

School of Engineering

Introduction to Electrical Machines

Mark Sandford

Functions of electrical Machines

- ☐ Elec power - into
 - ☐ Electrical machine – producing
 - ☐ Mechanical power + losses
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- ☐ Mechanical power – into
 - ☐ Electrical machine – producing
 - ☐ Electrical power + losses.
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Electrical Machine Technologies

☐ Electro magnetic

- Mag field affecting ferrous particles

☐ Electrostatic

- Balloon on a ceiling

☐ Piezo Electric

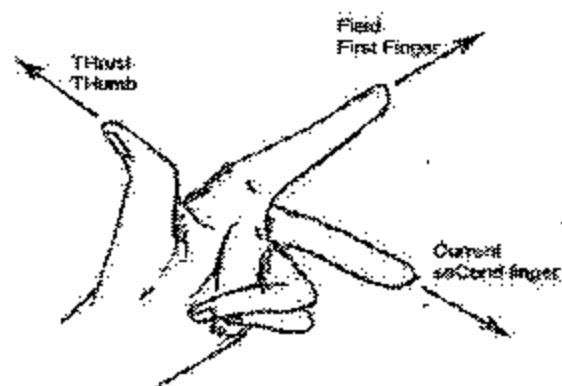
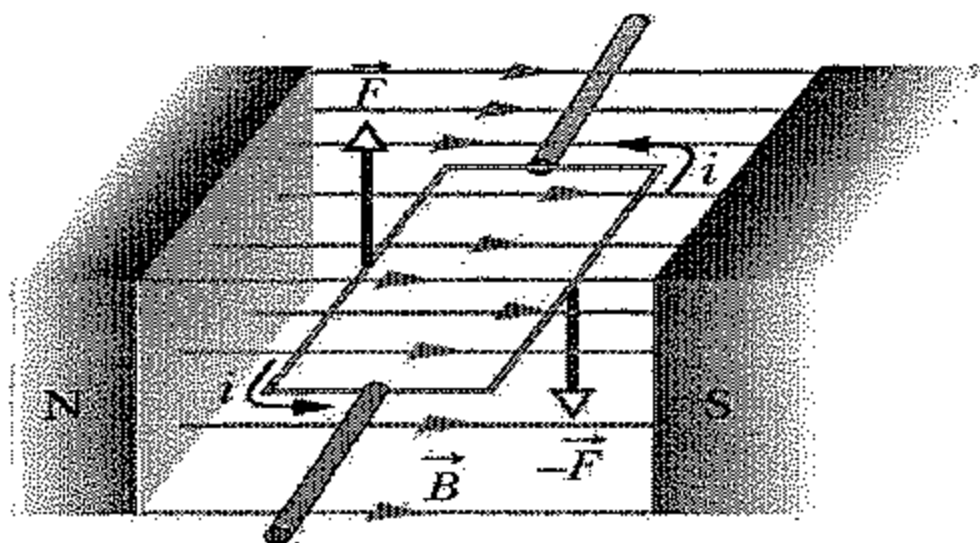
- Generates a mechanical force IJ printers

☐ Thermoelectric

- Produces heat – to steam to mechanical
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Reasons for Using Electrical Machines

- ☐ Availability of power source
 - ☐ Relatively simple construction
 - ☐ Controllability
 - ☐ Noise and pollution
 - ☐ Efficiency
 - ☐ Scalability of size
 - ☐ Self starting
 - ☐ Generally capable of functioning as a generator
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N: Magnetic north pole

