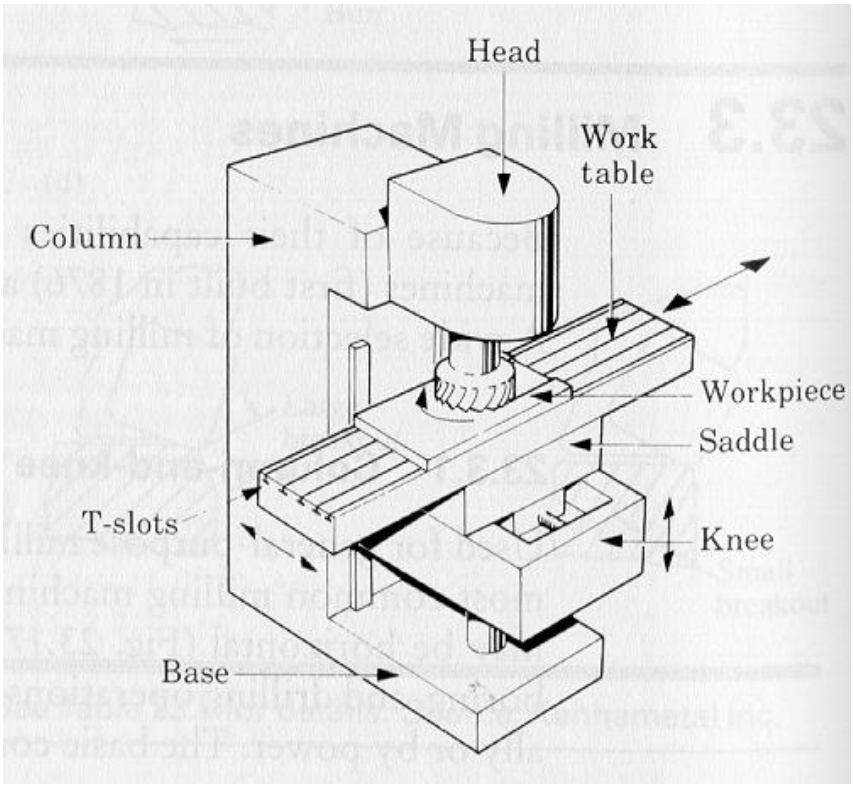
CNC Basic Hardware



Concrete Bed CNC Turning

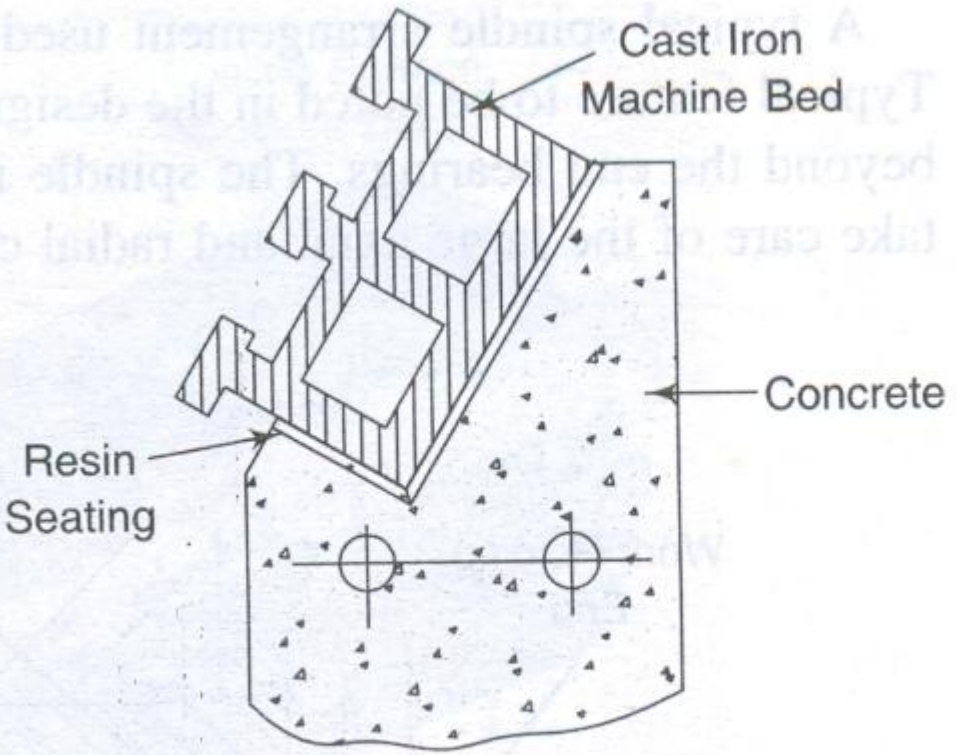
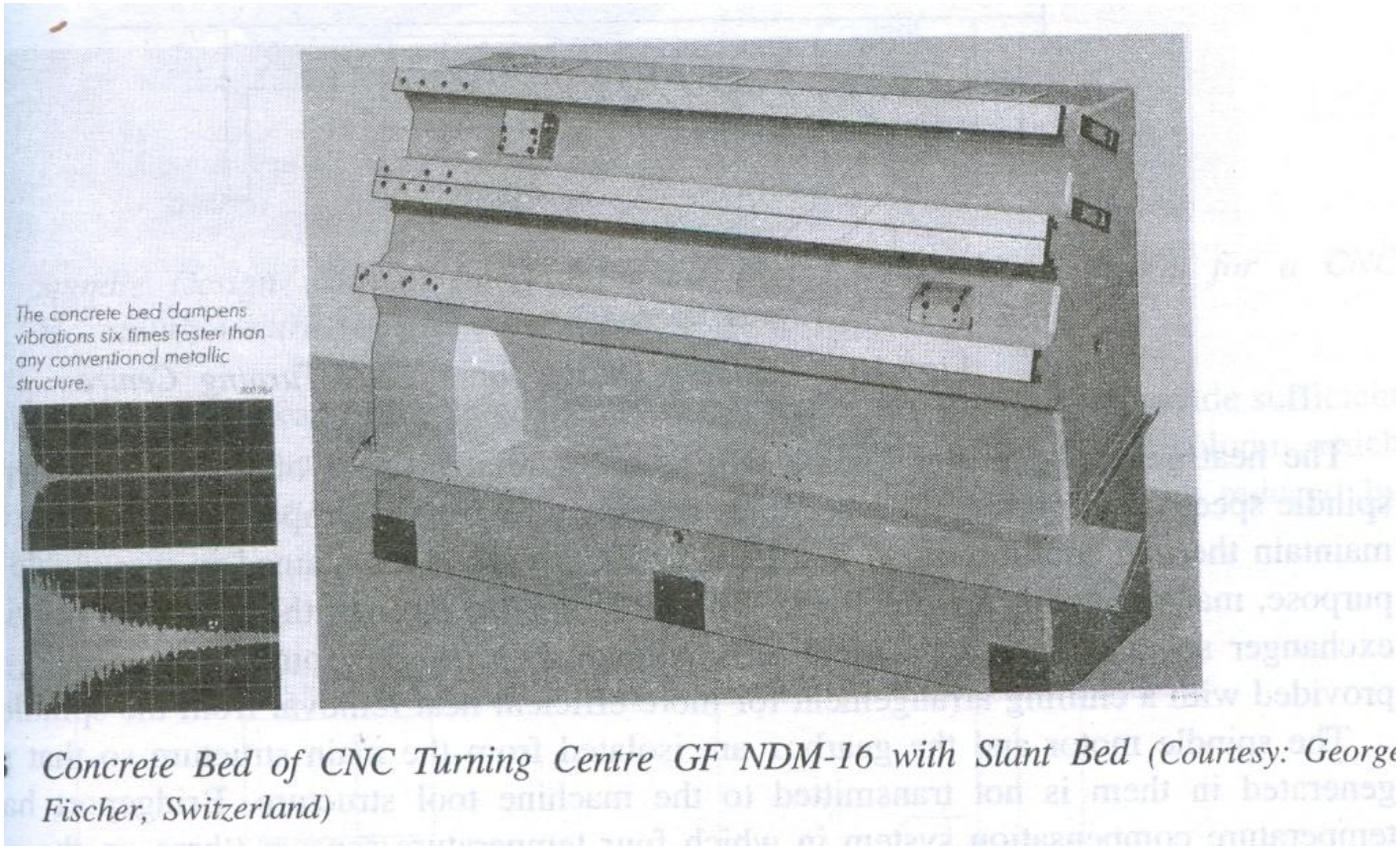


