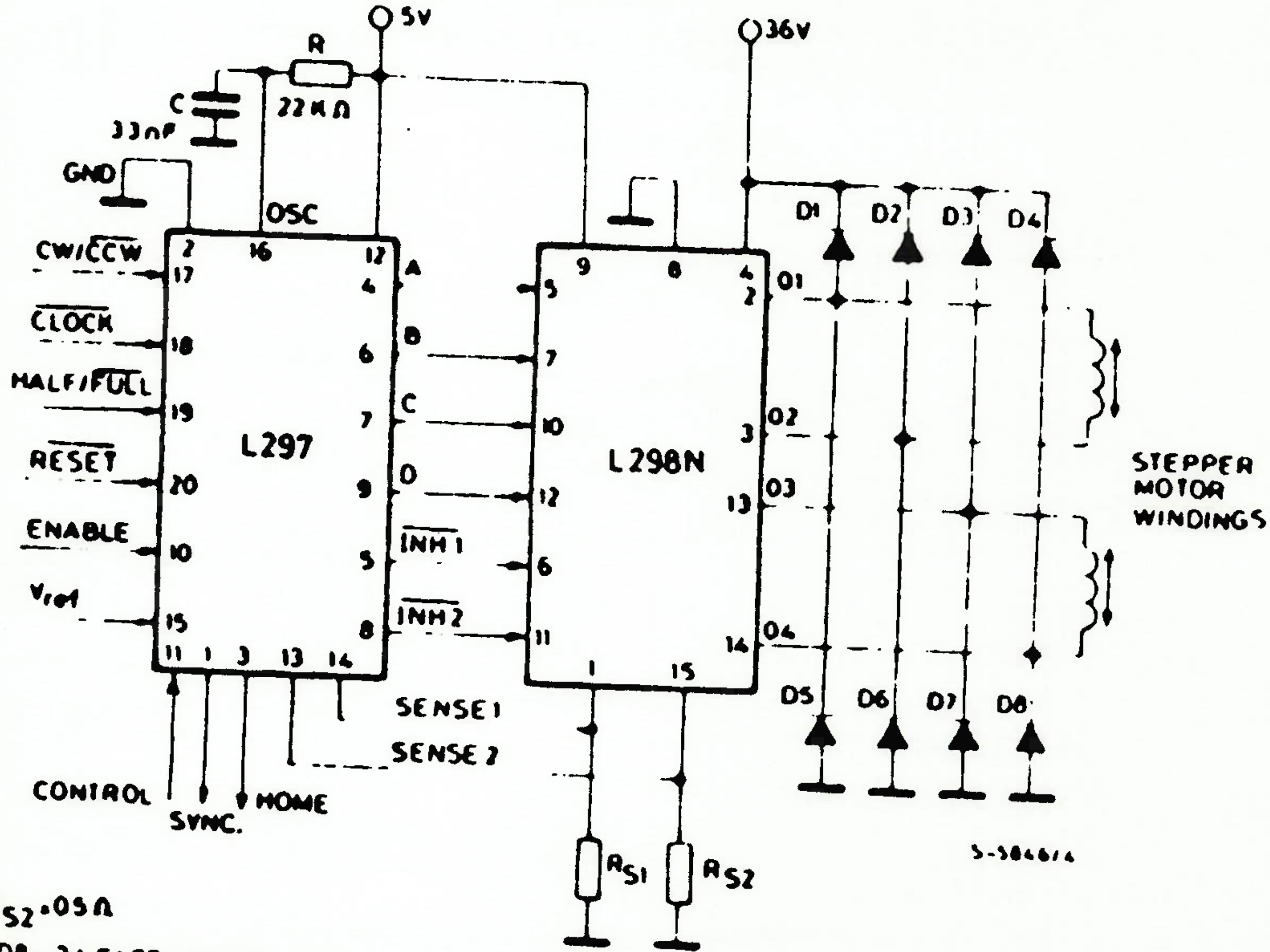
Fig 6 shows a bidirectional DC motor control Schematic Diagram for which only one bridge is needed. The external bridge of diodes D1 to D4 is made by four fast recovery elements (t_{rr} ≤ 200 nsec) that must be chosen of a VF as low as possible at the worst case of the load current.

The sense output voltage can be used to control the current amplitude by chopping the inputs, or to provide overcurrent protection by switching low the enable input.

The brake function (Fast motor stop) requires that the Absolute Maximum Rating of 2 Amps must never be overcome.

When the repetitive peak current needed from the load is higher than 2 Amps, a paralleled configuration can be chosen (See Fig.7)

An external bridge of diodes are required when inductive loads are driven and when the inputs of the



$R_{S1}R_{S2}$ = 0.5 Ω

D1 to D8 = 2A FAST DIODES

DESIGN ENGINEER'S GUIDE TO DC STEPPER MOTORS

1.0 PURPOSE

The purpose of this guide is to acquaint the designer with basic characteristics of DC stepper motors and associated drives. Their advantages and capabilities as digital motion control devices are also discussed.

1.1 BASIC DESCRIPTION

The stepper motor is a device which translates electrical pulses into mechanical movements. The output shaft rotates or moves through a specific angular rotation for each incoming pulse or excitation. This angle or displacement per movement is repeated precisely with each succeeding pulse translated by appropriate drive circuitry. The result of this precise, fixed and repeatable movement is the ability to accurately position. Unlike a conventional motor, which has a free running shaft, the stepper motor shaft rotates in fixed, repeatable, known increments. The stepper motor therefore allows control of load velocity, distance and direction. Initial positioning accuracy of a load being driven by a stepper motor is excellent. The repeatability (the ability to position through the same pattern of movements a multiple number of times) is even better. The only system error introduced by the stepper motor is its single step error, which is generally less than 5% of one step. Most significantly, this error is noncumulative, regardless of distance positioned or number of times repositioning takes place. The stepper motor is generally controlled by a DC power supply and drive/logic circuitry which will be discussed in this guide.

1.2 STEPPER MOTOR TECHNOLOGY

As the use of stepper motor systems has increased in a broad base of applications, terminology has evolved which required definition.

A. Step Angle - This is the specific angular increment the motor shaft will move each time the winding polarity is changed. It is specified in degrees.

B. Steps Per Revolution - This term describes the total number of steps required for the motor shaft to rotate 360°, or one complete revolution. The number is calculated by dividing the step angle into 360°.

C. Steps Per Second - This is the number of steps accomplished by the motor in one second of time. This figure replaces the rpm value of a standard drive motor. See Section 7 for formulas used to calculate this value.

motor in a single step movement. The error is noncumulative, i.e., it does not increase as additional steps are taken. In a linear system with a resolution of 0.001 inch. a 3% accuracy motor would introduce a maximum of 0.00003 inch error into the system. This total error would not accumulate or increase with total distance moved or number of movements made.

E. Holding Torque - With the motor shaft at standstill (zero rpm condition), Holding Torque is the amount of torque, from an external source, required to break the shaft away from its holding position. It is measured with rated current and voltage applied to the motor. Holding torque is a basic characteristic of stepper motors and provides positioning integrity under standstill, or rest, conditions.

F. Residual Torque - This is the torque present at standstill under power off conditions and is a result of the permanent magnetic flux acting on the stator poles. Residual torque is present under power off conditions only with a motor of permanent magnet rotor design.

G. Step Response - When given a command to take a step, a stepper motor will respond within a specific time period. This time period, or "time for a single step", is a function of the torque-to-inertia ratio of the motor and of the characteristics of the electronic drive system. Ratings given are for no-load conditions and are generally expressed in milliseconds.

H. Torque-To-Inertia Ratio - This ratio is calculated by dividing the rated holding torque of the motor in ounce-inches by its rotor inertia in ounce-inch-seconds squared. The better the torque-to-inertia ratio, the better the step response. When dealing with step response problems, it is important to know the torque-to-inertia ratio of the motor.

I. Resonance - Stepper motors are a "spring response" system and, as such, have certain "natural" frequency characteristics. When a motor's natural frequency, or "resonance" is reached, an increase in the audible level of the motor's operation can be detected. In cases of severe resonance, the motor may lose steps and/or oscillate about a point. The frequency at which this occurs depends on the motor and the load. In many applications, it may not occur to any perceptible degree. However, the designer should realize that this condition can exist and specific facts about the resonant characteristics of a particular motor should be obtained from the manufacturer.

J. Drives - This is a broad term used to describe the circuitry which controls the stepper motor. It usually consists of a power supply, sequencing logic and power output switching components. These drives are generally categorized as Translators, Translator/Oscillators or Indexers.

K. Translator - An electronic control with circuitry to convert pulses into the switching sequence which will operate the motor one step for each pulse received. Translators usually have no counting capability.

L. Translator/Oscillator - Includes translator circuitry together with a built-in oscillator which can serve as a pulse source.

M. Indexer - An electronic control which includes the translator function plus additional circuitry to control the number of steps taken as well as direction and velocity.

N. Pulse Rate - The rate at which windings are switched. Where one pulse equals one motor step, the pulse rate is also the motor stepping rate.

O. Ramping - This is the process of controlling the pulse frequency to accelerate the motor from base speed to running speed as well as to decelerate the motor from running speed to base speed. Ramping increases the ability to drive the motor and load to higher speeds, particularly with large inertial loads.

P. Slew Rate - An area of high speed where the motor can run unidirectionally in synchronism. However, it cannot start, stop or reverse at this rate. A stepper motor is brought to a slewing rate using acceleration and is then decelerated to a stop under conditions where no step loss can be tolerated.

Q. Damping - Damping is defined as the reduction or elimination of step overshoot. It is used where settling down time is important, Damping methods used include mechanical, electronic and viscous means.

1.3 STEP ANGLE

The step angle of a SLO-SYN Step Motor is 1.8°, equivalent to 200 steps per revolution.

2.0 BASIC CONSTRUCTION AND OPERATION

Operation of a stepper motor is related to basic permanent magnet theory, where "likes" repel and "opposites" attract. If the stator windings in Figure 1 are energized such that Stator A is the North Pole, Stator B is the South Pole and the permanent magnet rotor is positioned with its polarity as shown, it is impossible to determine the direction of rotation. However if, as shown in Figure 2, two additional Stator poles C and D are added and energized so that polarities appear as shown, we would then be able to dictate the direction of rotor rotation. In this case, the direction would be counterclockwise with the rotor aligning itself between the "average" South Pole and the "average" North Pole, as shown in Figure 3.

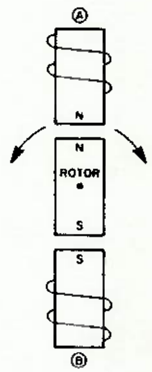


FIGURE 1

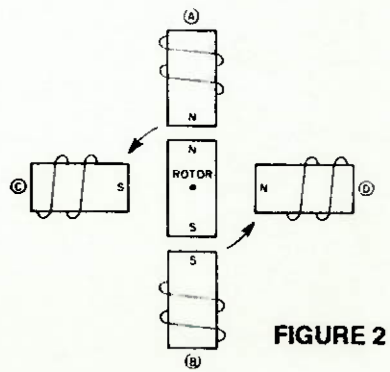


FIGURE 2

teeth are machined on each stator pole as well as on the rotor. In the final analysis, the number of teeth on the rotor and stator determines the step angle that will be achieved each time the polarity of one winding is changed. The rotor/stator tooth configuration for a 1.8° stepper is shown in Figure 4.

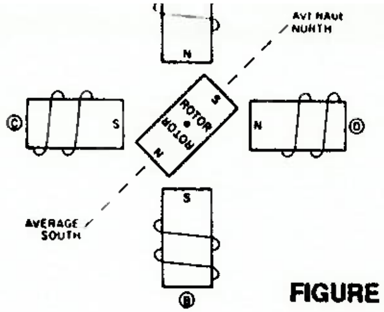


FIGURE 3

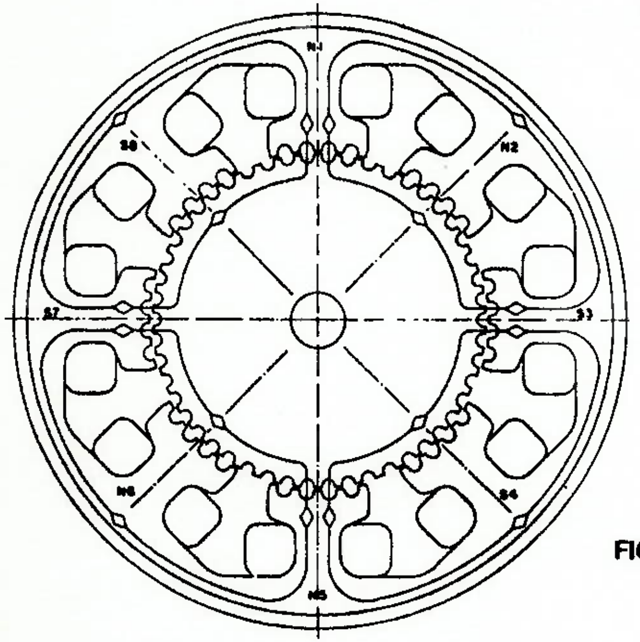


FIGURE 4

3.0 RATINGS

The chart lists typical ratings for SLO-SYN Stepper Motors as shown in our catalogs. While the voltage rating is straightforward, note that the current requirements are given in "amperes per winding". Using the typical four-step switching sequence, two windings are 'on' at any given time. Therefore, the total current requirement of the motor is twice the "amperes per winding" value given in the chart. Inductance and resistance values are also given "per winding".

