Servo Systems

Department of Mechanical Engineering
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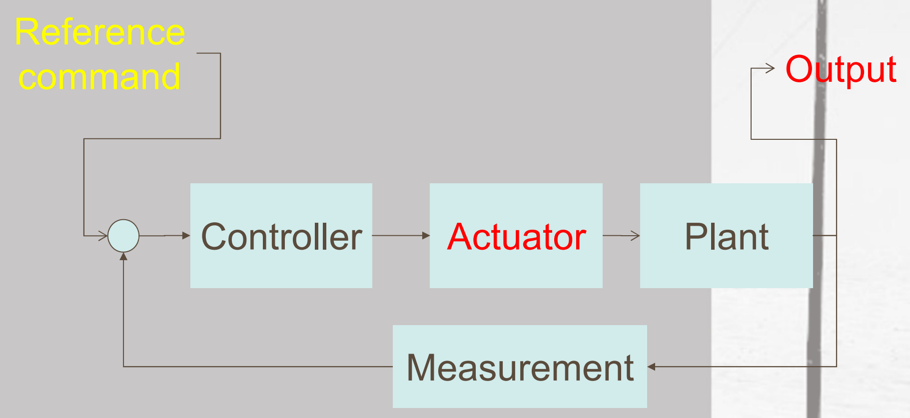
4/7/2010

A Control System



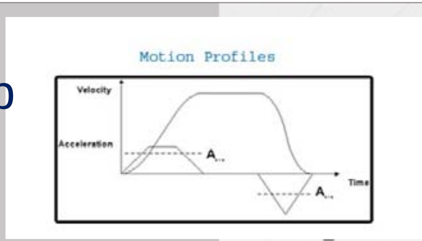
Outline

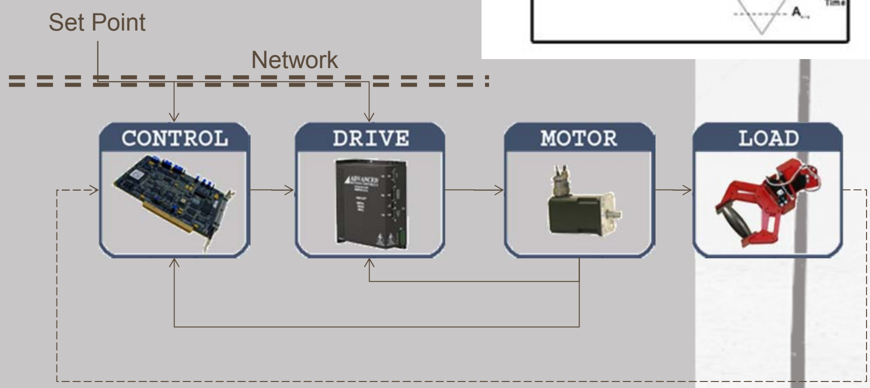
- Motors
  - Synchronous motor
  - Induction motor
  - DC motor
  - BLDC
  - PMAC
  - PWM principle
  - Driver design

Servo vs. Process System

- A **servomechanism** is a feedback control system in which the controlled variable is a (mechanical) position, velocity, torque, frequency, etc.
- A **process control** generally refers to control of other variables as liquid level, pressure, temperature, density, concentration, or chemical composition.

Servo System Loop





http://www.a-m-c.com/content/m101/generalservosystems.html

Motors

http://en.wikipedia.org/wiki/Motor

- Electric motor – a machine that converts electricity into a mechanical motion
  - AC motor, an electric motor that is driven by alternating current
    - **Synchronous motor**
    - **Induction motor**
  - DC motor, an electric motor that runs on direct current electricity
    - **Brushed DC electric motor**
    - **Brushless DC motor**
  - **Linear motor**
  - **Stepper motor**
- **Servo motor** – an electric motor that operates a servo, commonly used in robotics

Calculating Magnetic Field

- *Magnetic Field Intensity*: where μ is the *permeability*

$$H \equiv B/\mu$$

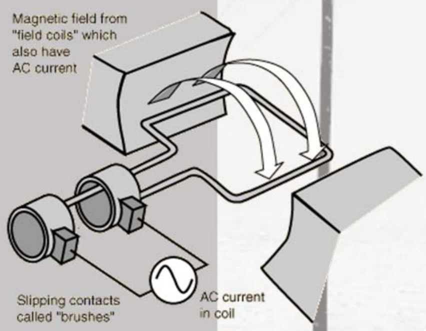
- *Magnetomotive force* (*mmf*):

$$\mathcal{F} = \oint H dl$$

AC SYNCHRONOUS MOTOR

AC Synchronous Motor

- A synchronous electric motor is an AC motor distinguished by a rotor spinning with coils passing magnets at the **same rate** as the alternating current and resulting magnetic field which drives it. Another way of saying this is that it has **zero slip** under usual operating conditions

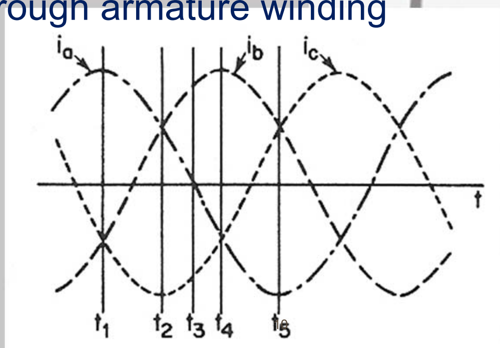


http://www.mwit.ac.th/~Physicslab/hbase/magnetic/motorac.html

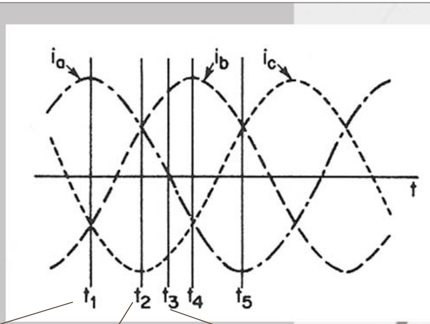
http://en.wikipedia.org/wiki/Synchronous_motor

