# Lectures on Mechanics

Lesson#1

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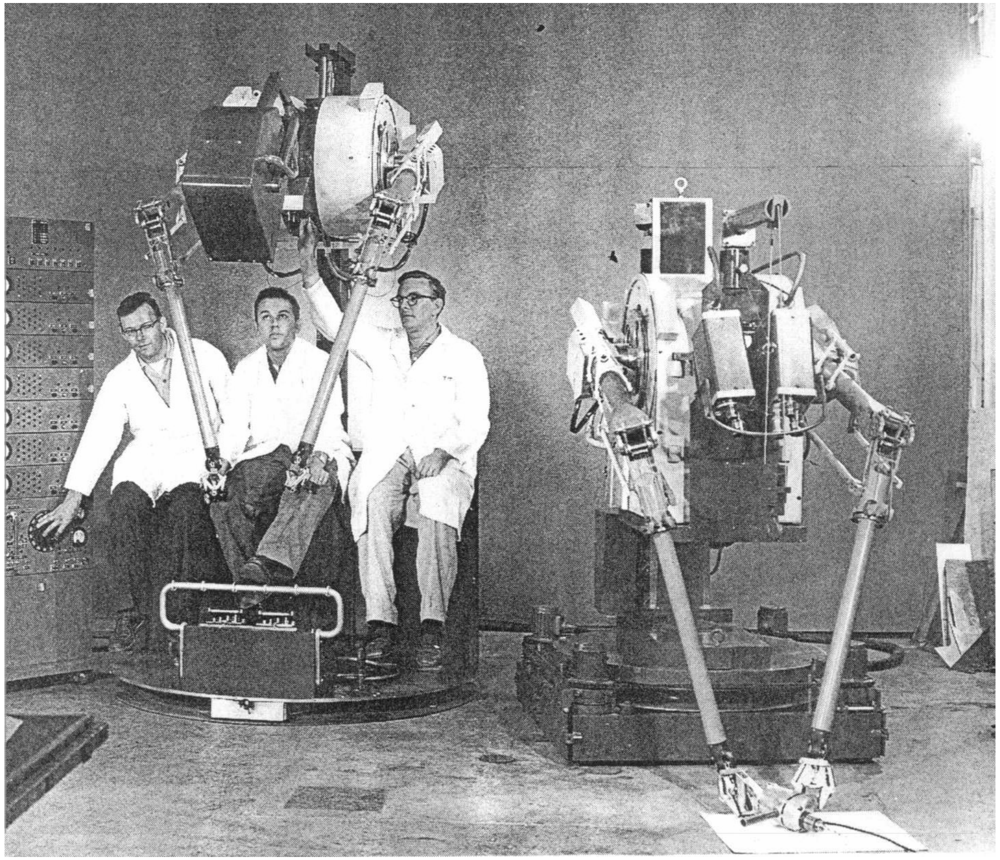

**LESSONS TIME TABLE (pls. take note)**

**28/11 h9/12- mech components 1 (3h)**
**4/12 h9/12  mech components 2 (3h)**
**11/12 h9/12 mech technologies (3h)**
**16/12 h 9/12 (in TLR)  - mech technologies tlr workshop**
**18/12 h9/12- robotic (3h) TO BE REARRANGED**

# STUDENT LIST

**Baizid Khelifa**
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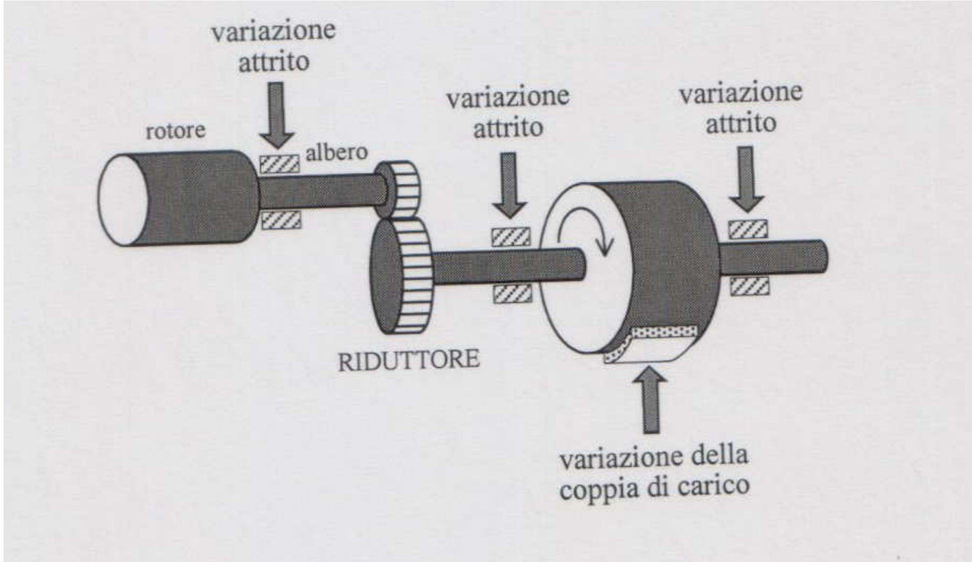
**Palyart Lamarche Jean-Christophe**
**Patra Niranjan**

# POWER TRANSMISSION

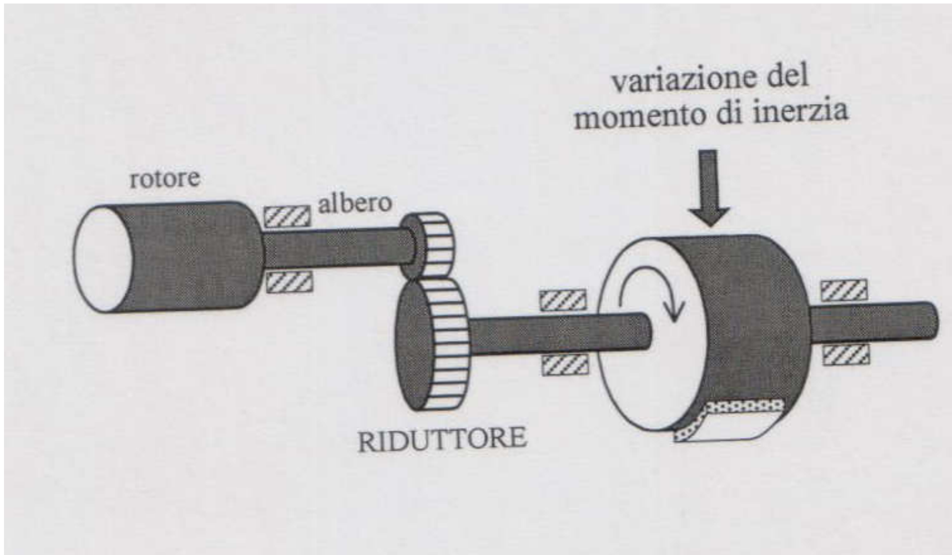
## Mechanical load characterization

The **apparatus load** can be divided into two classes:

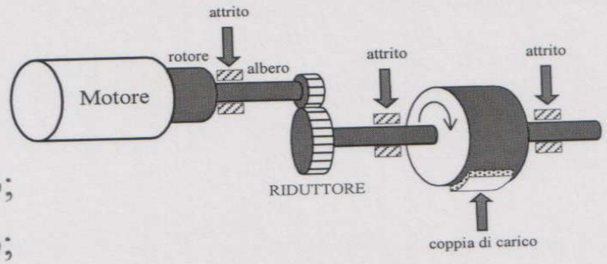
**Dissipative load** when energy supplied by the actuator is used to provide work e.g. tool machining like turning, milling etc. or lost for friction compensation e.g. industrial mixers or fans, rail drive, lifting.




**Inertial load** when energy supplied by the actuator is used to accelerate and/or to brake the load e.g. robots, high speed automatic positioning devices, metropolitan wheel drive



## LATO MOTORE:




Andamento della coppia di carico;

Andamento della coppia di attrito;

Inerzia del carico;

Coppia Motrice: $C_m$ = Coppia Inerziale: $J\dot{\omega}$ + Coppia Dissipativa: $C_v + C_a + C_c$

$$C_m = J\dot{\omega} + C_v + C_a + C_c$$

Coppia Inerziale

associata all'energia necessaria per accelerare e decelerare il carico

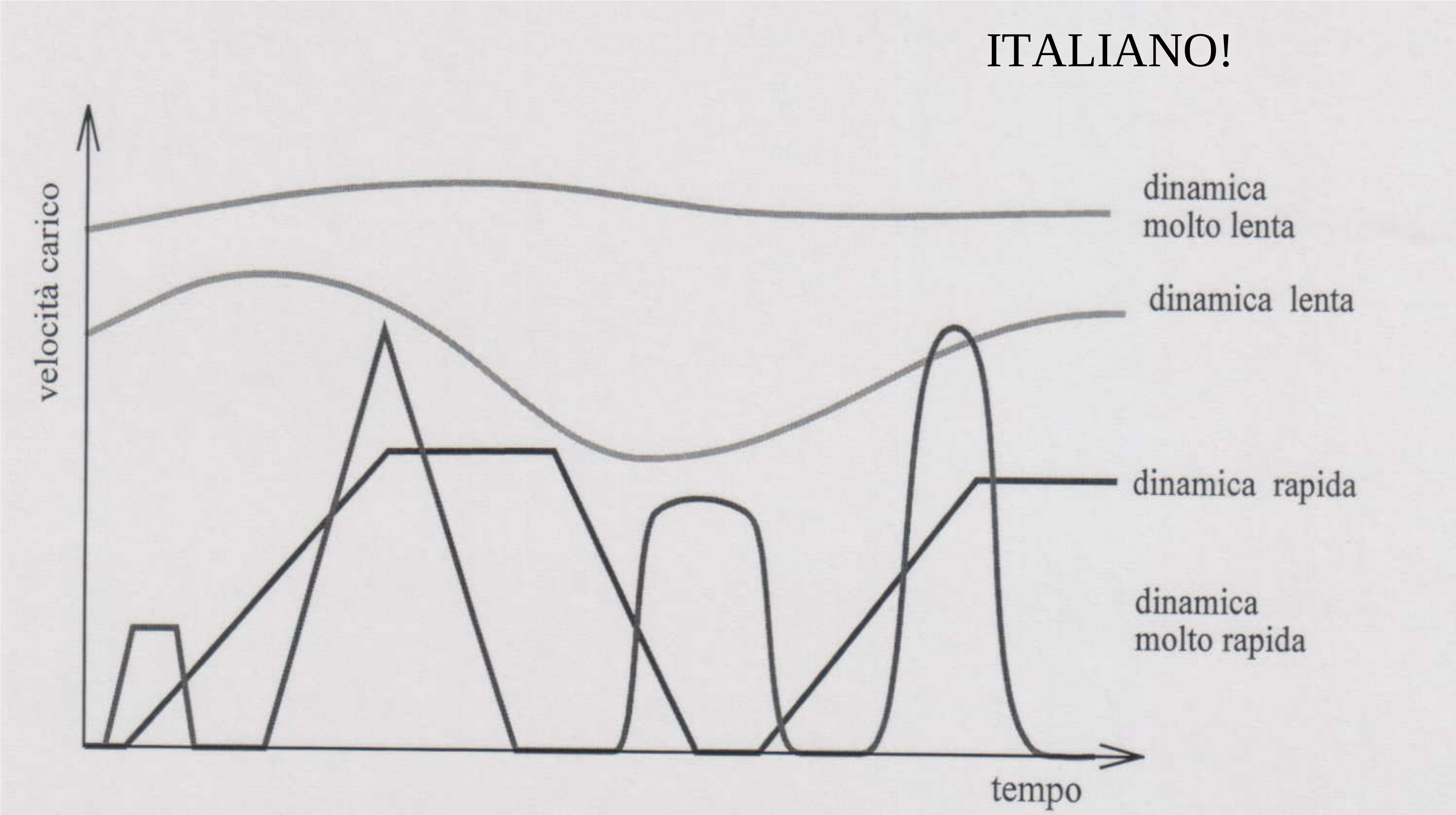
Coppia Dissipativa

associata all'energia dissipata e/o utilizzata dal carico

COPPIA DISSIPATIVA =

- Coppia di carico $C_c$
- \+ Coppia di attrito =
  - Coppia di attrito viscoso $C_v$
  - \+ Coppia di attrito secco $C_a$ =
    - Coppia di attrito statico o di primo distacco
    - \+ Coppia di attrito dinamico o di Coulomb $C_{a,d}$

# DYNAMIC LOAD CHARACTERIZATION

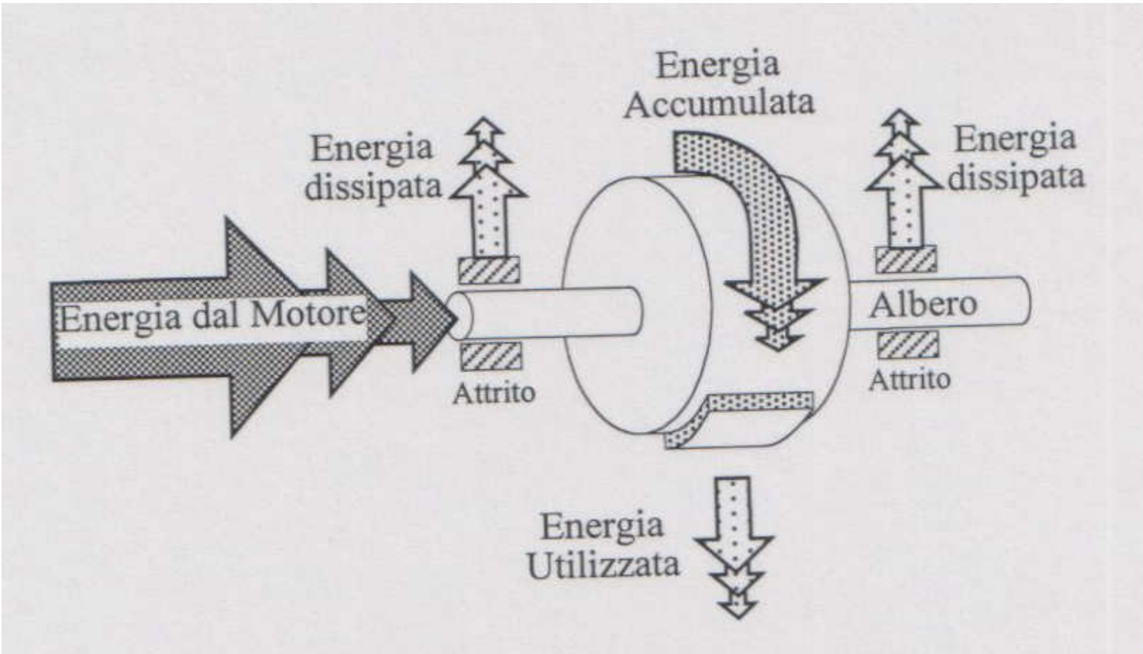


**VERY SLOW DYNAMIC :** $J \, d\omega/dt \ll Cv + Ca + Cc$

**SLOW DYNAMIC :** $J \, d\omega/dt < Cv + Ca + Cc$

**FAST DYNAMIC :** $J \, d\omega/dt > Cv + Ca + Cc$

**VERY FAST DYNAMIC :** $J \, d\omega/dt \gg Cv + Ca + Cc$



# ACTUATORS

**what does it mean?**

**How many different kind of actuator can you remember?**

# ACTUATORS
**(first approximation list)**

## ELECTRIC ACTUATORS

## PNEUMATIC ACTUATORS

## HYDRAULIC ACTUATORS

...