Fig. 10.2 *Schematic of a Concrete Bed of a CNC Turning Centre*

Concrete Bed CNC Turning



Concrete Bed of CNC Turning Centre GF NDM-16 with Slant Bed (Courtesy: George Fischer, Switzerland)

Spindle Design

- Spindle provide the motion & power for the machining
- Machining force is directly transmitted to the spindle as axial and radial force.
- Spindle deflection should be minimized

Spindle Design

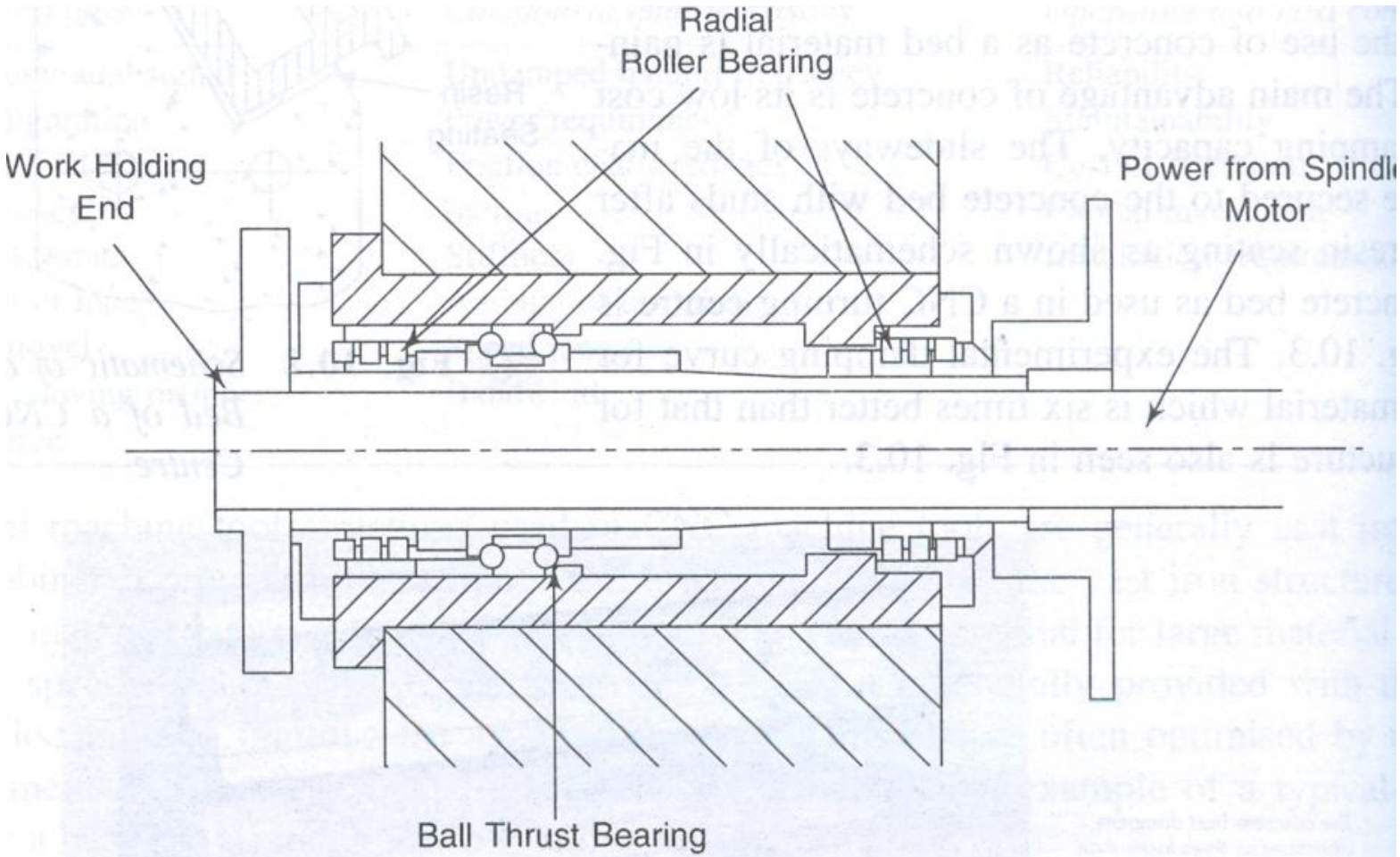


Fig. 10.4 *Spindle Design for a CNC Turning Centre*

Spindle Design

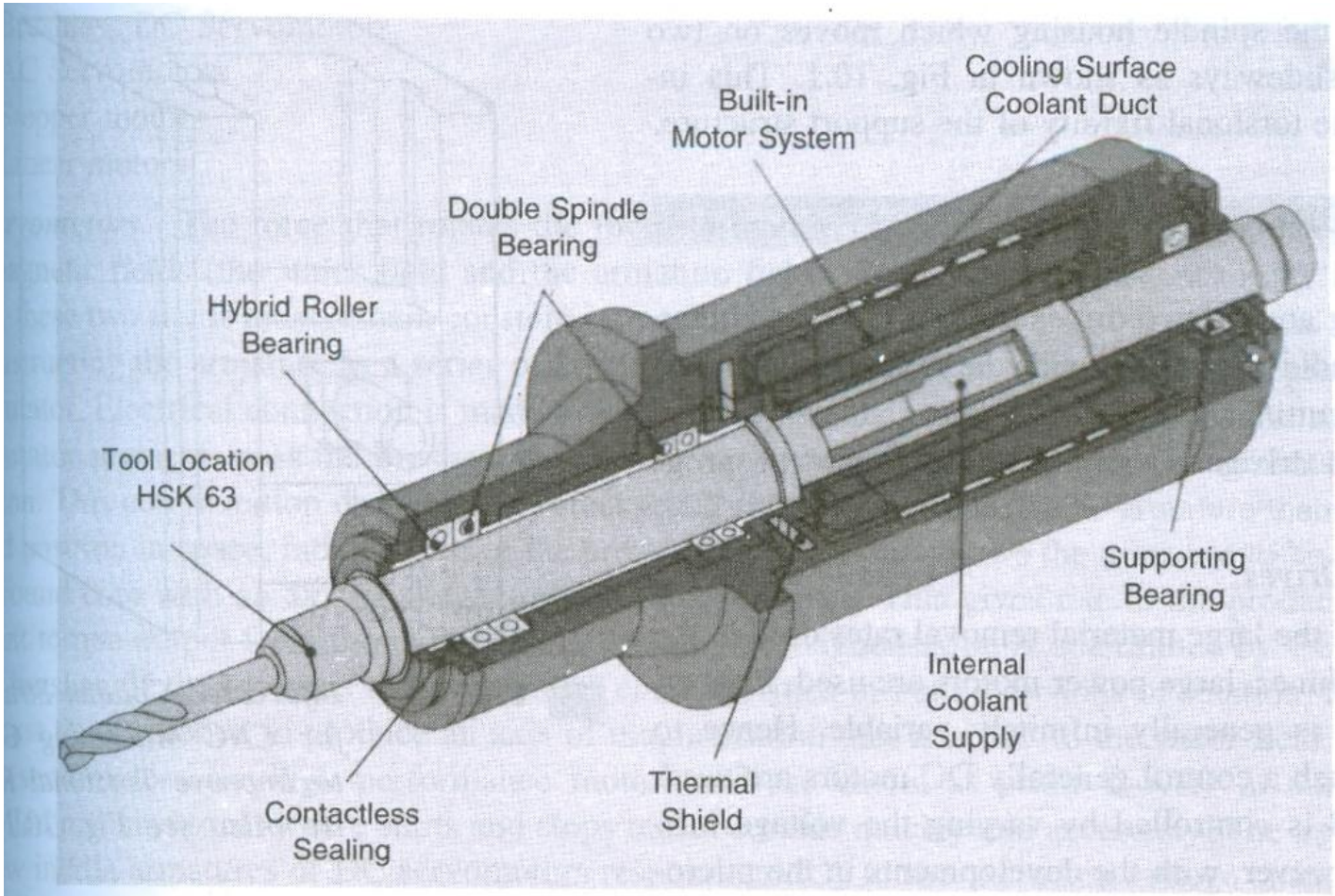
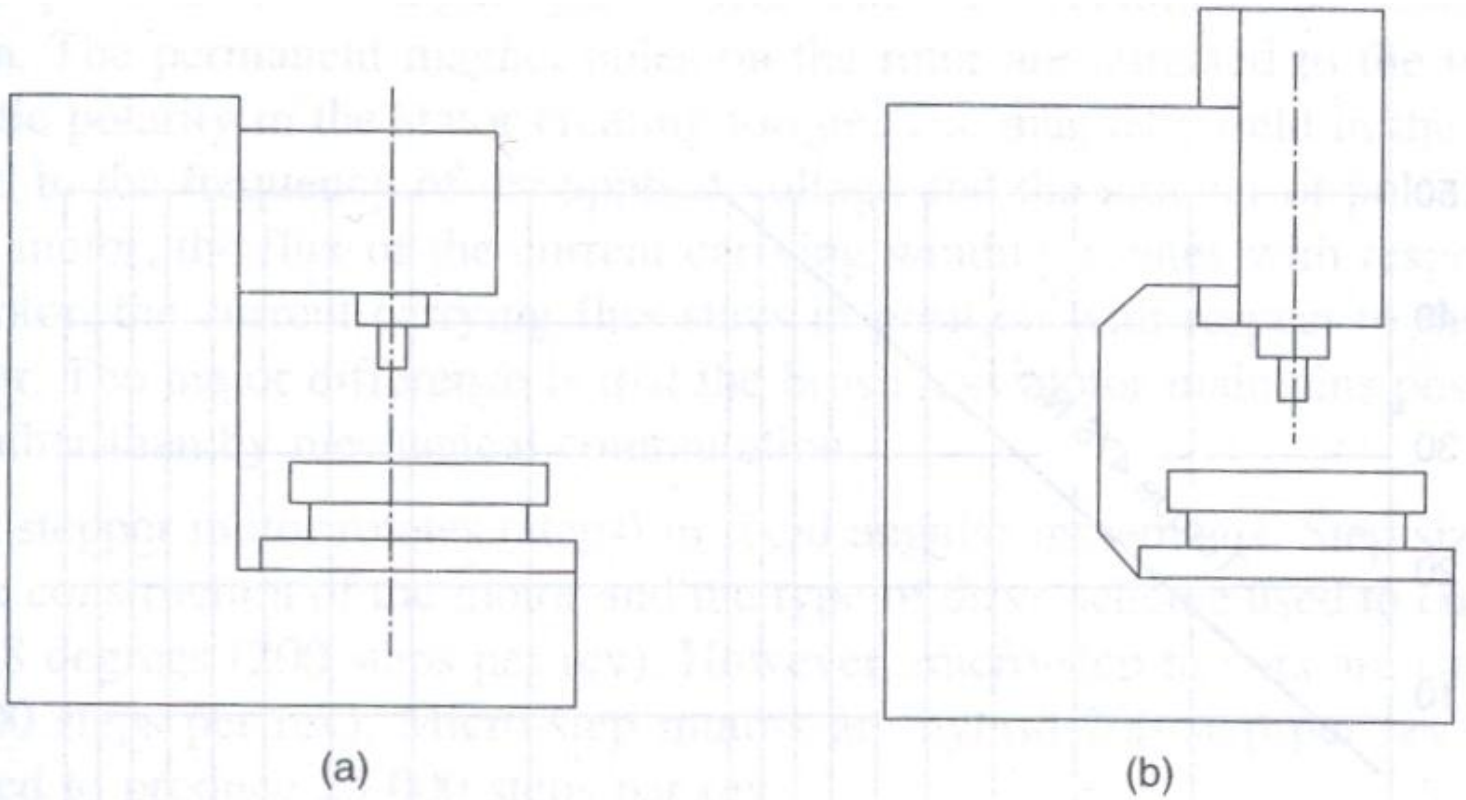


Fig. 10.5 *Spindle Design with an Integral Spindle Motor and Cooling System for a CNC Machining Centre (Courtesy: Hüller Hille GMBH, Germany)*

Spindle Assembly



Spindle Assembly with the Slideways of CNC Vertical Axis Machining Centre

Drives

- Two drives used in CNC m/c
- Spindle drives to provide the main spindle power for cutting
- Feed drives to drive the axis as per the programme

Spindle Drives

- DC motors

  -large power is required

  -speed is controlled by varying the voltage infinitely

- AC motors

  -microprocessor controlled frequency converters is used in modern CNC m/c

  -AC drives used for positioning the spindle axis

Feed Drives used in CNC m/c

- DC Servo motor