Rotating Magnetic Field

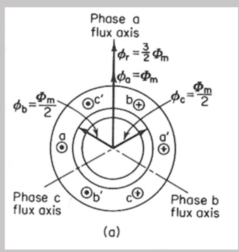
- Apply three-phase voltage to a three-phase stator winding creates a rotating field.
- Rotor → ***induced*** emf → (*working emf* in rotor winding) → current through armature winding
- Three phase currents through phase a, b, c →→

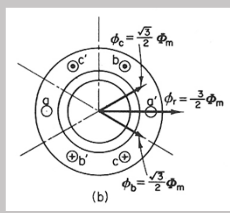


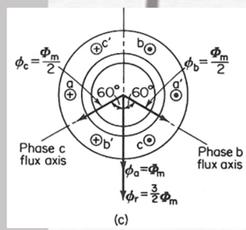
- Three phase current



- Time t_1 t_2 t_3







Mathematially

- Subject one phase (phase *a*) of the stator winding with alternating *mmf* value

$$\mathcal{F}_a = \mathcal{F}_m \cos \omega t \cos \alpha$$

- One obtain an alternating field that *behaves* as the **projection** of the magnetomotive force on the axis of phase *a*.
- Phase *b* and phase *c* mmf's

$$\mathcal{F}_b = \mathcal{F}_m \cos(\omega t - 120°) \cos(\alpha - 120°)$$

$$\mathcal{F}_c = \mathcal{F}_m \cos(\omega t - 240°) \cos(\alpha - 240°)$$

- The total *mmf* $\mathcal{F}_r = \mathcal{F}_a + \mathcal{F}_b + \mathcal{F}_c$

- Substitute

$\cos x \cos y = \frac{1}{2}\cos(x-y) + \frac{1}{2}\cos(x+y)$

- We get,

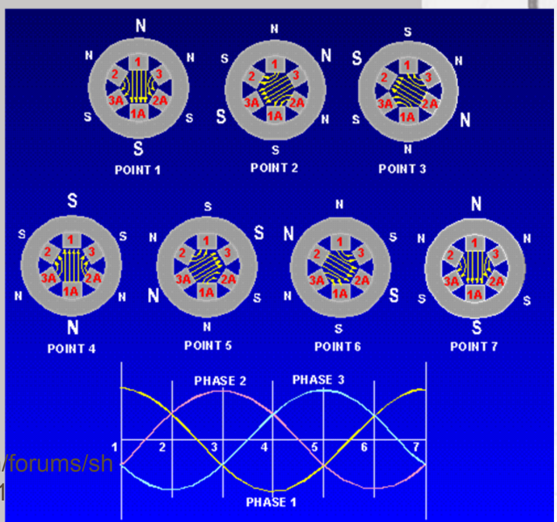
$$\mathcal{F}_r = \frac{1}{2}\mathcal{F}_m[\cos(\omega t - \alpha) + \cos(\omega t + \alpha) + \cos(\omega t - \alpha)$$
$$+ \cos(\omega t + \alpha - 240°) + \cos(\omega t - \alpha) + \cos(\omega t + \alpha - 120°)]$$

- Taking into account the cos's are 120° apart (sums up to "zero")

$$\mathcal{F}_r = \frac{3}{2}\mathcal{F}_m \cos(\omega t - \alpha)$$

- The projection of a rotating field of constant amplitude

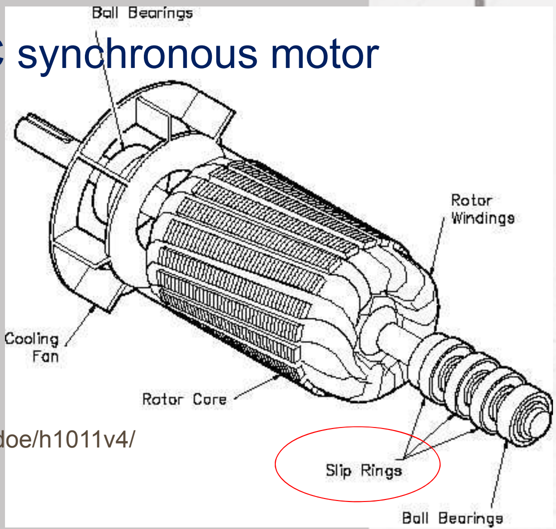
Rotating Magnetic Field



http://www.wattflyer.com/forums/showthread.php?p=462911

Rotor for AC Synchronous Motor

- **Rotor** for an AC synchronous motor
  - Slip rings to generate the required rotor field



http://www.tpub.com/content/doe/h1011v4/css/h1011v4_32.htm

Typical Spec. – AC Synchronous Motor

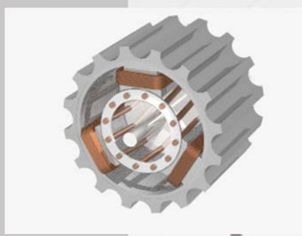
http://www.diytrade.com/china/4/products/1609079/Ac_synchronous_motor.html

- specifications: Model 49TYJ-B-3
- Rated voltage 24V, 36V, 100V, 120V, 220/240V
- Power consumption <4W
- Input current <25mA
- Rated frequency 50/60Hz
- torque >0.06N.m
- Speed 2.5/3, 5/6, 10, 15, 33/40rpm
- Starting voltage <176V
- Insulation resistance >100MΩ
- Noise <45db
- Coil temperature rise 60K
- CW,CCW or free direction
- pkg 27x27x21cm
- weight 125PCS(25x5),15kg
- Pricing: **$ 0.44-0.88**

http://www.diytrade.com/china/4/products/5573420/st_series_motor_single-phase_a_c_synchronous_genrator.html