# ACTUATORS

**TABLE 14.5.3 Lower Power Actuator Principles**

| Electro-mechanical | Fluid power | Alternative concepts |
|---|---|---|
| Direct Current (DC) motor | Hydraulic actuators | Piezoelectric |
| Alternating Current (AC) motor | Pneumatic actuators | Magnetostrictive |
| Stepper motor | | Electrochemical |
| Electromagnetic | | Thermo-bimetal |
| Linear motor | | Shape Memory Alloy |
| | | Electrostatic |

# Each actuator has its own characteristic

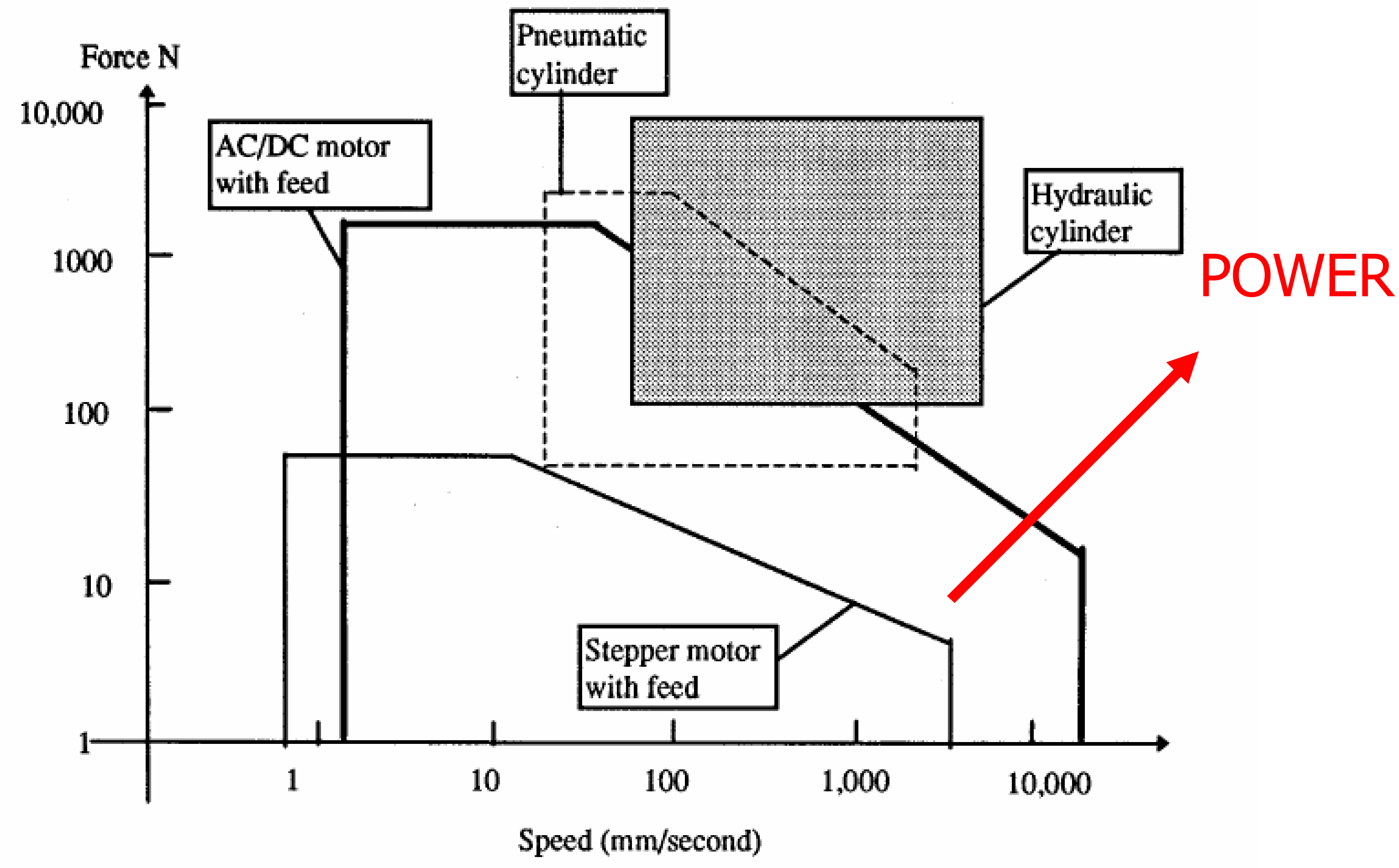



FIGURE 14.5.11 Force vs. speed for common actuators.

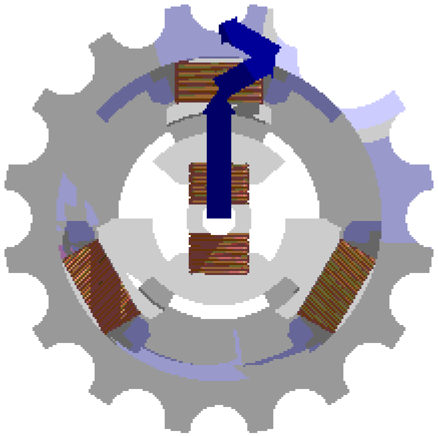
# The choice between different option is not always unique

**TABLE 14.5.4 Comparison between Common Actuators**

| Actuator type | Static linearity | Non-linearity | | | Accuracy |
|---|---|---|---|---|---|
| | | Friction | Backlash | Hysteresis | mm |
| AC/DC motor with feed | A | B–C | B–C | B–C | 0.005–100 |
| Stepper motor with feed | A | B–C | B–C | B–C | 0.01–50 |
| Hydraulic cylinder | | C | | | 0.01–100 |
| Pneumatic cylinder | | C | | | 0.1–100 |

*Symbols:* A good, negligible; B: average, common; C: bad, significant.

# ELECTRIC ACTUATORS



## Electro magnetic principia (Lorentz Law)

# ELECTRIC ACTUATORS (both linear and rotational)

**AC motor**

**DC brushed motor**

**Stepper motor**

**Brushless motor**

***Torque and linear motors***

# AC motor

Through electromagnetic induction, the rotating magnetic field induces a current in the conductors in the rotor, which in turn sets up a counterbalancing magnetic field that causes the rotor to turn in the direction the field is rotating

# AC motor speed

The nominal synchronous speed is obtained by

$$Ns = 120F / p$$

where

$Ns$ = Synchronous speed, in revolutions per minute
$F$ = AC power frequency
$p$ = Number of poles per phase winding

# AC motor speed

Actual RPM for an induction motor will be less than this calculated synchronous speed by an amount known as *slip* that increases with the torque produced. With no load the speed will be very close to synchronous. When loaded, standard motors have between 2-3% slip

As an example, a typical four-pole motor running on 50 Hz might have a nameplate rating of 1430 RPM at full load, while its calculated speed is 1500.

# AC motor control

The state of the art in the AC motor control is the digital inverter

Standard inverters may control the AC ref frequency, controlling consequently the speed of the motor.
The resulting characteristic of the motor is linear. The torque decrease linearly with the speed.

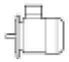
# AC motor control

Vectorial inverters lead to a flat characteristics with constant power over the full speed range.

AC motor can be controlled by an inverter either in open or closed loop adding an external sensor that close the speed loop.

Nominal open loop speed tolerance on vectorial inverter may be lower than 2%.

# AC motor range – 2 poles

| Pn kW |  | | n $min^{-1}$ | Mn Nm | η % | cos φ | In A (400V) | Is/In | Ms/Mn | Ma/Mn | Jm x $10^{-4}$ $kgm^2$ | IM B5   |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.18 | BN 63A | 2 | 2700 | 0.64 | 53 | 0.78 | 0.63 | 3.0 | 2.1 | 2 | 2.0 | 3.5 |
| 0.25 | BN 63B | 2 | 2700 | 0.88 | 62 | 0.78 | 0.75 | 3.3 | 2.3 | 2.3 | 2.3 | 3.9 |
| 0.37 | BN 63C | 2 | 2750 | 1.29 | 64 | 0.79 | 1.06 | 3.9 | 2.6 | 2.6 | 3.3 | 5.1 |
| 0.37 | BN 71A | 2 | 2810 | 1.26 | 70 | 0.78 | 0.98 | 4.8 | 2.8 | 2.6 | 3.5 | 5.4 |
| 0.55 | BN 71B | 2 | 2810 | 1.87 | 73 | 0.77 | 1.41 | 5.0 | 2.9 | 2.8 | 4.1 | 6.2 |
| 0.75 | BN 71C | 2 | 2800 | 2.6 | 74 | 0.77 | 1.90 | 5.1 | 3.1 | 2.8 | 5.0 | 7.3 |
| 0.75 | BN 80A | 2 | 2800 | 2.6 | 74 | 0.78 | 1.88 | 4.8 | 2.6 | 2.2 | 7.8 | 8.6 |
| 1.1 | BN 80B | 2 | 2800 | 3.8 | 76 | 0.77 | 2.71 | 4.8 | 2.8 | 2.4 | 9.0 | 9.5 |
| 1.5 | BN 80C | 2 | 2800 | 5.1 | 80 | 0.81 | 3.3 | 4.9 | 2.7 | 2.4 | 11.4 | 11.3 |
| 1.5 | BN 90SA | 2 | 2870 | 5.0 | 78 | 0.78 | 3.6 | 5.9 | 2.7 | 2.6 | 12.5 | 12.3 |
| 1.85 | BN 90SB | 2 | 2880 | 6.1 | 79 | 0.79 | 4.3 | 6.2 | 2.9 | 2.6 | 16.7 | 14 |
| 2.2 | BN 90L | 2 | 2880 | 7.3 | 79 | 0.79 | 5.1 | 6.3 | 2.9 | 2.7 | 16.7 | 14 |
| 3 | BN 100L | 2 | 2860 | 10.0 | 80 | 0.80 | 6.8 | 5.7 | 2.6 | 2.2 | 31 | 20 |
| 4 | BN 100LB | 2 | 2870 | 13.3 | 82 | 0.81 | 8.7 | 5.9 | 2.7 | 2.5 | 39 | 23 |
| 4 | BN 112M | 2 | 2900 | 13.2 | 83 | 0.84 | 8.3 | 6.9 | 3 | 2.9 | 57 | 28 |
| 5.5 | BN 132SA | 2 | 2890 | 18.2 | 83 | 0.85 | 11.3 | 6 | 2.6 | 2.2 | 101 | 35 |
| 7.5 | BN 132SB | 2 | 2900 | 25 | 84 | 0.86 | 15.0 | 6.4 | 2.6 | 2.2 | 145 | 42 |
| 9.2 | BN 132M | 2 | 2900 | 30 | 86 | 0.87 | 17.7 | 6.9 | 2.8 | 2.3 | 178 | 53 |
| 11 | BN 160MR | 2 | 2910 | 36 | 87 | 0.86 | 21 | 7.0 | 2.9 | 2.5 | 210 | 65 |
| 15 | BN 160MB | 2 | 2930 | 49 | 88 | 0.86 | 29 | 7.1 | 2.6 | 2.3 | 340 | 84 |
| 18.5 | BN 160L | 2 | 2930 | 60 | 89 | 0.86 | 35 | 7.6 | 2.7 | 2.3 | 420 | 97 |
| 22 | BN 180M | 2 | 2930 | 72 | 89 | 0.87 | 41 | 7.8 | 2.6 | 2.4 | 490 | 109 |
| 30 | BN 200LA | 2 | 2960 | 97 | 90 | 0.88 | 55 | 7.9 | 2.7 | 2.9 | 770 | 140 |

The IEC-normalized BN motors comply with all the applicable international standards, including the EMC and LV Directives. They are available in the 0.06 - 30 kW range in the foot and the flange mounting version, the latter in both the IM B5 and the IM B14 configuration. Single and dual pole version available with generally, three brake options offered, one DC and two AC supply, lending further flexibility to the system. Finally, all motors are inverter duty.

NB: power is traditionally fraction of HP, ref size is 0.75 kW=1HP

# AC motor range 4,6 poles..

| Pn kW | | | n $min^{-1}$ | Mn Nm | η % | cos φ | In A (400V) | $\frac{Is}{In}$ | $\frac{Ms}{Mn}$ | $\frac{Ma}{Mn}$ | Jm x $10^{-4}$ $kgm^2$ | IMB5 Kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.06 | BN 56A | 4 | 1350 | 0.42 | 47 | 0.62 | 0.30 | 2.6 | 2.3 | 2.0 | 1.5 | 3.1 |
| 0.09 | BN 56B | 4 | 1350 | 0.64 | 52 | 0.62 | 0.40 | 2.6 | 2.5 | 2.4 | 1.5 | 3.1 |
| 0.12 | BN 63A | 4 | 1310 | 0.88 | 51 | 0.68 | 0.50 | 2.6 | 1.9 | 1.8 | 2.0 | 3.5 |
| 0.18 | BN 63B | 4 | 1320 | 1.30 | 53 | 0.68 | 0.72 | 2.6 | 2.2 | 2.0 | 2.3 | 3.9 |
| 0.25 | BN 63C | 4 | 1320 | 1.81 | 60 | 0.69 | 0.87 | 2.7 | 2.1 | 1.9 | 3.3 | 5.1 |
| 0.25 | BN 71A | 4 | 1375 | 1.74 | 62 | 0.77 | 0.76 | 3.3 | 1.9 | 1.7 | 5.8 | 5.1 |
| 0.37 | BN 71B | 4 | 1370 | 2.6 | 65 | 0.77 | 1.07 | 3.7 | 2.0 | 1.9 | 6.9 | 5.9 |
| 0.55 | BN 71C | 4 | 1380 | 3.8 | 69 | 0.74 | 1.55 | 4.1 | 2.3 | 2.3 | 9.1 | 7.3 |
| 0.55 | BN 80A | 4 | 1390 | 3.8 | 72 | 0.77 | 1.43 | 4.1 | 2.3 | 2.0 | 15 | 8.2 |
| 0.75 | BN 80B | 4 | 1400 | 5.1 | 75 | 0.78 | 1.85 | 4.9 | 2.7 | 2.5 | 20 | 9.9 |
| 1.1 | BN 80C | 4 | 1400 | 7.5 | 75 | 0.79 | 2.68 | 5.1 | 2.8 | 2.5 | 25 | 11.3 |
| 1.1 | BN 90S | 4 | 1400 | 7.5 | 73 | 0.77 | 2.82 | 4.6 | 2.6 | 2.2 | 21 | 12.2 |
| 1.5 | BN 90LA | 4 | 1410 | 10.2 | 77 | 0.77 | 3.7 | 5.3 | 2.8 | 2.4 | 28 | 13.6 |
| 1.85 | BN 90LB | 4 | 1400 | 12.6 | 77 | 0.78 | 4.4 | 5.2 | 2.8 | 2.6 | 30 | 15.1 |
| 2.2 | BN 100LA | 4 | 1410 | 14.9 | 78 | 0.76 | 5.4 | 4.5 | 2.2 | 2.0 | 40 | 18.3 |
| 3 | BN 100LB | 4 | 1410 | 20 | 80 | 0.78 | 6.9 | 5 | 2.3 | 2.2 | 54 | 22 |
| 4 | BN 112M | 4 | 1420 | 27 | 83 | 0.78 | 8.9 | 5.6 | 2.7 | 2.5 | 98 | 30 |
| 5.5 | BN 132S | 4 | 1440 | 36 | 84 | 0.80 | 11.8 | 5.5 | 2.3 | 2.2 | 213 | 44 |
| 7.5 | BN 132MA | 4 | 1440 | 50 | 85 | 0.81 | 15.7 | 5.7 | 2.5 | 2.4 | 270 | 53 |
| 9.2 | BN 132MB | 4 | 1440 | 61 | 86 | 0.81 | 19.1 | 5.9 | 2.7 | 2.5 | 319 | 59 |
| 11 | BN 160MR | 4 | 1440 | 73 | 87 | 0.82 | 22.3 | 5.9 | 2.7 | 2.5 | 360 | 70 |
| 15 | BN 160L | 4 | 1460 | 98 | 89 | 0.82 | 29.7 | 5.9 | 2.3 | 2.1 | 650 | 99 |
| 18.5 | BN 180M | 4 | 1460 | 121 | 89 | 0.81 | 37.0 | 6.2 | 2.6 | 2.5 | 790 | 115 |
| 22 | BN 180L | 4 | 1465 | 143 | 89 | 0.82 | 45 | 6.5 | 2.5 | 2.5 | 1250 | 135 |
| 30 | BN 200L | 4 | 1465 | 196 | 90 | 0.83 | 58 | 7.1 | 2.7 | 2.8 | 1650 | 157 |