ELECTRICAL RATINGS

Motor Type		Typical Time For Single Step (mS)	Nominal DC Volts	Rated Amperes Per Winding	Nominal Resistance Per Winding (25°C) Ohms	Nominal Inductance Per Phase (Milli-Henrys)
3% Accuracy	5% Accuracy					
UNIPOLAR RATINGS (6-LEAD DRIVE)						
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M061-LS08 M061-LE08	–	2.0	1.25	3.8	0.33	0.635
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M062-LS06 M062-LE06	–	–	2.6	3.1	0.88	2.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M063-LS06 M063-LE06	–	2.6	3.36	2.9	1.16	2.85
M063-LS09 M063-LE09	[illegible]	[illegible]	[illegible]	[illegible]	0.49	1.15
M091-FC06	M091-FD06	3.9	2.6	3.1	0.85	4.12
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.85	4.12
–	M091-FD-8009 M091-FD-8109	3.1	1.7	4.7	0.36	1.5
[illegible]	M092-FD310	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
–	M092-FD-8008 M092-FD-8108	4.0	3.0	4.0	0.75	3.56
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.76
–	M093-FD-301	3.4	1.54	11.0	0.14	0.85
[illegible]	[illegible]	[illegible]	[illegible]	5.5	0.48	3.19
–	M093-FD-8014	3.4	2.27	7.0	0.324	2.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.37	2.3
–	M111-FD-8016	4.4	1.7	8.0	0.21	1.1
[illegible]	M112-FD08	[illegible]	[illegible]	3.8	1.53	14.0
–	M112-FJ-327	6	2.26	9.2	0.246	2.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.60	5.3
–	M172-FD-306	24	2.35	15	0.15	1.98
[illegible]	[illegible]	[illegible]	[illegible]	20	0.075	1.06
–	M172-FD-8030	24	2.35	15	0.15	1.98
[illegible]	[illegible]	[illegible]	[illegible]	20	0.075	1.06

Motor Type		Typical Time For Single Stop (mS)	Nominal DC Volts	Rated Amperes Per Winding	Nominal Resistance Per Winding (25°C) Ohms	Nominal Inductance Per Phase (Milli-Henrys)
3% Accuracy	5% Accuracy					
BIPOLAR RATINGS (4-LEAD DRIVE)						
M061-LF-408	–	–	3.0	0.5	15.9	61.0
M062-LF-402	–	–	6.6	1.0	6.6	33.0
M063-LF-401	–	–	5.64	1.0	[illegible]	29.0
–	M091-FF-401	–	6.8	1.0	6.8	52.0
–	M092-FF-402	–	[illegible]	2.0	1.7	[illegible]
–	M093-FF-402	–	4.5	3.0	1.5	16.9
–	M111-FF-401	–	[illegible]	3.4	[illegible]	17.7
–	MX111-FF-401U	–	4.0	3.4	1.14	17.7
–	M112-FF-401	–	1.95	4.0	0.49	8.80
–	MX112-FF-401	–	1.95	4.0	0.49	8.80
–	M113-FF-401	–	4.5	6.0	0.75	17
–	M172-FF-401	–	2.6	4.0	0.65	14,6

4.0 THE FOUR-STEP SWITCHING SEQUENCE

SLO-SYN Stepper Motors are normally operated using the four-step switching sequence. Each time one of the switches indicated in the chart is transferred, the motor takes a "step. After four steps, the same two windings will be "on" as when the sequence was started. The rotor moves on-fourth of a tooth pitch for every step taken; so for every four steps, the rotor moves one full tooth pitch. With 50 teeth on the rotor, four steps/full tooth pitch x 50 teeth/revolution = 200 steps per revolution. The step angle is, therefore, a function of the number of teeth on the rotor and the switching sequence.

FOUR STEP INPUT SEQUENCE
(FULL-STEP MODE)*

STEP	SW1	SW2	SW3	SW4
1	ON	OFF	ON	OFF
2	ON	OFF	OFF	ON
3	OFF	ON	OFF	ON
4	OFF	ON	ON	OFF
1	ON	OFF	ON	OFF

* See Figure 5 for switch wiring

The eight-step sequence is often called "electronic half-stepping". With this method, the rotor moves half its normal distance per step. For example, a 1.8° (200 step per revolution) motor would become a 0.9° (400 step per revolution) motor. The advantages of operating in this mode include finer resolution, the reduction of resonant amplitudes and greater speed capability.

EIGHT STEP INPUT SEQUENCE
HALF-STEP MODE*

STEP	SW1	SW2	SW3	SW4
1	ON	OFF	ON	OFF
2	ON	OFF	OFF	OFF
3	ON	OFF	OFF	ON
4	OFF	OFF	OFF	ON
5	OFF	ON	OFF	ON
6	OFF	ON	OFF	OFF
7	OFF	ON	ON	OFF
8	OFF	OFF	ON	OFF
1	ON	OFF	ON	OFF

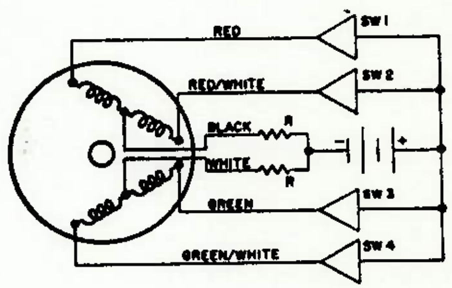
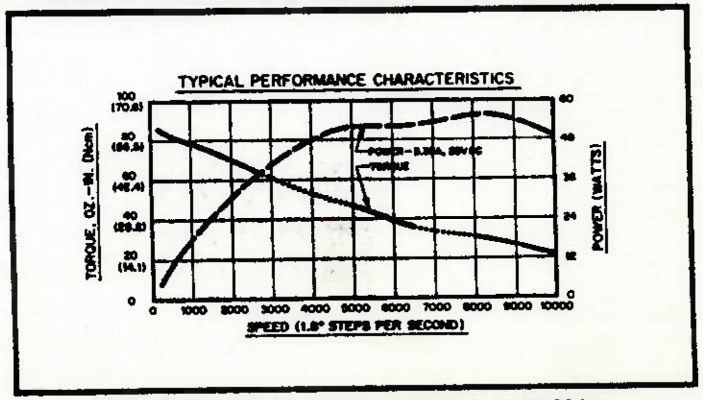


Figure 5

6.0 TORQUE-SPEED RELATIONSHIP

As the stepping rate increases, the back EMF (Electromotive Force) produced by the motor causes the current, and the motor torque, to decrease. Figure 6 shows a torque vs. speed curve for the M062-LE09 motor. Note that at standstill (zero steps per second) the torque output is 85 ounce-inches while at 2000 steps per second the torque has decreased to 70 ounce-inches.

A torque vs. speed curve must be used in the process of selecting a stepper motor. Note that the speed must be given in steps per second, not in rpm.



M062-LE09 Motor With 3.5 Ampere, 28 Vdc
Bipolar Chopper Drive
Figure 6

from "rpm" into "steps per second". The following formulas may be used:

1. Converting rpm into steps per second with a 1.8° step angle, 200 step per revolution motor:

   Steps Per Second = RPM x 3.34

2. For other step angles, use the following general formula:

   Steps Per Second = (rpm) (Steps per Revolution/60)

3. To find the rpm rate when the steps per second rate is known, use the following:

   For a 1.8°, 200 step per revolution motor

   rpm = Steps Per Second/3.34

8.0 HANDLING INERTIAL LOADS (Acceleration/Deceleration Time Allowed)

Stepper Motors are not limited to a specific "maximum moment of inertia" due to their ability to be accelerated to and decelerated from any given speed.

Moving an inertial load is a function of time and torque. The more time allowed to move a particular distance, the more inertia that can be moved.

The required torque can be calculated when the total value of inertia, the time allowed to accelerate and decelerate (acceleration rate) and the step angle of the motor are known.

The following formula applies:

Tj = (j) (α) (k) where:

Tj = Torque required to move the inertia (oz-in)
j = Total system inertia including inertia of motor rotor (lb-in²)
α = Acceleration rate (steps per second²) (time element)
k = A constant. For 1.8° step motors, the constant is 1.31×10^{-3}

Further defining α:

$$\alpha = \frac{\Delta V \text{ (sps)}}{\Delta T \text{ (seconds)}} \qquad \frac{\text{(change in velocity)}}{\text{(change in time)}}$$

Note that increasing the ΔT factor (time) will decrease α. Inserting α into the formula, then, will decrease the torque requirement. This example clearly illustrates that, if enough time is allowed, the required torque becomes very low.

IMPORTANT: The "Tj" value in the formula is the torque required to move the **inertia** only and **does not** include the **friction** torque requirement of the system. Friction torque must be added to get the total torque requirement. For example: assume that Tj equals 35 ounce-inches and frictional torque equals 50 ounce-inches. Total torque required would then be 50 + 35, or 85 ounce-inches at the speed specified. The proper motor can now be determined by consulting a torque vs. speed curve and selecting the motor which produces 85 ounce-inches at the desired speed and acceleration rates.

Allowed)

At stepping rates above 50 steps per second where no acceleration/deceleration time is allowed, the following formula may be used:

Tj = (j) (α) (k) where
Tj = Torque required to move the inertial load (oz-in)
j = Total system inertia including rotor j of motor)lb-in²)

$$\alpha = \frac{V^2}{2} \qquad \frac{(SPS)^2}{2}$$

k = Constant (1.31×10^{-3} for a 1.8 stepper motor)

EXAMPLE: **An application requires a 1.8 stepper motor to move 200 steps in one second with an inertial load of 1.5 lb-in². Friction torque is 25 oz-in. No acceleration/deceleration is allowed. An M092 frame size motor is desired.**

Solution:

$$T = (j) \frac{(V^2)}{2} (k)$$

j = 1.5 lb-in² + M092 rotor j of 0.42 lb-in² = 1.92 lb-in²
k = 1.31×10^{-3} (constant)

Tj = (1.92) ($200^2/2$) (1.31×10^{-3})

Tj = (1.92) (20×10^3) (1.31×10^{-3})
Tj = 50.3 oz-in (torque required to move inertia)
+ TFriction of 25.0 oz-in

Total torque required: 75.3 oz-in @ 200 steps per second

9.0 HOLDING TORQUE VS. TORQUE AT STANDSTILL

True holding, or **"breakaway" torque is measured at rated** voltage and current. For **this reason, there is often confusion between holding torque and torque at zero steps per second with a given "drive". Typically at "standstill", a drive does not** provide **rated** voltage and current to the motor due to a safety factor. Therefore, the standstill **torque value at zero steps per second is generally less than true** holding torque at **rated** voltage and current.