AC INDUCTION MOTOR

AC Induction Motor

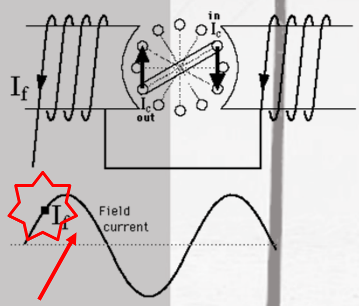


- An induction motor (or asynchronous motor or **squirrel-cage motor**) is a type of **alternating current** motor where power is supplied to the rotor by **means of electromagnetic induction**.
  - Sometimes called a **rotating transformer**
    the stator (stationary part) is the primary side
    the rotor (rotating part) is the secondary side.
  - Induction motors are **the preferred choice for industrial motors** due to their **rugged construction, absence of brushes** (which are required in most DC motors) and — thanks to modern power electronics — the **ability to control the speed** of the motor.

http://en.wikipedia.org/wiki/Induction_motor

AC Induction Motor

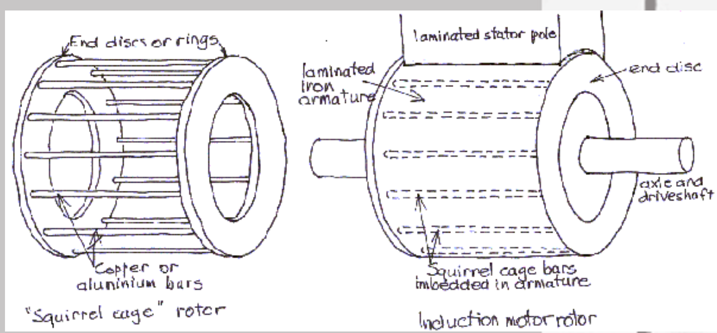
- The field coil is in the direction shown and **increasing**. The induced voltage in the coil shown drives current and results in a clockwise torque.



http://www.mwit.ac.th/~Physicslab/hbase/magnetic/indmot.html#c1

AC Induction Motor

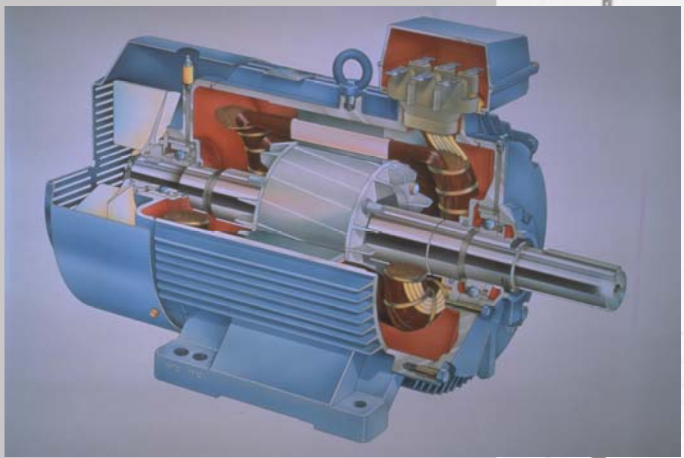
- Induction motor rotor – there is no current supplied to the rotating coils. The coils are closed loops.



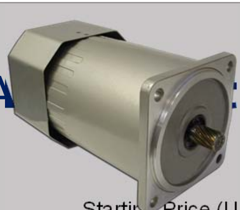
http://www.hsc.csu.edu.au/physics/core/motors/2698/Phy935net.htm

AC Induction Motor (cut away view)

- No slip rings



http://www.electrical-res.com/induction-motors-as-generators/



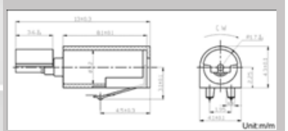
A…ion Motors

http://acinductionmotor.com/products/type.php?tID=422&cID=167

Series #	Starting Price (USD) 1 Piece	Starting Price (USD) 50 Piece	Input Voltage (VAC)	Frequency (Hz)	Motor Speed (RPM)	Pull-In Torque (oz-in)	Max Torque (oz-in)	Motor Length (in)
ACP-M-2IK6	$43.40	$39.70	110 or 220	60	1800	5.7	14	2.9
ACP-M-3IK15	$49.00	$43.40	110 or 220	60	1800	12.5	25	3.1
ACP-M-4IK25	$54.60	$50.90	110 or 220	60	1800	54	60	3.3
ACP-M-5IK40	$69.50	$62.10	110 or 220	60	1800	91	96	4.2
ACP-M-5IK60	$86.30	$78.90	110 or 220	60	1800	119	146	4.7
ACP-M-5IK90	$106.90	$97.50	110 or 220	60	1800	208	220	5.3
ACP-M-5IK120	$118.10	$106.90	110 or 220	60	1800	312	312	5.3
ACP-M-[illegible]	$131.10	$119.90	110 or 220	60	1800	336	396	5.3

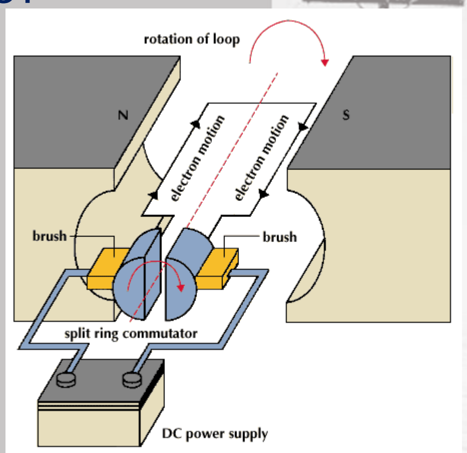
DC MOTORS

Brushed DC Motor



Vibrator for Cell Phone
Φ 3.2 mm, 1.3 g

http://mms2053.globalwebs.biz/tier/front/bin/ptdetail.phtml?Part=A041&Category=200112767



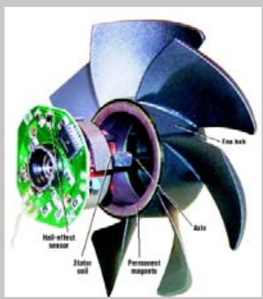
http://kids.britannica.com/comptons/art-53254/In-a-DC-motor-electrons-from-the-DC-power-supply?&articleTypeId=31

DC Servomotors

Brushless DC Motor

- A brushless DC (BLDC) motor is a synchronous electric motor ***powered by direct-current*** (DC) electricity and having an ***electronic commutation system***, rather than a mechanical commutator and brushes.
- In BLDC motors, current to torque and voltage to rpm are linear relationships.

