

PMR2450 - Projeto de Máquinas

Mecatrônica - EPUSP

# Sistema de movimentação de uma máquina CNC

## Controlador, drivers e motores

Julio Cezar Adamowski

agosto/2005

# Controlador CNC

## Modos: manual e automático

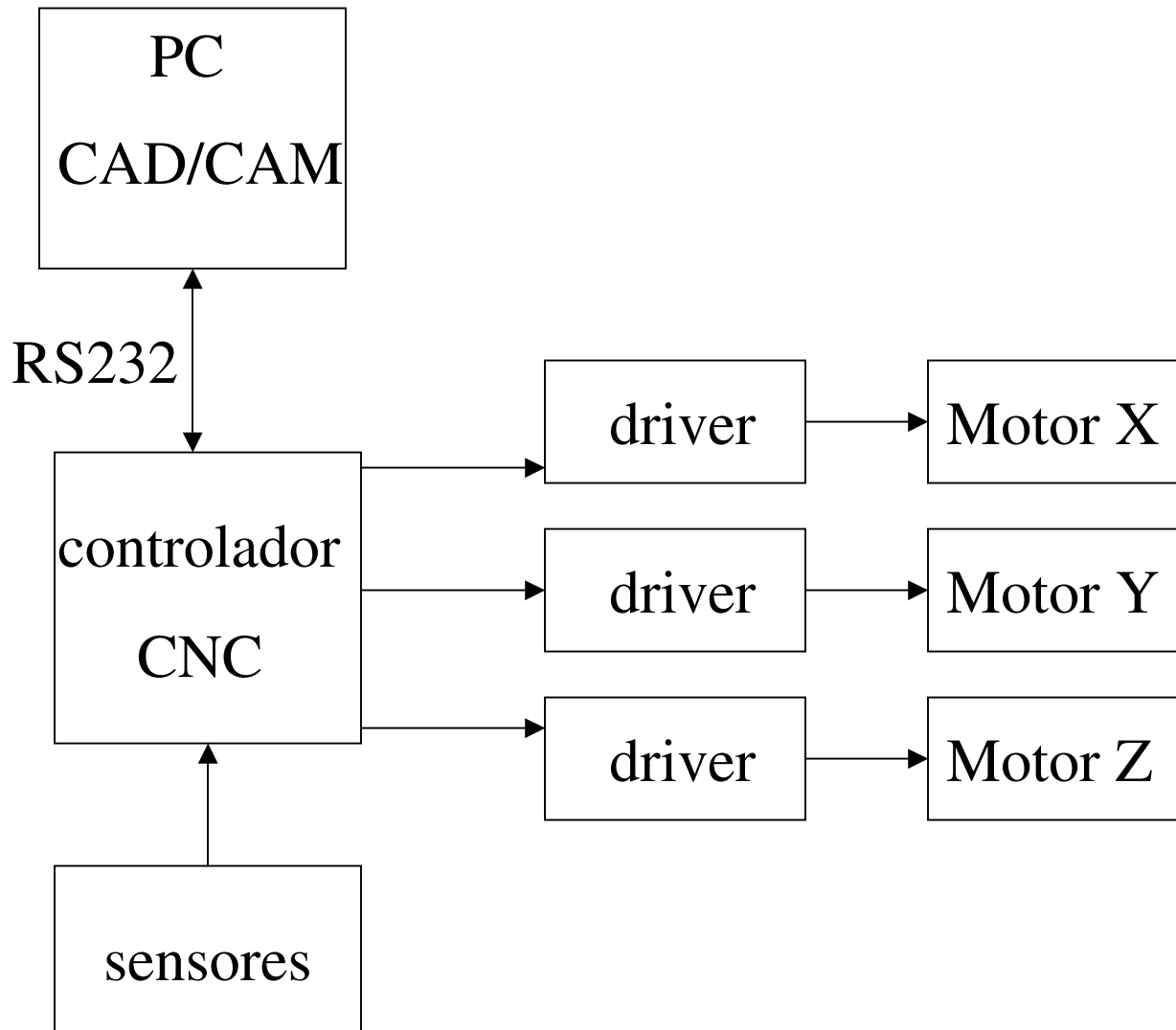
**Manual:** seleciona eixo, define velocidade, movimentação manual do eixo , define zero peça, define velocidade, recebe programa\*, liga/desliga eixo árvore, etc.

**Automático:** seleciona programa, executa programa\*\*.

\* Recebe programa: o controlador se prepara para receber bloco de comandos através da RS232

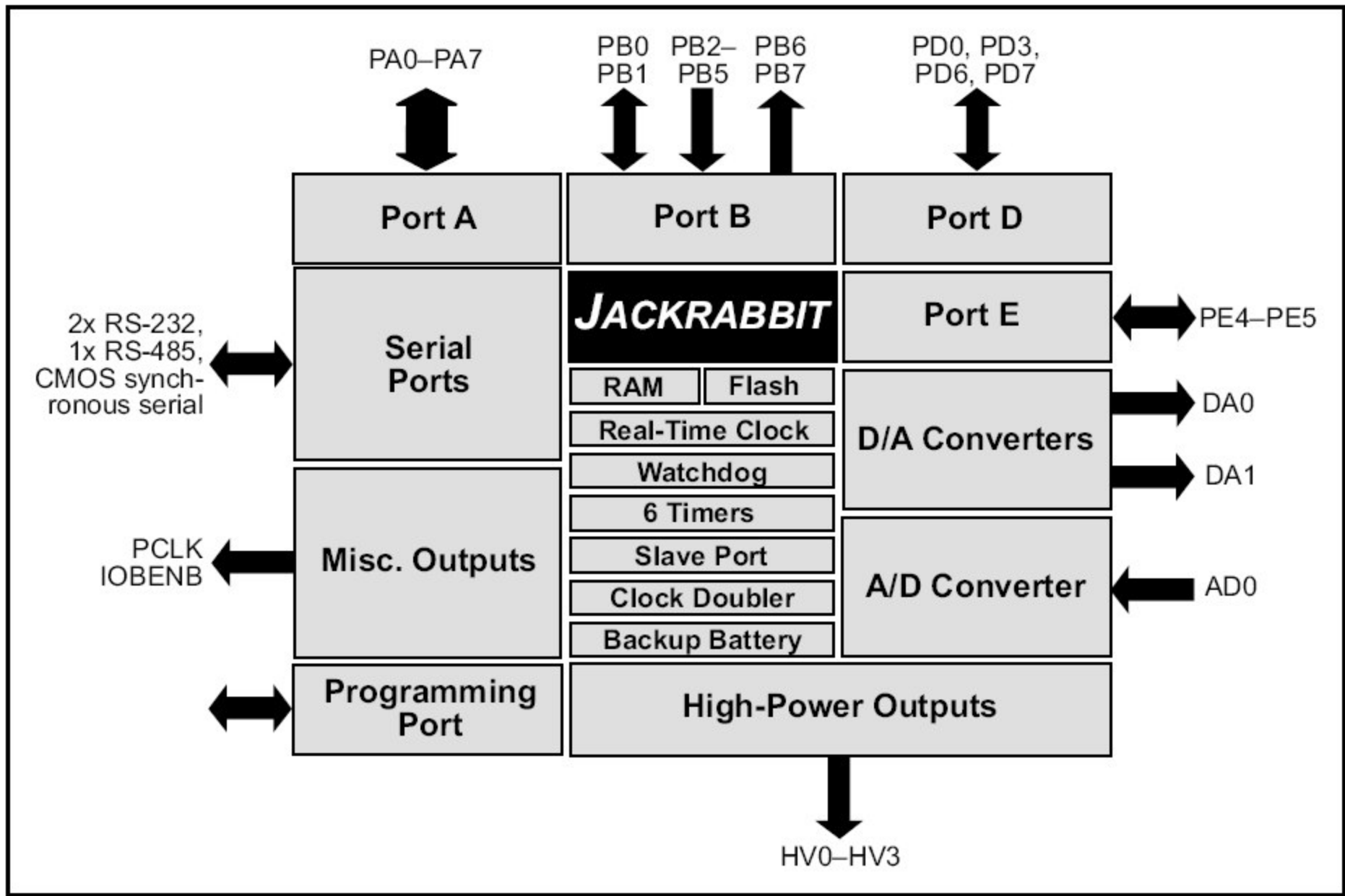
\*\* Execução do programa: interpreta linguagem G, aciona motores de forma sincronizada (interpolações linear, circular)