- Brushless DC Servo motor
- AC Servo motor
- Stepper motor
- Linear motor

DC Electric Motors

- *Electric Motors or Motors* convert electrical energy to mechanical motion

- Motors are powered by a source of electricity – either AC or DC.

- *DC Electric Motors* use Direct Current (DC) sources of electricity:
  - Batteries
  - DC Power supply

- *Principle of How Motors Work:*
- Electrical current flowing in a loop of wire will produce a magnetic field across the loop.

  When this loop is surrounded by the field of another magnet, the loop will turn, producing a force (called torque) that results in mechanical motion.

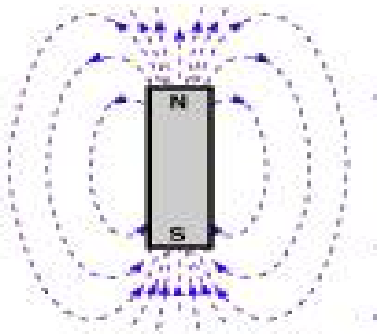
Motor Basics

- Motors are powered by electricity, but rely on principles of magnetism to produce mechanical motion.

- Inside a motor we find:
  - Permanent magnets,
  - Electro-magnets,
  - Or a combination of the two.

Magnets

- A magnet is an object that possesses a magnetic field, characterized by a North and South pole pair.
- A **permanent magnet** (such as this bar magnet) stays magnetized for a long time.

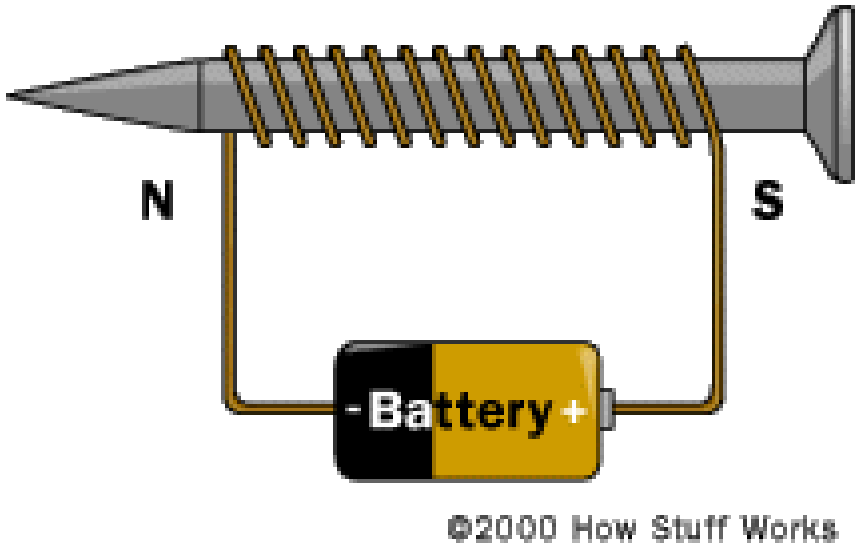


Bar Magnet

- An **electromagnet** is a magnet that is created when electricity flows through a coil of wire. It requires a power source (such as a battery) to set up a magnetic field.