MECHANICAL SPECIFICATIONS, 1/8° SLO-SYN® STEPPER MOTORS

BASIC MOTOR SERIES	MINIMUM HOLDING TORQUE (1) OZ.-IN. (2) (Ncm) (3)	MINIMUM RESIDUAL TORQUE (2) OZ.-IN. (Ncm)	NOMINAL ROTOR INERTIA LB-IN2 (kg-cm2)	TYPICAL TORQUE TO INERTIA RATIO (RAD./SEC.2)	NUMBER OF LEADS OR TERMINALS	SHAFT DIAMETER INCHES (mm)	MAXIMUM OVERHANG LOAD LBS (kg)	MAXIMUM THRUST LOAD LBS (kg)
M061	53 (37.4)	1 (0.71)	0.04 (0.12)	32 x 10³ (3)	4, 6 or 8	0.250 (6.35)	15 (6.8)	25 (11.3)
M062	100 (70.6)	1.4 (0.99)	0.08 (0.23)	30 x 10³ (3)	4, 6 or 8	0.250 (6.35)	15 (6.8)	25 (11.3)
M063	150 (106)	2.5 (1.77)	0.11 (0.32)	33 x 10³ (3)	4, 6 or 8	0.250 (6.35)	15 (6.8)	25 (11.3)
M091	150 (106)	2 (1.41)	0.23 (0.67)	15.6 x 10³ (3)	4, 6 or 8	3.75 (9.53)	25 (11.3)	50 (22.7)
M092	300 (212)	3.9 (2.75)	0.42 (1.23)	17.2 x 10³ (3)	4, 6 or 8	0.375 (9.53)	25 (11.3)	50 (22.7)
M093	450 (318)	6.9 (4.87)	0.64 (1.87)	16.8 x 10³ (3)	4, 6 or 8	0.375 (9.53)	25 (11.3)	50 (22.7)
M111 MX111(4)	625 (441)	6 (4.24)	1.34 (3.93)	11.2 x 10³ (3)	4, 6 or 8	0.375 (9.63)	25 (11.3)	50 (22.7)
M112-FD	1125 (794)	12 (8.47)	2.75 (8.06)	9.8 x 10³ (3)	4, 6 or 8	0.500 (12.7)	25 (11.3)	50 (22.7)
M112-FJ MX112(4)	1125 (794)	12 (8.47)	2.75 (8.06)	9.8 x 10³ (3)	4, 6 or 8	0.625 (15.88)	25 (11.3)	50 (22.7)
MH112	1760 (1243)	85 (60)	3.22 (9.42)	13.1 x 10³ (3)	4 or 8	0.625 (15.88)	50 (22.7)	100 (45.4)
M172	2700 (1907)	50 (35.3)	21 (61.5)	3.1 x 10³ (3)	4, 6 or 8	0.625 (15.88)	50 (22.7)	100 (45.4)
MH172	5330 (3764)	50 (35.3)	21 (61.5)	6.1 x 10³ (3)	4 or 8	0.75 (19.05)	100 (45.4)	150 (68)

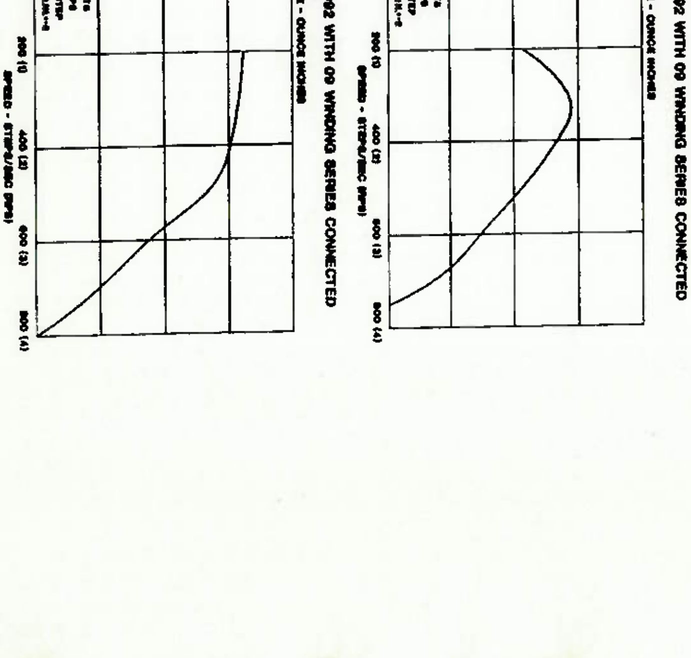
(1) Both windings at rated current.
(2) Values shown are for reference information and are correct to the best of our knowledge at time of publication, but are subject to change without notice. Parameters to be used as part of a specification should be verified with the factory.
(3) Operation below rated current will reduce torque and may degrade step accuracy.
(4) Available only with 4 leads.

Microstepping is a method of step motor control that allows the rotor to be positioned at places other than the 1.8° or 0.9° locations provided by the full-step and half-step methods. Microstepping positions occur between these two angular points in the rotation of the rotor.

The most commonly used microstep increments are 1/5, 1/10, 1/16, 1/32, 1/125 and 1/250 of a full step. These increments have been chosen by Superior Electric to simplify control of both US and metric units of measurement, and also allow finer positioning resolution. While a full step of 1.8° will give a positioning resolution of 0.001 inch when the motor is driving through a lead screw that has a 0.2000 inch leads, resolutions of 0.000008 inch or less are theoretically possible using microstepping.

Another major benefit of microstepping is that it reduces the amplitude of resonance that occurs when the motor is operated at its natural frequency or at subharmonics of that frequency. The improved step response and reduced amplitude of the natural resonances result from the finer step angle. Figure 7 shows two typical Torque vs. Speed curves. The blank area at the beginning of each curve represents the area where resonance may occur.

Selection of a Superior Electric drive which provides microstepping operation allows the user to obtain the benefits of smoother step motor performance and finer step resolution.



Typical Torque Vs. Speed Curves Showing Area Of Resonance
Figure 7

90 to 160 steps per second depending on the motor model, an increase in the audible noise and vibration levels of the motor may occur. In actual use, the frequency at which the resonance will occur can vary widely, depending on the characteristics of the load.

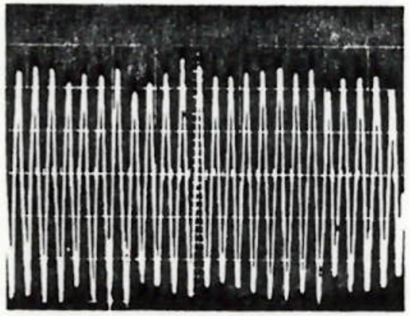
In applications where the motor must be operated at its "natural frequency", **inertial loading** (a flywheel) can be added to reduce resonance and allow satisfactory performance.

The natural frequency is **lowered** as inertia is increased.Another method is to operate at a higher stepping rate whenever possible. Also, the characteristics of the electronic drive can be changed to permit a "softer" step. However, this will result in a trade-off of torque - speed performance. Resonance can also occur at some higher harmonic of the "primary" resonant region (90 to 160 steps per second), but it is normally much less severe in these regions.

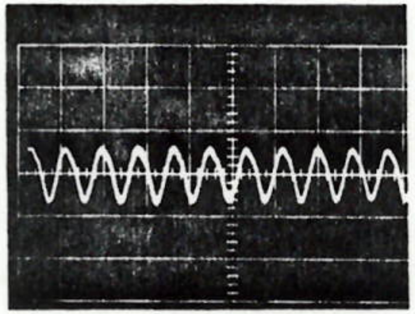
13.0 LANCHESTER DAMPERS

As discussed in Section 12.0, the effects of resonance can be reduced or eliminated by adding inertia (a flywheel) to the system. Adding inertia, however, can cause a reduction in overall system performance, especially where the friction load component is substantial.

SLO-SYN Step Motors are available with a viscous coupled inertial damper, called a Lanchester Damper. This device incorporates a light-weight aluminum outer shell which is driven by the motor shaft. A heavier flywheel located within the light-weight housing is caused to rotate by the "shear" effect of a fluid located between the outer rotating shell and the internal inertial flywheel. The results are good damping characteristics with little loss of overall performance. Figure 8 shows typical instantaneous velocity variations of an undamped motor operating in the primary resonance region while Figure 9 shows the dramatic reduction of these velocity variations when the Lanchester Damper is applied.



UNDAMPED MOTOR
FIGURE 8



DAMPED MOTOR
FIGURE 9

14.0 ENCODER MOTORS

For those desiring an indication of true shaft position, a complete line of Encoder Motors is available. The encoder outputs produce one pulse for each step taken by the motor. These signals are in "phase quadrature" (two-channel output, 90° phase shift between the two channels) with one of those signals used as a reference for up and down counting. A third channel is also available as a "zero reference" or revolution counter whereby one output pulse per revolution is provided. Figure 10 shows a typical configuration and pulse output.

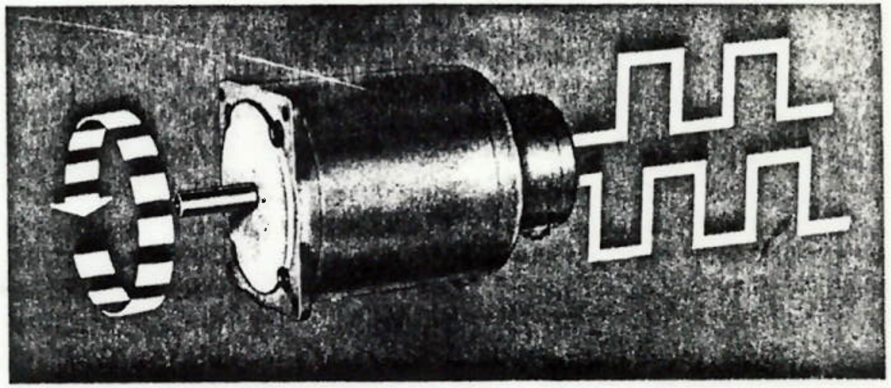


FIGURE 10

15.0 SPECIAL CAPABILITY STEPPER MOTORS

SLO-SYN Stepper Motors can be produced in a wide variety of special configurations, including:

A. Double Ended Shaft - Having a shaft that extends from both ends of the motor. Available in all models.

B. Explosion-Proof - Meet Underwriters Laboratories specifications for Class 1, Group D or Class 2, Groups E, F and G service.

C. Special Environment - Include High Temperature, Militarized, Limited Vacuum, Radiation Resistant and Splash-Proof models.

D. Special Windings - Electrical characteristics can be designed to perfectly match your drive for optimum performance.

E. Special Shaft Configurations - Flats, keyways, tapers, holes, knurls, threads, splines, etc. are available.

F. Winding Configurations - two-phase, three-phase or four-phase motors designed for single or dual winding excitation can be produced, depending on the model chosen.

For many years, Superior Electric has produced a wide variety of special motors to meet specific customer application needs. If you have a need for a "customized" stepper motor, contact us. Chances are, we've done it before!

information required when selecting a stepper motor. Before these formulas can be used, however, it is necessary to obtain detailed information about the application. The more complete the data, the more accurate the motor selection which will result.

The required data is as follows:

I. Clearly define the application

II. Determine the mechanical requirements

- A. Size and weight
- B. Mounting method
- C. Resolution - steps per revolution, linear increment
- D. Accuracy required - percent error
- E. Shaft Configuration - double-ended, keyway, etc.
- F. Runout
- G. Special environment capability
- H. Damper
- I. Encoder
- J. Leads or terminals
- K. Gearing, lead screws - define

III. Load Requirements

- A. Torque at standstill (power on)
- B. Torque at standstill (power off - detent)
- C. Torque at speed (running or "slew")
- D. Inertia (reflected)
- E. Distance versus time data
  1. Average speed
  2. maximum speed
- F. Acceleration and deceleration time allowed
- G. Single step response time
- H. Settling time

IV. Electronic drive description

- A. Type of drive
  1. Translator - pulse-to-step conversion
  2. Translator/Oscillator - Translator plus built in Oscillator
  3. Indexer - controls count, direction, etc.
- B. Source
  1. Customer built
  2. Purchased
- C. Drive design type
  1. Unipolar L/R
  2. Bipolar L/R
  3. Bilevel
  4. Constant current bipolar chopper
  5. Other - define
- D. Power supply capabilities
  1. AC input
  2. DC voltage
  3. DC current

- E. Drive control logic
  1. Input pulse characteristics
  2. Ramping
  3. Damping
  4. Open- or closed-loop
  5. Full/half-step, microstep

16.1 SELECTING DC STEPPER MOTORS -FORMULAS

Before the correct SLO-SYN Stepper Motor for a particular application can be selected, the following information must be determined:

a) operating speed in steps per second	**e) time to accelerate in milliseconds**
b) torque in ounce-inches	**f) time to decelerate in milliseconds**
c) load inertia in lb-in²	**g) type of drive system to be used**
d) required step angle	**h) size and weight considerations**

Once this information is known, the best motor/drive combination can be determined using the torque vs. speed curves in the SLO-SYN Motors and Drives catalog and the formulas which follow.

1. **Torque** (oz-in) = Fr
   where F = Force (in ounces) required to drive the load
   r = Radius (in inches)

2. **Moment of Inertia**

$$I\ (\text{lb-in}^2) = \frac{Wr^2}{2} \quad \text{for a disk}$$

or

$$I\ (\text{lb-in}^2) = \frac{W}{2}(r_1^2 + r_2^2) \quad \text{for a cylinder}$$

Where W = Weight in pounds
r = Radius in inches

a. overcome any frictional load in the system
b. start and stop all inertial loads, including that of its ow otor

The basic rotary relationship is:

$$T = I\alpha/24$$

where T = torque in ounce-inches
I = moment of inertia in lb-in²
α = angular acceleration in radians per second²

Angular acceleration (α) is a function of the change in velocity (ω) and the time required for the change.

$$\alpha = \frac{\omega_2 - \omega_1}{t}$$

or, if starting from zero

$$\alpha = \frac{\omega}{t}$$

where ω = angular velocity in radians per second
t = time in seconds

$$\text{since} \quad \omega = \frac{\text{steps per second}}{\text{steps per revolution}} \times 2\pi$$

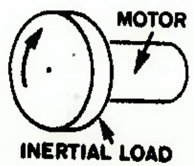
angular velocity and angular acceleration can also be expressed in steps per second (ω') and steps per second² (α), respectively.