| Pn kW | | | n $min^{-1}$ | Mn Nm | η % | cos φ | In A (400V) | $\frac{Is}{In}$ | $\frac{Ms}{Mn}$ | $\frac{Ma}{Mn}$ | Jm x $10^{-4}$ $kgm^2$ | IMB5 Kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.09 | BN 63A | 6 | 880 | 0.98 | 41 | 0.53 | 0.60 | 2.1 | 2.1 | 1.8 | 3.4 | 4.6 |
| 0.12 | BN 63B | 6 | 870 | 1.32 | 45 | 0.60 | 0.64 | 2.1 | 1.9 | 1.7 | 3.7 | 4.9 |
| 0.18 | BN 71A | 6 | 900 | 1.91 | 56 | 0.69 | 0.67 | 2.6 | 1.9 | 1.7 | 8.4 | 5.5 |
| 0.25 | BN 71B | 6 | 900 | 2.7 | 62 | 0.71 | 0.82 | 2.6 | 1.9 | 1.7 | 10.9 | 6.7 |
| 0.37 | BN 71C | 6 | 910 | 3.9 | 66 | 0.69 | 1.17 | 3 | 2.4 | 2.0 | 12.9 | 7.7 |
| 0.37 | BN 80A | 6 | 910 | 3.9 | 68 | 0.68 | 1.15 | 3.2 | 2.2 | 2.0 | 21 | 9.9 |
| 0.55 | BN 80B | 6 | 920 | 5.7 | 70 | 0.69 | 1.64 | 3.9 | 2.6 | 2.2 | 25 | 11.3 |
| 0.75 | BN 80C | 6 | 920 | 7.8 | 70 | 0.65 | 2.38 | 3.8 | 2.5 | 2.2 | 28 | 12.2 |
| 0.75 | BN 90S | 6 | 920 | 7.8 | 69 | 0.68 | 2.31 | 3.8 | 2.4 | 2.2 | 26 | 12.6 |
| 1.1 | BN 90L | 6 | 920 | 11.4 | 72 | 0.69 | 3.2 | 3.9 | 2.3 | 2.0 | 33 | 15 |
| 1.5 | BN 100LA | 6 | 940 | 15.2 | 73 | 0.72 | 4.1 | 4 | 2.1 | 2.0 | 82 | 22 |
| 1.85 | BN 100LB | 6 | 930 | 19.0 | 75 | 0.73 | 4.9 | 4.5 | 2.1 | 2.0 | 95 | 24 |
| 2.2 | BN 112M | 6 | 940 | 22 | 78 | 0.73 | 5.6 | 4.8 | 2.2 | 2.0 | 168 | 32 |
| 3 | BN 132S | 6 | 940 | 30 | 76 | 0.76 | 7.5 | 4.8 | 1.9 | 1.8 | 216 | 36 |
| 4 | BN 132MA | 6 | 950 | 40 | 78 | 0.77 | 9.6 | 5.5 | 2.0 | 1.8 | 295 | 45 |
| 5.5 | BN 132MB | 6 | 945 | 56 | 80 | 0.78 | 12.7 | 5.9 | 2.1 | 1.9 | 383 | 56 |
| 7.5 | BN 160M | 6 | 955 | 75 | 84 | 0.81 | 15.9 | 5.9 | 2.2 | 2.0 | 740 | 83 |
| 11 | BN 160L | 6 | 960 | 109 | 87 | 0.81 | 22.5 | 6.5 | 2.5 | 2.3 | 970 | 103 |
| 15 | BN 180L | 6 | 970 | 148 | 88 | 0.82 | 30 | 6.2 | 2.0 | 2.4 | 1550 | 130 |
| 18.5 | BN 200LA | 6 | 960 | 184 | 88 | 0.81 | 37 | 5.9 | 2.0 | 2.3 | 1700 | 145 |

# AC motor PROS/CONS

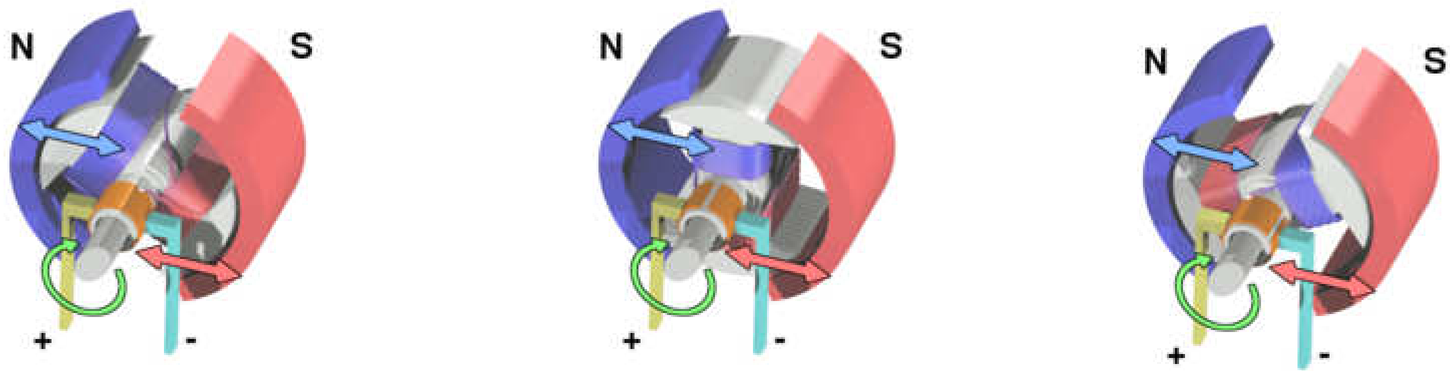
## PROS:

**Widely used industrially**
**No commutation**
**If required flexible control is available**
**Rugged**
**Wide range (<0.1 W:>> 1kW)**

## CONS:

**NO POSITION LOOP IS POSSIBLE**
**Low dynamics**
**Low torque/weight ratio**

# DC brushed motor



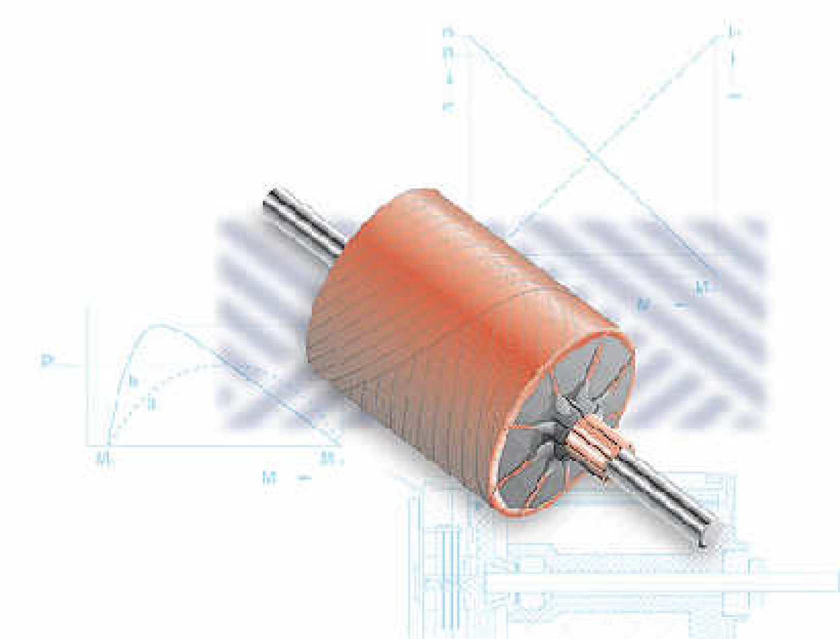

**General principia: static magnet and rotating coils**
**Coil commutation with "brushes"**

# DC brushed motor:

**Wound field DC motor** **(magnet replaced by coils: magnetic field strenght controlled by fixed coil currents )**

**Universal motor** **( wound fieldAC operated brushed motor, low cost- only copper no magnets)**

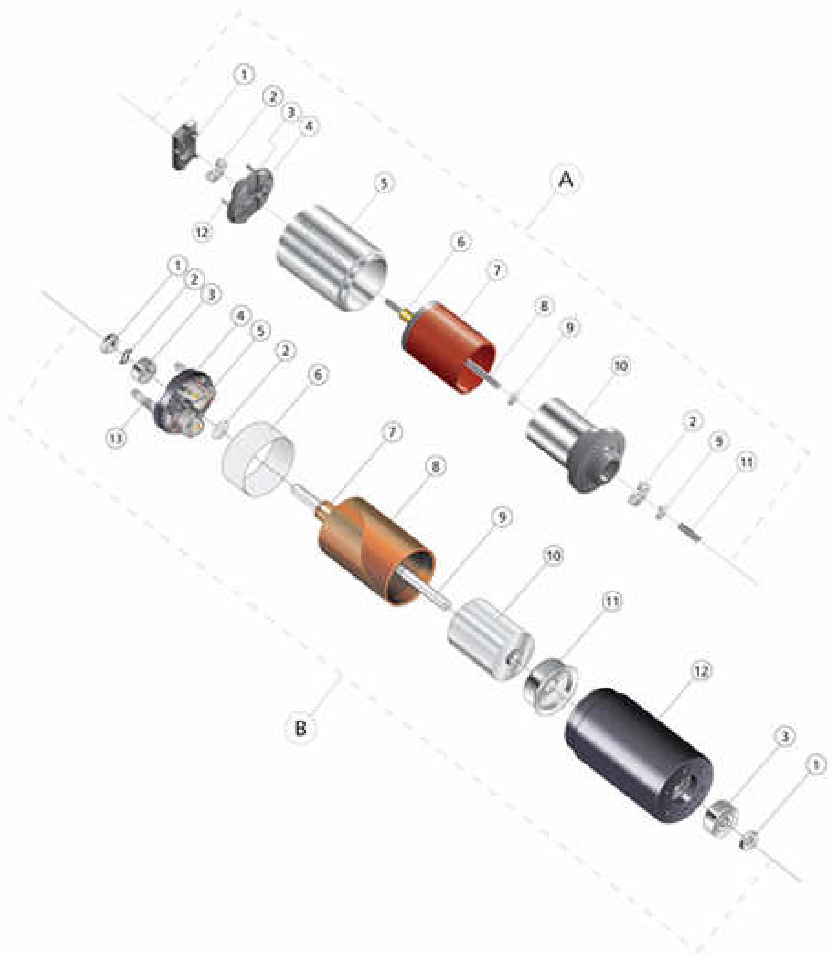
**Low inertia small size motor** **(small power high efficency high speed motors)**



## The "System FAULHABER®" Rotor Coil

The motor concept is simple yet revolutionary: a lightweight ironless copper coil rotates around a stationary permament magnet instead of rotating a heavy iron armature wound with copper wire.
Dr. Fritz Faulhaber's invention launched a whole new era in drive technology.
The FAULHABER System provides solutions for the ever more complex world of miniature drives.

# Low inertia small size DC motor
## (exploded view)




Micromotors C.C.

| A. Precious Metal Commutation | |
|---|---|
| 1 | End cap |
| 2 | Ball bearing |
| 3 | Brush cover |
| 4 | Brushes |
| 5 | Housing |
| 6 | Commutator |
| 7 | Coil |
| 8 | Shaft |
| 9 | Washer |
| 10 | Magnet |
| 11 | Bushing |
| 12 | Terminals |

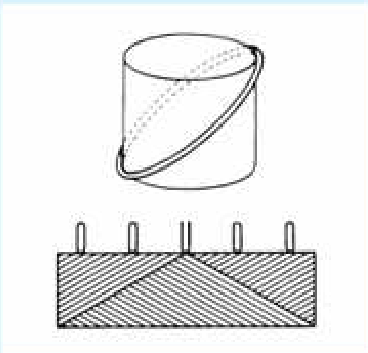
| B. Graphite Commutation | |
|---|---|
| 1 | Retaining ring |
| 2 | Spring washer |
| 3 | Ball bearing |
| 4 | Brush cover |
| 5 | Graphite brushes |
| 6 | Isolation ring |
| 7 | Commutator |
| 8 | Coil |
| 9 | Shaft |
| 10 | Magnet |
| 11 | Magnet support |
| 12 | Housing |
| 13 | Terminals |

## Motor-Characteristics

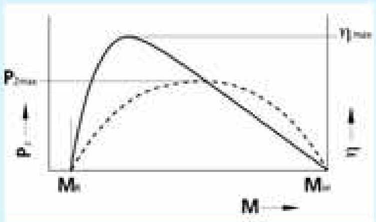
Coreless DC-Motors with the FAULHABER skew wound coil have linear performance characteristics.

- High power-to-volume ratio
- Low starting voltage
- Low inertia
- Very rapid starting
- High efficiency
- Linear voltage-speed relationship
- Linear current-torque relationship
- High precision assures long life

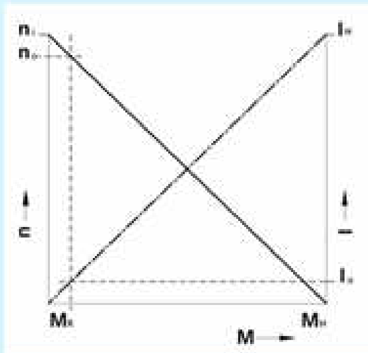
**P** = Power
**M** = Torque
**η** = Efficiency
**n** = Speed
**I** = Current



Skew wound coil




Output power and efficiency
as a function of torque




Current and speed
as functions of torque

**Take care: low inertia means low mass: low thermal inertia..It's really easy to get too hot!.. Take a look at continuous performances vs. peak performances !!**

# ..some equations about the fundamental electic motor (valid for both DC brushed and brushless)..

**The electrical equation is:**

$$V_T = I_R + L dI/dt + K_B\omega \qquad (1)$$

Where
$V_T$ = the terminal voltage across the active commutated phase
I = the sum of the phase currents into the motor
R = the equivalent input resistance of the active commutated phase
L = the equivalent input inductance of the active commutate phase
$K_B$ = the back EMF constant of the active commutated phase
$\omega$ = the angular velocity of the rotor

If the electrical time constant of the brushless DC motor is substantially less than the period of commutation, the steady state equation describing the voltage across the motor is:

$$V_T = I_R + K_B\omega \qquad (2)$$

The torque developed by the brushless DC motor is proportional to the input current.