## Controlador CNC: diagrama de blocos

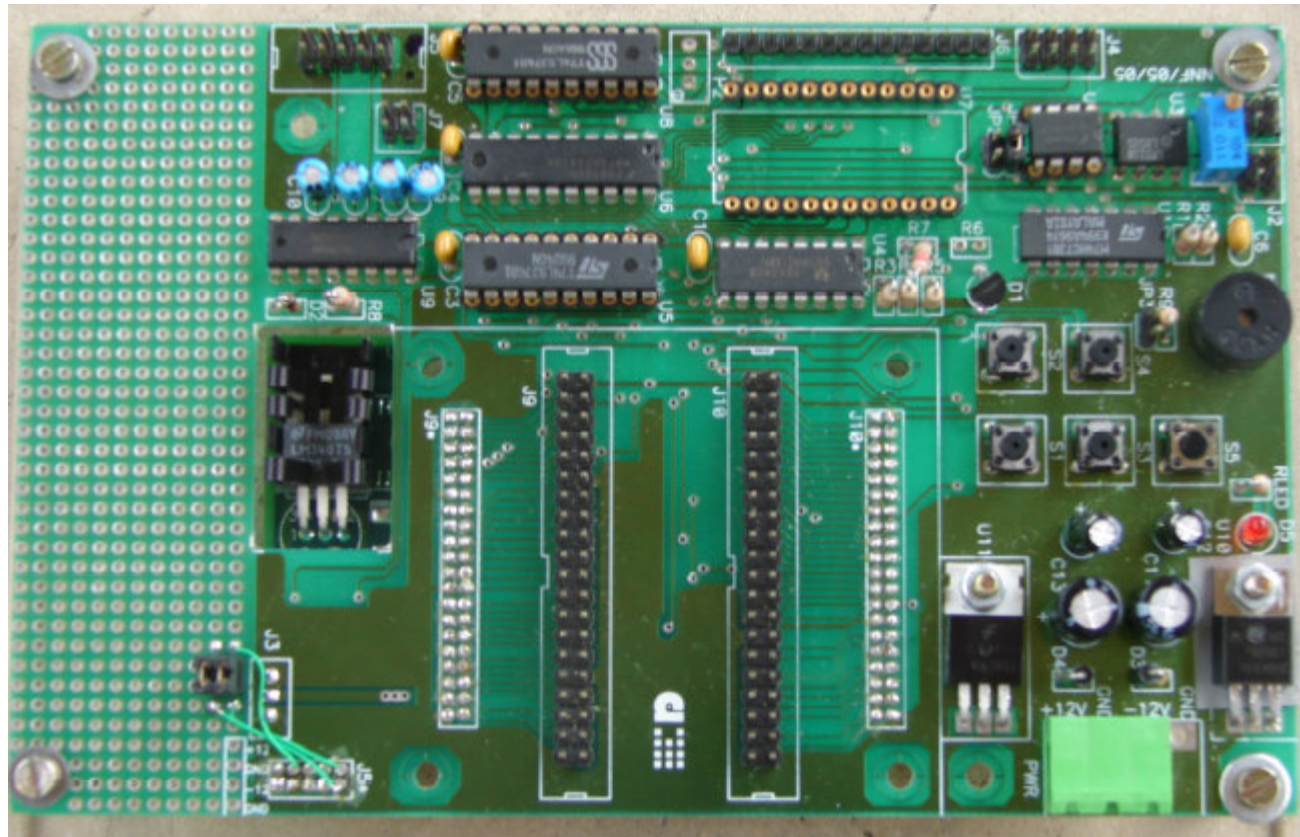


# Controlador CNC





# Placa de interface com o JackRabbit



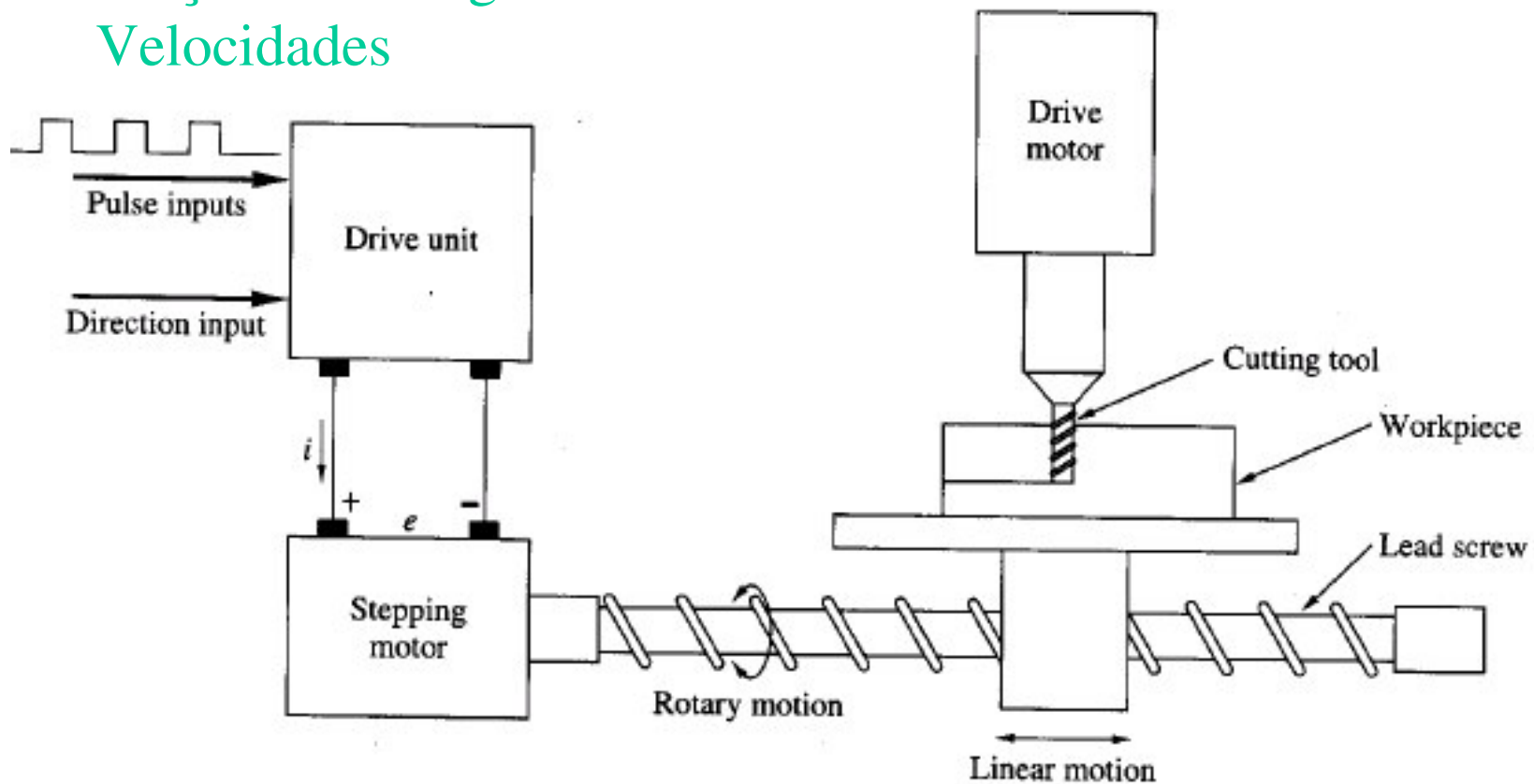
## Sistema de Movimentação

Mecânica, eletrônica, motores, sensores

Forças inerciais

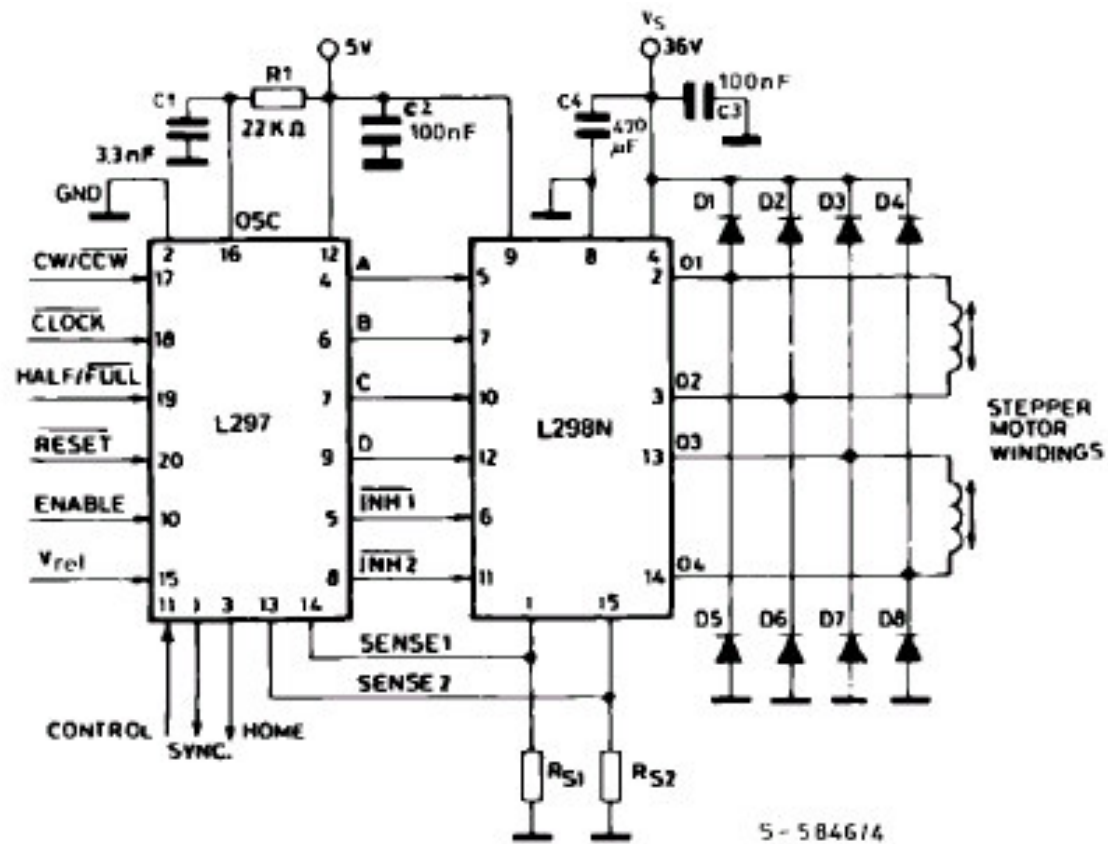
Forças de usinagem

Velocidades



Motor de passo: malha aberta → 400 passos por volta

# Driver do motor de passo



$R_{S1} R_{S2} = 0.5 \Omega$

D1 to D8 = 2 Fast Diodes

$V_F \leq 1.2 @ I = 2 A$