A Simple Electromagnet

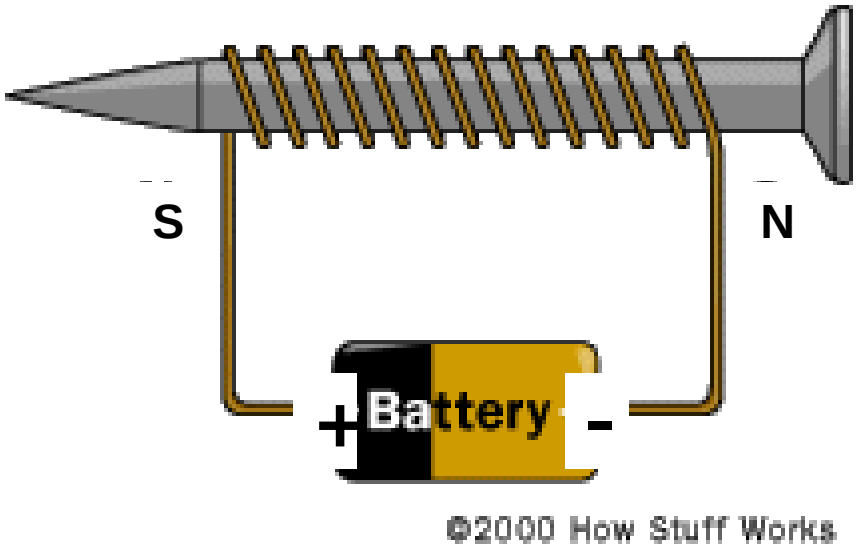
- A Nail with a Coil of Wire



- Q – How do we set up a magnet?
- A – The battery feeds current through the coil of wire. Current in the coil of wire produces a magnetic field (as long as the battery is connected).

A Simple Electromagnet

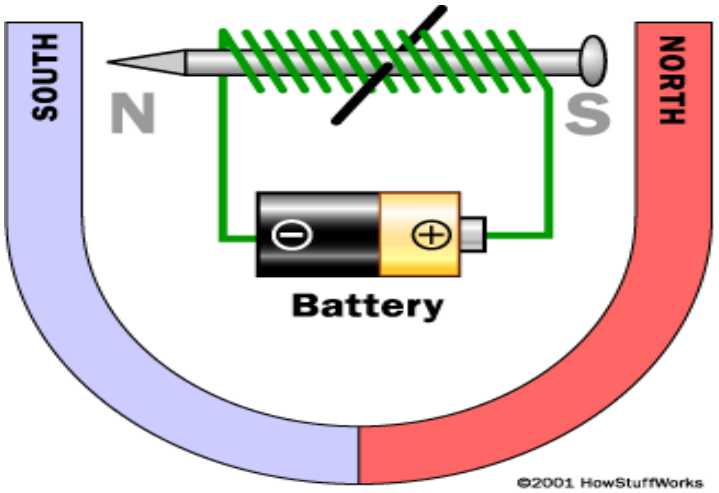
- A Nail with a Coil of Wire



- Q - How do we reverse the poles of this electromagnet?
- A – By reversing the polarity of the battery!

The Electromagnet in a Stationary Magnetic Field

- If we surround the electromagnet with a stationary magnetic field, the poles of the electromagnet will attempt to line up with the poles of the stationary magnet.

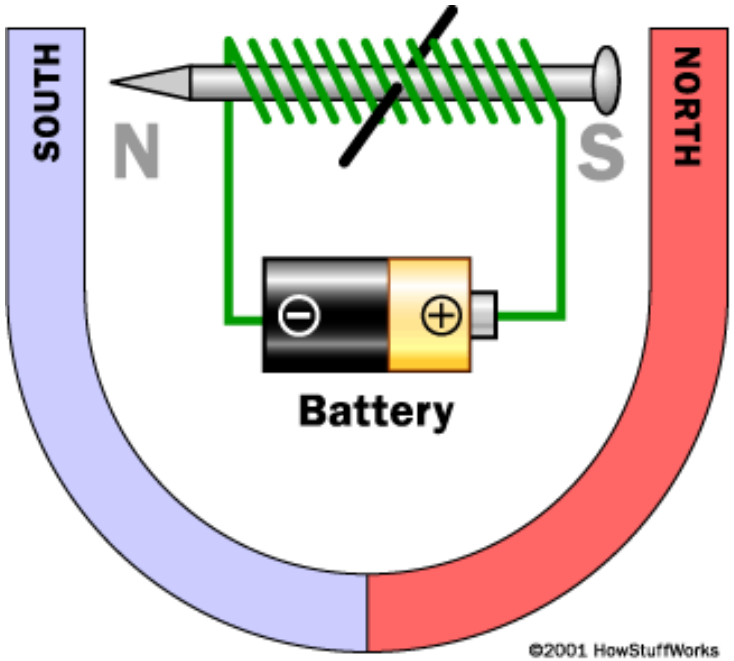


OPPOSITE POLES ATTRACT!

- The rotating motion is transmitted to the shaft, providing useful mechanical work. This is how DC motors work!

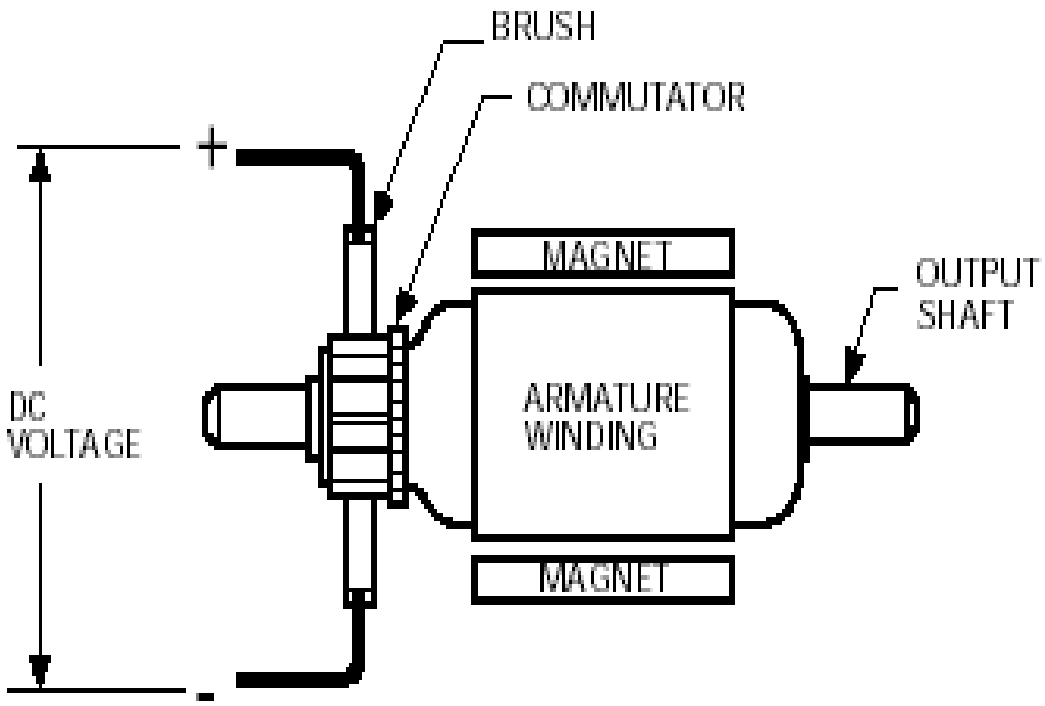
DC Motor Operation Principles

- Once the poles align, the nail (and shaft) stops rotating.
- How do we make the rotation continue?