$T = I K_T$

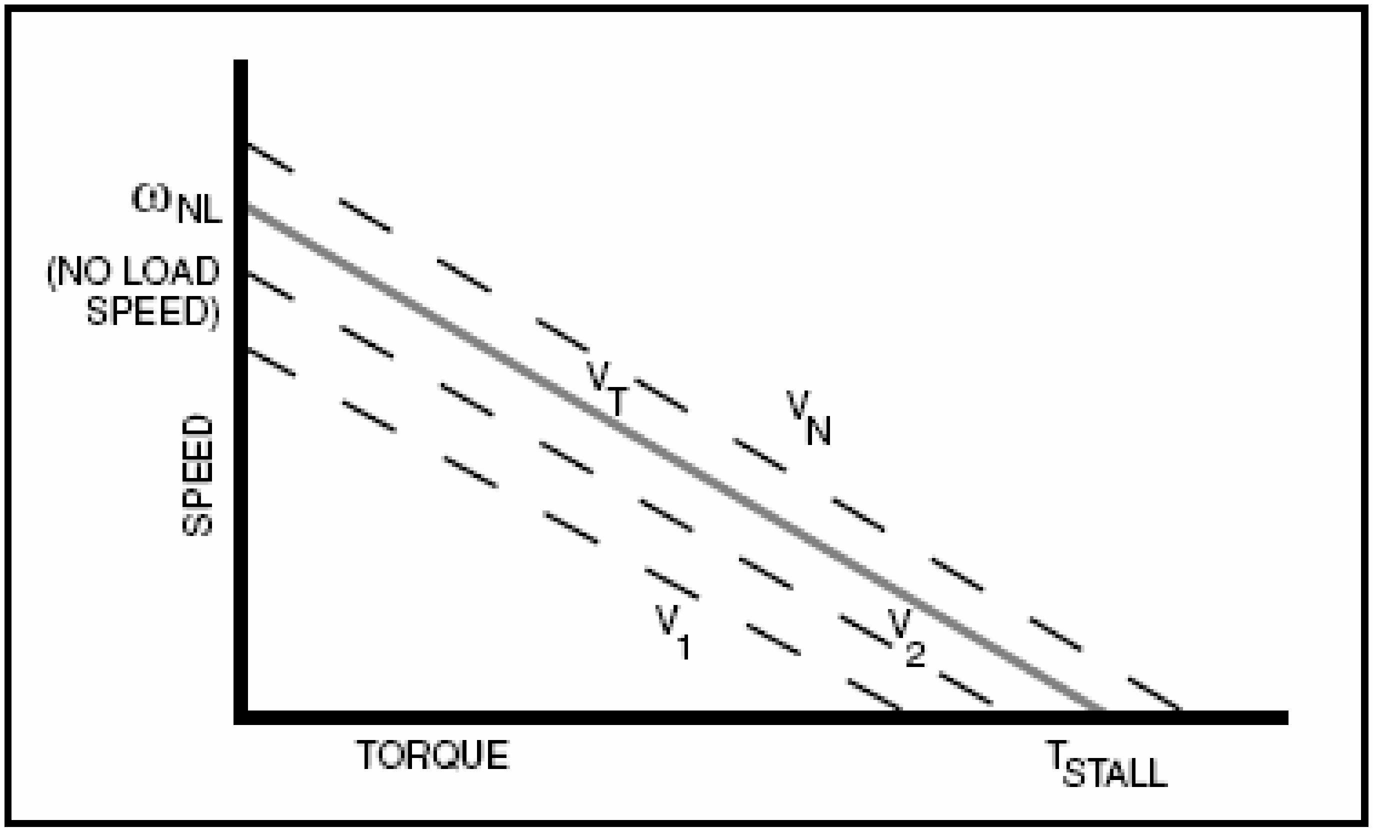
Where $K_T$ = the torque sensitivity

If we solve for I and substitute into Equation (2) we obtain:

$V_T = T/ K_T R + K_B \omega$ (3)

**The first term is the voltage required to give the required torque**

**The second term is the voltage rise for the back EMF**




*Speed torque characteristic curves.*

# Faulhaber DC brushed motor range (good for robotics)

**DC-Micromotors**

| Type | Commutation | Outer Ø (mm) | Length (mm) | Shaft Ø (mm) | Nominal voltage (Volt) | No-load speed (rpm) | Stall torque (mNm) | Output power (Watt) |
|---|---|---|---|---|---|---|---|---|
| 0615 ... S | Precious Metal | 6 | 15 | 1,5 | 1,5 ... 4,5 | 20 200 | 0,24 | 0,12 |
| 0816 ... S | Precious Metal | 8 | 16 | 1,5 | 3 ... 8 | 16 500 | 0,41 | 0,18 |
| 1016 ... G | Precious Metal | 10 | 16 | 1,5 | 3 ... 12 | 18 400 | 0,87 | 0,42 |
| 1024 ... S | Precious Metal | 10 | 24 | 1,5 | 3 ... 12 | 14 700 | 2,89 | 1,11 |
| 1219 ... G | Precious Metal | 12 | 19 | 1,5 | 4,5 ... 15 | 16 200 | 1,19 | 0,50 |
| 1224 ... S | Precious Metal | 12 | 24 | 1,5 | 6 ... 15 | 13 100 | 3,69 | 1,3 |
| 1319 ... SR | Precious Metal | 13 | 19 | 1,5 | 6 ... 24 | 14 600 | 2,91 | 1,10 |
| 1331 ... SR | Precious Metal | 13 | 31 | 1,5 | 6 ... 24 | 10 600 | 11,20 | 3,11 |
| 1336 ... C | Graphite | 13 | 36 | 2 | 6 ... 24 | 9 200 | 8,40 | 2,02 |
| 1516 ... S | Precious Metal | 15 | 16 | 1,5 | 1,5 ... 12 | 17 200 | 0,99 | 0,41 |
| 1516 ... SR | Precious Metal | 15 | 16 | 1,5 | 6 ... 12 | 12 900 | 1,61 | 0,54 |
| 1524 ... SR | Precious Metal | 15 | 24 | 1,5 | 3 ... 24 | 10 800 | 7,12 | 1,92 |
| 1624 ... S | Precious Metal | 16 | 24 | 1,5 | 3 ... 24 | 14 400 | 5,16 | 1,87 |
| 1717 ... SR | Precious Metal | 17 | 17 | 1,5 | 3 ... 24 | 14 000 | 5,38 | 1,97 |
| 1724 ... SR | Precious Metal | 17 | 24 | 1,5 | 3 ... 24 | 8 600 | 13,20 | 2,83 |
| 1727 ... C | Graphite | 17 | 27 | 2 | 6 ... 24 | 7 800 | 11,6 | 2,37 |
| 2224 ... SR | Precious Metal | 22 | 24 | 2 | 3 ... 36 | 8 200 | 21,40 | 4,55 |
| 2230 ... S | Precious Metal | 22 | 30 | 1,5 / 2 | 3 ... 40 | 9 600 | 14,70 | 3,69 |
| 2232 ... SR | Precious Metal | 22 | 32 | 2 | 6 ... 24 | 7 400 | 59,2 | 11 |
| 2233 ... S | Precious Metal | 22 | 33 | 1,5 / 2 | 4,5 ... 30 | 9 300 | 18,40 | 3,85 |
| 2342 ... CR | Graphite | 23 | 42 | 3 | 6 ... 48 | 9 000 | 91,40 | 20,50 |
| 2642 ... CR | Graphite | 26 | 42 | 4 | 12 ... 48 | 6 400 | 139 | 23,2 |
| 2657 ... CR | Graphite | 26 | 57 | 4 | 12 ... 48 | 6 400 | 286 | 47,9 |
| 3242 ... CR | Graphite | 32 | 42 | 5 | 12 ... 48 | 5 400 | 193 | 27,3 |
| 3257 ... CR | Graphite | 32 | 57 | 5 | 12 ... 48 | 5 900 | 547 | 84,5 |
| 3557 ... C | Graphite | 35 | 57 | 4 | 6 ... 32 | 5 000 | 122 | 15 |
| 3557 ... CS | Graphite | 35 | 57 | 4 | 9 ... 48 | 5 700 | 188 | 28,1 |
| 3863 ... C | Graphite | 38 | 63 | 6 | 12 ... 48 | 6 700 | 1 290 | 226 |

# ..some relevant data..

**Series 1024 ... S**

| | 1024 N | | | 003 S | 006 S | 012 S | |
|---|---|---|---|---|---|---|---|
| 1 | Nominal voltage | $U_N$ | | 3 | 6 | 12 | Volt |
| 2 | Terminal resistance | R | | 2,3 | 10,8 | 31,6 | Ω |
| 3 | Output power | $P_{2\ max.}$ | | 0,97 | 0,81 | 1,11 | W |
| 4 | Efficiency | $\eta_{max.}$ | | 79 | 78 | 79 | % |
| 5 | No-load speed | $n_o$ | | 13 800 | 13 200 | 14 700 | rpm |
| 6 | No-load current (with shaft ø 1,0 mm) | $I_o$ | | 0,016 | 0,008 | 0,004 | A |
| 7 | Stall torque | $M_H$ | | 2,69 | 2,34 | 2,89 | mNm |
| 8 | Friction torque | $M_R$ | | 0,03 | 0,03 | 0,03 | mNm |
| 9 | Speed constant | $k_n$ | | 4 658 | 2 231 | 1 240 | rpm/V |
| 10 | Back-EMF constant | $k_E$ | | 0,215 | 0,448 | 0,806 | mV/rpm |
| 11 | Torque constant | $k_M$ | | 2,05 | 4,28 | 7,70 | mNm/A |
| 12 | Current constant | $k_I$ | | 0,488 | 0,234 | 0,130 | A/mNm |
| 13 | Slope of n-M curve | $\Delta n/\Delta M$ | | 5 135 | 5 630 | 5 090 | rpm/mNm |
| 14 | Rotor inductance | L | | 26 | 100 | 344 | µH |
| 15 | Mechanical time constant | $\tau_m$ | | 6 | 7 | 6 | ms |
| 16 | Rotor inertia | J | | 0,12 | 0,12 | 0,12 | gcm² |
| 17 | Angular acceleration | $\alpha_{max.}$ | | 224 | 195 | 241 | ·10³rad/s² |
| 18 | Thermal resistance | $R_{th1}$ / $R_{th2}$ | 14 / 41 | | | | K/W |
| 19 | Thermal time constant | $\tau_{w1}$ / $\tau_{w2}$ | 5,0 / 289 | | | | s |
| 20 | Operating temperature range: | | | | | | |
| | – motor | | – 30 ... + 85 | | | | °C |
| | – rotor, max. permissible | | + 85 | | | | °C |
| 21 | Shaft bearings | | sintered bronze sleeves | | | | |
| 22 | Shaft load max.: | | | | | | |
| | – with shaft diameter | | 1,0 | | | | mm |
| | – radial at 3 000 rpm (1,5 mm from bearing) | | 0,5 | | | | N |
| | – axial at 3 000 rpm | | 0,1 | | | | N |
| | – axial at standstill | | 20 | | | | N |
| 23 | Shaft play: | | | | | | |
| | – radial | ≤ | 0,03 | | | | mm |
| | – axial | ≤ | 0,2 | | | | mm |
| 24 | Housing material | | steel, black coated | | | | |
| 25 | Weight | | 8,8 | | | | g |
| 26 | Direction of rotation | | clockwise, viewed from the front face | | | | |
| **Recommended values** | | | | | | | |
| 27 | Speed up to | $n_{e\ max.}$ | | 12 000 | 12 000 | 12 000 | rpm |
| 28 | Torque up to | $M_{e\ max.}$ | | 1,27 | 1,21 | 1,28 | mNm |
| 29 | Current up to (thermal limits) | $I_{e\ max.}$ | | 0,636 | 0,291 | 0,170 | A |

Check out:
Nominal torque is 50% peak torque

On bigger motor same kind ratio may be 1/5!

Remember nominal speed..we will discuss

motor is not always the limiting element of the chain

# ..some industrial sizes..

## BCS series  DC servomotors

### The proven and valuable choice when it comes to DC servomotors

The motors of the BCS series are of the permanent magnet type and will allow an approx. 400% peak torque over the rated torque. The particular construction guarantees extreme smoothness in operation, even at low speed.

**Locked Rotor Torque**
0,05 Nm ... 7,7 Nm

**Speed**
1.500, 2.000, 3.000, 4.000 min$^{-1}$

**Rated Voltage**
24 ... 180 Vdc

**Momentary Peak Torque**
400/500% over LRT

**Degree of Protection**
IP54

**Configurations**
IM B5 and IM B14 Flange Mount

**Options**
Failsafe DC Brake
Tacho-generator

## BC series  DC motors

### A comprehensive range of permanent magnet DC motors

The motors of the BC series are the simple, proven and economical solution to the requirements of DC drives. The materials and the design concepts exploited allow the use of BC motors under the severest duty and with 4-quadrants thyristor converters. Motors can be operated in the −20 to +40 °C temperature range and are IP54 protected and class F isolated.

**Torque Range**
0,3 Nm ... 4,5 Nm

**Speed**
1.500, 2.000, 3.000 min$^{-1}$

**Supply**
12, 24, 36, 48,65, 110, 180, Vdc

**Configurations**
IM B5 and IM B14 Flange Mount

**Ventilation**
BC110 ... BC140 non-ventilated
BC220 ... BC310 TEFC

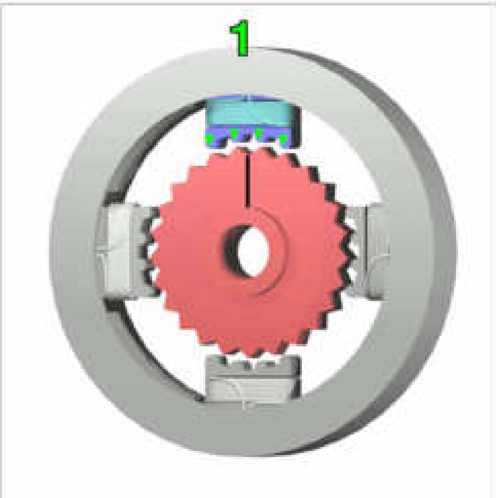
# DC brushed motor PROS/CONS

## PROS:

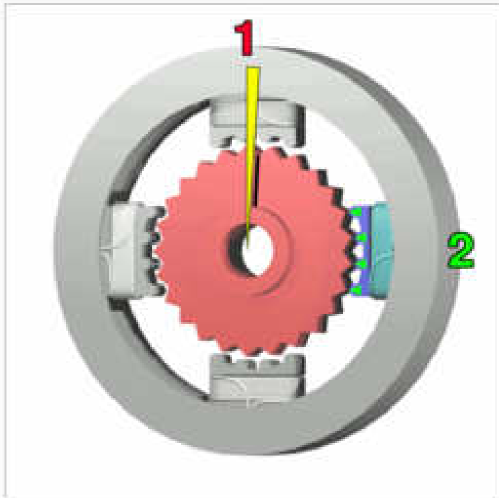
**DC driven**
**Easy to control (mechanical commutation)**
**Wide range (<0.1 W:>> 1kW)**

## CONS:

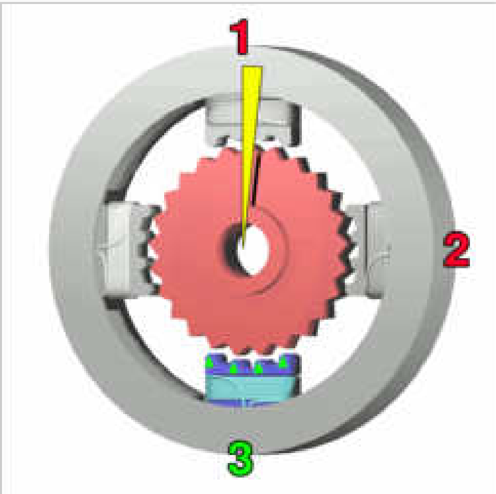
**Brushes wear out**
**Mechanical commutation may be critical**
**Limits in high speed (..low inertia rotors availables on low power motors..)**
**High power motors require wound field motor (cannot have HUGE magnets!)**



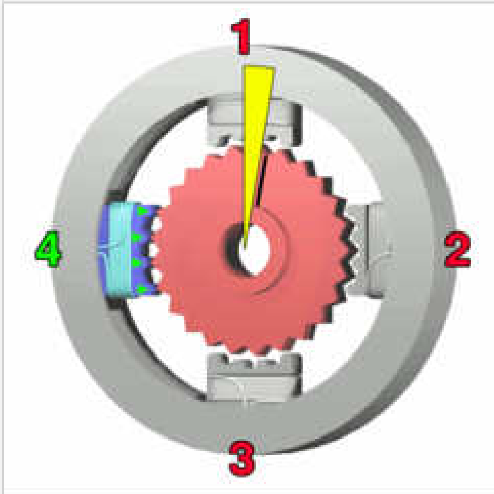

The top electromagnet (1) is charged, attracting the topmost four teeth of a sprocket.