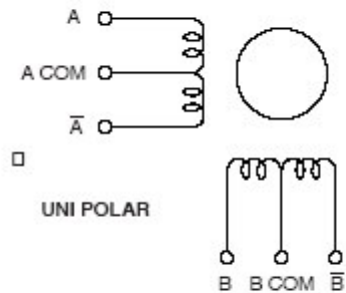
$t_{rr} \leq 200 ns$



# Motor de passo

## Configurações dos enrolamentos

• UNIPOLAR Winding Diagram  
6 Lead Wire Configuration

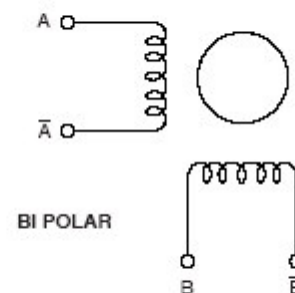


(Dual)

Step	A	B	$\bar{A}$	$\bar{B}$	A-B -COM
1	-	-	0	0	+
2	0	-	-	0	+
3	0	0	-	-	+
4	-	0	0	-	+

CW Rotation Facing Mounting End

• BIPOLAR Winding Diagram  
4 Lead Wire Configuration



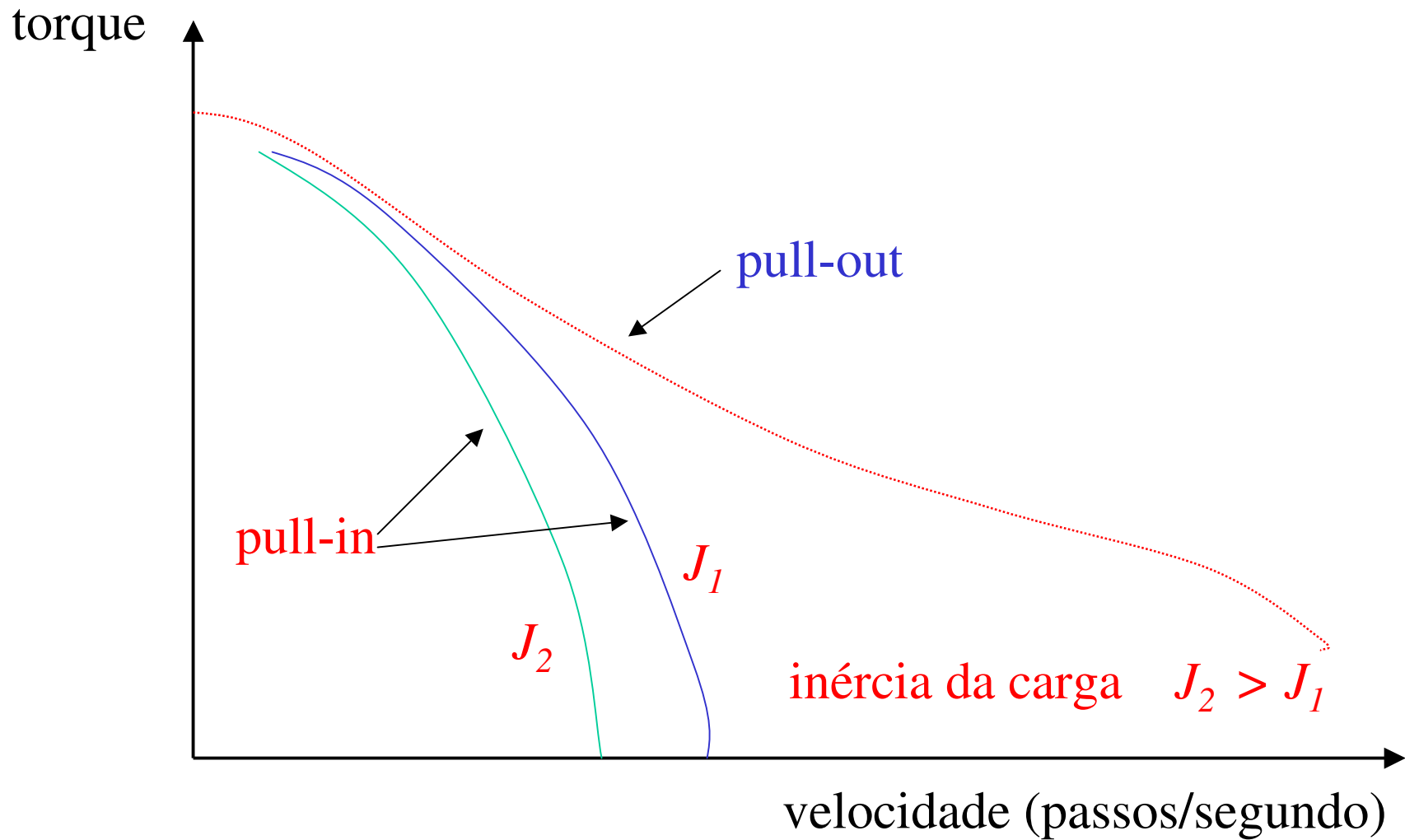
• BIPOLAR Switching Sequence  
4 Lead Wire Configuration