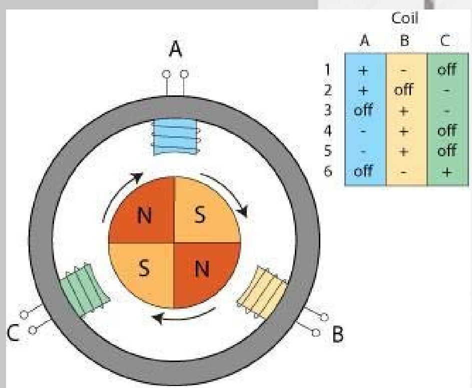
Structure of BLDC Motor



http://mechatronic-design.com/articles/Keeping%20cool_Figure_01.jpg

http://en.wikipedia.org/wiki/File:Poles.jpg

Electronic Commutation



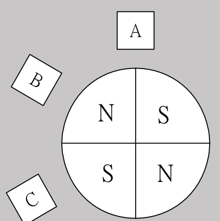
Six commutation phases "move" the electromagnetic field, which causes the permanent magnets on the rotor to move the motor shaft.

http://www.ecnmag.com/uploadedImages/Ecn/Articles/ec9OES100a.jpg

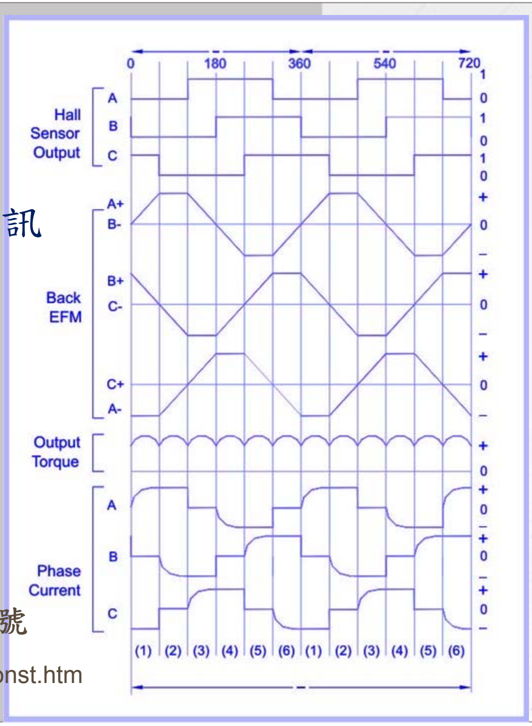
BLDC Motor

Hall Sensors

- 提供轉子的位置資訊
- 輸出0或1的信號



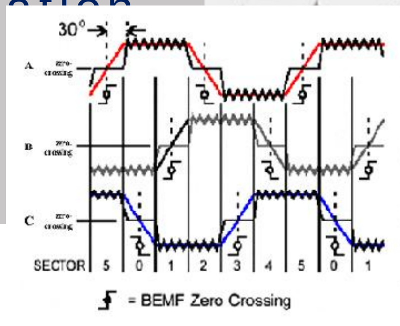
霍爾感應器位置

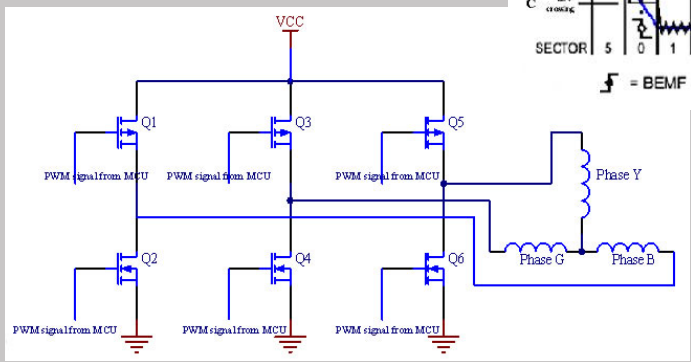


輸出信號

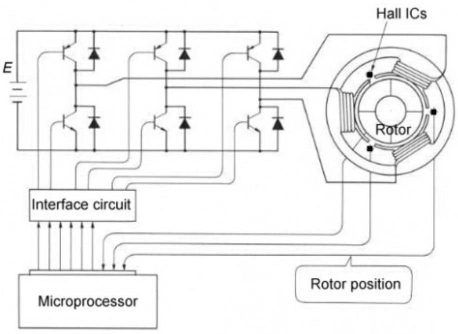
http://indiadiesel.com/bldc_const.htm

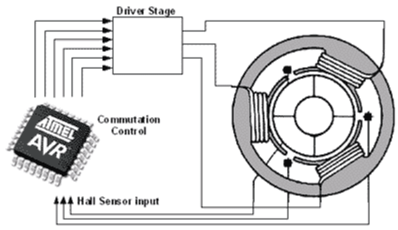
Electronic Commutation





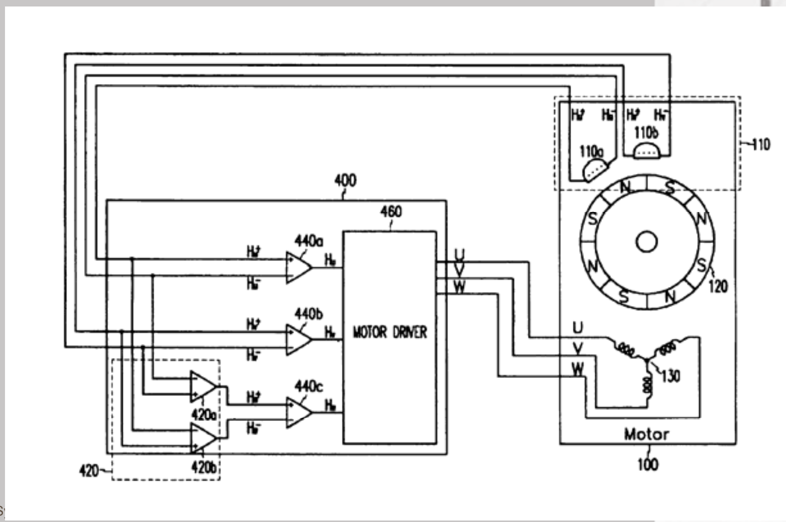
Electronic Commutation





AVR® 8-Bit RISC - Applications - Three-phase Brushless DC Motors

Block Diagram of BLDC Driver



永磁同步馬達

PERMANENT MAGNET SYNCHRONOUS MOTOR (PMSM)