The top electromagnet (1) is turned off, and the right electromagnet (2) is charged, pulling the nearest four teeth to the right. This results in a rotation of 3.6°.




The bottom electromagnet (3) is charged; another 3.6° rotation occurs.




The left electromagnet (4) is enabled, rotating again by 3.6°. When the top electromagnet (1) is again charged, the teeth in the sprocket will have rotated by one tooth position; since there are 25 teeth, it will take 100 steps to make a full rotation.

# Stepper Motor

*An internal rotor containing permanent magnets or a large iron core with salient poles is controlled by a set of external windings that are switched electronically*

The control is generally made in open loop

Closed loop generally exists as option.

Linear version with thread integrated in the rotor and translating screw (or screw integrated in the rotor and traslating nut)

Interesting solutions with motor unit with embedded control board

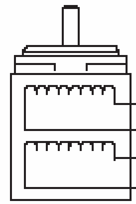
Sophisticate driver monitors the winding current to sense the right step commutation (if a “step” is missed the control compensates)

# ..some stepper examples..

**small size (NEMA 14)**

# STEPPER SIZE 14

## *1.8° ENHANCED HYBRID STEPPING MOTOR*

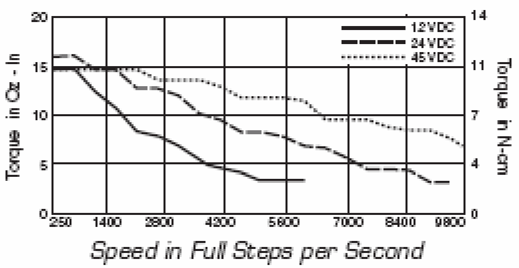


| Motor Connection | |
|---|---|
| WIRE COLOR | PHASE |
| black | ØA |
| green | Ø$\overline{A}$ |
| red | ØB |
| blue | Ø$\overline{B}$ |

| Part Number | Holding Torque oz-in [N-cm] | Phase Current Amps | Number of Leads | Phase Resistance ohms | Phase Inductance mH | Detent Torque oz-in [N-cm] | Rotor Inertia oz-in-sec² [kg-cm²] | LMax Length inches [mm] | Weight oz [g] |
|---|---|---|---|---|---|---|---|---|---|
| M-1410-0.75[X]* | 10 (7) | 0.75 | 4 | 4.3 | 4 | 1.4 (1.0) | 0.00017 (0.012) | 1.02 (26) | 4.2 (120) |

## *TORQUE-SPEED CURVES*

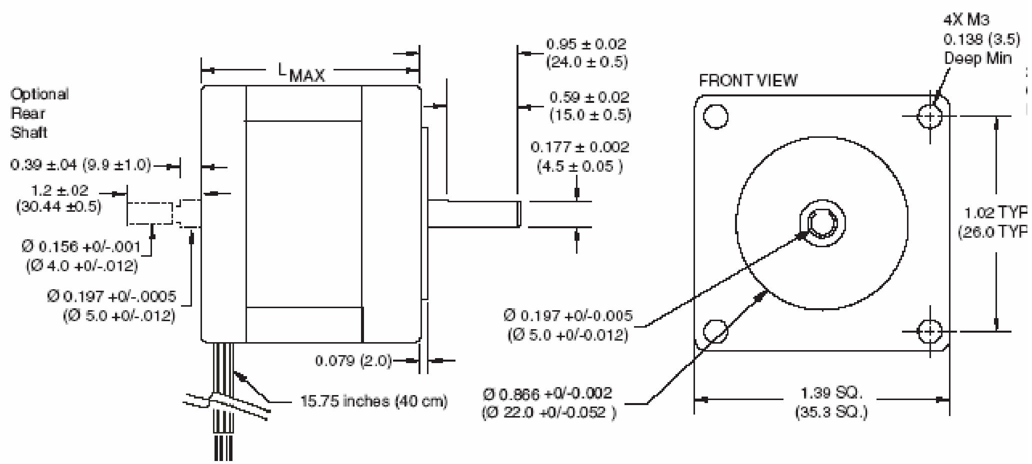
**M-1410-0.75, 0.75 Amps RMS**




Torque decreases with speed, slope is function of winding voltage.
Speed in steps per second (200 step per turn)

## *MECHANICAL SPECIFICATIONS*

Dimensions in Inches (mm)

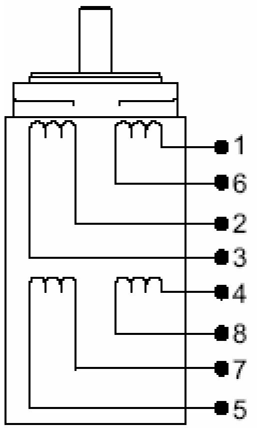


**BIG size (NEMA 42)**

# SIZE 42 1.8° HYBRID STEPPING MOTORS

| Specifications S=Single Shaft (D=Double Shaft) | Holding Torque oz-in (N-cm) | Phase Current Amps | | Number of Leads | Phase Resistance Ohms | | Phase Inductance mH | | Detent Torque oz-in (N-cm) | Rotor Inertia oz-in-sec$^2$ (kg-cm$^2$) | $L_{MAX}$ Length inches (cm) | Weight oz (gm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Series | Parallel | | Series | Parallel | Series | Parallel | | | | |
| M2-4247-S (D) | 810 (572) | 5.0 | 10.0 | 8 | 0.46 | 0.115 | 24.64 | 6.16 | 13.0 (9.2) | 0.055 (3.8838) | 5.39 (13.69) | 216 (6125.6) |
| M2-4270-S (D) | 1440 (1017) | 5.0 | 10.0 | 8 | 0.88 | 0.220 | 29.81 | 7.45 | 26.0 (18.4) | 0.114 (8.0502) | 7.55 (19.18) | 320 (9072) |
| M2-4288-S (D) | 2100 (1483) | 5.0 | 10.0 | 8 | 1.00 | 0.250 | 22.24 | 5.56 | 39.0 (27.5) | 0.172 (12.1458) | 9.72 (24.69) | 424 (12020.4) |

## *CONNECTION*



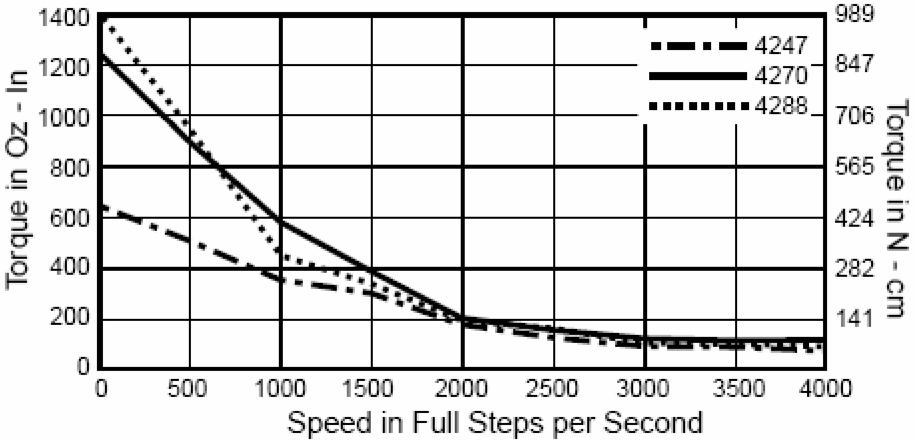

**Motor Connection**

| WIRE NO. | SERIES | PARALLEL |
|---|---|---|
| 1 | A | A |
| 2 | Connect Together | A |
| 6 | Connect Together | $\overline{A}$ |
| 3 | $\overline{A}$ | $\overline{A}$ |
| 4 | B | B |
| 7 | Connect Together | B |
| 8 | Connect Together | $\overline{B}$ |
| 5 | $\overline{B}$ | $\overline{B}$ |

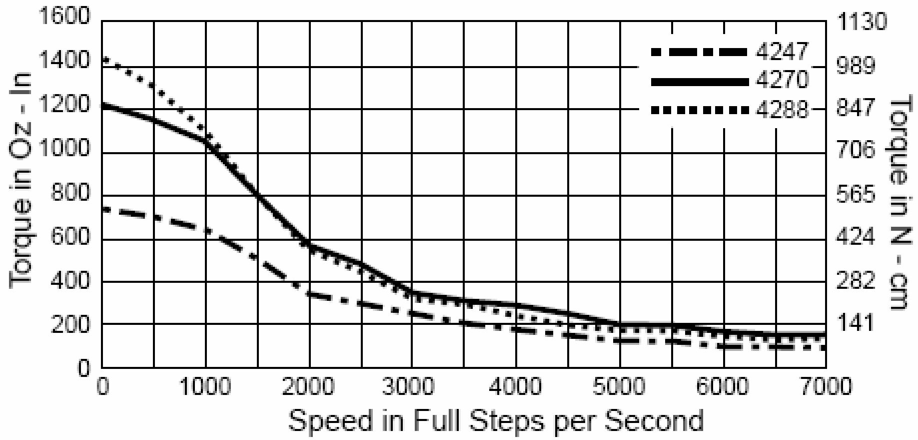
Same FRAME (frontal dimension, rotor diameter)
Several stack length
(we will see that this is typical for most motors)

## *TORQUE SPEED CURVES*

### Series: 5 Amps RMS, 75 VDC

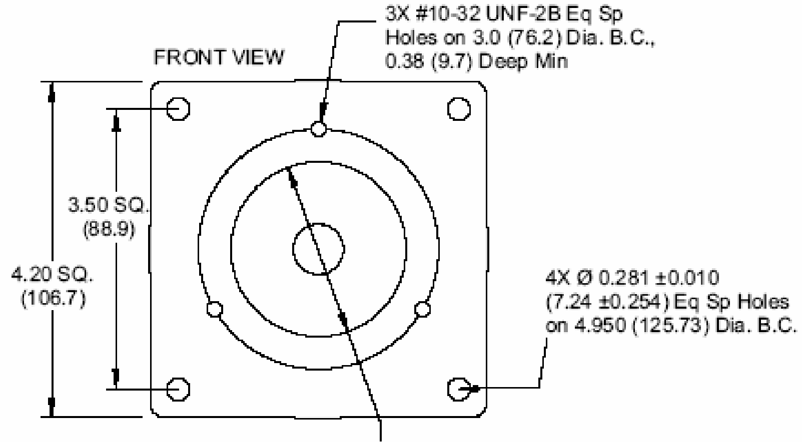


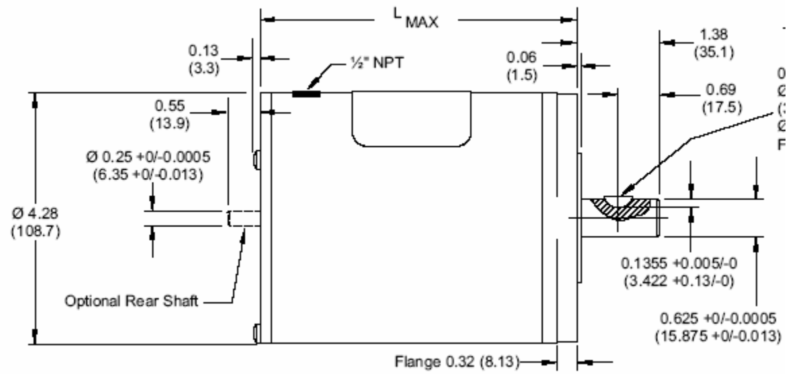

### Parallel: 9 Amps RMS, 75 VDC




## *MECHANICAL*

Dimensions in Inches (mm)




Changing the connection beteween coils
change the motor characteristic

# Stepper motor PROS/CONS

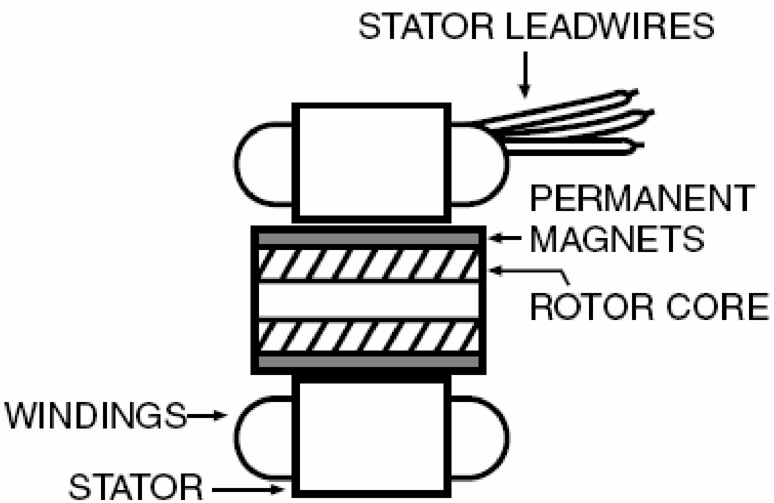
## PROS:

**For low power low cost application good for simple position control: motor is controlled in steps (angle);**
**Ideally direct drive;**
**With embedded control may be a simple and cheap solution for small positioning units.**

## CONS:

**At high dynamics or for unexpected overload may "loose the step" without noticing (this may be avoided adding closed loop control)**

# Brushless Motor




**In a brushless motor the field of the stator is commutated electronically to follow the position of the rotor**

# Brushless Motor

**Using high efficency magnet in the rotor high power density may be reached**

**In some application the magnetic rotor may be external to an internal fixed coil group (eg. direct drive wheel with magnet on wheel and coils on hub)**

# Brushless Motor

**Brushless have several advantages over conventional motors:**
**Higher efficiency than  AC motors.**

**Without commutation that wear out, the life of a brushless motor can be significantly longer compared to a DC motor using brushes**
**(Commutation also tends to cause a great deal of electrical and RF noise);**

# Brushless Motor

**The commutation feedback may be done using:**

**A set of hall sensors that detect the magnetic poles of the rotor (see next lesson about sensors);**

**Another feedback device as a Resolver or an Encoder coupled to the rotor shaft (see next lesson about sensors);**

**The back EMF of the winding (sensor-less)**

# ..again the same equations about the (brushless) electic motor..

**The electrical equation is:**

$V_T = I_R + L dI/dt + K_B \omega$ (1)

Where

$V_T$ = the terminal voltage across the active commutated phase

$I$ = the sum of the phase currents into the motor

$R$ = the equivalent input resistance of the active commutated phase

$L$ = the equivalent input inductance of the active commutate phase

$K_B$ = the back EMF constant of the active commutated phase

$\omega$ = the angular velocity of the rotor

If the electrical time constant of the brushless DC motor is substantially less than the period of commutation, the steady state equation describing the voltage across the motor is:

$V_T = I_R + K_B \omega$ (2)

The torque developed by the brushless DC motor is proportional to the input current.