(Dual)

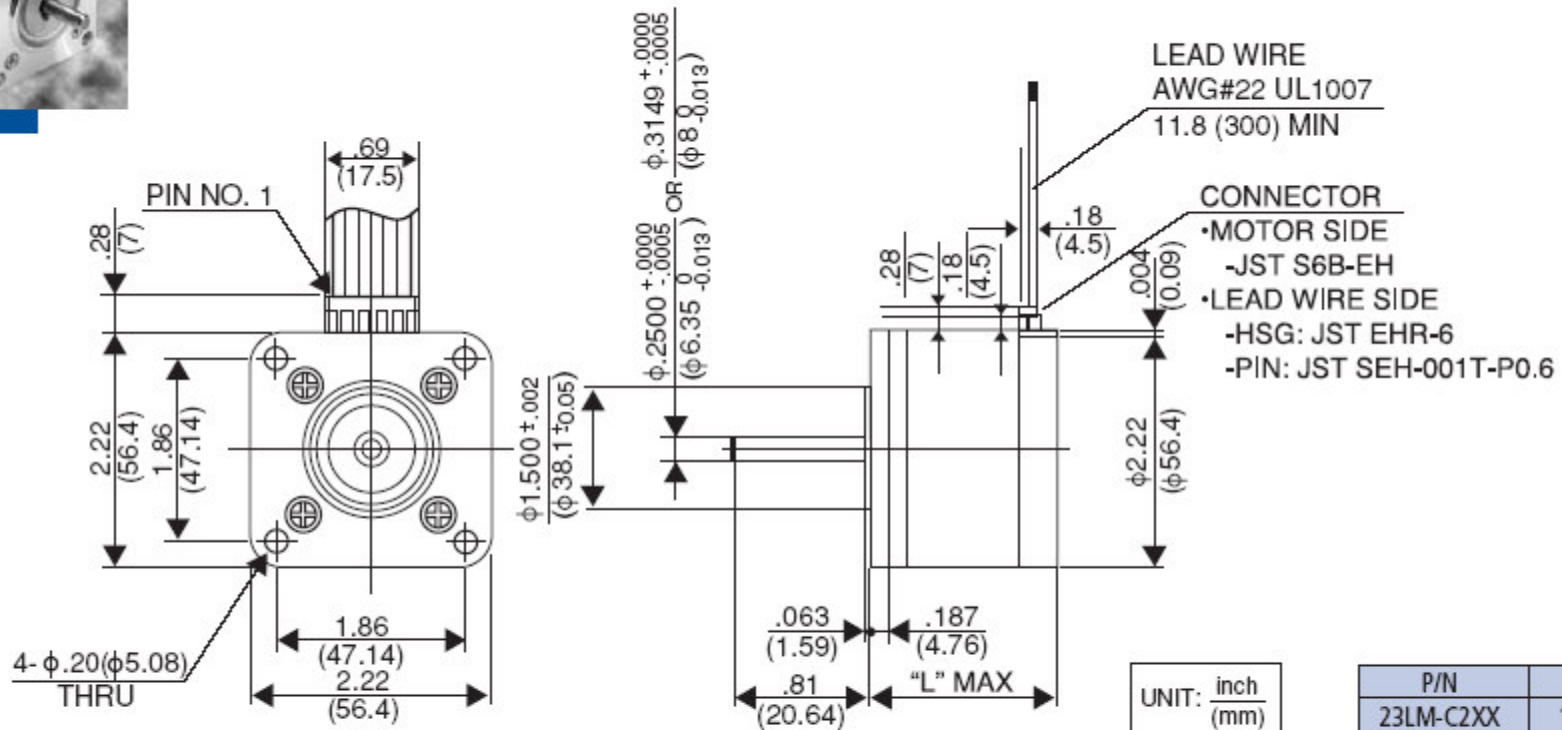
Step	A	B	$\bar{A}$	$\bar{B}$
1	+	+	-	-
2	-	+	+	-
3	-	-	+	+
4	+	-	-	+

CW Rotation Facing Mounting End

## Motor de passo: curva torque x velocidade



Acoplamento motor - carga



P/N	"L"
23LM-C2XX	1.61 (41)
23LM-C3XX	1.95 (49.5)
23LM-C0XX	2.22 (56.5)