SAMPLE CALCULATIONS

A. Calculating torque required to rotationally accelerate an inertial load

$$T = 2 \times I_o \frac{\omega'}{t} \times \frac{\pi Ø}{180} \times \frac{1}{24}$$

where T = torque required in oz-in
I_o = inertial load in lb-in²
π = 3.1416
Ø = step angle in degrees
ω' = step rate in steps per second



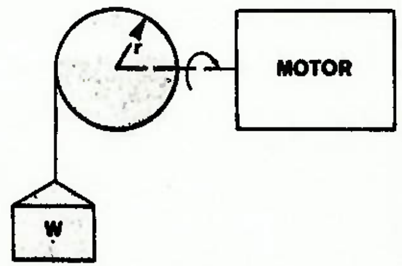
EXAMPLE: assume the following conditions:

Inertia = 9.2 lb-in²
step angle = 1.8°
acceleration = from 0 to 1000 steps per second in 0.5 second

$$T = 2 \times 9.2 \times \frac{1000}{0.5} \times \frac{\pi \times 1.8}{180} \times \frac{1}{24}$$

T = 48.2 oz-in torque required to

B. Calculating torque required to accelerate and raise a weight using a drum and string.



The total torque which the motor must supply includes the torque required to:

a. accelerate the weight
b. accelerate the drum
c. accelerate the motor rotor
d. lift the weight

The rotational equivalent of the weight and the radius of the drum is:

$$I_{(eq)} = Wr^2$$

where $I_{(eq)}$ = equivalent inertia in lb-in²
W = weight in lbs
r = radius of drum in inches

Drum	3 inches O.D., 1.5 inches radius
Velocity	15 ft per second
Time to Reach Velocity	0.5 second
Motor Rotor Inertia	2.5 lb-in²
Drum Inertia	(3" dia. x 2" lg., steel) 4.5 lb-in²

$I_{(eq)}$ = 5 x (1.5)² = 11.25 lb-in²
I (drum) = 4.50 lb-in
I (rotor) = 2.50 lb-in
I (total) = 18.25 lb-in²

since the velocity is 15 ft per second using a 3" drum, the velocity in rev. per second can be calculated

$$\text{speed} = \frac{15 \times 12}{3 \times \pi} = 19.1 \text{ rev per second}$$

The motor step angle is 1.8°, or 200 steps per revolution.

Therefore:

$$\omega' = 19.1 \times 200 = 3820 \text{ steps per second}$$

$$T = 2 \times I_o \times \frac{\omega'}{t} \times \frac{\pi \times \varnothing}{180} \times \frac{1}{24}$$

$$T = 2 \times 18.25 \times \frac{3820}{0.5} \times \frac{3.1416 \times 1.8}{180} \times \frac{1}{24}$$

T = 364 oz-in = torque required to accelerate the system

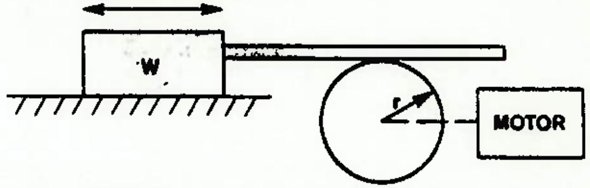
Torque required to lift the weight equals

T = wr
= 80 x 1.5
= 120 oz-in

total torque required is, therefore:

364 oz-in (torque to accelerate)
120 oz-in (lifting torque)
484 oz-in (total torque)

C **Calculating the torque required to accelerate a mass moving horizontally and driven by a rack and pinion or similar device.**



The total torque which the motor must provide includes the torque required to:

a. accelerate the weight, including that of the rack
b. accelerate the gear
c. accelerate the motor rotor
d. overcome the frictional losses

to calculate the rotational equivalent of the weight:

$I_{(eq)} = w r^2$

where w = weight in lbs
r = radius in inches

EXAMPLE

assume:

weight	= 5 lb
gear pitch diameter	= 3 inches
gear radius	= 1.5 inches
velocity	= 15 feet per second
time to reach velocity	= 0.5 second
pinion inertia	= 4.5 lb-in²
motor rotor inertia	= 2.5 lb-in²

$I_{(eq)}$ = w r² = 5 x (1.5)² = 11.25 lb-in2
I pinion = 4.5 lb-in²
I rotor = 2.5 lb-in²
I total = 18.25 lb-in²

Velocity is 15 feet per second with a 3" pitch diameter gear.

Therefore:

$$\text{Speed} = \frac{15 \times 12}{3 \times \pi} = 19.1 \text{ rev. per second}$$

$\omega = 19.1 \times 200 = 3820$ steps per second

To calculate the torque needed to accelerate the system:

$$T = 2 \times I_o \times \frac{\omega'}{t} \times \frac{\pi \varnothing}{180} \times \frac{1}{24}$$

$$T = 2 \times 18.25 \times \frac{3820}{0.5} \times \frac{3.1416 \times 1.8}{180} \times \frac{1}{24}$$

$$T = 364 \text{ oz-in}$$

To calculate torque needed to slide the weight, assume a frictional force of 6 oz.

T friction = 6 x 1.5 = 9 oz-in

Total torque required = 364 oz-in
+ 9 oz-in
= 373 oz-in

Lead Screw Formulas and Sample Calculations

1. **Linear Speed**

$$\text{Linear Speed (ipm)} = \frac{\text{steps/sec.}}{\text{steps/rev.}} \times 60 \times \frac{1}{p}$$

where p = lead screw pitch (threads per inch)

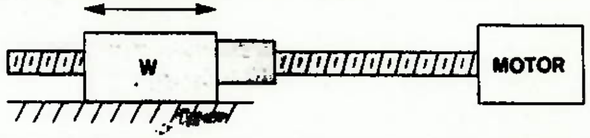
2. **Axial Force**

$$\text{Force (lb)} = \frac{2\pi}{16} \times T \times p \times \text{eff.}$$

where T = torque in oz-in
p = lead screw pitch (threads per inch)
eff. = lead screw efficiency expressed as a decimal: 90% = 0.90

Note: Ball-nut lead screws are generally 85% to 95% efficient. Acme screws are generally 35% to 45% efficient, but can be as high as 85%.

A. Calculating the torque required to accelerate a mass moving horizontally and driven by a ball bearing lead screw and nut.



The total torque the motor must provide includes the torque required to:

a. accelerate the weight
b. accelerate the lead screw
c. accelerate the motor rotor
d. overcome the frictional force

to calculate the rotational equivalent of weight w:

$$I_{(eq)} = w \times \frac{1}{p^2} \times (1/2\pi)^2$$

where w = weight in lbs
p = pitch in threads per inch
$I_{(eq)}$ = equivalent polar inertia in lb-in²

to calculate lead screw inertia (steel screw)

I screw = D^4 x length x 0.028

EXAMPLE

weight	=	1000 lb
velocity	=	0.15 ft per second
time to reach velocity	=	0.1 second
ball screw diameter	=	1.5 inches
ball screw length	=	48 inches
ball screw pitch	=	5 threads per inch
motor rotor inertia	=	2.5 lb-in²
friction force to slide weight	=	6 oz

$$I_{(eq)} = w \times \frac{1}{p^2} \times 0.025$$

$$I_{(eq)} = 1000 \times \frac{1}{25} \times 0.025$$

$I_{(eq)}$ = 1.0 lb-in²

I (screw) = D^4 x length x 0.028

I (screw) = 5.06 x 48 x 0.028

I (screw) = 6.8 lb-in²

I (screw) = 6.8 lb-in²
$I_{(eq)}$ = 1.0
I rotor = 2.5 lb-in²
I total = 10.3 lb-in

Torque to accelerate system

$$T = 2 \times I_o \times \frac{\omega'}{t} \times \frac{3.1416 \times 1.8}{180} \times \frac{1}{24}$$

$$T = 2 \times 10.3 \times \frac{1800}{0.1} \times \frac{3.1416 \times 1.8}{180} \times \frac{1}{24}$$

$$T = 484 \text{ oz-in}$$

Torque to overcome friction

$$F = 0.393 \times T \times p \times \text{eff.}$$

$$6/16 = 0.393 \times T \times 0.90$$

where F = frictional force in lb-in
T = torque in oz-in
p = lead screw pitch in threads per inch
T = 0.22 oz-in

Total torque required = 0.22 oz-in
484.00 oz-in
484.22 oz-in

CONVERSION FACTORS

INERTIA

slug-ft² x 4600	=	lb-in²
lb-ft² x 144	=	lb-in²
oz-in² x 0.0625	=	lb-in²
lb-ft-sec² x 4600	=	lb-in²
lb-ft-sec² x 384	=	lb-in²
oz-in-sec² x 24	=	lb-in²
gm-cm² x 0.000342	=	lb-in²
kp-m-sec² x 33,500	=	lb-in²

METRIC - DECIMAL EQUIVALENTS

1 inch	=	2.54 cm
1 cm	=	0.3937 inch
1 pond (gm)	=	0.03527 oz
1 oz	=	28.35 pond (gm)
1 kp)kg)	=	2.205 pound
1 gm-cm	=	0.0139 oz-in
1 kg-cm	=	1 kp-cm = 13.9 oz-in
1 hp	=	746 watts

16.2 SELECTING DC STEPPER MOTORS-INCH UNITS

The following information will serve to amplify the application data given previously.

1) The torque required to accelerate a mass rotationally is found from the fundamental relationship that Torque = moment of inertia times angular acceleration $T = I_o \alpha$.

This is a relation based on the rotational mass. Gravitational units, such as pound-inches squared, must be converted into mass units by applying the gravitational constant. This constant is 32.2 feet per second squared, which has been rounded to 32 feet per second squared for our use. As an illustration, assume an inertia of 9.2 lb-in².

9.2 x 16 = 147.2 oz-in²
Gravitational constant (g) = 32 ft per sec²
g = 32 x 12 = 384 in. per sec²
The moment of inertia in mass units and in compatible units, therefore, is:

$$I_o (\text{oz-in sec}^2) = \frac{I_o (\text{lb-in}^2) \times 16}{g (\text{in/sec}^2)}$$

$$= I_o (\text{lb-in}^2) \times \frac{16}{384}$$

$$= I_o (\text{lb-in}^2) \times \frac{1}{24}$$

$$9.2 \text{ lb-in}^2 = 9.2 \times \frac{1}{24} \text{ oz-in-sec}^2 = 0.383 \text{ oz-in-sec}^2$$

radians, or one radian = 57.3 degrees (approximately). Acceleration is the change of velocity per unit of time. In the rotational case being considered, velocity is expressed in radians per second and is denoted by ω (omega). The angular velocity for a stepper motor is therefore equal to the stepping rate (steps per second) times the step angle in radians

$$\text{Step angle (radians)} = \text{step angle (degrees)} \times \frac{2\pi}{360}$$

Assume a 200 step per revolution (1.8° per step) motor running at 1000 steps per second.

$$\omega = 1000 \times 1.8 \times \frac{2\pi}{360}$$

$$= 31.42 \text{ radians per second}$$

The angular acceleration, α is the rate of change of angular velocity per unit of time (seconds). If the change is from zero speed, or velocity, the angular acceleration is the final angular velocity (ω_2) divided by the time taken to reach that velocity.

Assume the above motor reaches the speed of 1000 steps per second in 0.5 second. The angular velocity is:

$$\alpha = \frac{\omega_2}{t} = \frac{31.42}{0.5} = 62.84 \text{ rad. per sec}^2$$

If the change of velocity is from a first speed (ω_1) to a second speed (ω_2), the acceleration is:

$$\alpha = \frac{\omega_2 - \omega_1}{t}$$

To obtain the acceleration torque in oz-in, the inertia must be expressed in oz-in-sec² and the acceleration in radians/sec².