$T = I K_T$

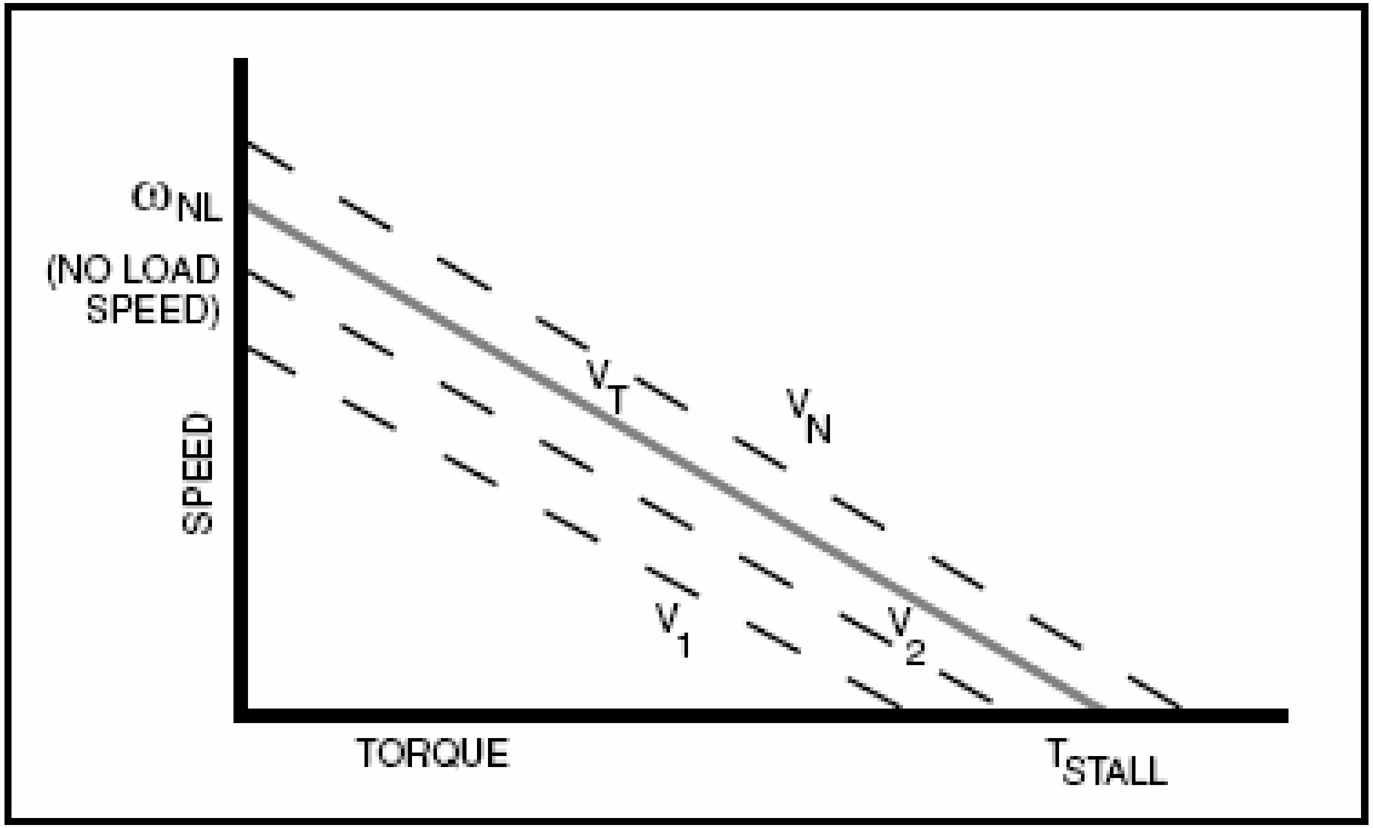
Where $K_T$ = the torque sensitivity

If we solve for I and substitute into Equation (2) we obtain:

$V_T = T / K_T R + K_B \omega$ (3)

**The first term is the voltage required to give the required torque**

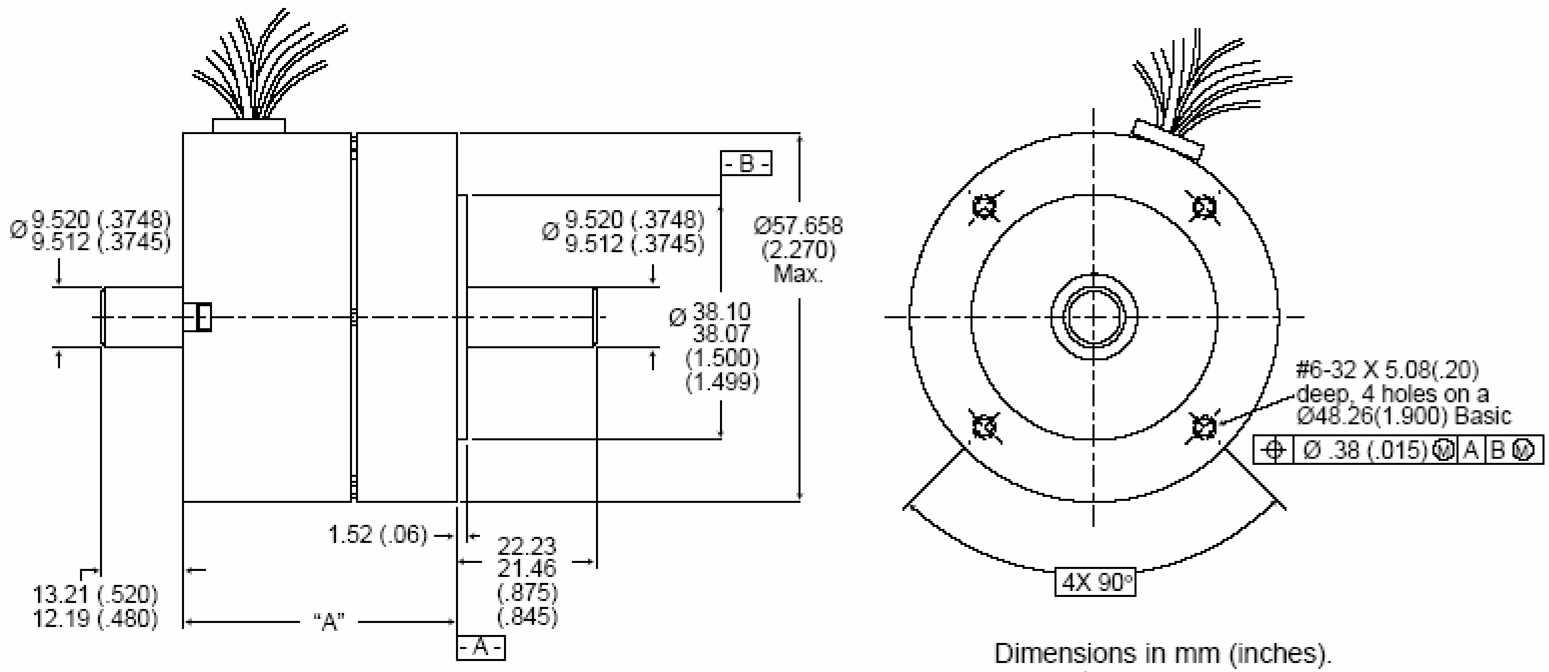
**The second term is the voltage rise for the back EMF**




*Speed torque characteristic curves.*

# A brushless motor

## RBEH-0121X-X00




Dimensions in mm (inches).
Product designed in inches.
Metric conversions provided for reference only.

Notes:

1) Shaft end play: with a 9 lb reversing load, the axial displacement shall be .013-.15 (.0005-.006).
2) For a C.C.W. rotation, as viewed from pilot end, energize per excitation sequence table.
3) V-AB, V-BC and V-CA is back EMF of motor phases AB, BC and CA respectively, aligned with sensor output as shown for C.C.W. rotation only.

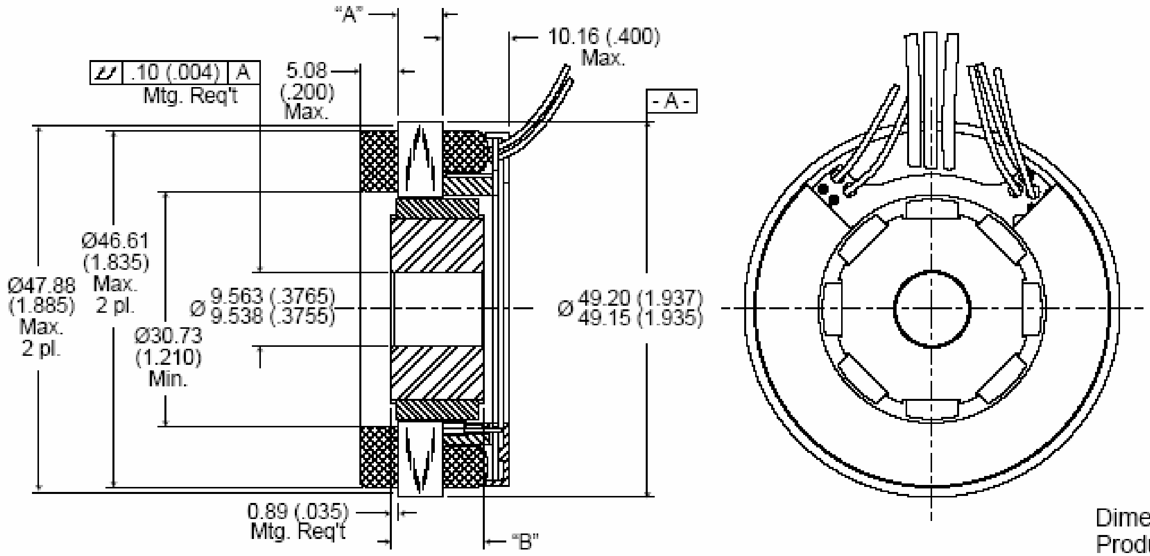
| MODEL NUMBER | RBEH-01210 | RBEH-01211 | RBEH-01212 | RBEH-01213 | RBEH-01214 | RBEH-01215 |
|---|---|---|---|---|---|---|
| "A" Dimension | 43.05 (1.695) | 50.04 (1.970) | 56.39 (2.220) | 62.74 (2.470) | 70.36 (2.770) | 88.14 (3.470) |

# A brushless motor (iCub) – FRAMELESS

## RBE(H) Motor Series

DIMENSIONS

### RBE-0121X-X00




Dimensions in mm (inches).
Product designed in inches.
Metric conversions provided for reference only.

| MODEL NUMBER | RBE-01210 | RBE-01211 | RBE-01212 | RBE-01213 | RBE-01214 | RBE-01215 |
|---|---|---|---|---|---|---|
| "A" Dimension | 5.72 (0.225) | 12.7 (0.500) | 19.05 (0.750) | 25.4 (1.000) | 33.02 (1.300) | 50.8 (2.000) |
| "B" Dimension | 12.07 (0.475) | 19.05 (0.750) | 25.4 (1.000) | 31.75 (1.250) | 39.37 (1.550) | 57.15 (2.250) |
| Tolerance ± .010 on "A" Dimension. | | | | | | |

Notes:

1) For a C.W. rotation, as viewed from lead end, energize per excitation sequence table.
2) V-AB, V-BC and V-CA is back EMF of motor phases AB, BC and CA respectively, aligned with sensor output as shown for C.W. rotation only.
3) Mounting surface is between Ø 47.88 (1.885) and Ø 49.17 (1.936) on both sides.

For a given diameter 6 different lenghts

# RBE(H) Motor Series

## RBE(H) 01210 MOTOR SERIES PERFORMANCE DATA

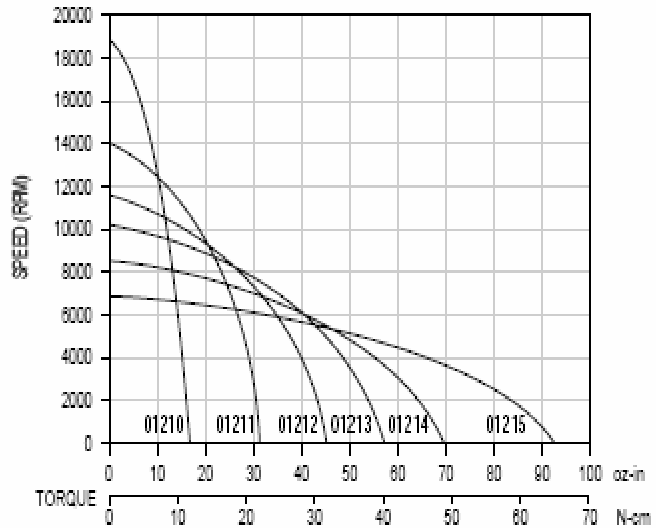
| Motor Parameters | | Symbols | Units | 01210 | 01211 | 01212 | 01213 | 01214 | 01215 |
|---|---|---|---|---|---|---|---|---|---|
| Max Cont. Output Power | | HP Rated | HP | 0.142 | 0.204 | 0.243 | 0.272 | 0.290 | 0.310 |
| at 25°C amb. | | P Rated | Watts | 106 | 152 | 181 | 203 | 216 | 231 |
| Speed at Rated Power | | N Rated | RPM | 13800 | 9680 | 8100 | 7152 | 6230 | 5100 |
| Max Mechanical Speed | | N Max | RPM | 18000 | 18000 | 18000 | 18000 | 18000 | 18000 |
| Continuous Stall Torque | | Tc | oz-in | 16.4 | 31.6 | 43.5 | 54.8 | 66.2 | 90.4 |
| at 25°C amb. | | | N-m | 0.115 | 0.223 | 0.307 | 0.387 | 0.467 | 0.639 |
| Peak Torque | | Tp | oz-in | 48.4 | 114 | 168 | 222 | 282 | 435 |
| | | | N-m | 0.342 | 0.806 | 1.18 | 1.57 | 1.99 | 3.07 |
| Max Torque | | Tsl | oz-in | 48.4 | 114 | 168 | 222 | 282 | 435 |
| for Linear KT | | | N-m | 0.342 | 0.806 | 1.18 | 1.57 | 1.99 | 3.07 |
| Motor Constant | | Tm | oz-in/ $\sqrt{W}$ | 4.00 | 7.12 | 9.50 | 11.7 | 13.9 | 18.4 |
| | | | N-m/ $\sqrt{W}$ | 0.028 | 0.050 | 0.067 | 0.083 | 0.098 | 0.130 |
| Thermal Resistance* | | Rth | °C/Watt | 4.25 | 3.86 | 3.68 | 3.55 | 3.44 | 3.27 |
| Viscous Damping | | Fi | oz-in/RPM | 1.30E-04 | 2.96E-04 | 4.46E-04 | 5.97E-04 | 7.78E-04 | 1.20E-03 |
| | | | N-m/RPM | 9.18E-07 | 2.09E-06 | 3.15E-06 | 4.22E-06 | 5.49E-06 | 8.48E-06 |
| Max Static Friction | | Tf | oz-in | 1.70 | 2.13 | 2.53 | 2.92 | 3.40 | 4.50 |
| | | | N-m | 0.0120 | 0.015 | 0.018 | 0.021 | 0.024 | 0.032 |
| Max Cogging Torque | | Tcog | oz-in | 0.41 | 0.66 | 0.88 | 1.10 | 1.37 | 2.00 |
| Peak to Peak | | | N-m | 0.0029 | 0.0046 | 0.0062 | 0.0078 | 0.0097 | 0.014 |
| Frameless Motor | Inertia | Jmf | oz-in-sec$^2$ | 7.30E-04 | 1.20E-03 | 1.70E-03 | 2.10E-03 | 2.70E-03 | 4.00E-03 |
| | | | Kg-m$^2$ | 5.15E-06 | 8.47E-06 | 1.20E-05 | 1.48E-05 | 1.91E-05 | 2.82E-05 |
| | Weight | Wtf | oz | 4.5 | 7.2 | 9.6 | 12.1 | 15.1 | 22.0 |
| | | | Kg | 1.26E-01 | 2.03E-01 | 2.74E-01 | 3.44E-01 | 4.28E-01 | 6.24E-01 |
| Housed Motor | Inertia | Jmh | oz-in-sec$^2$ | 7.60E-04 | 1.30E-03 | 1.80E-03 | 2.20E-03 | 2.80E-03 | 4.20E-03 |
| | | | Kg-m$^2$ | 5.37E-06 | 9.18E-06 | 1.27E-05 | 1.55E-05 | 1.98E-05 | 2.97E-05 |
| | Weight | Wth | oz | 11.3 | 14.2 | 16.8 | 19.5 | 22.6 | 30.0 |
| | | | Kg | 3.20E-01 | 4.02E-01 | 4.77E-01 | 5.52E-01 | 6.41E-01 | 8.50E-01 |
| No. of poles | | P | | 8 | 8 | 8 | 8 | 8 | 8 |