PMSM

金永機電有限公司 TEL:(04)2562 9176 台中縣神岡鄉神清路171號之1

PMSM Excitation

- Smoother sinusoidal excitation for PMSM

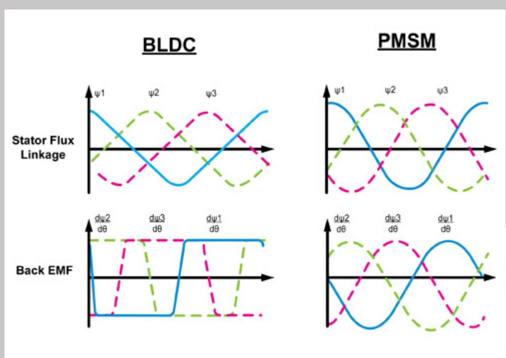
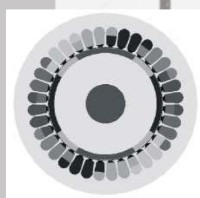


Figure 1. PMSM vs. BLDC BEMF Waveforms



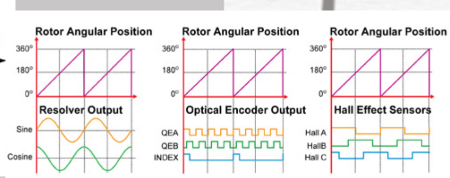
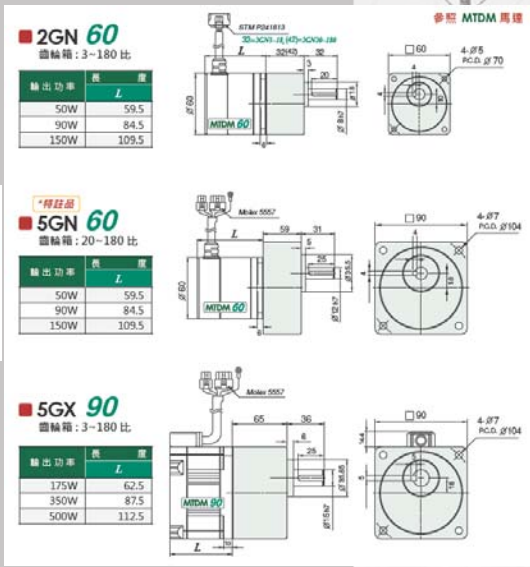


Figure 2. Sensor Output Waveforms (not to scale)

http://www.ecnmag.com/Articles/2009/10/Comparing-motor-control-techniques/

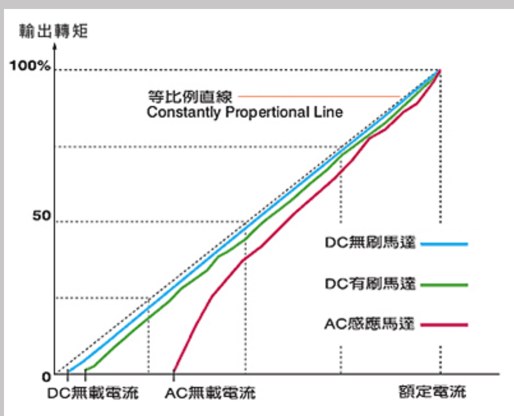
Reducer



http://www.bldcmotor.com.tw/?f=GearReducer

Servo Systems

Current – Torque Characteristics



http://www.bldcmotor.com.tw/?f=DcBrushless Motor (Reducer & Transmission Tech. Co.)