PIN NO. VS PHASE

A	A COM	$\bar{A}$	B	B COM	$\bar{B}$
RED	BLK	YEL	BLU	WHT	ORG
6	5	4	3	2	1

## Model Specifications

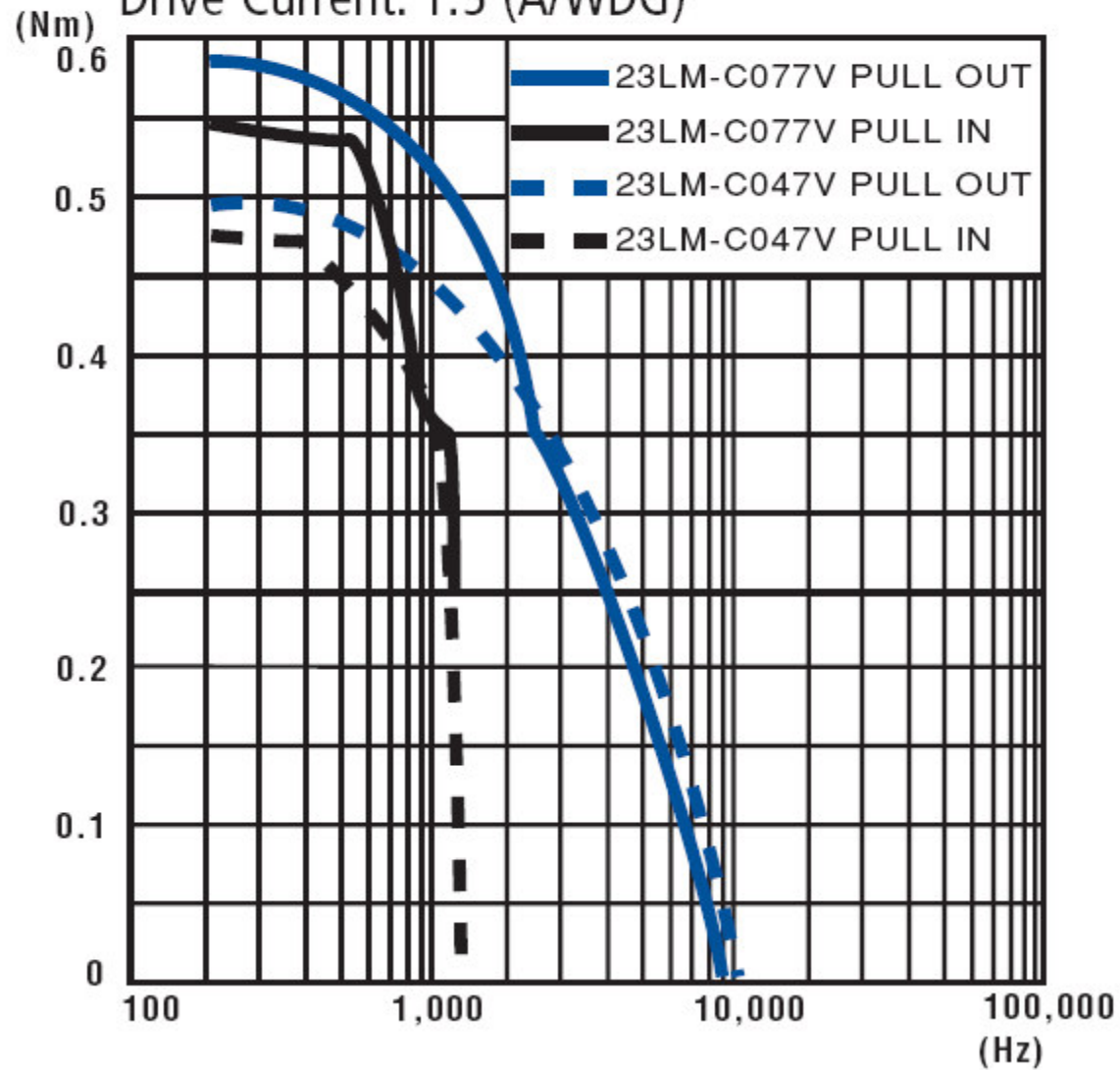
Model Number	Step Angle	Drive Sequence	Rated Current/Wdg	Winding Resistance	Holding Torque	Inductance	Rotor Inertia	Detent Torque	Weight
	Degrees		Amps	Ohms	Nm (kg-cm)	mH	kg-cm <sup>2</sup>	Nm (g-cm)	g
23LM-C202V	1.8°	UNIPOLAR	1.0	3.5	0.314 (3.2)	4.0	0.055	0.0492 (500)	360
23LM-C222V	1.8°	BIPOLAR	1.0	3.5	0.374 (3.8)	6.4	0.055	0.0492 (500)	360
23LM-C250V	1.8°	UNIPOLAR	1.5	1.55	0.314 (3.2)	2.5	0.055	0.0492 (500)	360
23LM-C252V	1.8°	BIPOLAR	1.5	1.55	0.374 (3.8)	4.0	0.055	0.0492 (500)	360
23LM-C304V	1.8°	UNIPOLAR	1.0	5.0	0.544 (5.5)	9.1	0.110	0.0540 (550)	450
23LM-C344V	1.8°	BIPOLAR	1.0	5.0	0.614 (6.2)	15.0	0.110	0.0540 (550)	450
23LM-C343V	1.8°	UNIPOLAR	1.5	2.2	0.544 (5.5)	3.5	0.110	0.0540 (550)	450
23LM-C355V	1.8°	BIPOLAR	1.5	2.2	0.614 (6.2)	5.5	0.110	0.0540 (550)	450
23LM-C004V	1.8°	UNIPOLAR	1.0	7.0	0.624 (6.3)	14.0	0.160	0.0588 (600)	540
23LM-C054V	1.8°	BIPOLAR	1.0	7.0	0.794 (7.0)	22.1	0.160	0.0588 (600)	540
23LM-C047V	1.8°	UNIPOLAR	1.5	3.1	0.624 (6.3)	6.1	0.160	0.0588 (600)	540
23LM-C077V	1.8°	BIPOLAR	1.5	3.1	0.794 (7.0)	9.8	0.160	0.0588 (600)	540

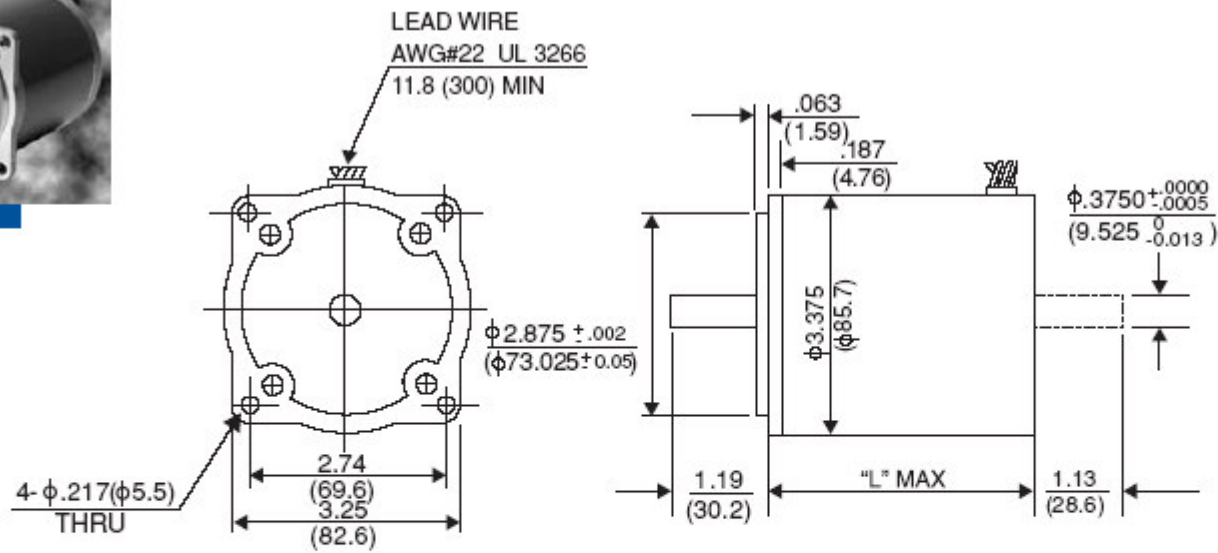
Model No.: 23LM-C047V, C077V

Driver: Chopper Dual

Supply Voltage: 24.0 (Volt)

Drive Current: 1.5 (A/WDG)





UNIT: inch  
(mm)

P/N	"L"
34PM-C1XX	3.69 (93.7)
34PM-C0XX	2.44 (61.9)