For each motor different electric characteristic are available

| Winding Constants | Symbols | Units | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Current at Cont. Torque | Ic | Amps | 5.41 | 3.89 | 6.95 | 5.81 | 3.63 | 9.06 | 5.42 | 3.38 | 8.45 | 5.77 | 4.00 | 8.88 | 6.15 | 3.73 | 8.61 | 5.46 | 3.31 | 7.64 |
| Current at Peak Torque | Ip | Amps | 15.0 | 10.6 | 18.9 | 20.0 | 10.6 | 26.8 | 20.0 | 10.6 | 26.8 | 22.5 | 13.4 | 30.1 | 25.3 | 13.4 | 35.8 | 25.3 | 13.4 | 35.8 |
| Torque Sensitivity | Kt | oz-in/Amp | 3.34 | 4.64 | 2.60 | 5.80 | 9.30 | 3.72 | 8.49 | 13.6 | 5.45 | 10.0 | 14.5 | 6.50 | 11.3 | 18.7 | 8.08 | 17.4 | 28.7 | 12.4 |
| | | N-m/Amp | 0.0236 | 0.0328 | 0.0183 | 0.0410 | 0.0657 | 0.0263 | 0.0600 | 0.0962 | 0.0385 | 0.0707 | 0.102 | 0.0459 | 0.0799 | 0.132 | 0.0571 | 0.123 | 0.203 | 0.0878 |
| Back EMF constant | Kb | V/KRPM | 2.47 | 3.43 | 1.92 | 4.29 | 6.88 | 2.75 | 6.28 | 10.1 | 4.03 | 7.41 | 10.7 | 4.81 | 8.36 | 13.8 | 5.97 | 12.9 | 21.2 | 9.19 |
| Motor Resistance | Rm | Ohms | 0.698 | 1.38 | 0.431 | 0.664 | 1.75 | 0.276 | 0.803 | 2.11 | 0.334 | 0.733 | 1.55 | 0.307 | 0.666 | 1.82 | 0.336 | 0.890 | 2.43 | 0.450 |
| Motor Inductance | Lm | mH | 0.280 | 0.54 | 0.17 | 0.32 | 0.83 | 0.13 | 0.44 | 1.1 | 0.18 | 0.47 | 0.97 | 0.20 | 0.48 | 1.3 | 0.25 | 0.71 | 1.9 | 0.36 |

*Rth assumes a housed motor mounted to a 4.0" x 3.75" x 0.25" aluminum heatsink or equivalent

## Continuous Duty Capability for 130°C Rise — RBE - 01210 Series



# Low inertia brushless from faulhaber..

**Brushless DC-Motors** with integral Drive Electronics *

| Type | Commutation | Outer Ø (mm) | Length (mm) | Shaft Ø (mm) | Nominal voltage (Volt) | No-load speed (rpm) | Starting torque (mNm) | Output power (Watt) |
|---|---|---|---|---|---|---|---|---|
| 1525 ... BRC | Electronic* | 15 | 25 | 2 | 9 ... 15 | 16 000 | 3,6 | 2,3 |
| 1935 ... BRE | Electronic * | 19 | 35 | 3 | 6 ... 12 | 7 650 | 4,4 | 1,8 |
| 3153 ... BRC | Electronic * | 31 | 53 | 4 | 9 ... 24 | 5 200 | 33 | 15,5 |

| **Download** > **Technical information** (.pdf 350 Kb) | English | Deutsch | Français | Italiano |
|---|---|---|---|---|
| Brushless DC-Motors | | | | |

**Brushless DC-Servomotors**

| Type | Commutation | Outer Ø (mm) | Length (mm) | Shaft Ø (mm) | Nominal voltage (Volt) | No-load speed (rpm) | Starting torque (mNm) | Output power (Watt) |
|---|---|---|---|---|---|---|---|---|
| 0620 ... B | Electronic | 06 | 20 | 1 | 6 ... 12 | 47 000 | 0,73 | 1,58 |
| 1628 ... B | Electronic | 16 | 28 | 1,5 | 12 ... 24 | 29 900 | 12 | 11 |
| 2036 ... B | Electronic | 20 | 36 | 2 | 12 ... 48 | 19 500 | 23 | 20 |
| 2444 ... B | Electronic | 24 | 44 | 3 | 24 ... 48 | 23 000 | 115 | 37 |
| 3056 ... B | Electronic | 30 | 56 | 4 | 12 ... 48 | 8 840 | 100 | 49 |
| 3564 ... B | Electronic | 35 | 64 | 4 | 12 ... 48 | 12 200 | 401 | 109 |
| 4490 ... B | Electronic | 44 | 90 | 6 | 24 ... 48 | 11 000 | 2 758 | 201 |
| 4490 ... BS | Electronic | 44 | 90 | 6 | 24 ... 48 | 6 060 | 1 689 | 212 |

| **Download** > **Technical information** (.pdf 750 Kb) | English | Deutsch | Français | Italiano |
|---|---|---|---|---|
| Brushless DC-Servomotors | | | | |

**Brushless DC-Servomotors** with integrated Motion Controller *

| Type | Commutation | Outer Ø (mm) | Length (mm) | Shaft Ø (mm) | Nominal voltage (Volt) | No-load speed (rpm) | Starting torque (mNm) | Output power (Watt) | Instruction manual Download |
|---|---|---|---|---|---|---|---|---|---|
| 3564 ... BC | Electronic * | 35 | 83 | 4 | 24 | 9 000 | 160 | 70 | (1208 KB) |

# Typical industrial range..

| | | | | Winding A (230V) | | Winding 4 (400V) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Stall Torque [Nm] | Peak Torque [Nm] | Stall Current [Arms] | Peak Speed [rpm] @230V | Peak Speed [rpm] @400V | Stall Current [Arms] | Peak Speed [rpm] @400V | Length without Brake [mm] | Flange Size [mm] |
| BL 040 | 0.3 | 1.3 | 1.02 | 10000 | - | - | - | 112 | 41 |
| BL 055 | 0.68 | 2.8 | 1.36 | 7700 | 11000 | 0.76 | 7000 | 140 | 57 |
| BL 071 | 0.8 | 4.8 | 2.23 | 8200 | 11000 | 1.27 | 10000 | 100 | 70 |
| BL 072 | 1.85 | 11.1 | 4.12 | 7600 | 11000 | 2.17 | 7800 | 120 | 70 |
| BL 073 | 2.72 | 16.3 | 3.83 | 5300 | 8200 | 2.26 | 5500 | 138 | 70 |
| BL 074 | 3.43 | 20.6 | 4.34 | 4600 | 7100 | 2.32 | 4500 | 156 | 70 |
| BL 111 | 2.9 | 17.3 | 3.6 | 4300 | 6900 | 2.13 | 4400 | 124 | 106 |
| BL 112 | 5.0 | 30.1 | 6.4 | 4400 | 7100 | 3.52 | 4400 | 149 | 106 |
| BL 113 | 8.4 | 50.4 | 10.4 | 4700 | 7400 | 5.99 | 4400 | 174 | 106 |
| BL 114 | 10.6 | 63.7 | 13.1 | 4900 | 7900 | 7.53 | 4400 | 199 | 106 |
| BL 115 | 13.9 | 83.1 | 17.1 | 4700 | 7700 | 9.89 | 4400 | 224 | 106 |
| BL 141 | 13.6 | 81.6 | 13.7 | 3700 | 6000 | 7.46 | 3500 | 193 | 140 |
| BL 142 | 17.4 | 104.6 | 15.2 | 3300 | 5400 | 8.17 | 3000 | 214 | 140 |
| BL 143 | 26.8 | 160.5 | 19.4 | 2750 | 4500 | 10.68 | 2500 | 258 | 140 |
| BL 144 | 33.0 | 198.2 | 18.3 | 2300 | 3700 | 9.90 | 1900 | 300 | 140 |

Generally industrial range motors are defined in terms of nominal torque at nominal speed (look at the flange sizes)