3) To accelerate an inertia of 9.2 lb-in² to 1000 steps per second in 0.5 second requires what torque?

$$T = I_o \text{ (oz-in-sec}^2) \times \text{ (rad/sec}^2)$$
$$= 0.383 \times 62.84$$
$$= 24.1 \text{ oz-in}$$

4) For 1.8° per step (200 step per revolution) motors, this may be restated as:

$$T \text{ (oz-in)} = I_o \text{ (lb-in}^2) \times \frac{\text{change in speed (steps per second)}}{\text{time for change (seconds)}} \times \frac{1.8 \times \pi}{24 \times 360}$$

$$= I_o \times \frac{\Delta s}{\Delta t} \times 1.31 \times 10^{-3}$$

16.3 SELECTING DC STEPPER MOTORS - METRIC UNITS

1) The torque required to accelerate a mass rotationally is found from the fundamental relationship that Torque = moment of inertia times angular acceleration: $T = I_o \alpha$

This is a relationship based on the rotational mass. Gravitational units, such as kg-cm squared, must be converted into mass units by applying the gravitational constant. This constant is 981 cm/sec squared, which has been rounded off to 980 cm/second squared for our use. As an example, assume an inertia of 26.9 kg-cm².

Gravitational constant is 980 cm/sec².

The moment of inertia in mass units and in compatible units, therefore, is:

$$I_o \text{ (kg-cm-sec}^2) = \frac{I_o \text{ (kg-cm}^2)}{g \text{ (cm/sec}^2)}$$

$$= I \text{ (kg-cm}^2) \times \frac{1}{980}$$

$$26.9 \text{ kg-cm}^2 \times \frac{1}{980} = 0.027 \text{ kg-cm-sec}^2$$

2) Angular acceleration alpha (α) in the expression $T = I_o \alpha$ is in units of radians per second squared.

A circle (360°) contains 2 pi radians: 360° = 2π radians, or one radian = 57.3 degrees (approximately). Acceleration is the change of velocity per unit of time. In the rotational case being considered, velocity is expressed in radians per second and is denoted by ω (omega). The angular velocity for a stepper motor is therefore equal to the stepping rate (in steps per second) times the step angle (in radians).

$$\text{Step Angle (radians)} = \text{step angle (degrees)} \times \frac{2\pi}{360}$$

Assume a 200 step per revolution (1.8° step angle) motor running at 1000 steps per second.

$$\omega = 1000 \times 1.8 \times \frac{2\pi}{360}$$

$$= 31.42 \text{ radians per second}$$

The angular acceleration (α) is the change of velocity per unit of time (seconds). If the change is from zero speed or velocity, the angular acceleration is the angular velocity (ω_2) divided by the time taken to reach that velocity.

Assume the above motor reaches the speed of 1000 steps per second in 0.5 second. The angular velocity is: $\omega_2 = 31.42$ radians per second.

$$\alpha = \frac{\omega_2}{t} = \frac{31.42}{0.5} = 62.84 \text{ radians per second}^2$$

acceleration is:

$$\alpha = \frac{\omega_2 - \omega_2}{t}$$

To obtain the acceleration torque in kg-cm, the inertia must be in kg-cm-sec².

3) What torque is required to accelerate an inertia of 26.9 kg-cm² to 1000 steps per second in 0.5 second?

$$T = I_o\ (\text{kg-cm-sec}^2) \times \text{rad/sec}^2$$

$$= 0.027 \times 62.84$$

$$= 1.7 \text{ kg-cm}$$

4) For 1.8° per step (200 steps per revolution) motors, this may be restated as:

$$T\ (\text{kg-cm}^2) = I_o \times \frac{\text{change in speed (steps/sec)}}{\text{time for change (seconds)}} \times \frac{1}{980} \times \frac{1.8 \times 2\pi}{360}$$

$$= I_o\ (\text{kg-cm}^2) \times \frac{\Delta s}{\Delta t} \times 3.2 \times 10^{-5}$$

$$T = 26.9 \times \frac{1000}{0.5} \times 3.2 \times 10^{-5}$$

$$= 1.72 \text{ kg-cm}$$

17.0 APPLICATIONS

The applications for SLO-SYN Stepper Motors are virtually unlimited. Listed here are some typical applications where reliability, repeatability and controllability are most important.

APPLICATION	USE
Computer Peripherals	
Floppy Disc	position magnetic pickup
Printer	carriage drive
Printer	rotate character wheel
Printer	paper feed
Printer	ribbon wind/rewind
Printer	position matrix print head
Tape Reader	index tape
Plotter	X-Y-Z positioning
Plotter	paper feed

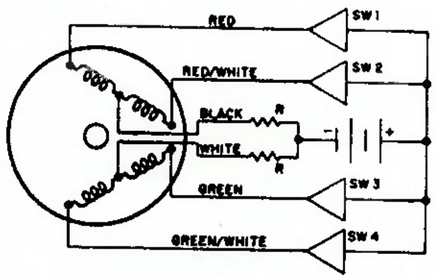
APPLICATION	USE
Business Machines	
Card Reader	position cards
Copy Machine	paper feed
Banking Systems	credit card positioning
Banking Systems	paper feed
Typewriters (automatic)	head positioning
Typewriters (automatic)	paper feed
Copy Machine	lens positioning
Card Sorter	route card flow
Process Control	
Carburetor Adjusting	air-fuel mixture adjust
Valve Control	fluid gas metering
Conveyor	main drive
In-Process Gaging	parts positioning
Assembly Lines	parts positioning
Silicon Processing	I. C. wafer slicing
I. C. Bonding	chip positioning
Laser Trimming	X-Y positioning
Liquid Gasket Dispensing	valve cover positioning
Mail Handling Systems	feeding and positioning letters
Machine Tool	
Milling Machines	X-Y-Z table positioning
Drilling Machines	X-Y table positioning
Grinding Machines	downfeed grinding wheel
Grinding Machines	automatic wheel dressing
Electron Beam Welder	X-Y-Z positioning
Laser Cutting	X-Y-Z positioning
Lathes	X-Y positioning
Sewing	X-Y table positioning
Graphics	
Printing Presses	roller drive
Printing Presses	ink pump
Phototypesetting Equipment	rotate character wheel and paper feed
Film Processing	index film frame-by-frame
Animation Cameras	control focus, fade, dissolve, etc.
Microfilm Systems	position film
Microfilm Systems	automatic focus
Medical	
I. V. Pump	control drip plate
X-Ray Equipment	scanning head positioning
X-Ray Equipment	position patient
Blood Analyzer	test tube positioning
Radiation Therapy	scanning head positioning

controls the motor.

The "drive" determines the performance characteristics of a given motor. Parameters such as speed , time for a single step, holding torque and settling time cab be controlled by the electronic drive.

18.1 L/R UNIPOLAR DRIVES

This is the simplest form of stepper motor control. It has a single-ended power supply, winding sequence logic, and series resistance between drive and motor, and provides good performance to 2000 steps per second. Other advantages include high reliability and low cost.



L/R Unipolar Drive
FIGURE 11

18.2 L/R BIPOLAR DRIVES

This type of drive requires two power supplies of equal current capability. They provide good intermediate speed performance (2k to 5k sps). They energize all windings simultaneously to achieve a 30% to 40% increase over unipolar L/R drives in low speed torque. An L/R bipolar drive requires a four-lead or an eight-lead stepper motor.

18.3 TWO LEVEL DRIVES

These drives utilize two power supplies to achieve fast current rise to initiate the step and to sustain the current during the entire move. They are well suited for applications requiring short, fast moves and provide good intermediate speed performance.

18.4 REACTIVE DRIVES

A reactive drive uses a choke on the input of the power supply. This allows voltage to increase as the stepping rate is increased. No series resistor is required. This type of drive provides good overall performance. It is more expensive than an L/R drive, but is more efficient.

18.5 CHOPPER DRIVES

This is a more complex drive that "chops" the current to achieve current limiting. High voltage that can be many time the rated voltage of the motor can be applied. These drives provide good overall performance and fast response, but are expensive.

19.0 TRANSLATORS

SLO-SYN Translators serve as the interface between a pulse source and the stepper motor. They contain the logic necessary to convert, or "translate" digital information into motor shaft rotation. The motor will move one step for each pulse received by the Translator.

The pulse source supplies the desired number of pulses at the specified or programmed rate, which provides the distance and speed information. Figure 12 shows this concept.

TRANSLATOR DRIVE SYSTEM
FIGURE 12

Some Translators can operate in an eight-step switching sequence (half-stepping). When this mode is used, one pulse input will cause the motor shaft to rotate one-half its normal distance. A 1.8° step angle motor will operate in steps of 0.9° in the half-step mode.

SLO-SYN Translators are available in both modular and packaged models in a wide range of power ratings. Modular models require an external power supply. Packaged versions are self-contained and have internal power supplies.

SLO-SYN Translator/Oscillators are also offered. Essentially, a Translator/Oscillator is a Translator with the addition of a built-in oscillator which may be used to provide the pulse and direction signals.

20.0 INDEXERS

A SLO-SYN Indexer is a complete stepper motor control package which provides control of:

- Speed (steps per second)
- Distance (number of steps per move)
- Direction (CW or CCW)

Both Preset Indexer and Programmable Indexer models are available. A SLO-SYN Preset Indexer is intended for control of simple, repetitive operations. It is used where an operation can be directed using a single line of data.

A SLO-SYN Programmable Indexer can store up to 400 lines of program information. They are designed for simplicity of programming and operation. Both modular and packaged models are offered.

Follow the procedure below to select the correct motor and drive combination for your application.

A. Select the step angle which will provide the desired linear resolution.
B. Select the type of drive - Translator, Translator/Oscillator, Preset Indexer or Programmable Indexer.
C. Select the specific drive that provides the speed range required.
D. Consult the literature which gives torque vs. speed curves for the selected drive used with appropriate motors.
E. Select the motor which provides the necessary step angle and torque at the required step rate.

EXAMPLE

An X-Y table must be positioned at a rate of 255 inches per minute (4.25 inches per second). The table is positioned by a 5-pitch ball nut lead screw. Linear resolution of 0.001 inch per motor step is required. The required torque is 51 ounce-inches, including the torque needed to accelerate the inertia. It is desired to have the motor drive the table a preselected distance each time a "Start" command is given.

Solution

A. Select the required motor step angle needed to achieve the correct linear resolution. In this case, a 1.8°, 200 step per revolution stepper will provide the desired 0.001 inch linear motion per motor step when operating a 5-pitch (five revolutions = 1 inch linear motion) lead screw.
B. Counting capability with the ability to store a single line of program information is needed. Therefore, a Preset Indexer should be selected.
C. The required speed is 4250 steps per second (5-pitch lead screw, 1000 steps= 1" linear motion; 4.25 inches/sec required = 4250 steps per second).
D. Consult the torque vs. speed curves in the SLO-SYN Motion Control catalog and select a Motor/Indexer combination that drive the load at the required step rate.

DISTRIBUTION COAST-TO-COAST AND INTERNATIONAL

Superior Electric products are available nationwide through an extensive authorized distributor network. These distributors offer literature, technical assistance and a wide range of models off the shelf for fastest possible delivery and service.

In addition, Superior Electric sales engineers and manufacturers' representatives are conveniently located to provide prompt attention to customers' needs. Call the nearest office listed for ordering and application information or for the address of the closest authorized distributor.