S: Magnetic south pole

B : Magnetic field

i : Electric current

F : Force produced by interaction of current and field

Fleming's left hand (motor) rule

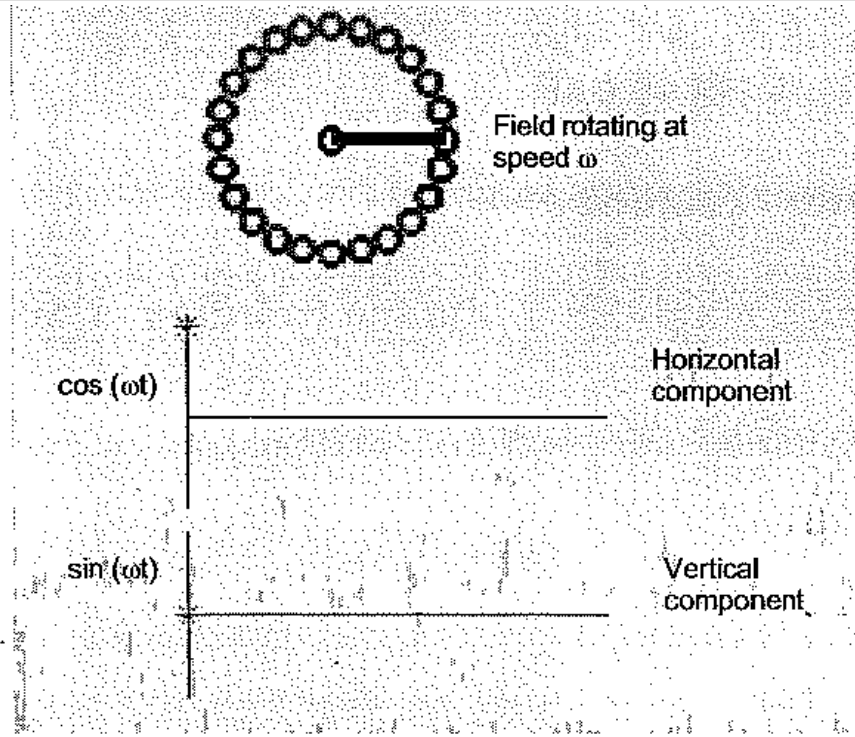
Rotational Electromotive Force (EMF)

- Voltage produced by changing magnetic flux
 - Proportional to flux, winding length and speed
 - In motor – opposes applied armature voltage
 - In a generator, produces the output voltage.
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Electrical Machine Terminology

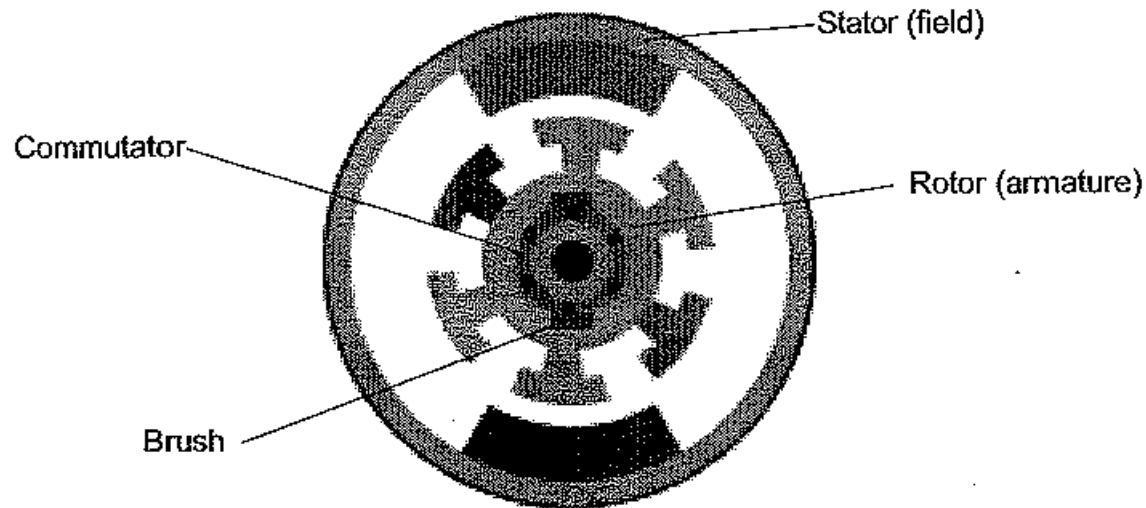
- Stator
 - Fixed part
 - Rotor
 - Rotating part
 - Field -magnetic excitation
 - Winding or magnet
 - Armature
 - Energised winding
-

Rotating magnetic field



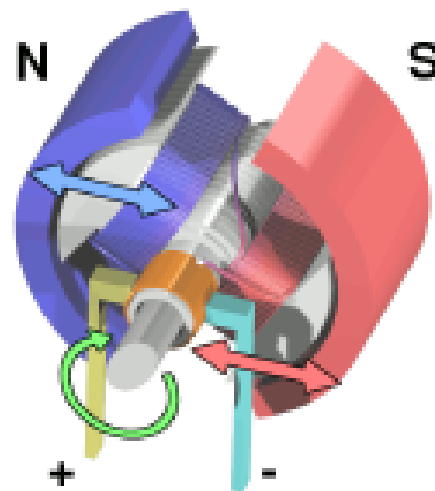
- Rotation can be produced by two (or more) sinusoidal amplitudes

DC Machine



- **Stator provides field**
 - **Commutator directs current to armature windings**
 - **Electrical power supplied / extracted via brushes**
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Brushed DC-Machine