Servo Systems

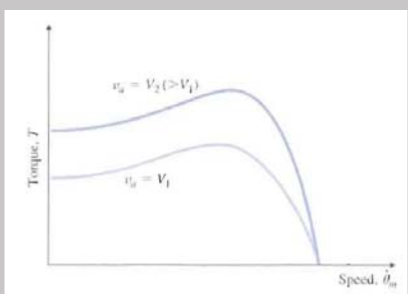
38

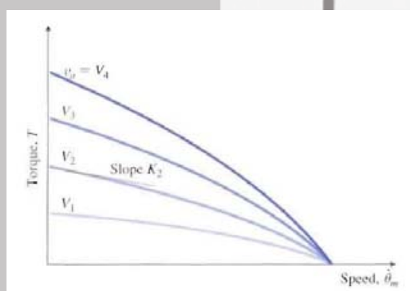
Servomotors

http://www.moog.com/noq/%5Fcapabilities%5F%5Fc1046/

Torque – Speed Characteristics

- Industrial motors vs. Servo motors

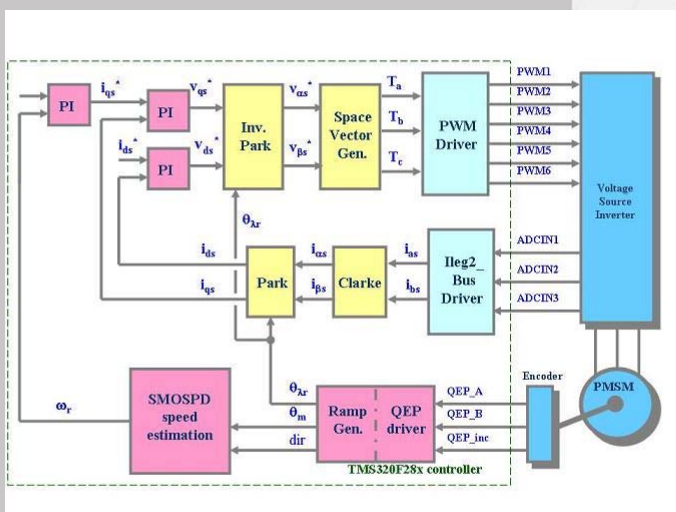




AC Servomotors

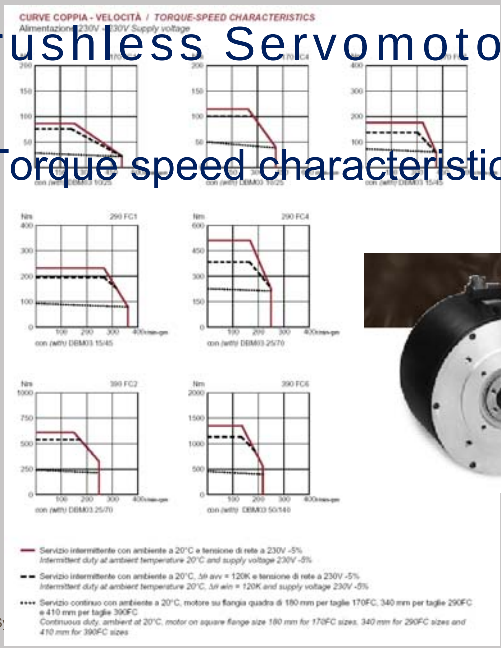
http://www.moog.com/noq/%5Fgeneral%5F%5Fc585/

PMSM Vector Control

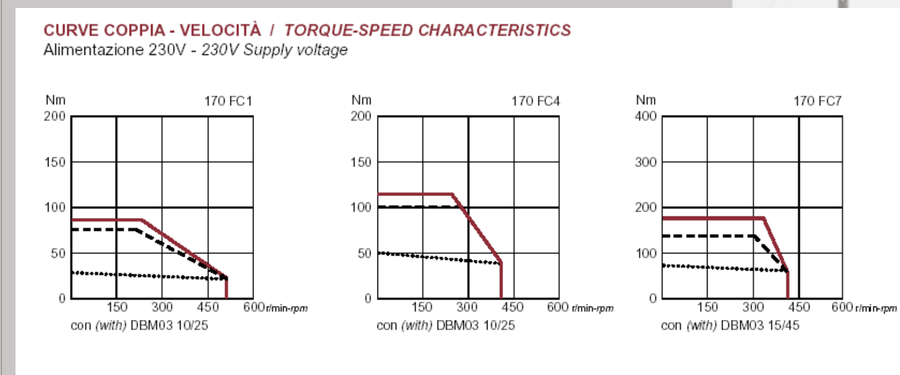


Brushless Servomotors

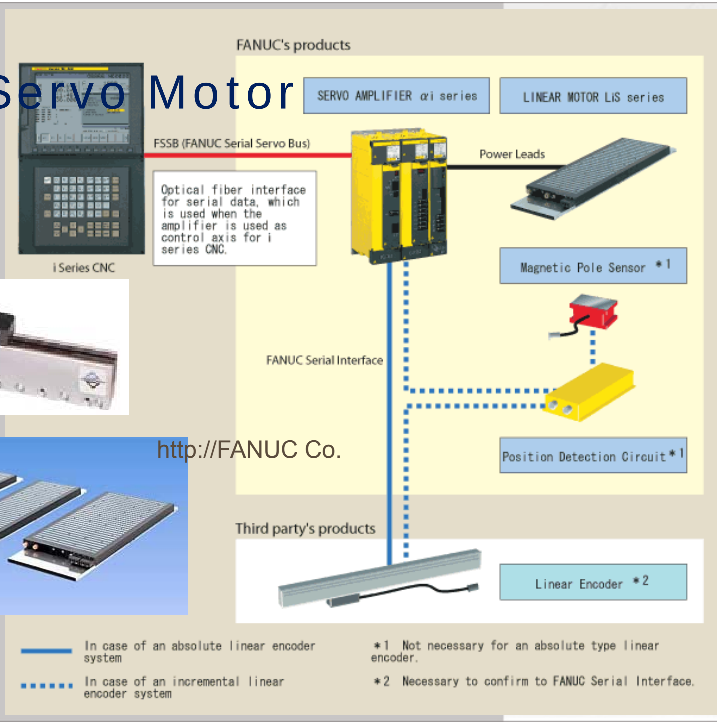
- Torque speed characteristics



Torque – Speed Characteristics



Linear Servo Motor



http://FANUC Co.

Stepper Motor

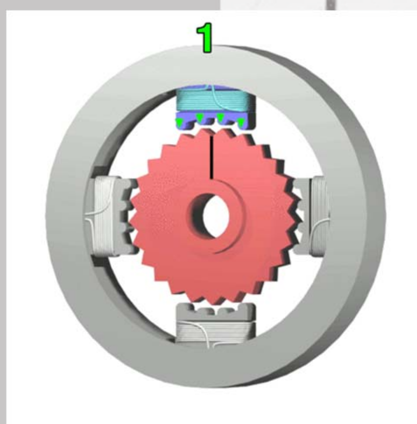
- A **stepper motor** (or step motor) is a brushless, synchronous electric motor that can divide a full rotation into a large number of steps. The motor's *position can be controlled precisely without any feedback mechanism* (see Open-loop controller), as long as the motor is carefully sized to the application.
  Stepper motors are *similar* to *switched reluctance motors* (which are very large stepping motors with a reduced pole count, and generally are closed-loop commutated.)

http://en.wikipedia.org/wiki/Stepper_motor

- 497 oz.in. Nema 23 Mounting Double Stack/Double Shaft Bipolar Stepper Motor.
- These 497 oz.in. stepper motors have 3/8" output shaft and a 1/4" end shaft so you can connect a manual positioning wheel.