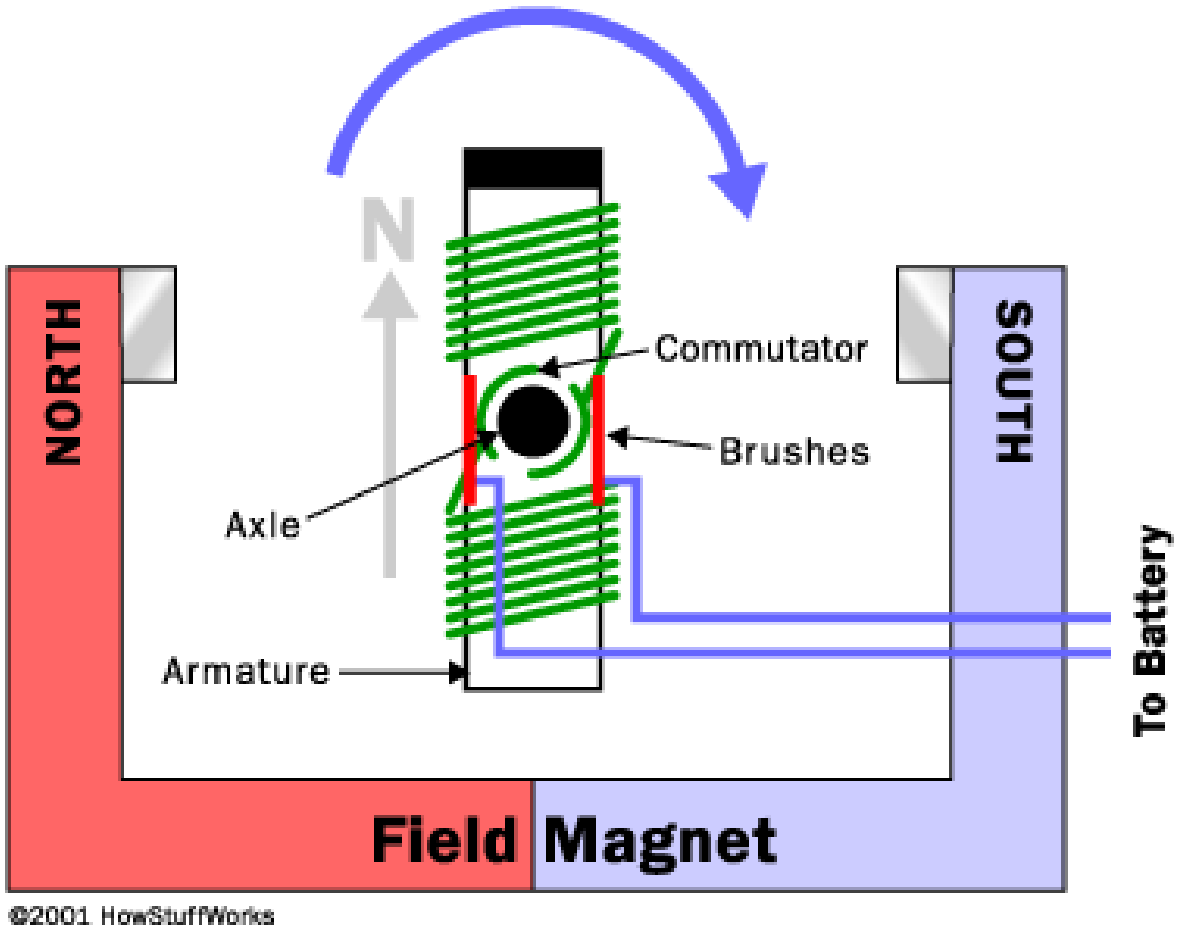


- By switching the poles of the electromagnet. When they line up again, switch the poles the other way, and so on.
- This way, the shaft will rotate *in one direction continuously*!

Brushed DC Motor Components

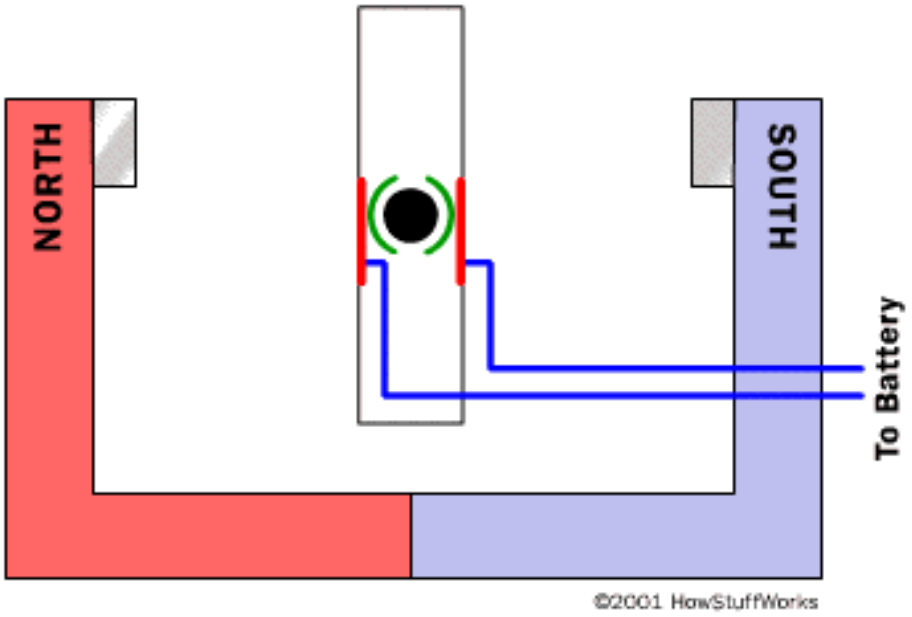


Brushed DC Motor Components



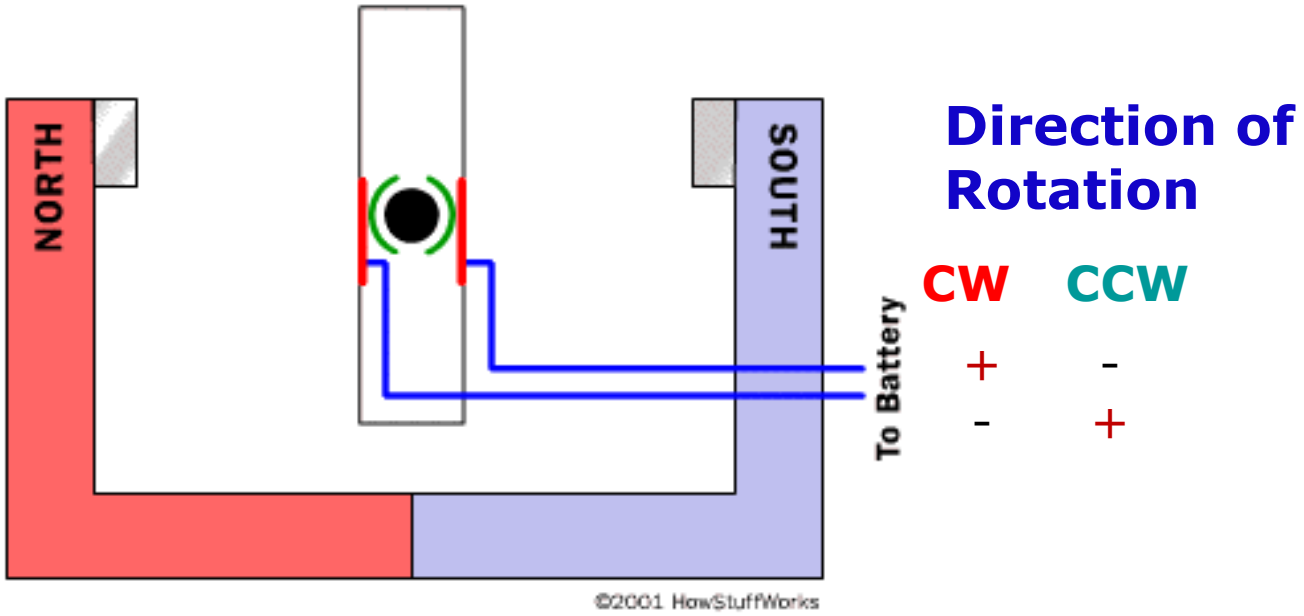
How the Commutator Works

- As the rotor turns, the commutator terminals also turn and continuously reverse polarity of the current it gets from the stationary brushes attached to the battery.