Wikipedia picture

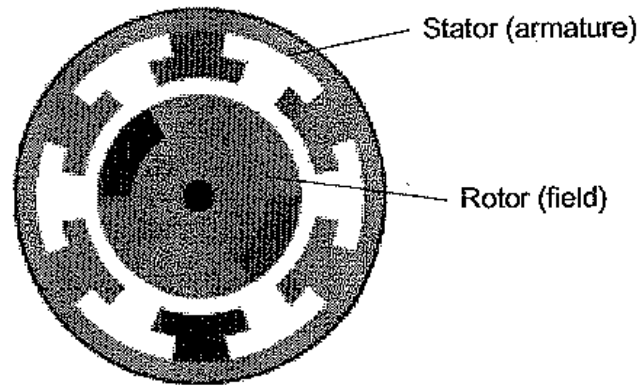
Brush-type DC motor:

- ▶ Rotor
- ▶ Stator
- ▶ Commutator
- ▶ Two subtypes:
 - Permanent magnet
 - Separately excited

Pros and cons

- + Simple to control
- Brushes require maintenance

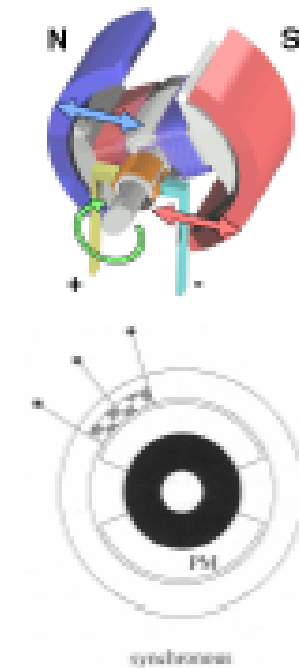
Brushless DC



- Rotor magnets provide field
 - Stator windings are switched by power electronics
 - Usually two or more armature phases
 - Rotor position must be known by control electronics
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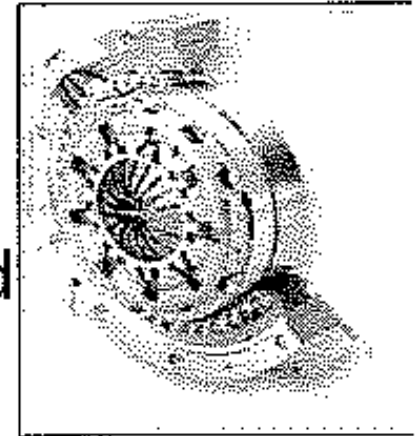
Brushless DC-Motor

- ▶ Solves DC commutator and brushes problem
 - ▶ Replace electromagnet in rotor with permanent magnet (PM).
 - ▶ Rotate field in stator.
- ▶ DC-motor is misleading
 - ▶ DC source as input
 - ▶ Electronically controlled commutation system AC
- ▶ Linear relations between
 - ▶ current and torque
 - ▶ voltage and rpm



Brushless DC

- **Brushless Permanent Magnet**
 - Uses permanent magnets on rotor and coils for stator
 - Current in stator coils is switched to rotate magnetic field
 - Most efficient but expensive

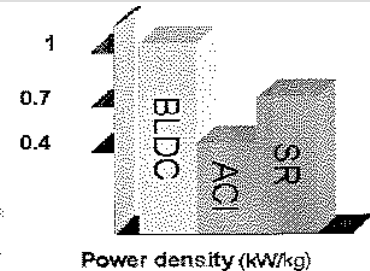
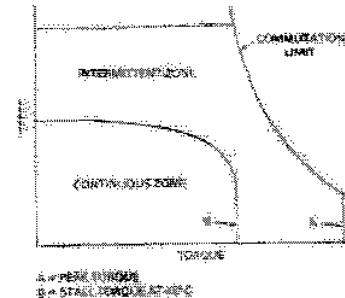
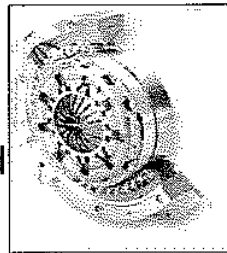


Brushless DC

- **High efficiency**
 - **High torque to inertia ratio and power density**
 - **High speed capability**
 - **Good thermal characteristics**
 - **Long service life**
 - **Low electrical noise**
 - **Moderate torque ripple**
 - **Power electronics and rotor sensing required**
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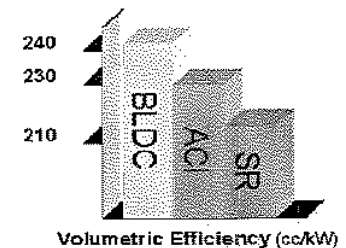
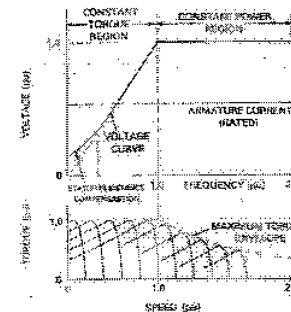
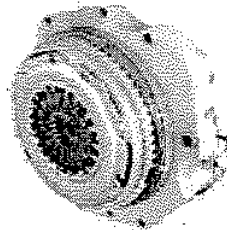
● Brushless Permanent Magnet