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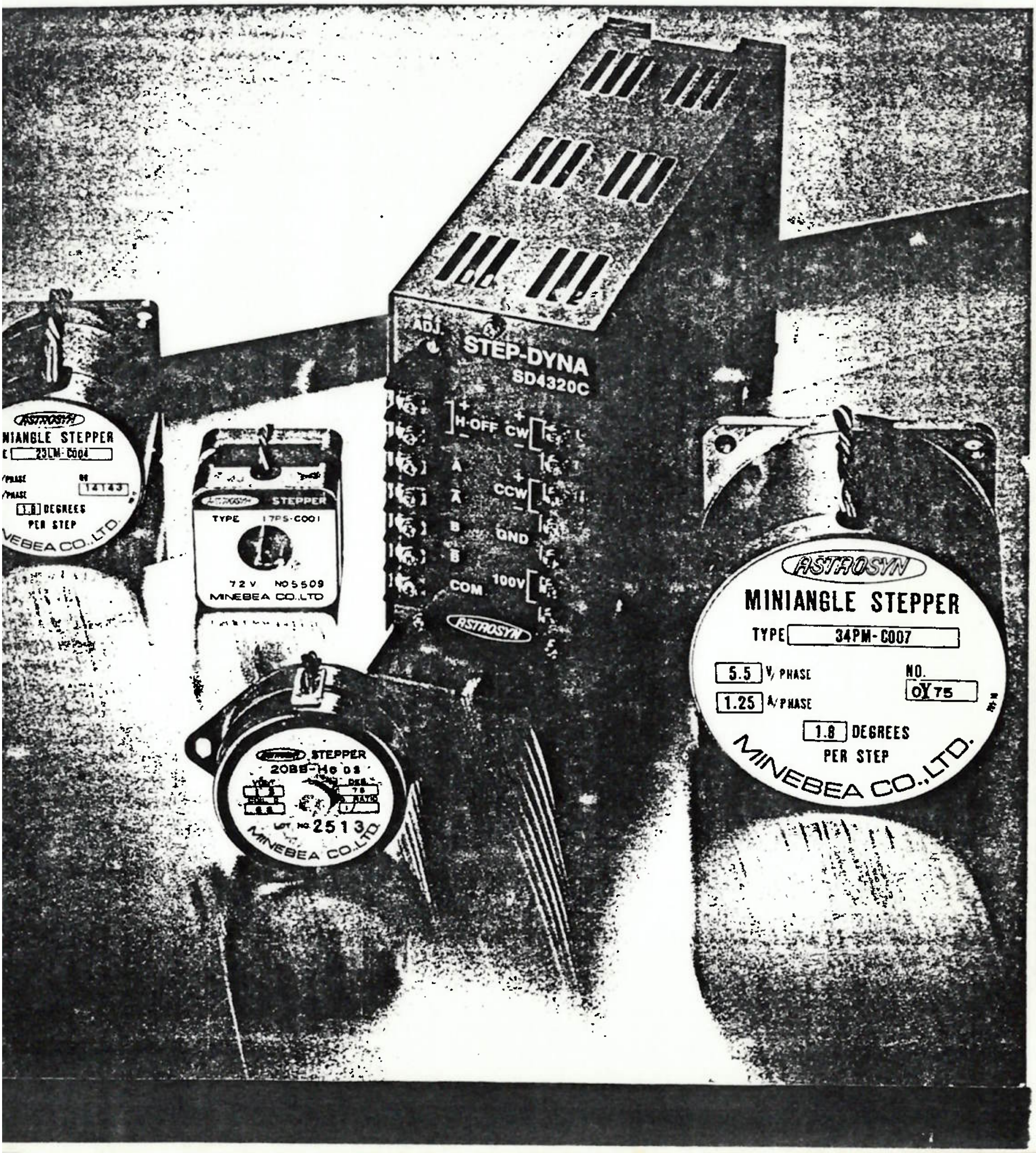
NMB
MINEBEA CO.,LTD.

NMB NHBB
NEW HAMPSHIRE BALL BEARINGS, INC.
9730 INDEPENDENCE AVENUE • CHATSWORTH, CA 91311
(818) 341 0820 • TWX 910 338 2171 • FAX

Stepping Motor

ASTROSYN

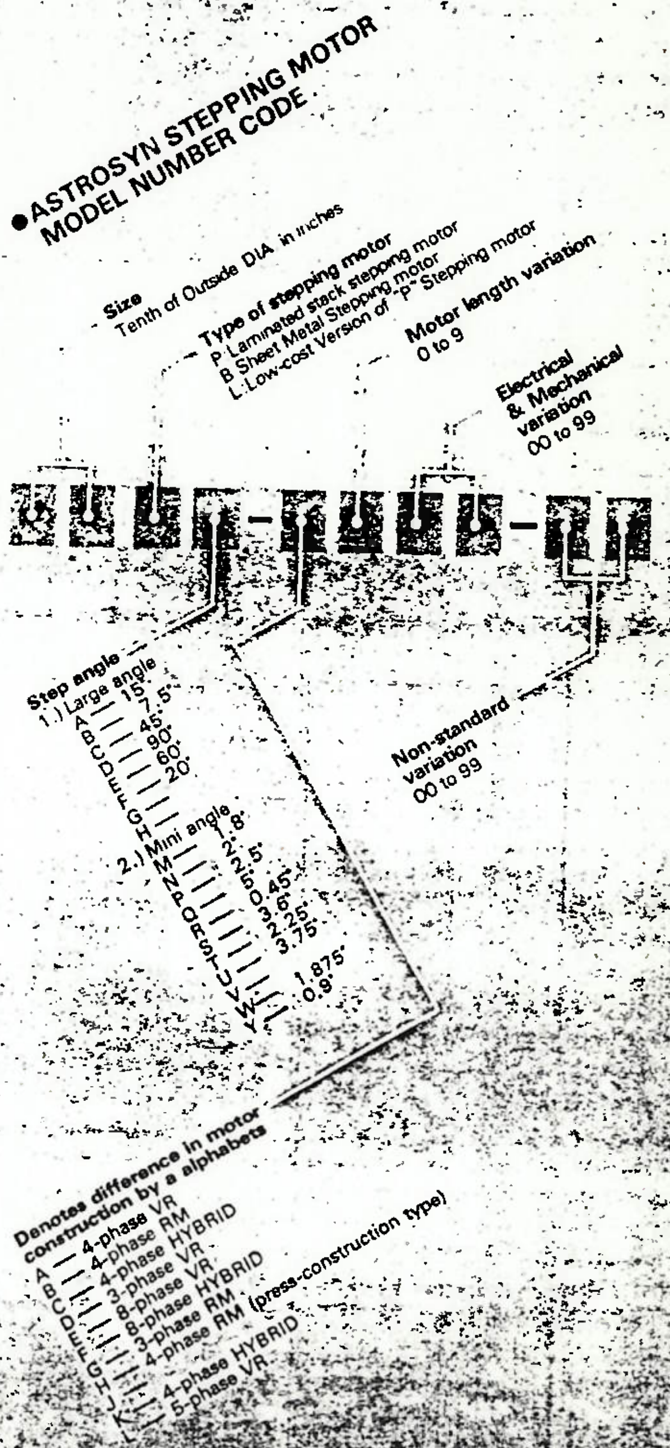


Stepping Motor

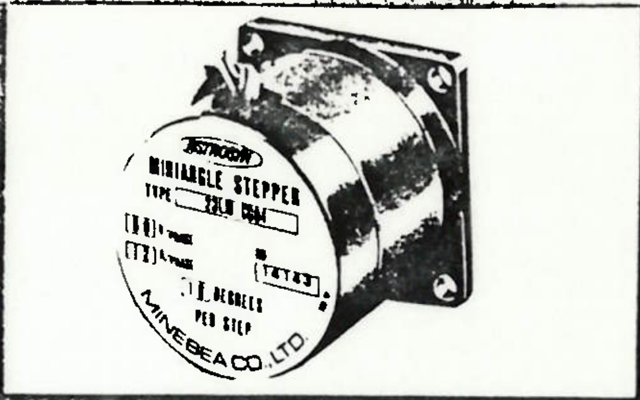
NMB/ASTROSYN is [illegible] of the wo[illegible] design and manufacturing of precision [illegible]cal devices.

Astrosyn stepping Motors are manufactured under very stringent quality control to insure long life and high reliability so that suitable to applicable such as computer peripheral equipment and numerical control machine. Astrosyn Stepping Motor is the broadest in the industry. Our range of standard motors offers a wide choice of sizes and of performance characteristics thus enabling an easy selection of a suitable motor for any specific application.

Astrosyn offers various Stepping Motor Drivers and also Custom made microprocessor controllers.

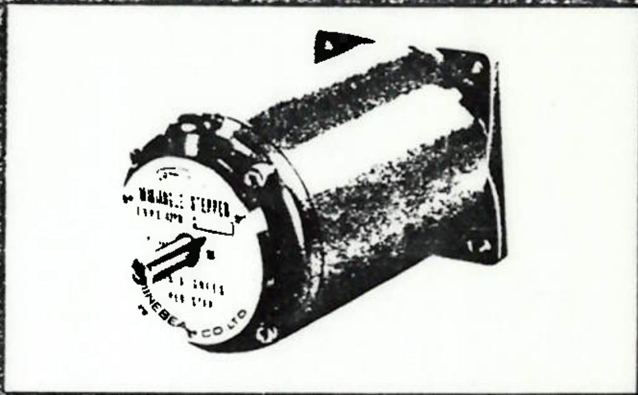


23LM-C0XX
SERIES



34PM-C00X
SERIES

42PM-C0XX/C1XX/C2XX/C3XX
SERIES



23BB-H00X/H05X
SERIES

fig.1 17PS-C0XX SERIES

Unit mm

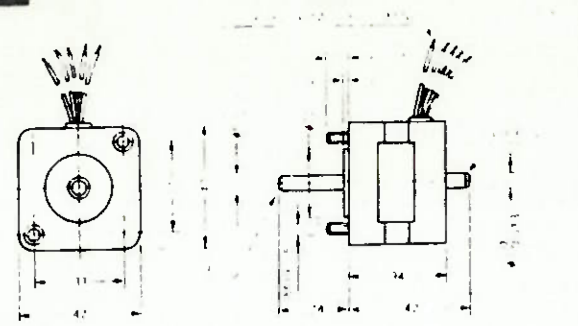


fig.4 34PM- SERIES

Unit mm

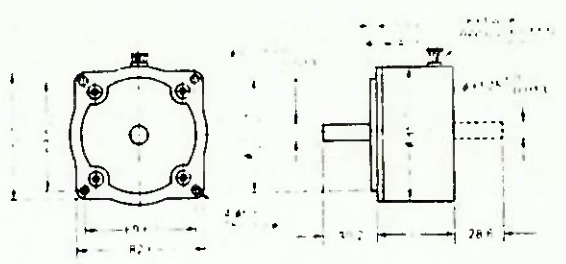


fig.2 23LM-SERIES

Unit mm

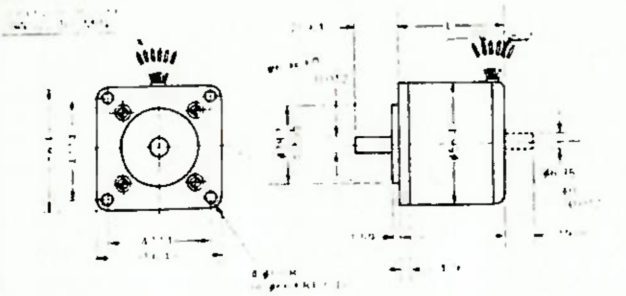


fig.5 42PM-C01X

Unit mm

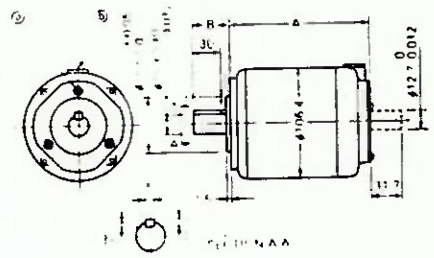


fig.3 23PM-SERIES

Unit mm

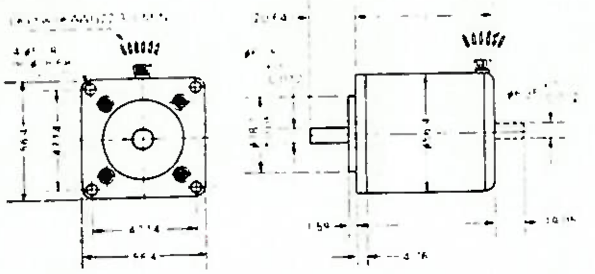


fig.6 42PMC02X/C1XX/C2XX

Unit:mm

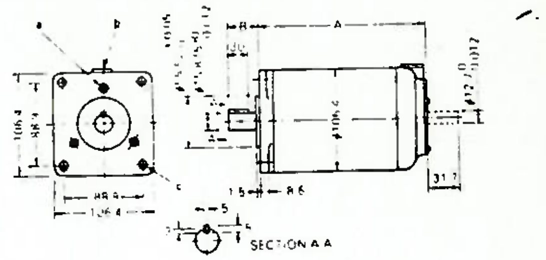


fig.7 17BA-H05X 17BB-H05X

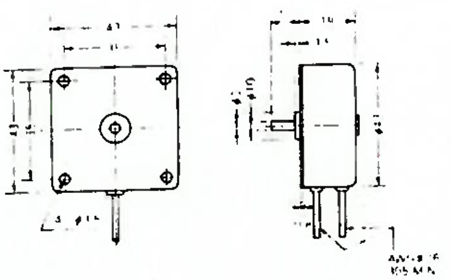


fig.8 20BB-H00X

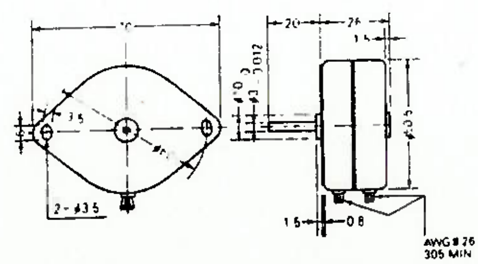


fig.2

23LM SERIES

SERIES	"L"
▲ C00X	57.15
C30X	50.8
A00X	57.15
A20X	41.3

fig.3

23PM SERIES
23RM SERIES
23PR SERIES
23PQ SERIES

SERIES	"L"
C10X	80.66
C20X PR-E20X	41.3
→ C40X	82.6
C50X	101.6
C60X	33.0
RM-C00X PR-E00X PQ-C00X	57.15

fig.4

34PM SERIES
34RM SERIES
34PR SERIES
34PN SERIES

SERIES	"L"
C00X RM-C00X PR-F00X PN-C00X	61.91
C10X	93.66
C20X	134.94

fig.5

ⓐ M6 TAPPED HOLE 3 PLACES 10 DEEP EQUALLY SPACED ON ϕ76.2

ⓑ GROMMET ID : ϕ14.2

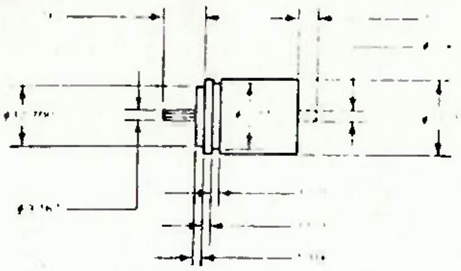
fig.6

ⓐ M6 TAPPED HOLE 3 PLACES 10 DEEP EQUALLY SPACED ON ϕ76.2

ⓑ GROMMET ID : ϕ14.2

fig.9 PRECISION SMALL-SIZED 08PA SERIES

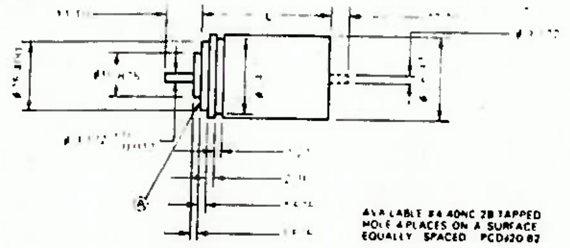
Unit mm



Pinion data O.D. 3.167 $^{+0}_{-0.012}$ D.P. 120
Teeth 13 Pressure angle 20
Pitch dia 2.751 Accuracy AGMA 12C