ecmarsh.com/cnc/electronics.htm

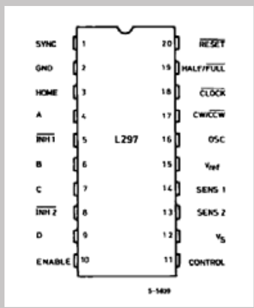
Stepper Motor Principle

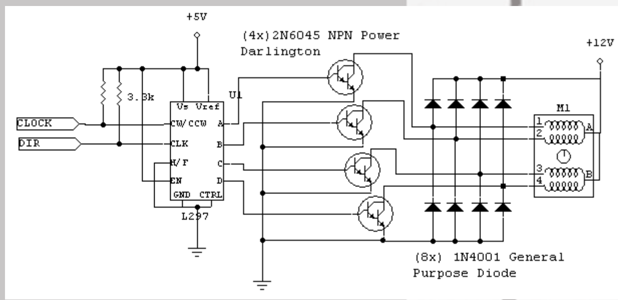


http://en.wikipedia.org/wiki/Stepper_motor

Stepper Motor Driver

- L297 Driver IC (STMicroelectronics)





http://www.electrical-res.com/unipolar-stepper-motor-driver/

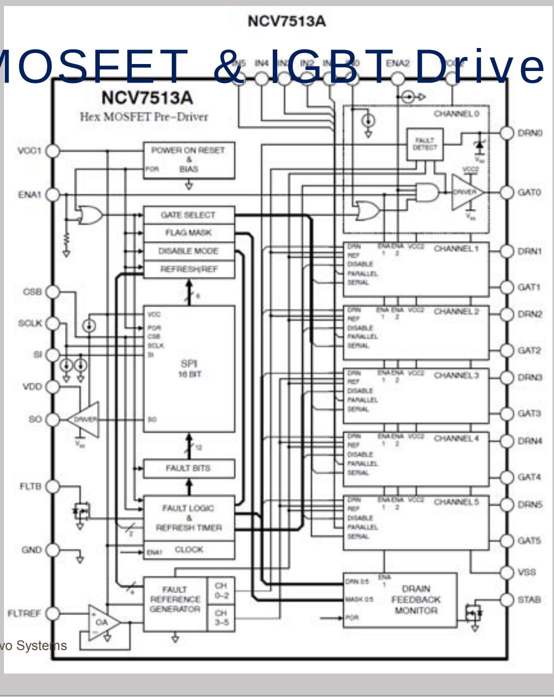
MOSFET & IGBT

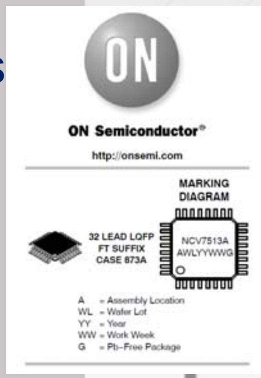
- Metal-Oxide-Semiconductor Field-Effect Transistor, **MOSFET**
- Insulated Gate Bipolar Transistor, **IGBT**


Mosfet (Fairchild)


IGBT (Mitsubishi)

MOSFET & IGBT Drivers





Servo Systems 51

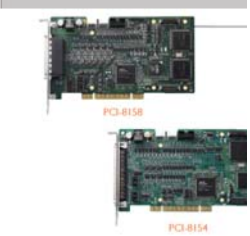
CONTROLLER IMPLEMENTATION AND INTERFACING

Encoder Servo Systems 52

Motion Control Cards

- Adlink PCI-8158
  - Advanced 8-axis Stepper & Servo Motion Control Card with Modular Design
- Features
  - 3 axes helical interpolation
  - Pulse output options: OUT/DIR, CW/CCW
  - Pulse output rate up to 6.55 Mpps
  - 2~4 axes linear interpolation
  - 2 axes circular interpolation
  - Hardware emergency input
  - Position/Speed change on-the-fly
  - Support manual pulse generator (MPG)

Adlink P



Specifications

Pulse Type Motion Control	
Max. Number of Axes	8
Pulse Output Rate	0.01 pps to 6.5 Mpps
Max. Acceleration Rate	245 Mpps²
Speed Resolution	16-bit
Encoder Input Rate	6.55 MHz under 4 x AB phase @ 1 M cable
Encoder Counter Resolution	28-bit
Positioning Range	-134,217,728 to +134,217,727 pulses (28-bit)
Counters	x 4 for each axis
Comparators	x 5 for each axis
Motion Interface I/O Signals	
Position Latch Input Pin	LTC
Position Compare Output Pin	CMP
I/O Pin	Differential and 2500 VRMS optically isolated
Incremental Encoder Signals Input Pin	EA and EB
Encoder Index Signal Input	EZ
Mechanical Signal Input Pin	±EL, SD, and ORG
Servomotor Interface I/O Pin	INP, ALM, ERC, RDY, SVON
General DO Pin	DO x 8 for DO/CMP
General DI Pin	GDI x 8 for DI/LTC/PCS/SD/CLR/EMG
Pulser Signal Input	PA and PB
Simultaneous Start/Stop Signal I/O Pin	STA and STP

PCI-8158 Software Support

Software Support

Windows® Platform

- Available for Windows Vista (32-bit)/XP/2000
- Recommended programming environments: VB/VC++/BCB/Delphi/VB.NET
- Various sample programs with source codes
- Customized API functions are possible

RTX (Windows Real Time Extension)

- RTX 5.x/6.x/8.1a

Linux Platform

- Redhat 9, kernel 2.4.x
- Fedora Core 3, kernel 2.6.9
- Fedora Core 4, kernel 2.6.11
- Fedora Core 5, kernel 2.6.15