# Brushless motor PROS/CONS

**PROS:**

**High performance**

**High efficency**

**CONS:**

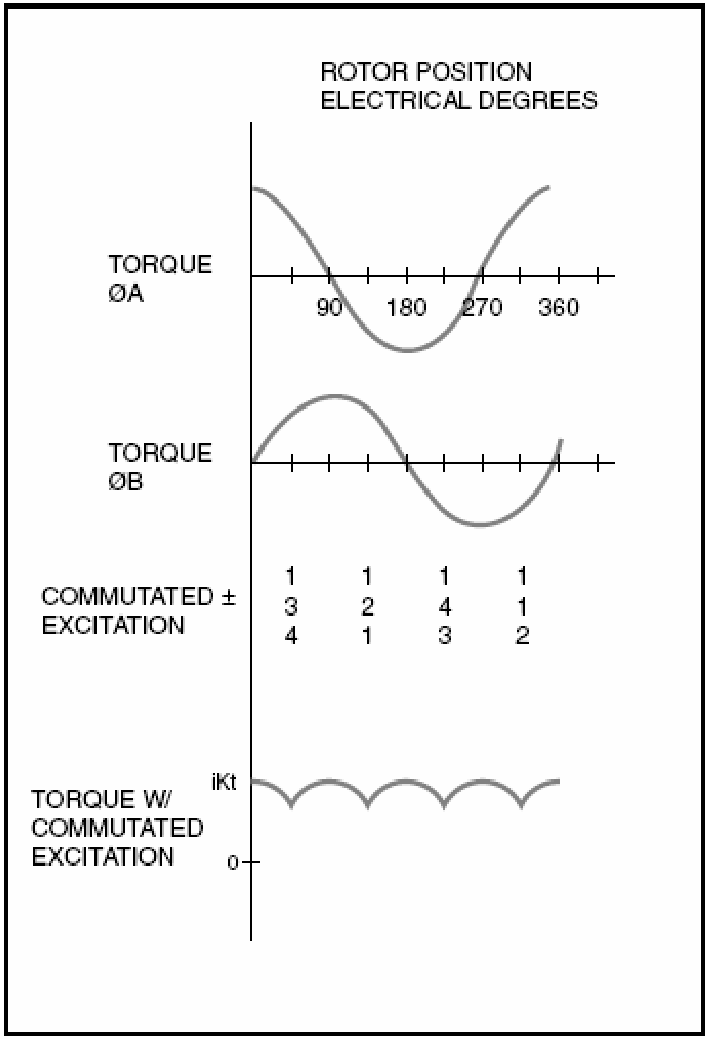
**Higher cost**

**Requires commutation control**

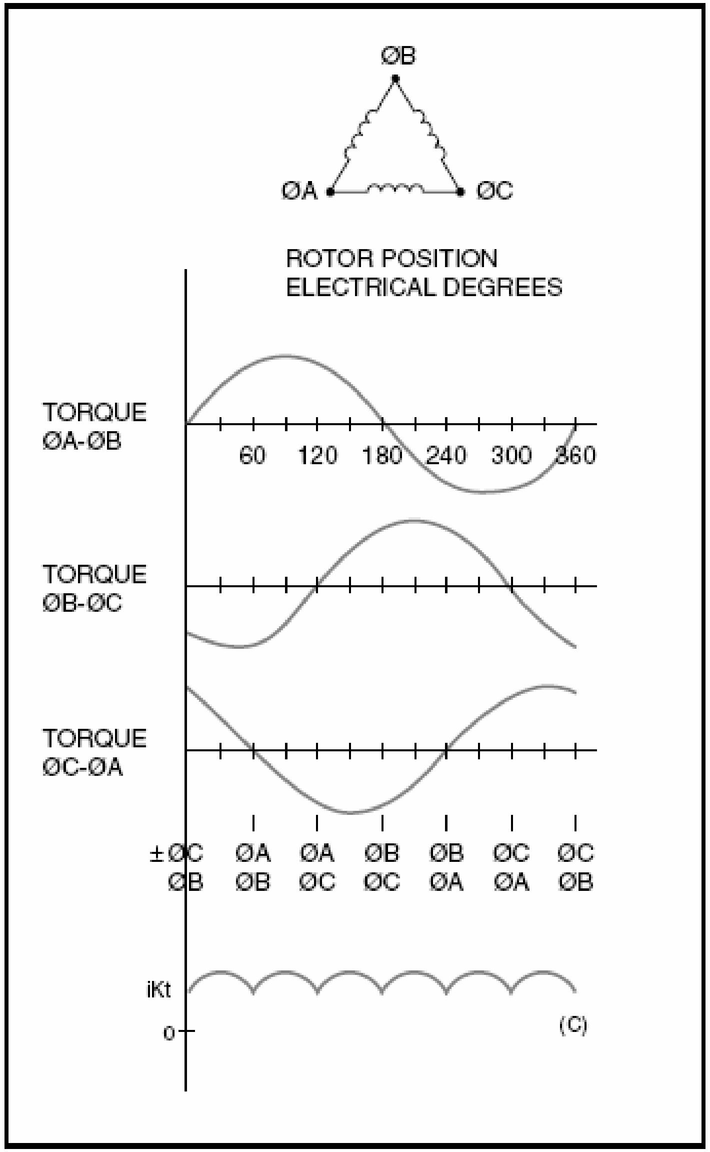
# Torque motors

**A torque motor is generically defined as a motor optimized to give high torques at low speed with low cog**

**Torque motor can be both brushed or brushless**




*Switch mode commutation of a two phase brushless DC motor.*




*Switch mode commutation of a three phase delta wound brushless DC motor.*

**Increasing the number of phases from 2 to 3 decrease the torque ripple form 17% to 7% of nominal torque**

**In a torque motor the number of poles per phase can be tipically 12 or 16 with <1% of torque ripple**

# RBE(H) Motor Series

## RBE(H) 01210 MOTOR SERIES PERFORMANCE DATA

| Motor Parameters | Symbols | Units | 01210 | 01211 | 01212 | 01213 | 01214 | 01215 |
|---|---|---|---|---|---|---|---|---|
| Max Cont. Output Power | HP Rated | HP | 0.142 | 0.204 | 0.243 | 0.272 | 0.290 | 0.310 |
| at 25°C amb. | P Rated | Watts | 106 | 152 | 181 | 203 | 216 | 231 |
| Speed at Rated Power | N Rated | RPM | 13800 | 9680 | 8100 | 7152 | 6230 | 5100 |
| Max Mechanical Speed | N Max | RPM | 18000 | 18000 | [illegible] | [illegible] | [illegible] | [illegible] |
| Continuous Stall Torque | Tc | oz-in | 16.4 | 31.6 | [illegible] | [illegible] | [illegible] | [illegible] |
| at 25°C amb. | | N-m | 0.115 | 0.223 | [illegible] | [illegible] | [illegible] | [illegible] |
| Peak Torque | Tp | oz-in | 48.4 | 114 | [illegible] | [illegible] | [illegible] | [illegible] |
| | | N-m | 0.342 | 0.806 | 1.18 | 1.57 | 1.99 | 3.07 |
| Max Torque | Tsl | oz-in | 48.4 | 114 | 168 | 222 | 282 | 435 |
| for Linear KT | | N-m | 0.342 | 0.806 | 1.18 | 1.57 | 1.99 | 3.07 |
| Motor Constant | Tm | $oz\text{-}in/\sqrt{W}$ | 4.00 | 7.12 | 9.50 | 11.7 | 13.9 | 18.4 |
| | | $N\text{-}m/\sqrt{W}$ | 0.028 | 0.050 | 0.067 | 0.083 | 0.098 | 0.130 |
| Thermal Resistance* | Rth | °C/Watt | 4.25 | 3.86 | 3.68 | 3.55 | 3.44 | 3.27 |
| Viscous Damping | Fi | oz-in/RPM | 1.30E-04 | 2.96E-04 | 4.46E-04 | 5.97E-04 | 7.78E-04 | 1.20E-03 |
| | | N-m/RPM | 9.18E-07 | 2.09E-06 | 3.15E-06 | 4.22E-06 | 5.49E-06 | 8.48E-06 |
| Max Static Friction | Tf | oz-in | 1.70 | 2.13 | 2.53 | 2.92 | 3.40 | 4.50 |
| | | N-m | 0.0120 | 0.015 | 0.018 | 0.021 | 0.024 | 0.032 |
| Max Cogging Torque | Tcog | oz-in | 0.41 | 0.66 | 0.88 | 1.10 | 1.37 | 2.00 |
| Peak to Peak | | N-m | 0.0029 | 0.0046 | 0.0062 | 0.0078 | 0.0097 | 0.014 |
| Frameless Motor – Inertia | Jmf | $oz\text{-}in\text{-}sec^2$ | 7.30E-04 | 1.20E-03 | 1.70E-03 | 2.10E-03 | 2.70E-03 | 4.00E-03 |
| | | $Kg\text{-}m^2$ | 5.15E-06 | 8.47E-06 | 1.20E-05 | 1.48E-05 | 1.91E-05 | 2.82E-05 |
| Frameless Motor – Weight | Wtf | oz | 4.5 | 7.2 | 9.6 | 12.1 | 15.1 | 22.0 |
| | | Kg | 1.26E-01 | 2.03E-01 | 2.74E-01 | 3.44E-01 | 4.28E-01 | 6.24E-01 |
| Housed Motor – Inertia | Jmh | $oz\text{-}in\text{-}sec^2$ | 7.60E-04 | 1.30E-03 | 1.80E-03 | 2.20E-03 | 2.80E-03 | 4.20E-03 |
| | | $Kg\text{-}m^2$ | 5.37E-06 | 9.18E-06 | 1.27E-05 | 1.55E-05 | 1.98E-05 | 2.97E-05 |
| Housed Motor – Weight | Wth | oz | 11.3 | 14.2 | 16.8 | 19.5 | 22.6 | 30.0 |
| | | Kg | 3.20E-01 | 4.02E-01 | 4.77E-01 | 5.52E-01 | 6.41E-01 | 8.50E-01 |
| No. of poles | P | | 8 | 8 | 8 | 8 | 8 | 8 |

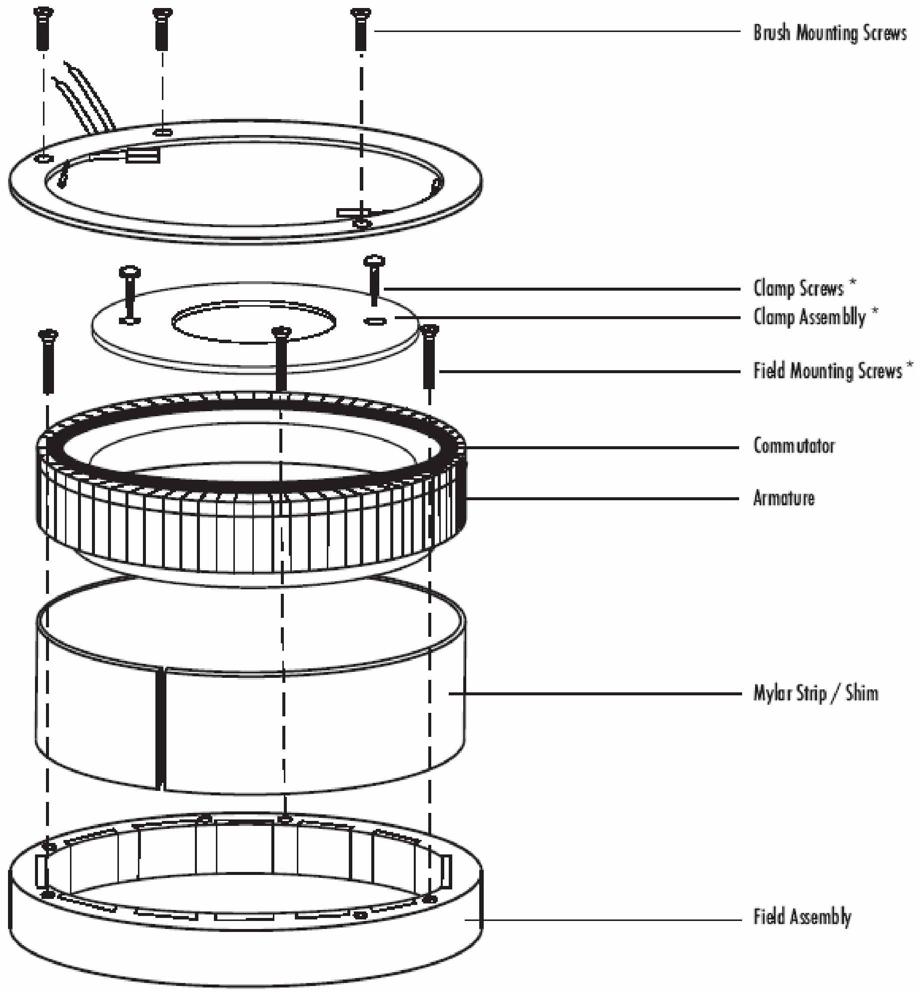
As example the icub motor has 8 pole pairs and the torque ripple is typically about 2% of nominal torque..

**Advantage of the torque motor is that it can DIRECT DRIVE the load with no need of mechanical reduction**

**High torques generally requires high current and high weight (strong magnet and lot of copper!)**

**Direct drive motor are tipically used where high precison high control bandwith with no backlash is required**

**Altought the efficency is high direct drive motors are generally liquid cooled..**




Direct drive two axis stabilized platform for traking (military application – exploded view of a brushed DC torque motor)

# Typical torque motor (ETEL)

## TMB torque motor's advantages:

- Designed for the most demanding applications
- Liquid cooling channels
- 600VDC bus voltage
- Very high continuous torque
- Very high peak torque

### TMB torque motors main features:

- More than 50 standard models available
- External diameters from 160 to 1'260 mm
- Large hollow shaft: 60 to 1'100 mm
- Peak torque from 38 to 31'000 Nm
- Maximum rated speed up to 5'000 rpm
- Low torque ripple

# Some reference data

## Check difference between dry and liquid cooled performances

| Motor type | Ext. Ø [mm] | Int. Ø [mm] | Stator length [mm] | Cont. torque [Nm] | Cont. torque water cooled [Nm] | Peak torque [Nm] |
|---|---|---|---|---|---|---|
| TMB0140-030 | 160 | 60 | 70 | 7 | 19 | 38 |
| TMB0140-050 | 160 | 60 | 90 | 14 | 33 | 64 |
| TMB0140-070 | 160 | 60 | 110 | 19 | 48 | 89 |
| TMB0140-100 | 160 | 60 | 140 | 28 | 70 | 127 |
| TMB0140-150 | 160 | 60 | 190 | 44 | 107 | 191 |
| TMB0175-030 | 198 | 90 | 80 | 15 | 32 | 68 |
| TMB0175-050 | 198 | 90 | 100 | 27 | 57 | 113 |
| TMB0175-070 | 198 | 90 | 120 | 37 | 82 | 158 |
| TMB0175-100 | 198 | 90 | 150 | 52 | 119 | 226 |
| TMB0175-150 | 198 | 90 | 200 | 82 | 184 | 339 |
| TMB0210-030 | 230 | 140 | 70 | 30 | 68 | 121 |
| TMB0210-050 | 230 | 140 | 90 | 53 | 123 | 206 |
| TMB0210-070 | 230 | 140 | 110 | 73 | 177 | 292 |
| TMB0210-100 | 230 | 140 | 140 | 101 | 259 | 420 |
| TMB0210-150 | 230 | 140 | 190 | 157 | 400 | 633 |
| TMB0291-030 | 310 | 200 | 80 | 60 | 139 | 249 |
| TMB0291-050 | 310 | 200 | 100 | 106 | 242 | 416 |
| TMB0291-070 | 310 | 200 | 120 | 147 | 345 | 582 |
| TMB0291-100 | 310 | 200 | 150 | 207 | 500 | 831 |
| TMB0291-150 | 310 | 200 | 200 | 324 | 765 | 1'250 |
| TMB0360-030 | 385 | 265 | 90 | 106 | 213 | 424 |
| TMB0360-050 | 385 | 265 | 110 | 182 | 377 | 707 |
| TMB0360-070 | 385 | 265 | 130 | 246 | 539 | 990 |
| TMB0360-100 | 385 | 265 | 160 | 345 | 791 | 1'410 |
| TMB0360-150 | 385 | 265 | 210 | 531 | 1'200 | 2'120 |
| TMB0450-030 | 485 | 345 | 90 | 178 | 368 | 699 |
| TMB0450-050 | 485 | 345 | 110 | 306 | 634 | 1'160 |
| TMB0450-070 | 485 | 345 | 130 | 416 | 898 | 1'630 |
| TMB0450-100 | 485 | 345 | 160 | 578 | 1'290 | 2'330 |
| TMB0450-150 | 485 | 345 | 210 | 893 | 1'970 | 3'490 |
| TMB0530-030 | 565 | 420 | 90 | 253 | 512 | 997 |
| TMB0530-050 | 565 | 420 | 110 | 437 | 898 | 1'660 |
| TMB0530-070 | 565 | 420 | 130 | 596 | 1'280 | 2'330 |
| TMB0530-100 | 565 | 420 | 160 | 828 | 1'870 | 3'320 |
| TMB0530-150 | 565 | 420 | 210 | 1'280 | 2'860 | 4'990 |

| Motor type | Ext. Ø [mm] | Int. Ø [mm] | Stator length [mm] | Cont. torque [Nm] | Cont. torque water cooled [Nm] | Peak torque [Nm] |
|---|---|---|---|---|---|---|
| TMB0760-030 | 795 | 650 | 110 | 630 | 1'180 | 2'240 |
| TMB0760-050 | 795 | 650 | 130 | 1'160 | 2'060 | 3'740 |
| TMB0760-070 | 795 | 650 | 150 | 1'430 | 2'950 | 5'240 |
| TMB0760-100 | 795 | 650 | 180 | 1'970 | 4'290 | 7'480 |
| TMB0760-150 | 795 | 650 | 230 | 3'120 | 6'730 | 11'200 |
| TMB0990-030 | 1030 | 870 | 110 | 1'020 | 2'050 | 3'990 |
| TMB0990-050 | 1030 | 870 | 130 | 1'870 | 3'600 | 6'650 |
| TMB0990-070 | 1030 | 870 | 150 | 2'530 | 5'160 | 9'310 |
| TMB0990-100 | 1030 | 870 | 180 | 3'480 | 7'500 | 13'300 |
| TMB0990-150 | 1030 | 870 | 230 | 5'290 | 11'500 | 19'900 |
| TMB1220-030 | 1260 | 1100 | 110 | 1'690 | 3'150 | 6'230 |
| TMB1220-050 | 1260 | 1100 | 130 | 2'840 | 5'530 | 10'400 |
| TMB1220-070 | 1260 | 1100 | 150 | 3'830 | 7'920 | 14'500 |
| TMB1220-100 | 1260 | 1100 | 180 | 5'460 | 11'800 | 20'800 |
| TMB1220-150 | 1260 | 1100 | 230 | 8'020 | 17'600 | 31'200 |

# Linear motor

**A linear motor is a torque motor that is opened and flattened (!)**

**Main advantage of the linear motor is that most of the actuation are linear**

**As other torque motors linear motors are generally high power..**

# Linear motor ref. data

Thrust/weight ratio 10:20

| Motor type | Length LM [mm] | Width WM [mm] | Height H [mm] | Cont. force [N] | Peak force [N] | Motor mass (kg) |
|---|---|---|---|---|---|---|
| LMP07-050 | 228 | 102 | 72.6 | 621 | 1070 | 5.2 |
| LMP07-100 | 228 | 152 | 72.6 | 1220 | 2140 | 8.8 |
| LMP14-050 | 382 | 102 | 72.6 | 1200 | 1990 | 9.5 |
| LMP14-100 | 382 | 152 | 72.6 | 2410 | 3980 | 15.8 |
| LMP14-150 | 382 | 203 | 74.6 | 3570 | 5780 | 22.2 |
| LMP14-200 | 382 | 253 | 78.6 | 4740 | 7970 | 28.6 |
| LMP21-050 | 536 | 102 | 72.6 | 1850 | 2920 | 13.6 |
| LMP21-100 | 536 | 152 | 72.6 | 3620 | 5830 | 22.8 |
| LMP21-150 | 536 | 203 | 74.6 | 5380 | 8750 | 32.0 |
| LMP21-200 | 536 | 253 | 78.6 | 7130 | 11700 | 41.2 |
| LMP28-050 | 705 | 102 | 72.6 | 2460 | 3840 | 17.8 |
| LMP28-100 | 705 | 152 | 72.6 | 4820 | 7680 | 29.8 |
| LMP28-150 | 705 | 203 | 74.6 | 7160 | 11520 | 41.9 |
| LMP28-200 | 705 | 253 | 78.6 | 9490 | 15360 | 53.9 |
| LMP28-250 | 705 | 304 | 82.6 | 11800 | 19200 | 65.9 |

| Motor type | GL [mm] | GD [mm] | GW [mm] | GH [mm] | Cont. force [N] | Peak force [N] | Motor mass (kg) |
|---|---|---|---|---|---|---|---|
| ILM03-040 | 136 | 13 | 8 | 95 | 84 | 412 | 0.41 |
| ILM03-060 | 136 | 15 | 8 | 125 | 139 | 625 | 0.55 |
| ILM06-040 | 264 | 13 | 8 | 95 | 167 | 823 | 0.77 |
| ILM06-060 | 264 | 15 | 8 | 125 | 277 | 1247 | 1.03 |
| ILM09-040 | 392 | 13 | 8 | 95 | 250 | 1234 | 1.13 |
| ILM09-060 | 392 | 15 | 8 | 125 | 416 | 1871 | 1.51 |
| ILM12-040 | 520 | 13 | 8 | 95 | 334 | 1646 | 1.54 |
| ILM12-060 | 520 | 15 | 8 | 125 | 555 | 2494 | 2.06 |

Thrust/weight ratio 20:100

**(fine ! )**