PIN NO. VS PHASE

A	A COM	$\bar{A}$	B	B COM	$\bar{B}$
RED	BLK	RED/ WHT	GRN	WHT	GRN/ WHT

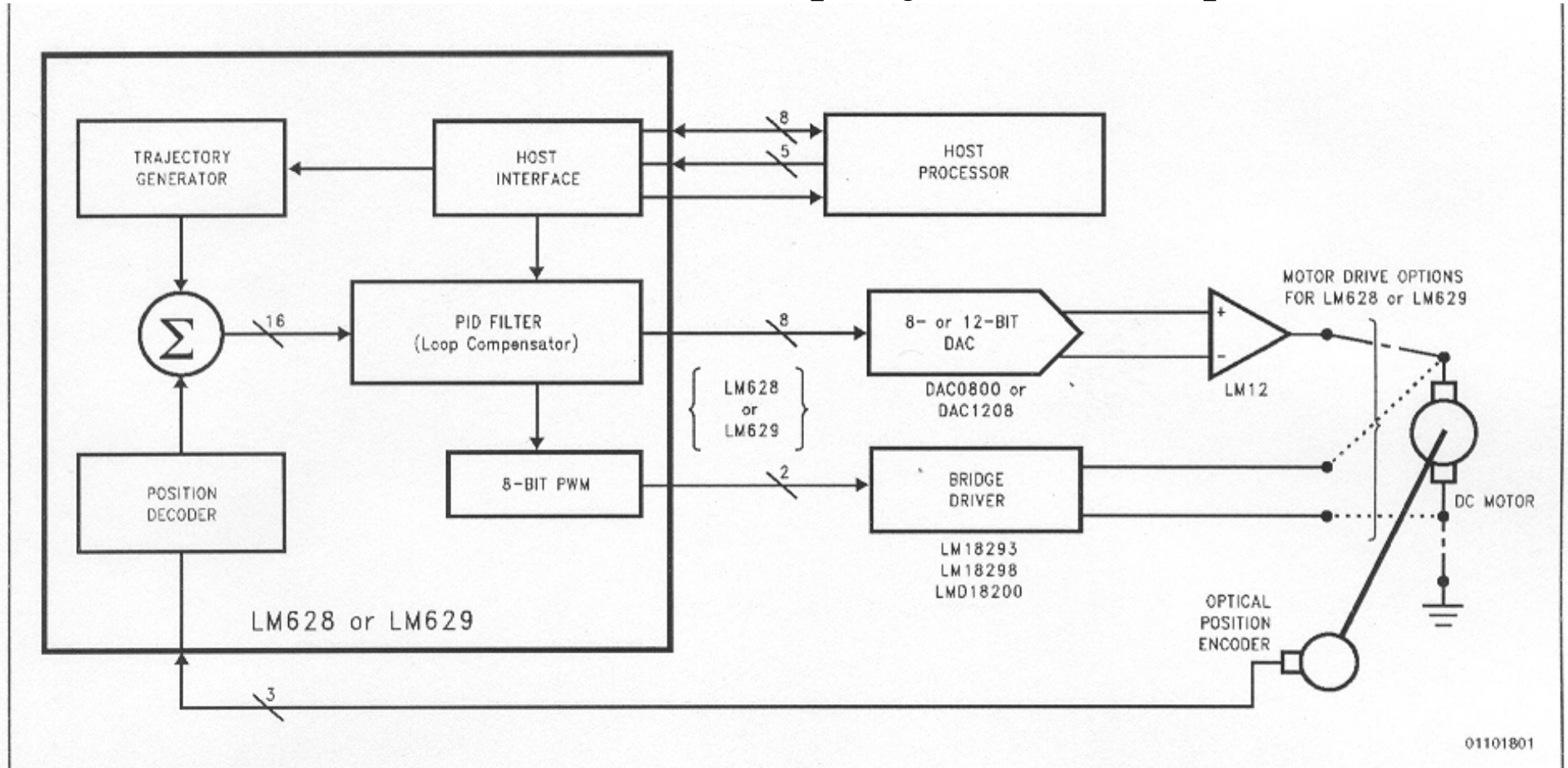
## Model Specifications

Model Number	Step Angle	Drive Sequence	Rated Current/Wdg	Winding Resistance	Holding Torque	Inductance	Rotor Inertia	Detent Torque	Weight
	Degrees		Amps	Ohms	Nm (kg-cm)	mH	kg-cm <sup>2</sup>	Nm (g-cm)	g
34PM-C101	1.8°	UNIPOLAR	4.00	0.75	1.961 (20)	3.50	1.1000	0.1275 (1300)	2,400
34PM-C108	1.8°	UNIPOLAR	1.00	12.00	1.961 (20)	56.00	1.1000	0.1275 (1300)	2,400
34PM-C007	1.8°	UNIPOLAR	1.25	4.40	1.177 (12)	14.50	0.5600	0.0883 (900)	1,400
34PM-C049	1.8°	UNIPOLAR	4.70	0.36	1.177 (12)	1.65	0.5600	0.0883 (900)	1,400

NOTE: Bipolar models also available.

# Acionamento do motor CC

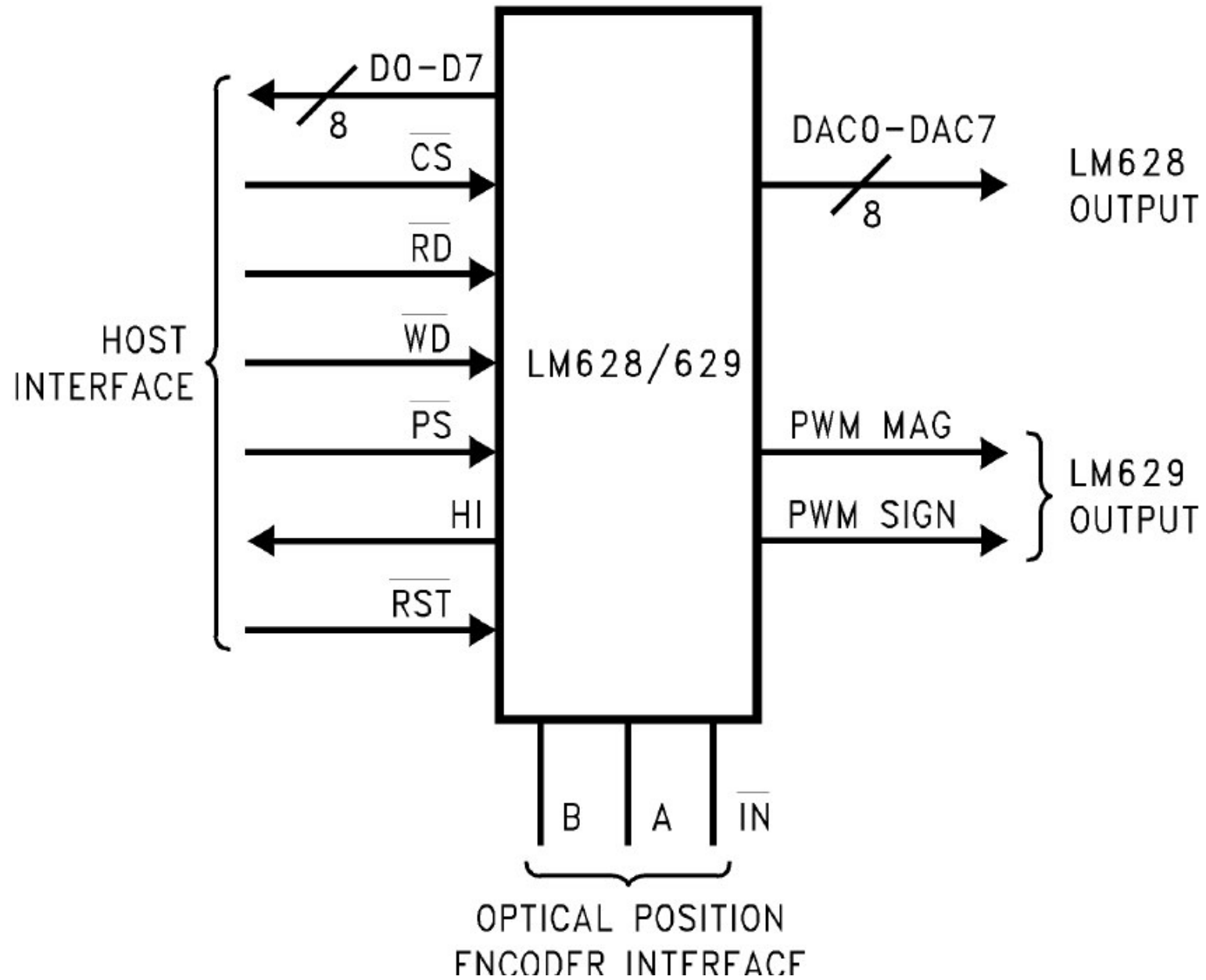
## Sensor de posição: encoder óptico



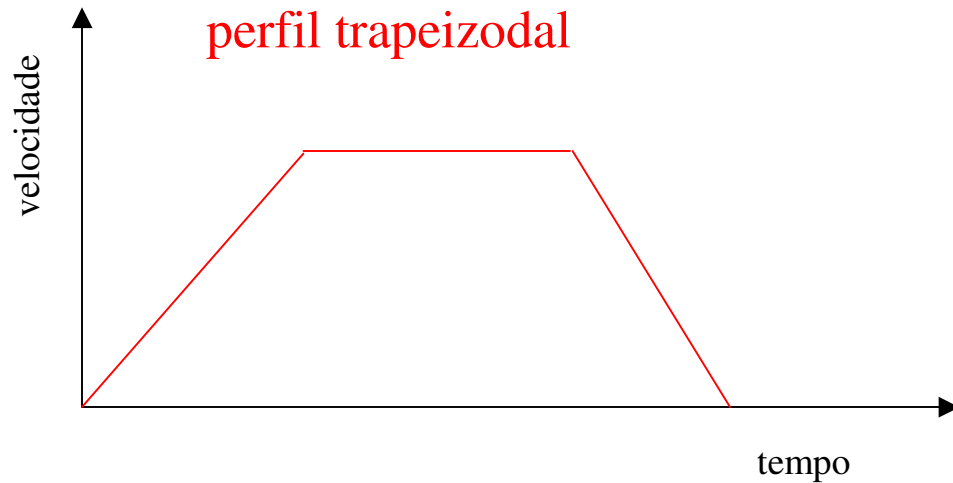
Motor CC: malha fechada



# Esquema de ligações do LM629



## Aceleração: perfil de velocidade



Curva de aceleração:

tabela com intervalo de tempos entre passos

Conversão deslocamento/passo do motor:

$$x = n \frac{p}{400}$$

$x$  = deslocamento (mm)