MotionCreatorPro 2™

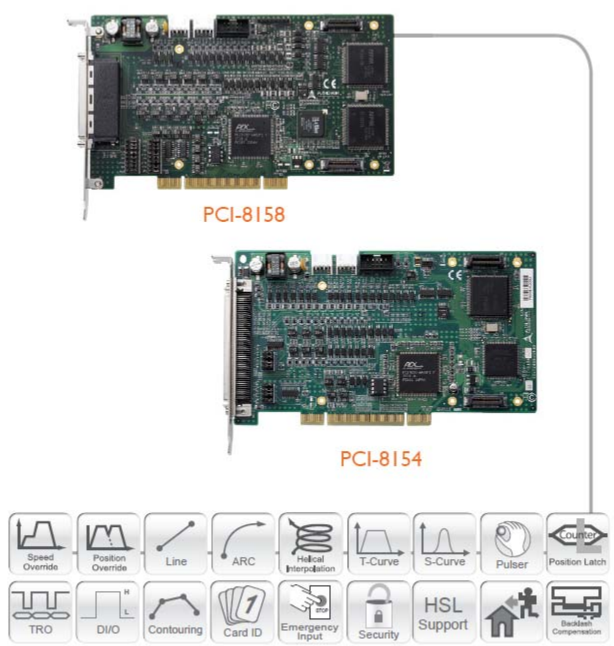
MotionCreatorPro 2 is a user-friendly Windows-based application development software package included with all distributed motion and I/O control modules.

MotionCreatorPro 2 provides simple configuration and real-time statuses of modules, in addition to precise positioning control with no effort.

(See page 1-23 for more information on MotionCreatorPro 2.)

Encoder Servo Systems

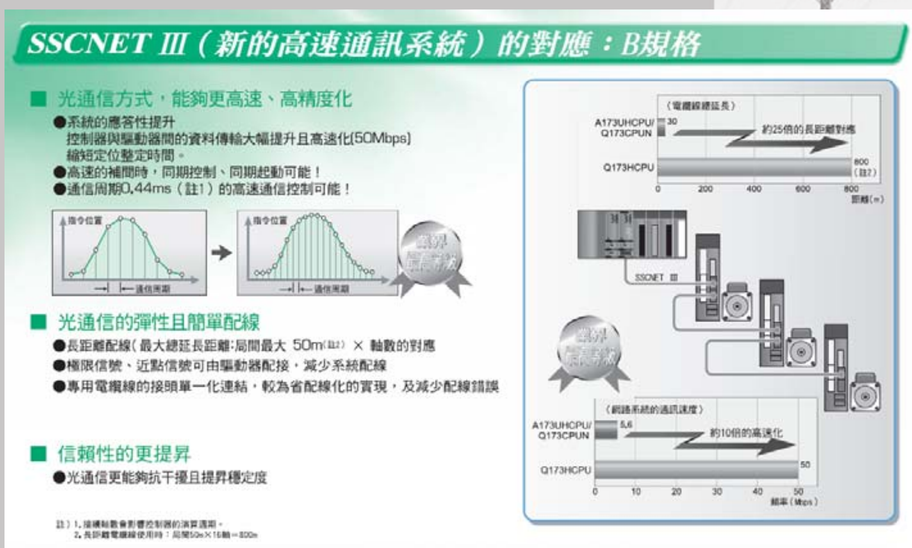
PC



Encoder Servo Systems

ALL DIGITAL DRIVER INTERFACE

Network Interface for Drivers



http://www.secfa.com.tw/ftp/伺服馬達MR-J3/MR-J3%20CATALOG(chinese).pdf

SSCNET

- SSCNET (Servo System Controller Network) is Mitsubishi Electric's dedicated Motion Control bus network. The motion controllers and servo amplifiers can be linked via the SSCNET network that offers the user: ease of connectivity, due to less wiring, high reliablilty and since the encoder output terminals are fitted as standard, greater flexibility for system integration.

Digital Control Interface I

- SERCOS
  - SERCOS (SErial Real-time COmmunication System) interface is a globally standardized open digital interface for the communication between industrial controls, motion devices (drives) and input output devices (I/O). It is classified as standard IEC 61491 and EN 61491. The SERCOS interface is designed to provide hard real-time, high performance communications between industrial motion controls and digital servo drives.

CAN-bus

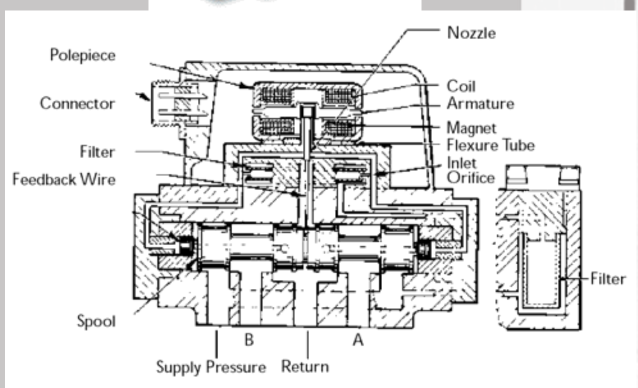
- Controller–area network (CAN or CAN-bus) is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a host computer.
  - Development of the CAN-bus started originally in 1983 at Robert Bosch GmbH.[1] The protocol was officially released in 1986 at the Society of Automotive Engineers (SAE) congress in Detroit, Michigan. The first CAN controller chips, produced by Intel and Philips, came on the market in 1987. Bosch published the CAN 2.0 specification in 1991.
  - CAN is one of five protocols used in the OBD-II vehicle diagnostics standard, mandatory for all cars and light trucks sold in the United States since 1996, and the EOBD standard, mandatory for all petrol vehicles sold in the European Union since 2001 and all diesel vehicles since 2004.[2]

Exercise

- Find the register that holds the up/down count in the interface card in our system.
- Determine what kind of servo motor is used in our lab.
- Hook up the servo motor and try to read the up/down pulse count from the interface card.

OTHER TYPES OF SERVO DEVICES

Servo Proportional Valve



Servo Pneumatic Valve

- Servo Valves

- Cylinders

http://marshbellofram.com/belfram/products/electro/type1000.htm

Exercise

- Find the register that holds the up/down count in the interface card in our system.
- Determine what kind of servo motor is used in our lab.
- Hook up the servo motor and try to read the up/down pulse count from the interface card.