- Uses permanent magnets on rotor and coils for stator
- Current in stator coils is switched to rotate magnetic field
- Most efficient but expensive



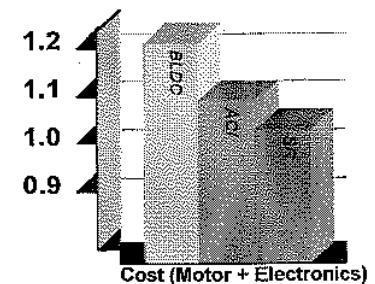
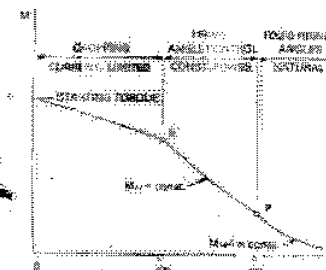
● Induction

- Used coils for stator and rotor
- Coils on rotor are unpowered for Induction machine, or powered for AC Synchronous machine

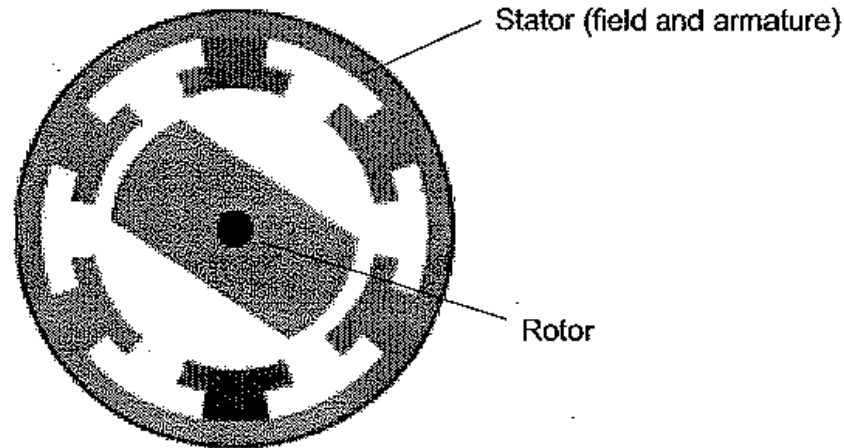


● Switched reluctance

- No permanent magnets
- Powered coils on stator
- Magnetically permeable material for rotor

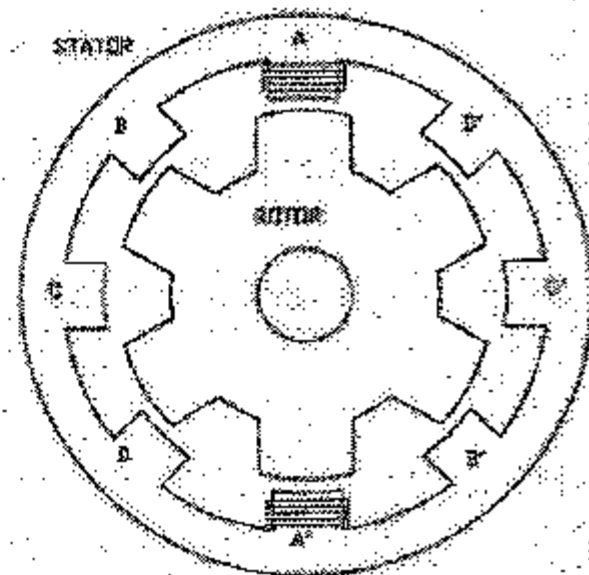


Switched reluctance Machine

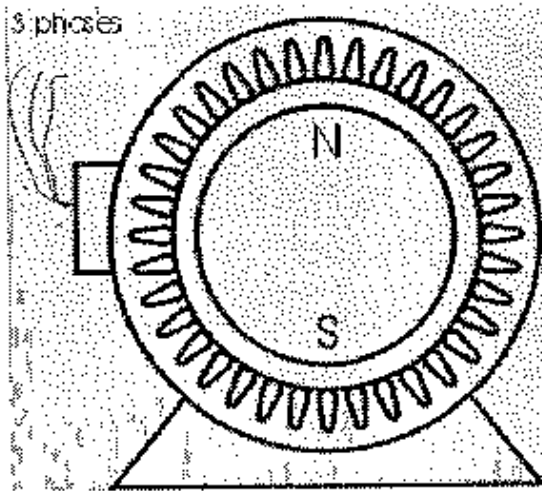


- **Stator windings switch field between poles**
- **Rotor is attracted to energised poles**
- **Usually three or more phases**
- **Stator windings can use unipolar excitation**