$p$  = passo do fuso (5 mm/volta)

$n$  = número de passos do motor

## Montagem da tabela de aceleração

$$\theta_{i+1} = \theta_i + v_i t_{i+1} + \frac{1}{2} \alpha (t_{i+1})^2$$

Considerando:

$$\Delta\theta = \theta_{i+1} - \theta_i = \frac{2\pi}{400}$$

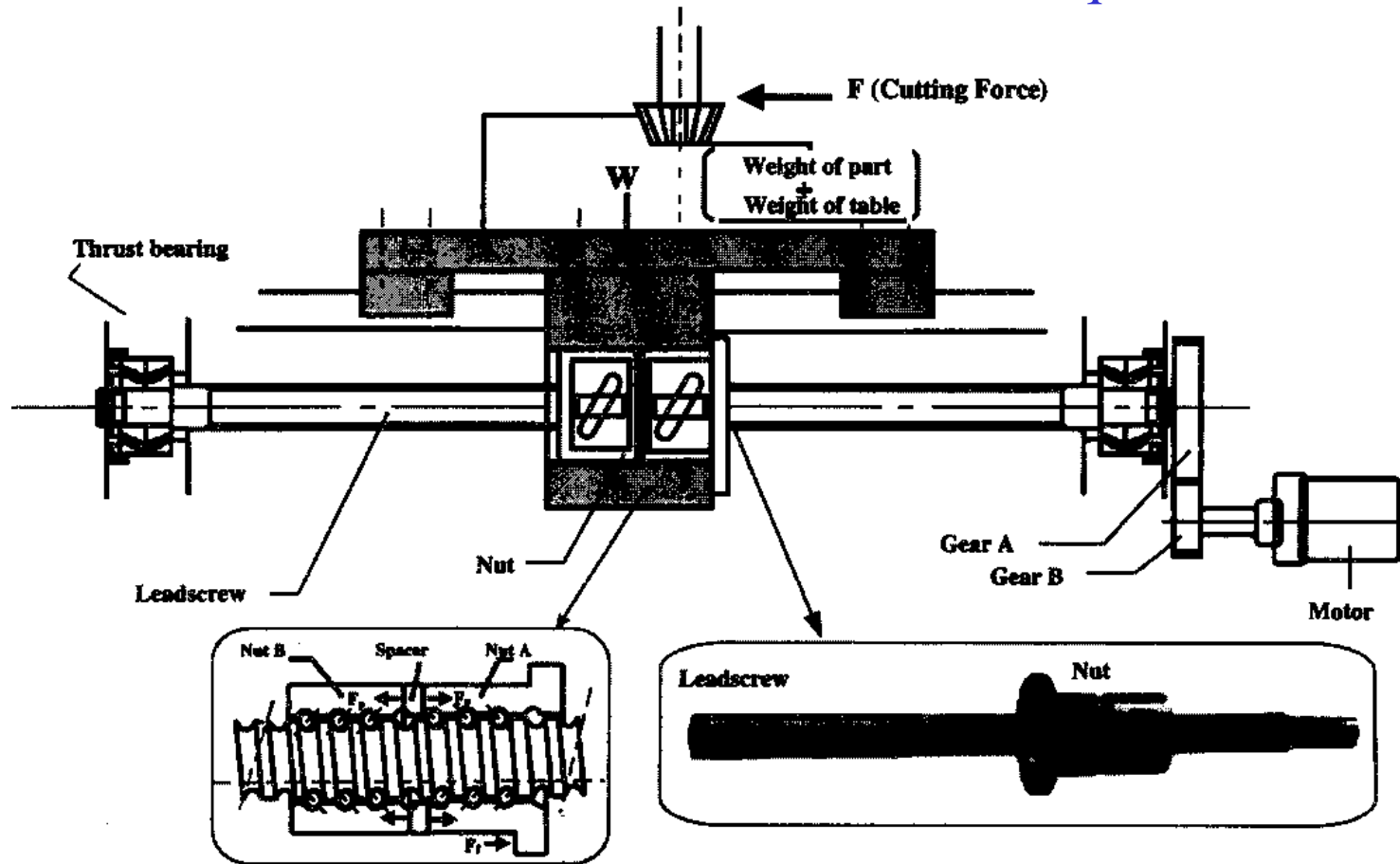
tem-se:

$$\frac{1}{2} \alpha (t_{i+1})^2 + v_i t_{i+1} - \frac{2\pi}{400} = 0 \quad i = 0, 1, 2, 3, \dots$$

onde:

$$v_i = v_{i-1} + \alpha t_i \quad i = 1, 2, 3, \dots \text{ e } v_0 = 0$$

## Sistema de acionamento: cálculo do torque no motor



Fuso: comprimento  $l$ , diâmetro  $d_f$ , passo  $p$ , massa  $m_f$

momento de inércia de massa  $J_f$

Torque estático devido ao atrito nas guias

$$T_{e\mu} = \frac{P}{2\pi} \mu_g \left[ (m_m + m_p)g + F_{cn} \right]$$

Torque devido à força de corte

$$T_{fc} = \frac{P}{2\pi} F_c$$

onde:

massa da mesa:  $m_m$

massa da peça:  $m_p$

coeficiente de atrito das guias:  $\mu_g$

força de corte:  $F_c$

componente da força de corte normal à mesa:  $F_{cn}$

## Cargas dinâmicas: inércia da carga refletida no eixo do motor

Inércia do conjunto peça e mesa:  $J_p$

$$J_p = (m_m + m_p) \left( \frac{p}{2\pi} \right)^2$$

Inércia da carga:  $J_c$

$$J_c = J_f + J_p \quad \text{sendo,} \quad J_f = m_f \left( \frac{d_f}{2} \right)^2$$

Torque a ser fornecido pelo motor:  $T$

$$T = \alpha(J_r + J_c) + T_{e\mu} + T_{fc}$$

onde,  $J_r =$  inércia do rotor do motor

# Casamento de inércias

torque total:

$$T = J_r \alpha_m + \frac{J_c \alpha_c}{n}$$

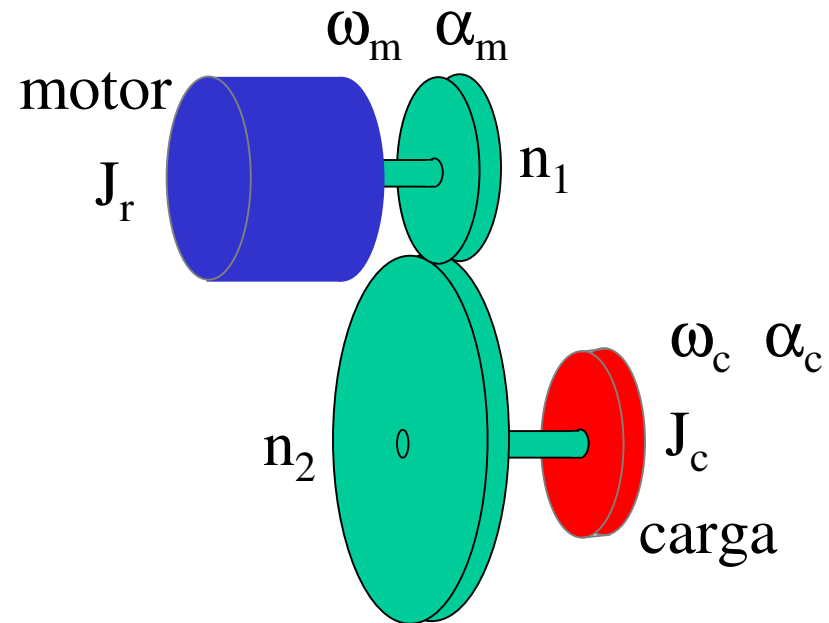
em função de  $n$ :