Controlling Motor Direction

- To change the direction of rotation:
  - –Simply switch the polarity of the battery leads going to the motor (that is, switch the + and – battery leads)



Brush DC Motor

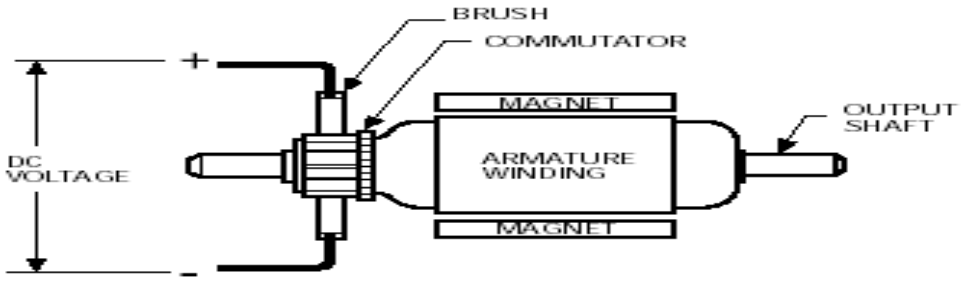


Figure 1

Description of Brush DC Motors:
In order for any DC motor to operate, the current to the motor coils must be continually switched relative to the field magnets. In a brush type unit, this is accomplished with carbon brushes contacting a slotted commutator cylinder which has each motor coil connected to a corresponding bar of the commutator. The switching continues as the motor rotates. With this arrangement, there are physical limitations to speed and life because of brush wear. Speed depends on amount of voltage applied.

Typical Use of Brush DC Motors:
•Variable speed applications (like all DC motors)
•Applications with simple controls

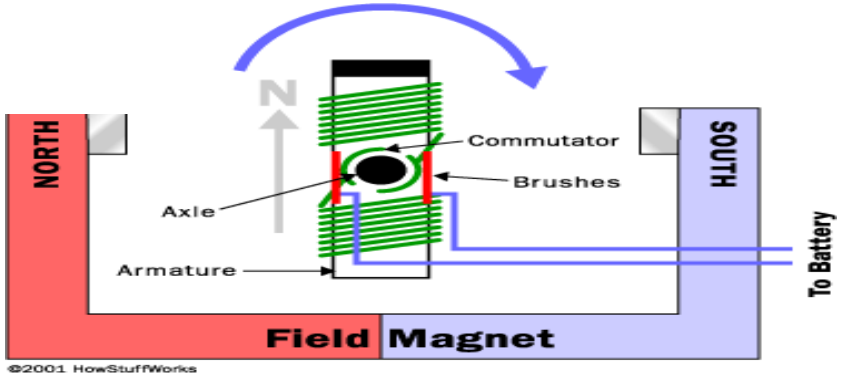


Figure 2

Advantage Over Brushless DC Motors:
•Cheaper (generally)
•Stand alone: requires no sensing (driver)
•Requires no controller
•Speed control is easier (via changing voltage only)

Inside a Toy Motor (Similar to TekBot Motor)

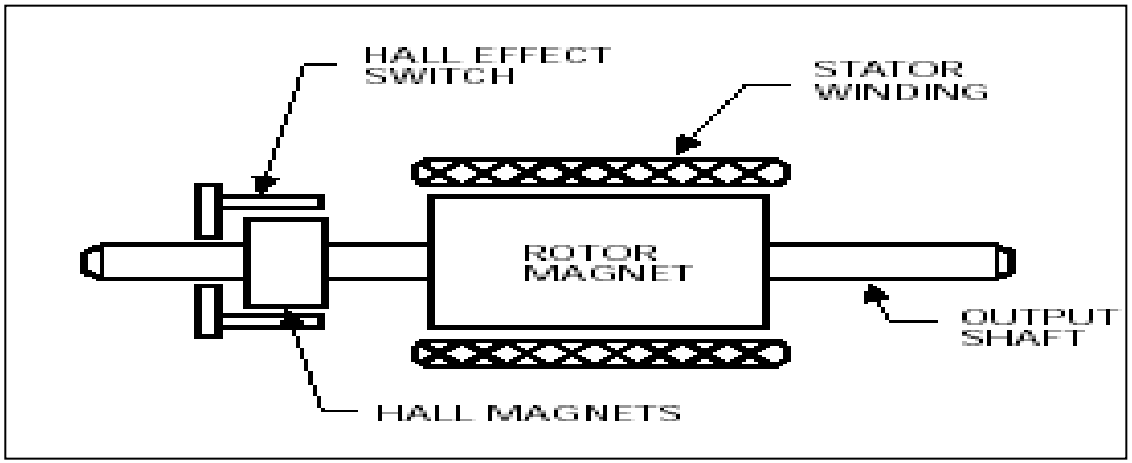
DC Motor Characteristics

- When power is applied, DC motors turn in one direction at a fixed speed.
- They are optimized to run at a fixed, usually high RPM.
- Torque is highest at the rated speed and lowest at low speeds.
- Speed can be varied if a (pulse width modulation) PWM controller is added.
- Almost all can be reversed.

DC Motor Characteristics

- Inexpensive and commonly available.
- Available in wide range of speeds and power.
- Suitable for turning, spinning, etc.
- Not suitable for positioning unless some kind of position feedback is added.
- If the applied load is greater than the capacity of the motor, the motor will stall and possibly burn out.

Brushless DC Motor

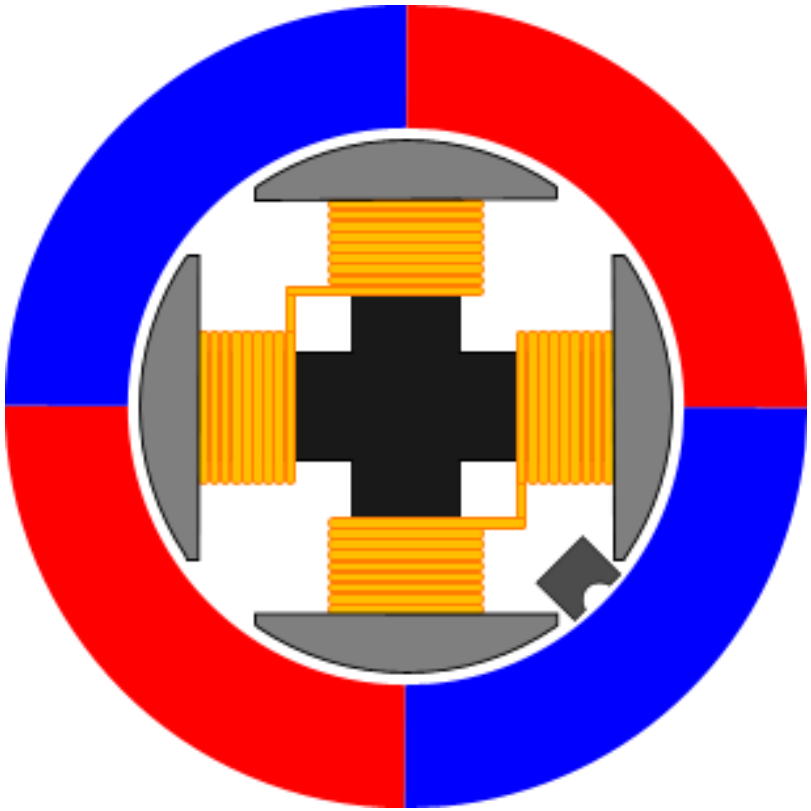


Description and Comparison to Brush Motors:
The main difference between Brushless and Brush concepts is the means of commutating the motor coils. In a BLDC motor, the position of the rotor is sensed and continually fed back to the commutation electronics to provide for appropriate switching.