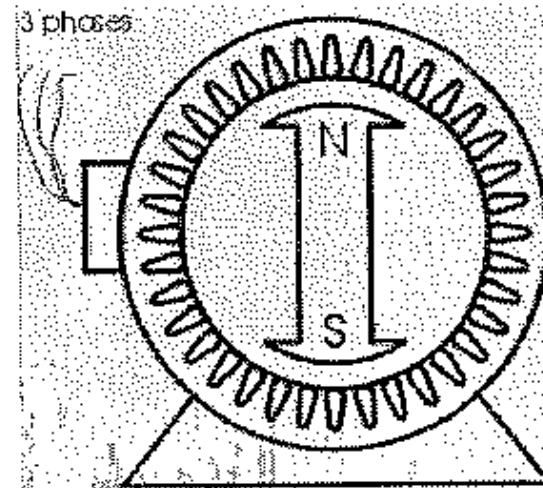
- **Low cost construction**
- **High speed, high torque capability**
- **High torque to inertia ratio and power density**
- **Capable of high temperature operation**
- **High fault tolerance**
- **High efficiency**
- **Good thermal characteristics**
- **Moderate to high torque ripple**
- **Power electronics and rotor sensing required**
- **Requires excitation supply to act as a generator**



Synchronous Machine



Permanent magnet rotor



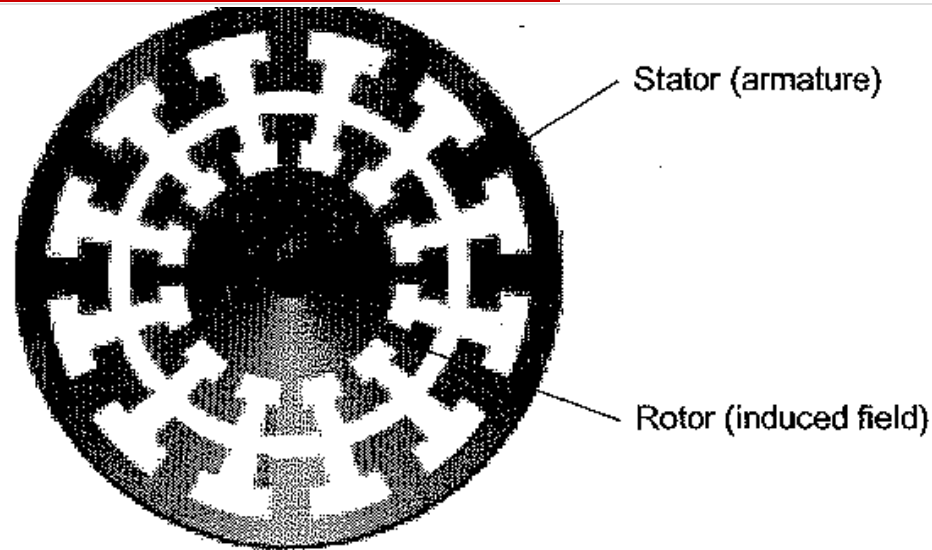
Wound rotor

- Stator windings produce rotating magnetic field
- Rotor is pulled along in synchronism with stator field

Synchronous machine

- **Operable directly from ac supply**
- **Speed depends on frequency of excitation**
- **Torque production only at synchronous speed**
- **High torque to inertia ratio**
- **Low torque ripple**
- **Commonly used as an ac generator**

AC Induction Machine

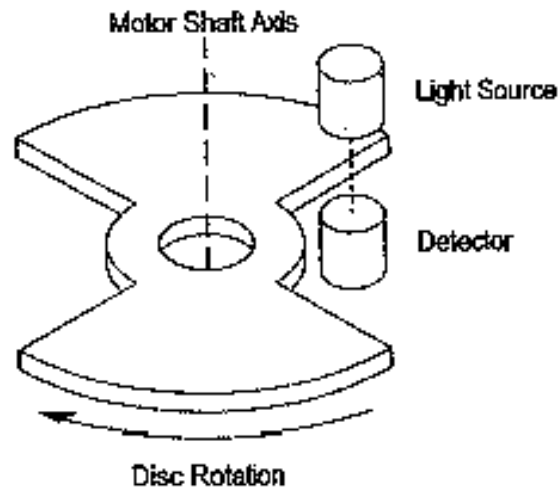


- **Stator windings produce rotating magnetic field**
- **Current induced in the rotor produces a field which interacts with the stator field, producing torque**
- **Speed of rotor is less than synchronous speed, the difference being called the 'slip'**