$$T(n) = J_r n \alpha_c + \frac{J_c \alpha_c}{n}$$

$n$  ótimo  $\rightarrow$  torque mínimo

$$\frac{dT(n)}{dn} = J_r \alpha_c - \frac{J_c \alpha_c}{n^2} = 0$$

$$\Rightarrow n = \sqrt{\frac{J_c}{J_r}}$$



Redução  $n = n_2/n_1$

## Potência do motor: carga inercial

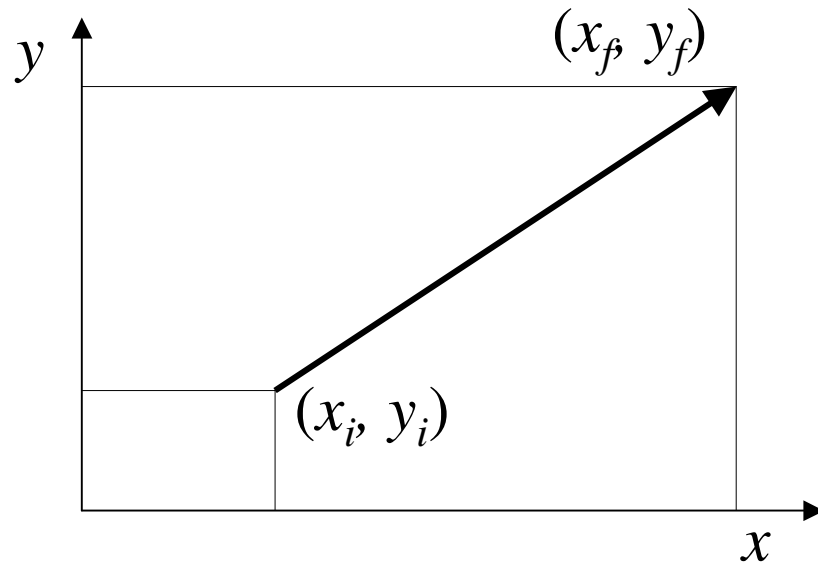
$$T\omega_m = \left( J_r n + \frac{J_c}{n} \right) \alpha_c \omega_c n$$

$$P_m = \left( \frac{J_c}{n^2} n + \frac{J_c}{n} \right) \alpha_c \omega_c n = 2J_c \alpha_c \omega_c$$

$$\Rightarrow P_m = 2P_c$$



# Interpolação linear



Motor de passo:

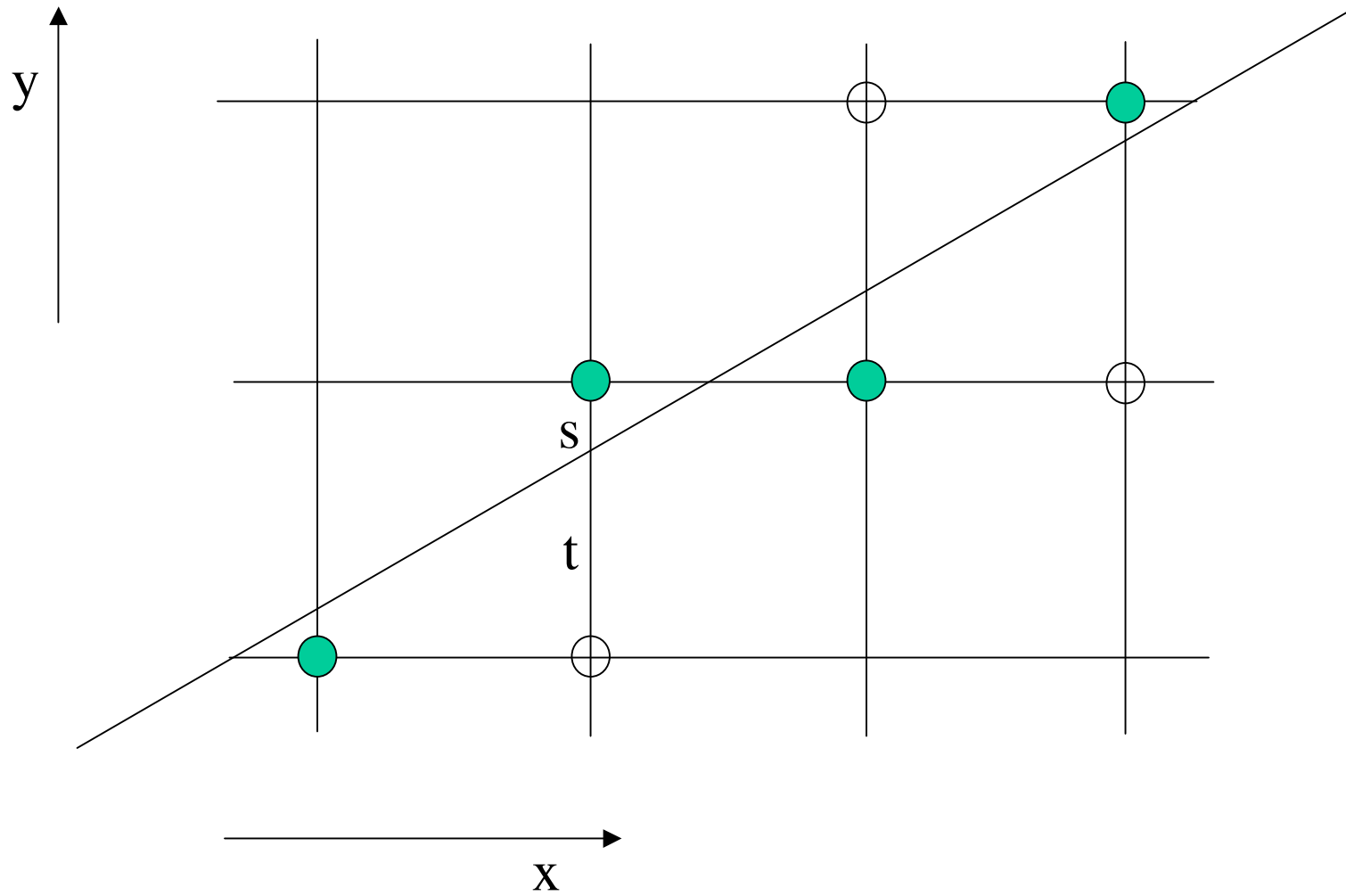
movimento incremental

Menor incremento: 
$$\Delta x = \frac{p}{400}$$

$p$  = passo do fuso ou perímetro da polia

eixo com maior deslocamento: 
$$x_f - x_i = n\Delta x$$

# Algoritmo de Bresenham



```

% Interpolacao linear: Algoritmo de Bresenham
% reta do ponto (x1,y1) ao ponto (x2,y2)
dx=abs(x2-x1);
dy=abs(y2-y1);
d=2*dy-dx;
inc1=2*dy;
inc2=2*(dy-dx);
x(1)=x1;
y(1)=y1;
xend=x2;
i=2;
while( x < xend)
    if x1 < x2
        x(i)=x(i-1)+1; % move motor x horário
    else
        x(i)=x(i-1)-1; % move motor x anti-horário
    end

    if d<0
        d=d+inc1;
        y(i)=y(i-1);
    else
        y(i)=y(i-1)+1; % move motor y
        d=d+inc2;
    end
    i=i+1;
end

```