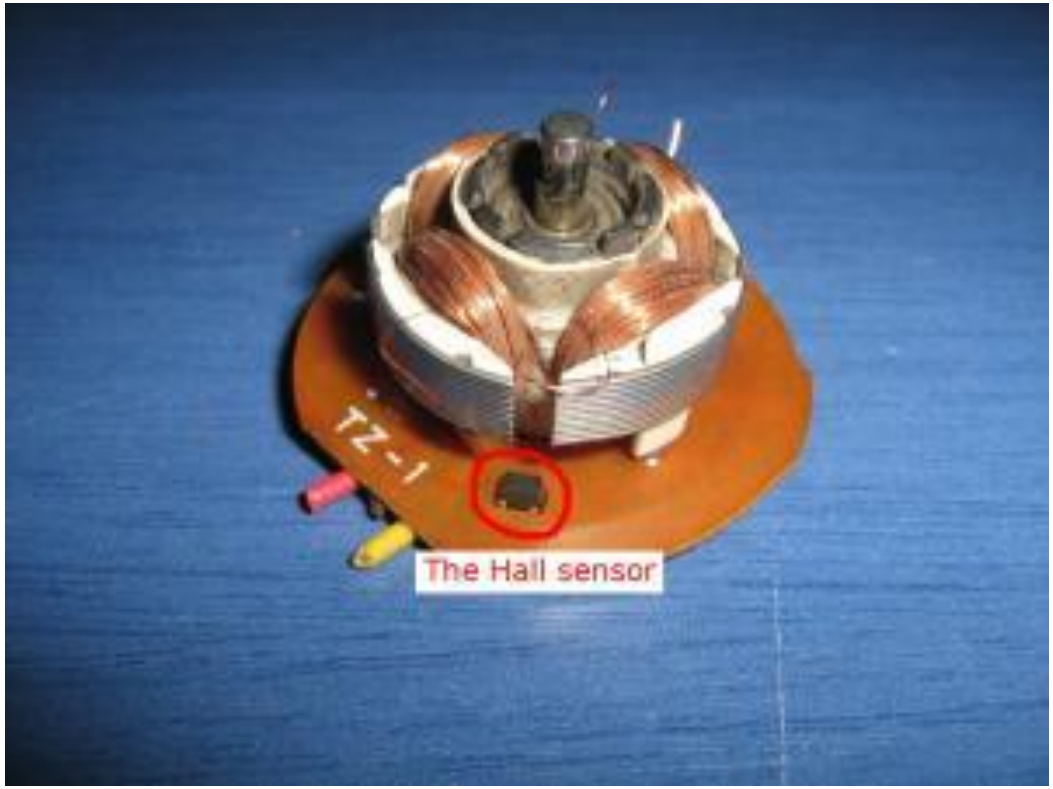
Hall effect

- current is flowing through an electrical conductor, and this conductor is placed perpendicular to a magnetic field, then a voltage is developed on this conductor on a right angle to the currents' path. This effect is called the "Hall effect", and the voltage developed is called "Hall voltage".
- The Hall voltage is measured in micro-volts.

Brushless DC Motor

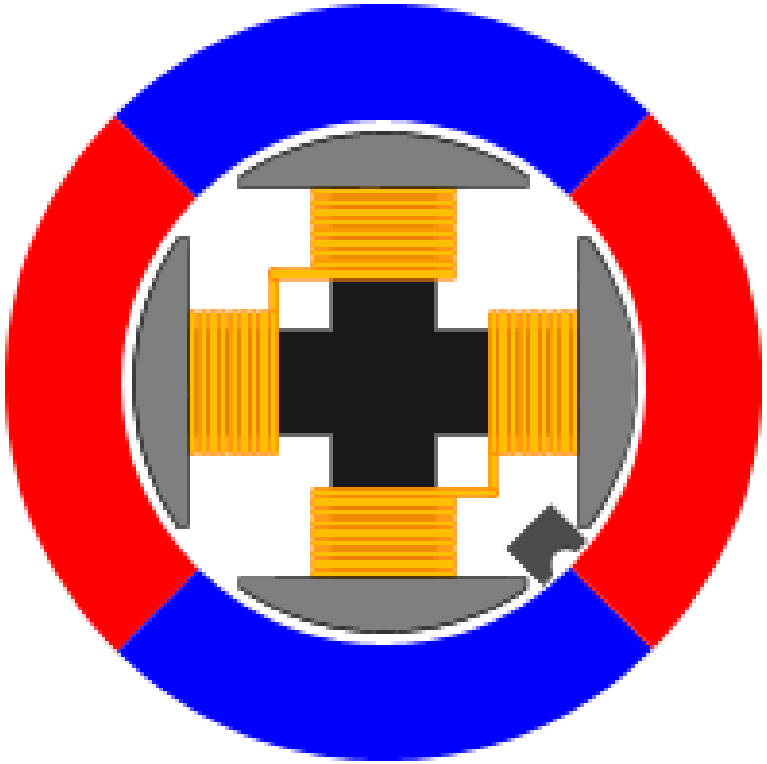


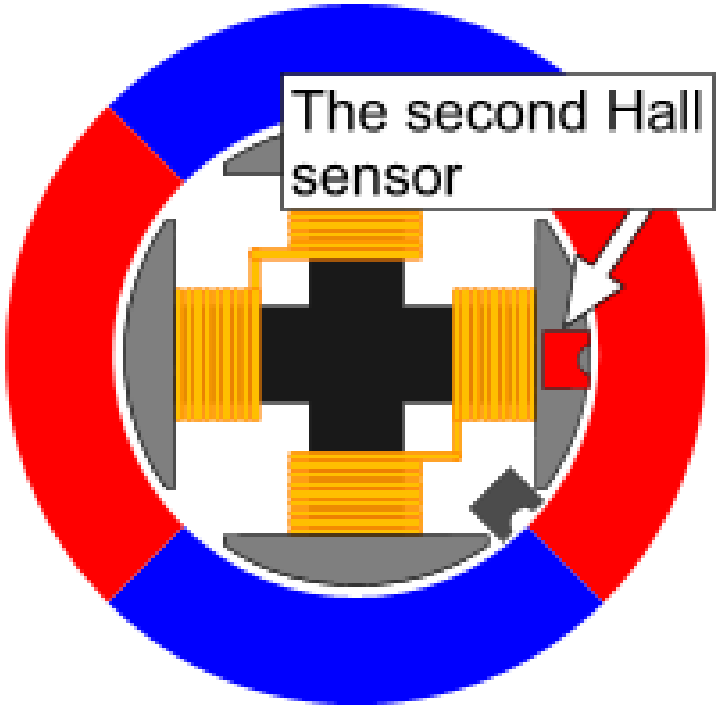
Brushless DC Motor



BLDCs have usually 4 coils and 4 magnets. Also, the Hall sensor is able not only to see if a magnetic field is in front of it, but also to distinguish if this is the North or the South pole. This is how a real BLDC motor looks like:

when the Hall sensor is between the two poles?





The second sensor will be placed with 45º difference from the first one:

Now, even if the first Hall sensor cannot get a proper reading, the second Hall sensor can clearly distinguish the magnetic pole. The controller will accept as "correct reading" the one that comes from the sensor with the most intense signal.

Brushless DC Motor

- The brushless motor, unlike the DC brushed motor, has the permanent magnets glued on the rotor.
- It has usually 4 magnets around the perimeter.
- The stator of the motor is composed by the electromagnets, usually 4 of them, placed in a cross pattern with 90^{o} angle between them.
- The major advantage of the brushless motors is that, due to the fact that the rotor carries only the permanent magnets, it needs of NO power at all.
- No connection needs to be done with the rotor, thus, no brush-commutator pair needs to be made! This is how the brushless motors took their name from.
-

Brushless DC Motor

- **Advantages of Brushless DC Motors:**
- Since there are no carbon brushes to wear out, a BLDC motor can provide significantly greater life being now only limited by bearing wear.

- BLDC motors also offer additional advantages as by-products of the inherent construction:
- **1. Higher efficiencies**
- **2. High torque to inertia ratios**
- **3. Greater speed capabilities**
- **4. Lower audible noise** ***As compared to Brush DC Motors
- **5. Better thermal efficiencies**
-

DC Servo Motors

- Servo motor requirements may include control of acceleration, velocity, and position to very close tolerances and allow for fast starts, stops and reversals, and very accurate control.
- DC servo motors consist of a DC motor combined with feedback for either position or speed.
- A system with a motor, feedback, and a controller which constantly adjusts the position or speed to in reaction to the feedback is called a closed-loop system
- Hobby Servos require a desired position signal to tell them where to turn to.