AC Induction Machine

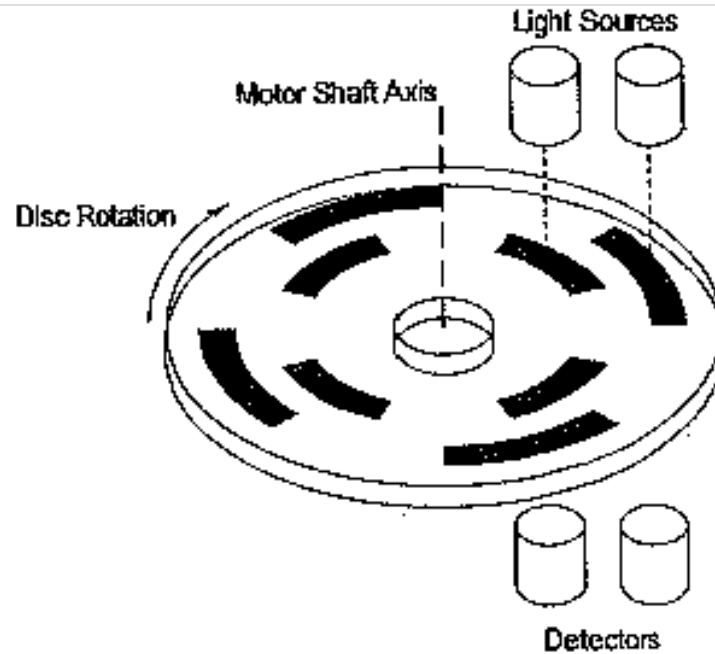
- **Robust construction**
 - **Operable directly from an ac supply**
 - **Self-starting**
 - **Rotor position sensing not required**
 - **Low torque ripple and noise**
 - **Low to moderate torque to inertia ratio**
 - **Reasonable torque at low speeds**
 - **Moderate power density**
-