fig.10 PRECISION SMALL-SIZED 11PX SERIES

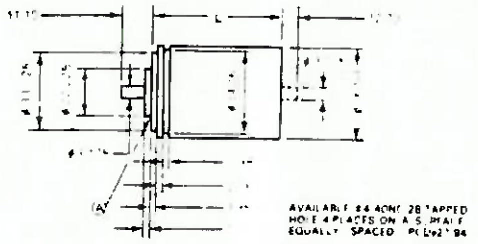
Unit mm



Front shaft will be machined with the following specification on request
Pinion 13T D.P. 120 Pressure angle 20
and Accuracy AGMA 12C

fig.11 PRECISION SMALL-SIZED 15PX SERIES.

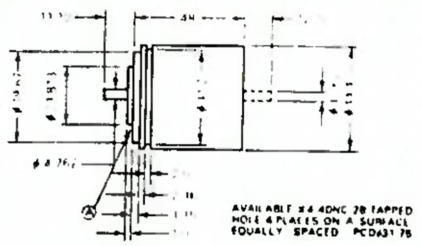
Unit mm



Front shaft will be machined with the following specification on request
Pinion 10T D.P. 96 Pressure angle 20
and Accuracy AGMA 12C

fig.12 PRECISION SMALL-SIZED 18PX SERIES.

Unit mm



Front shaft will be machined with the following specification on request
Pinion 15T. D.P. 96 Pressure angle 20°
and Accuracy AGMA 12C

fig.13 PRECISION SMALL-SIZED 20PX SERIES.

Unit mm

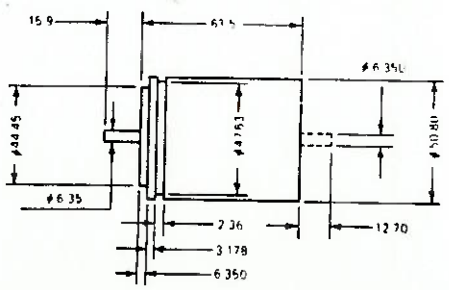


fig.14 23BB H00X H05X SERIES

Unit mm

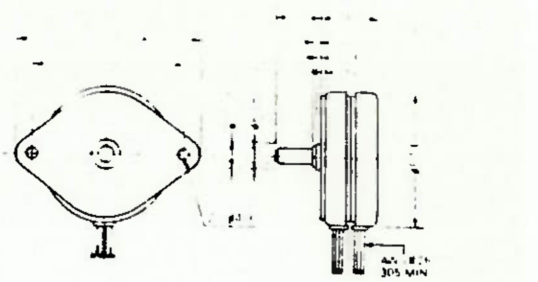
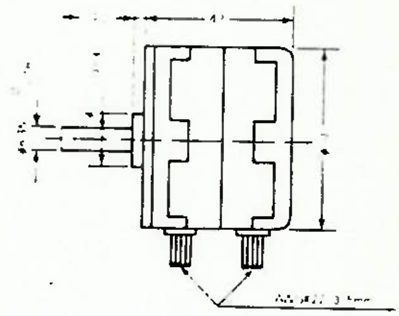


fig.15 28BB-HIXX SERIES

Unit mm



NMB Standard Lead Wire Color Code

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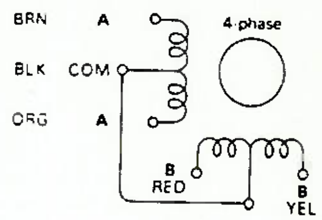

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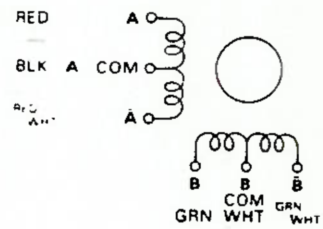

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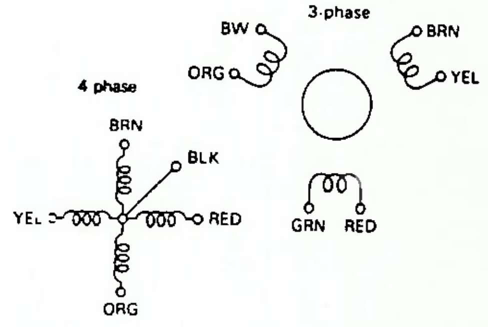
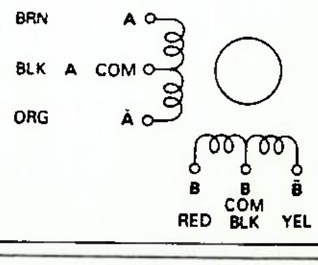


Sheet Metal Type



Type No. Single shaft	Double shaft	Step angle (deg/step)	Holding torque (kg·cm)	Detent torque (g·cm REF)	Rated voltage (V)	Rated current per phase (A)	Winding resistance per phase (Ω)
17PS-C031	-C032	3.6 NOTE 1	0.76	—	6	0.67	9
17PS-C033	-C034	3.6 ″	0.76	—	9	0.5	18
17PS-C035	-C036	3.6 ″	0.76	—	12	0.32	38
17PS-C037	-C038	3.6 ″	0.76	—	12	0.16	75
7PM-C021	-C022	1.8 ″	0.60	—	6	0.67	9
7PM-C033	-C034	1.8 ″	0.60	—	9	0.5	18
7PM-C035	-C036	1.8 ″	0.60	—	12	0.32	38
7PM-C037	-C038	1.8 ″	0.504	—	12	0.16	75
3LM-C033	-C034	1.8 ″	5.0	360	1.5	4.8	0.31
3LM-C035	-C036	1.8 ″	5.0	360	3	2.4	1.25
3LM-C004	-C001	1.8 ″	5.0	360	6	1.2	5
3LM-C005	-C002	1.8 ″	5.0	360	12	0.6	20
3LM-C006	-C003	1.8 ″	5.0	360	24	0.3	80
3LM-C302	-C301	1.8 ″	4.0	360	1.3	3.9	0.33
3LM-C307	-C038	1.8 ″	4.0	360	3	1.7	1.8
3LM-C309	—	1.8 ″	4.0	360	6	0.85	7.1
3LM-C315	—	1.8 ″	4.0	360	24	0.21	114
3PM-C108	-C109	1.8 ″	6.0	400	5.4	1.5	3.6
3PM-C202	-C201	1.8 ″	2.5	—	4.0	1.1	3.5
3PM-C228	-C229	1.8 ″	2.5	—	6.0	0.75	8
3PM-C226	-C227	1.8 ″	2.5	—	12.0	0.38	32
3PM-C401	-C402	1.8 ″	8.0	580	1.7	4.7	0.37
3PM-C406	-C407	1.8 ″	8.0	580	4.3	1.9	2.2
3PM-C501	-C502	1.8 ″	10.8	700	2.2	4.6	0.48
3PM-C503	-C504	1.8 ″	10.8	700	3.4	2.9	1.16
3PM-C603	—	1.8 ″	0.98	—	4	0.8	5
3PM-C602	—	1.8 ″	0.98	—	12	0.16	75
3LM-A003	-A004	1.8 ″	4.0	—	6	1.0	5.8
3LM-A202	-A021	1.8 ″	2.3	—	4	1.1	3.5
3LM-A203	—	1.8 ″	2.3	—	2	2.3	0.88
3LM-A206	—	1.8 ″	1.6	—	12	0.22	53
3LM-A220	—	1.8 ″	2.3	—	6	0.75	8
PM-C049	-C050	1.8 ″	10.0	600	1.7	4.7	0.36
PM-C006	-C001	1.8 ″	10.0	600	2.0	3.6	0.55
PM-C041	-C051	1.8 ″	10.0	600	2.6	3.1	0.85
PM-C007	-C002	1.8 ″	10.0	600	5.5	1.25	4.4
PM-C052	-C053	1.8 ″	10.0	600	5.6	1.6	3.5
PM-C008	-C003	1.8 ″	10.0	600	8.0	0.9	8.9
PM-C009	-C004	1.8 ″	10.0	600	14.0	0.7	20
PM-C110	-C111	1.8 ″	20.0	700	2.5	4.6	0.55
PM-C101	-C102	1.8 ″	20.0	700	3	4	0.75
PM-C108	-C109	1.8 ″	20.0	700	12	1	12

NOTE 1 STEP ACCURACY ±5% FOR STANDARD MOTOR
AVAILABLE ±3% FOR SPECIAL REQUIREMENT

Inductance per phase (mH)	Rotor inertia ($g \cdot cm^2$)	Weight (g)	Fig	Type No. Single shaft	Double shaft
5.6	17	200	1	17PS-C031	-C032
13	17	200	1	17PS-C033	-C034
22	17	200	1	17PS-C035	-C036
41	17	200	1	17PS-C037	-C038
5.6	17	200	1	17PM-C021	-C022
13	17	200	1	17PM-C033	-C034
23	17	200	1	17PM-C035	-C036
46	17	200	1	17PM-0C37	-C038
1	160	600	2	23LM-C033	-C034
3.5	160	600	2	23LM-C035	-C036
14	160	600	2	23LM-C004	-C001
56	160	600	2	23LM-C005	-C002
230	160	600	2	23LM-C006	-C003
0.63	110	510	2	23LM-C302	-C301
3.3	110	510	2	23LM-C307	-C308
13	110	510	2	23LM-C309	
190	110	510	2	23LM-C315	
9.0	200	930	3	23PM-C108	-C109
5	55	360	3	23PM-C202	-C201
10	55	360	3	23PM-C228	-C229
40	55	360	3	23PM-C226	-C227
0.8	200	930	3	23PM-C401	-C402
6.4	200	930	3	23PM-C406	-C407
1.2	320	1250	3	23PM-C501	-C502
2.9	320	1250	3	23PM-C503	-C504
—	52	330	3	23PM-C603	
—	52	330	3	23PM-C602	
—	90	530	2	23PM-A003	-A004
—	55	350	2	23LM-A202	-A201
—	55	350	2	23LM-A203	
—	55	350	2	23LM-A206	
—	55	350	2	23LM-A220	
1.65	560	1400	4	34PM-C049	-C050
1.7	560	1400	4	34PM-C006	-C051
4.12	560	1400	4	34PM-C041	-C051
18	560	1400	4	34PM-C007	-C002
—	560	1400	4	34PM-C052	-C053
2.9	560	1400	4	34PM-C008	-C004
70	560	1400	4	34PM-C009	-C004
2.76	1100	2400	4	34PM-C110	-C111
3.5	1100	2400	4	34PM-C101	-C102
56	1100	2400	4	34PM-C108	-C109