Rotor position measurement



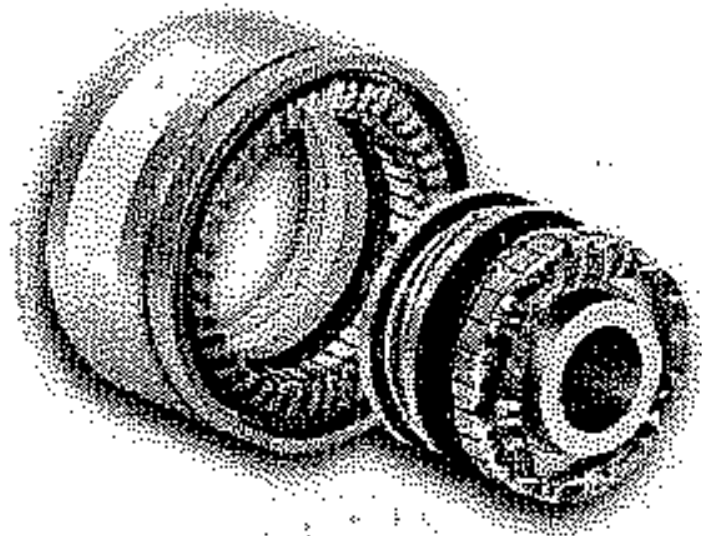
Single-bit digital

Rotor position measurement



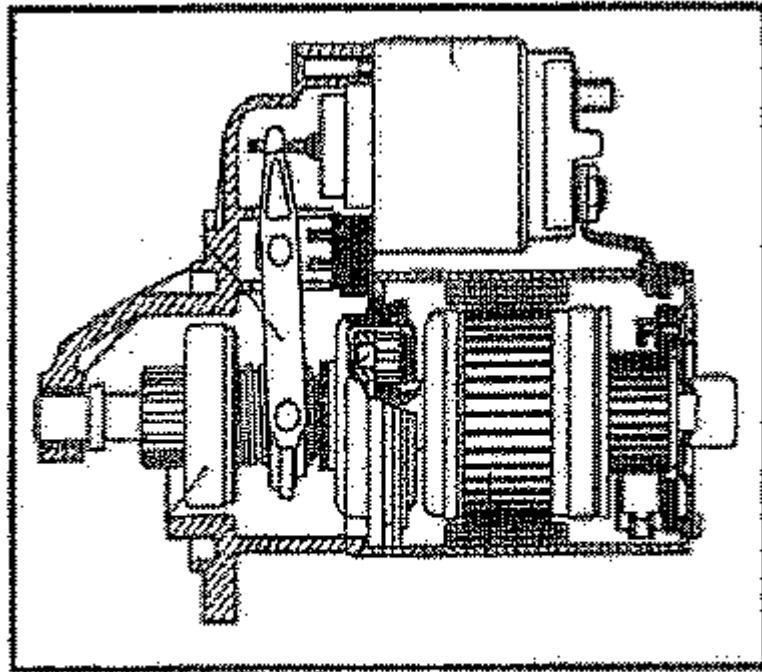
Multi-bit digital

Rotor position measurement



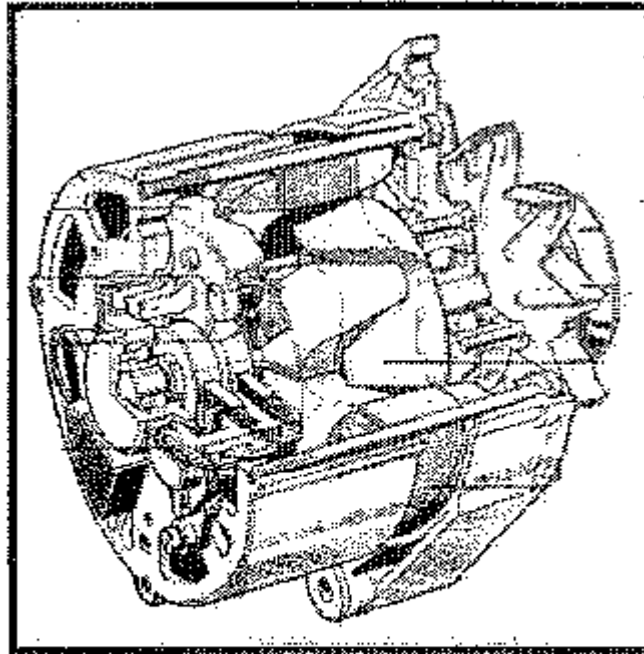
Sine-cosine resolver

Current starter technology



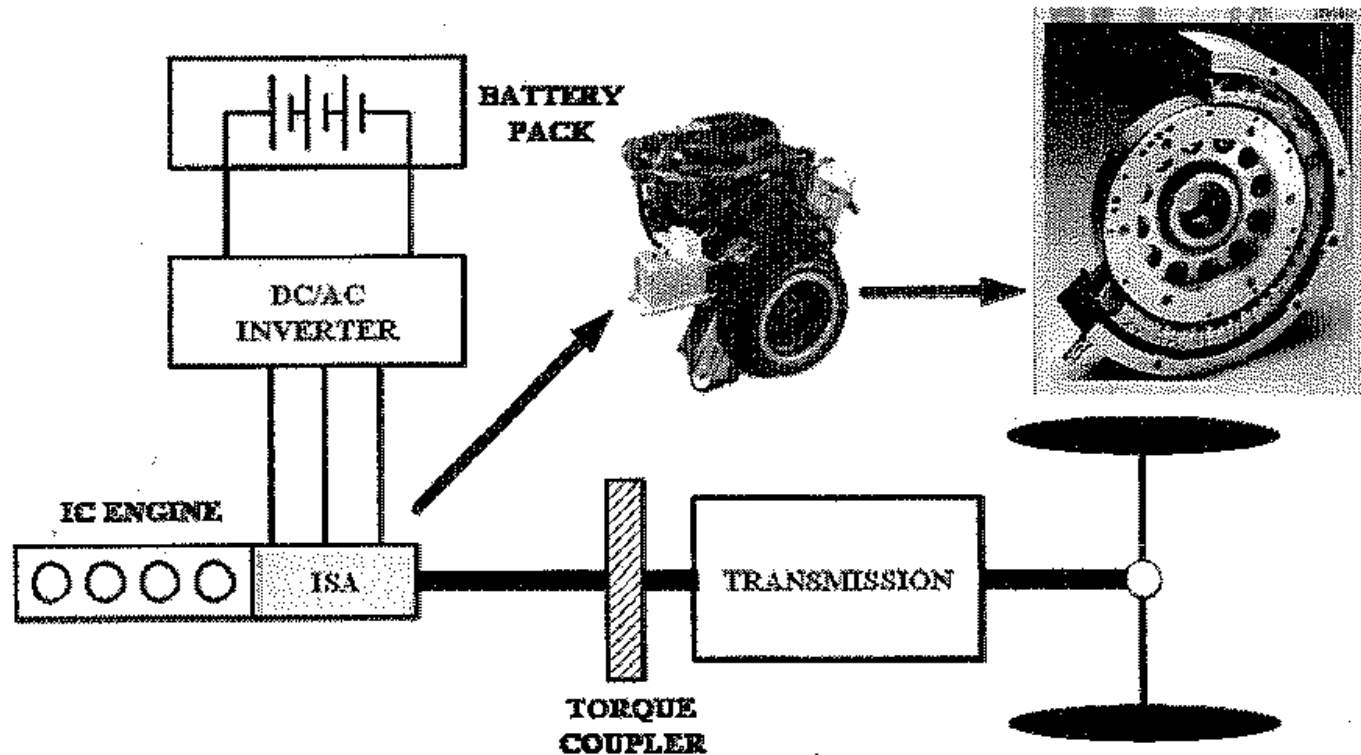
Conventional Starter
Brushed DC Machine

Current alternator technology



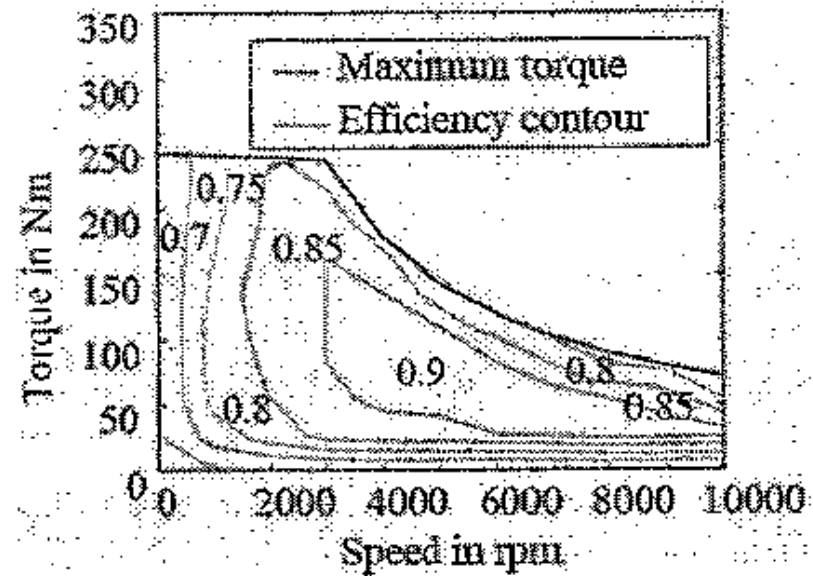
Conventional Alternator
(Claw-pole machine)

Integrated Starter - Alternator



Machine considerations

- Peak / Continuous ratings
- Efficiency
- Torque ripple
- Noise
- Reliability
- Cooling requirements
- Maintenance
- Operating environment
- Size
- Cost



Electrical machines in hybrid vehicles

Hybrid Vehicle	Motor	Power	Torque	Voltage
Mercedes-Benz Sprinter Van		70kW		
Toyota Prius	PMSyn	50kW @ 1200 – 1540rpm 44kW @ 0 – 400rpm	400Nm @ 0 – 1200rpm 350Nm @ 0 – 400rpm	500V max (276V Prius I)
Toyota Highlander (front motor)	PM	123kW @ 4500rpm	335Nm @ 0 – 1500rpm	650V
Toyota Highlander (rear motor)	PM	50kW @ 4610 – 5120rpm	130 Nm @ 0 – 610rpm	650V
Lexus RX400h (MG2)	PM	123kW	Peak torque @ 0 – 1500rpm	288V battery, 650V dc bus
Lexus RX400h (MGR)	PM	50kW	Peak torque of 881Nm	
Honda Accord	PM	12kW @ 840rpm	136 Nm @ 840rpm	144V
Honda Civic (manual)		10kW @ 2500 – 4000rpm	116	
Honda Civic (automatic)	BLDC	10kW @ 4000rpm	62Nm @ 1000rpm	
Honda Insight (manual)	PMSyn	10.4kW @ 3000rpm		
Honda Insight (automatic)		9.7kW @ 2000rpm	Approx. 34Nm	144V
Mercury Mariner (traction)	AC motor	70kW		330V
Mercury Mariner (generator)	AC motor	28kW		330V
Ford Escape	PMSyn	70kW @ 3000 – 5000rpm		400V max

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