Type No. Single shaft	Double shaft	Step angle (deg/step)		Holding torque (kg·cm)	Detent torque (g cm REF)	Rated voltage (V)	Rated current per phase (A)	Winding resistance per phase (Ω)
34PM-C213	-C214	1.8	NOTE 1	30.0	800	2	7	0.29
34PM-C211	-C212	1.8	〃	30 0	800	2.26	5.5	0.48
34PM-C201	-C202	1.8	〃	30.0	800	5	4.4	1.13
34PM-C206	-C205	1.8	〃	30.0	800	5	4.4	1.13
34PM-C209	-C208	1.8	〃	30.0	800	12	1.8	6.54
42PM-C102	-C013	1.8	〃	45.0	5000	2.3	6.2	0.37
42PM-C013	-C015	1.8	〃	45.0	5000	4.6	3.1	1.2
42PM-C022	-C023	1.8	〃	45.0	5000	3.6	4.0	0.9
42PM-C024	-C025	1.8	〃	45.0	5000	2.3	6.2	0.37
42PM-C026	-C027	1.8	〃	45.0	5000	7.0	1.5	4.6
42PM-C101	-C102	1.8	〃	81.0	11000	3.6	6.1	0.6
42PM-C103	-C104	1.8	〃	81.0	11000	1.8	12.7	0.14
42PM-C109	-C108	1.8	〃	81.0	11000	12.0	1.5	7.7
42PM-C201	-C202	1.8	〃	150.0	11000	4.3	6.1	0.7
42PM-C203	-C204	1.8	〃	150.0	11000	2.2	12.7	0.17
42PM-C301	—	1.8	〃	200.0	15000	7.0	10.0	0.7
42PM-C303	—	1.8	〃	200.0	15000	3.4	20.0	0.17
23PR-E001	—	0.45	〃	3.8	—	6.0	0.74, 0.46	8.1, 13.0
23PR-E201	-E202	0.45	〃	1.9	—	2.0	1.41, 0.89	1.42, 2.25
—	34PR-F001	0.45	〃	10.0	600	2.0	2.33, 1.27	0.86, 1.57
34PN-C003	34PN-C002	2.0	〃	7.5	600	5.4	1.7	3.2
23PQ-C001	23PQ-C002	5.0	〃	1.7	150	6.0	1.2	5.0
17BA-H051	—	15.0	NOTE 2	0.280	50	16	0.13	120
17BA-H052	—	15.0	〃	0.280	50	12	0.24	50
7BB-H051	—	7.5	〃	0.380	50	16	0.13	120
7BB-H052	—	7.5	〃	0.380	50	12	0.24	50
0BB-H051	—	7.5	〃	0.400	100	12	0.120	100
0BB-H052	—	7.5	〃	0.400	100	12	0.180	66
0BB-H053	—	7.5	〃	0.400	100	24	0.086	280
3BB-H005	—	7.5	〃	0.900	80	5	0.750	6.6
3BB-H002	—	7.5	〃	0.900	80	12	0.340	36.0
3BB-H003	—	7.5	〃	0.900	80	24	0.200	120.0
3BB-H031	—	7.5	〃	0.900	80	12	0.250	48.0

NOTE 1 STEP ACCURACY ± 5% FOR STANDARD MOTOR
NOTE 2 STEP ACCURACY ± 1 DEG FOR ALL "BA" TYPE
STEP ACCURACY ± 0 5DEG FOR ALL "BB" TYPE

Inductance per phase (mH)	Rotor inertia (g·cm²)	Weight (g)	Fig	Dimension "A"	Dimension "B"	Type No. Single shaft	Double shaft
2	1800	3500	4			34PM-C213	-C214
3.19	1800	3500	4			34PM-C211	-C212
7.5	1800	3500	4			34PM-C201	-C202
6.0	1800	3500	4			34PM-C206	-C205
45	1800	3500	4			34PM-C209	-C208
2.4	4500	3800	5	119.9	31.8	42PM-C012	-C013
8.8	4500	3800	5	119.9	31.8	42PM-C014	-C015
4.5	4500	3800	5	119.9	31.8	42PM-C022	-C023
2.4	4500	3800	5	119.9	31.8	42PM-C024	-C025
3.0	4500	3800	5	119.9	31.8	42PM-C026-	-C027
4.0	8500	6900	5	181.9	35.1	42PM-C101	-C102
1.0	8500	6900	5	181.9	35.1	42PM-C103	-C104
64.0	18500	6900	5	181.9	35.1	42PM-C109	-C108
5.8	13200	10500	5	243.0	35.1	42PM-C201	-C202
1.4	13200	10500	5	243.0	35.1	42PM-C203	-C204
5.8	13200	11000	5	270.0	35.1	42PM-C301	—
1.4	13200	11000	5	270.0	35.1	42PM-C303	—
	90	530	3			23PR-E001	—
	55	360	3			23PR-E201	-E202
	560	1400	4			—	34PR-F001
7.7	560	1400	4			34PN-C003	34PN-C002
9.3	160	590	3			23PQ-C001	23PQ-C002
55	6	100	7			17BA-H051	—
20	6	100	7			17BA-H052	—
55	6	100	7			17BB-H051	—
20	6	100	7		(gear ratio)	17BB-H052	—
70	10	180	8			20BB-H051	—
40	10	180	8			20BB-H052	—
180	10	180	8			20BB-H053	—
5	30	280	14			23BB-H005	—
30	30	280	14			23BB-H002	—
90	30	280	14			23BB-H003	—
40	30	280	14			23BB-H031	—

ype No.		Step angle	Holding torque	Detent torque	Rated voltage	Rated current per phase	Winding resistance per phase
ingle shaft	Double Shaft	(deg/step)	(kg·cm)	(g·cm REF)	(V)	(A)	(Ω)
3BB-H051	—	7.5	1.2	150	5	750	6.6
3BB-H052	—	7.5	1.2	150	12	340	36.0
3BB-H053	—	7.5	1.2	150	24	200	120.0
3BB-H054	—	7.5	1.2	150	12	250	48.0
8BB-H101(−H151)	—	7.5	2.6	350(250)	5	1.4	3.6
8BB-H102(−H152)	—	7.5	2.6	350(250)	14	0.52	27.0

(−H15X) : Ball bearing type

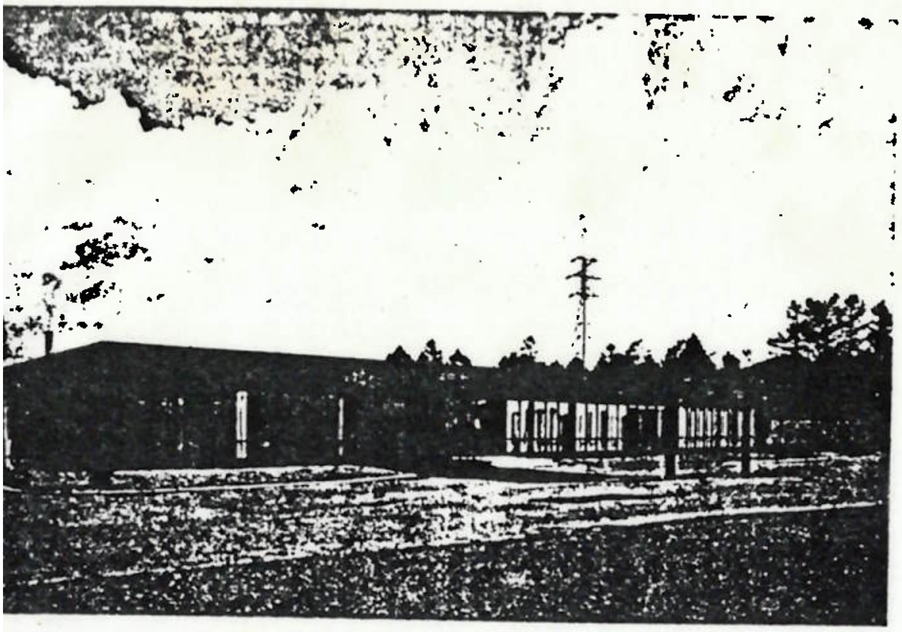
—	08PA-A001-01	15.0	0.048		28	0.28	100
3PA-D001-01	—	15.0	0.050		28	0.46	60
—	11PA-A001	15.0	0.420		28	0.51	55
—	11PA-D001	15.0	0.200		28	0.35	80
—	11PB-A101	7.5	0.160		28	0.25	95
IPD-B001	—	90.0	0.108		28	0.46	60
—	15PA-A001	15.0	0.500		28	0.80	35
—	15PA-D001	15.0	0.36		28	1.75	16
—	15PB-A001	7.5	0.430		28	0.51	55
5PD-B101		90.0	0.760		28	1.40	20
—	18PA-A001	15.0	0.700		28	0.51	55
3PD-B002	—	90.0	0.580		28	1.40	20
3PD-B003	—	90.0	0.280		12	0.32	37
—	20PA-A001	15.0	2.22		28	1.40	20
—	20PA-D001-01	15.0	3.5		28	2.80	10
—	20PA-D004	15.0	2.5		28	1.40	20
—	20PB-A001	7.5	2.0		28	1.40	20
PB-B001	—	90.0	1.15		28	2.30	12
PF-G001	—	120.0	0.7		28	0.86	28

		Synchronous speed (r.p.m.)	Input voltage (V)	Output torque (kg·cm)	Winding resistance (Ω)
RM-A001	—	60/72 (at 50/60Hz)	100/115	7.0	300
RM-A101	—	60/72 (at 50/60Hz)	100/115	9.0	300
RM-A004	—	60/72 (at 50/60Hz)	100/115	2.2	1100
RM-A011	—	200 (at60Hz)	100/115	0.50	1100

Inductanie per phase (mH)	Rotor inertia (g-cm²)	Weight (g)	Fig	Type No. Single shaft	Type No. Double shaft
5	30	280	14	23BB-H051	—
30	30	280	14	23BB-H052	—
90	30	280	14	23BB-H053	—
40	30	280	14	23BB-H054	—
6.2	150	700	15	28BB-H101 (–H151)	—
37.0	150	700	15	28BB-H102 (–H152)	—

Inductanie per phase (mH)	Rotor inertia (g-cm²)	Weight (g)	Fig	Number of winding phases ø	Excitation	Construction	Single shaft	Double shaft
—	0.2	40	9	4	Single	VR	—	08PA-A001-01
—	0.2	40	9	3	〃	VR	08PA-D001-01	—
—	1.0	135	10	4	〃	VR	—	11PA-A001
—	1.0	135	10	3	〃	VR	—	11PA-D001
—	2.2	115	10	4	〃	VR	—	11PB-A101
—	1.2	130	10	4	〃	PM	11PD-B001	—
—	0.7	185	11	4	〃	VR	—	15PA-A001
—	0.6	185	11	3	〃	VR	—	15PA-D001
—	2.2	185	11	4	〃	VR	—	15PB-A001
—	5.0	280	11	4	〃	PM	15PD-B101	—
—	5.0	370	12	4	1-2 phase	VR	—	18PA-A001
—	5.0	370	12	4	Single	PM	18PD-B002	—
—	5.0	370	12	4	1-2 phase	PM	18PD-B003	—
—	10.0	560	13	4	Single	VR	—	20PA-A001
—	10.0	740	13	3	〃	VR	—	20PA-D001-01
—	10.0	560	13	3	〃	VR	—	20PA-D004
—	10.0	560	13	4	〃	VR	—	20PB-A001
—	10.0	560	13	4	〃	PM	20PB-B001	—
—	10.0	560	13	3	〃	PM	20PF-G001	—

	Rotor inertia (g-cm²)	Resistor for phase shift (Ω)		Capacitor for Phase shift (μF AC330V)	Single shaft	Double shaft
—	560	400 (25W)	4	2.25 (50/60Hz)	34RM-A001	—
—	1100	300 (300W)	4	3.75/3.0 (50/60Hz)	34RM-A101	—
—	160	500 (5W)	3	0.75 (50/60Hz)	23RM-A004	—
—	160	500 (5W)	3	0.75 (50/60Hz)	23RM-A011	—



NEBEA CO.,LTD.

OR DIVISION)

FFICE
nko Bldg., No. 7, 3-Chome, Kanda-ogawacho, Chiyoda-ku, Tokyo, Japan
355 PHONE Tokyo03-292-2771

CTORY
4-Chome, Omori-nishi, Ohta-ku, Tokyo, Japan
612 PHONE Tokyo03-766-7631

VA FACTORY
73 Miyota Machi, Kitasaku-gun Nagano-ken, Japan
684 PHONE 02673-2-2200

FFICES

RTERS AND WESTERN REGIONAL OFFICE
pendence Ave. Chatsworth, CA 91311
494-1232 TLX:62-1340 FAX:213-709-0387 PHONE 213-785-2197

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N) CORPORATION
n Kaikan Bldg. 7-18, 3-Chome, Mita, Minato-Ku, Tokyo, Japan
12-2029 FAX:03-454-8935 PHONE:03-455-5011