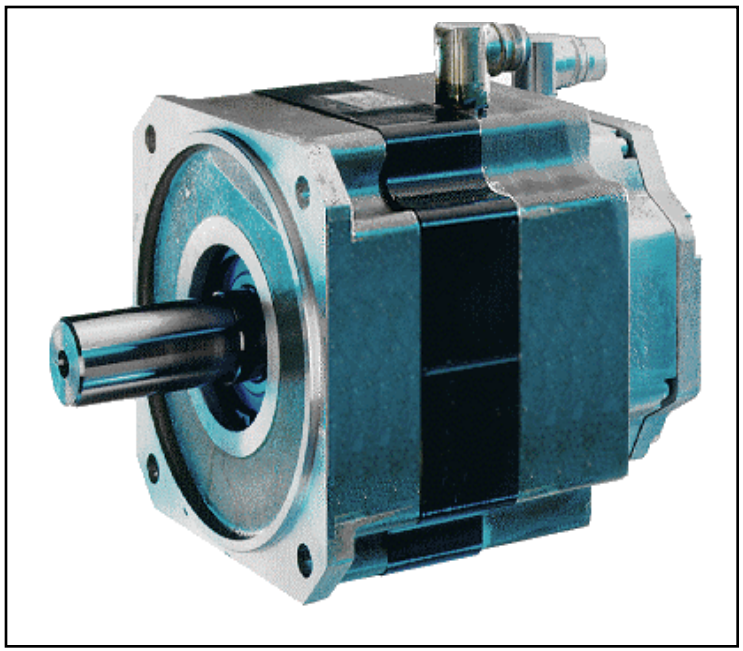
DC Servo Motors

- Once told where to go, a Hobby Servo uses its built-in controller and feedback system to hold its position.
- When power is applied, in the absence of a signal, a hobby servo goes to its central position
- The signal to control a hobby servo is non-trivial to generate.
- Hobby servos can also be modified to turn continuously, in which case the control signal is speed instead of position

Siemens High Performance Motor

Standard servo motor 1FK6

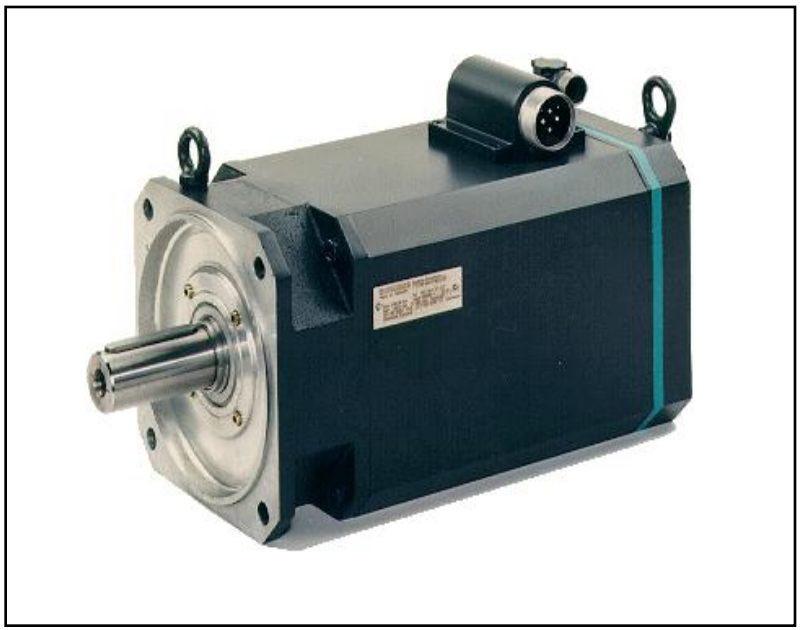
Permanantly exited synchronous AC servo motor



- extremely high power density and overload
- high standstill torque (e.g. for holding vertical position)
- Dynamic response due to low inertia
- Super High Dynamic for **1FK6 HD**
- compact build due to frameless design (flange and shaft compatible to 1FT6)
- integrated feedback system
- robust, essentially maintenance free build
- high level of protection (IP64)
- motor temperature monitoring with KTY 84
- rated power of 0.7 to 7 HP for rated speeds of 3000 4500(HD) and 6000 r.p.m.

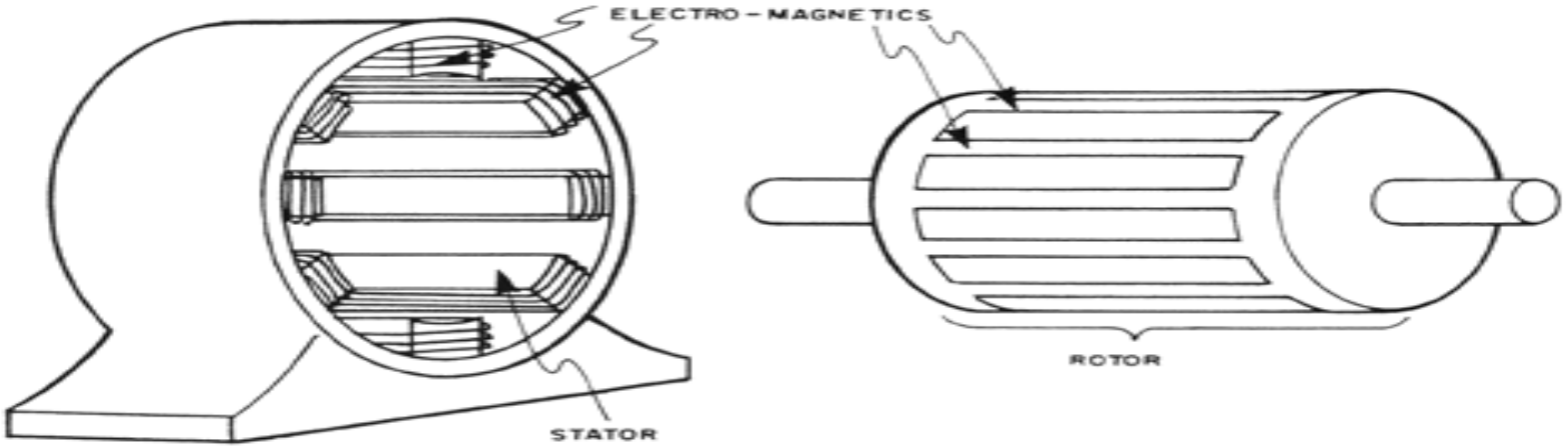
Premium servo motor 1FT6

Permanently excited synchronous AC servo motor



- extremely high power density and overload
- high standstill torque (e.g. for holding vertical position)
- high dynamic response due to low inertia
- very high efficiency and a very smooth running (low torque ripple)
- integrated feedback system
- robust, essentially maintenance free
- high level of protection (IP64)
- motor temperature monitoring with KTY 84
- rated power of 0.35 to 46 HP for rated speeds of 1500 to 6000 r.p.m.

AC Motors



General AC Motor Description:

•An AC motor has two basic electrical parts: a "stator" and a "rotor" as shown in Figure.

AC Motors

Figure 5

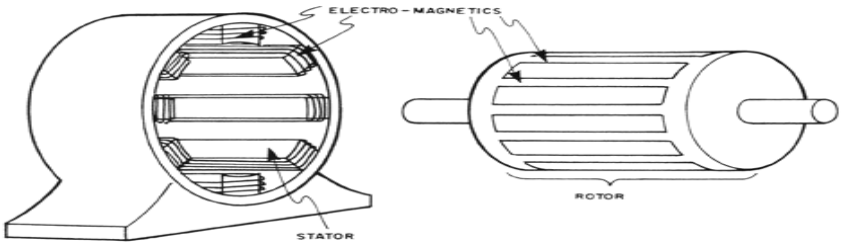


Figure 6

General AC Motor Description:

•The stator is in the stationary electrical component. It consists of a group of individual electro-magnets arranged in such a way that they form a hollow cylinder, with one pole of each magnet facing toward the center of the group.

•The rotor also consists of a group of electro-magnets arranged around a cylinder, with the poles facing toward the stator poles.

• We progressively change the polarity of the stator poles in such a way that their combined magnetic field rotates, then the rotor will follow and rotate with the magnetic field of the stator.

AC Motors

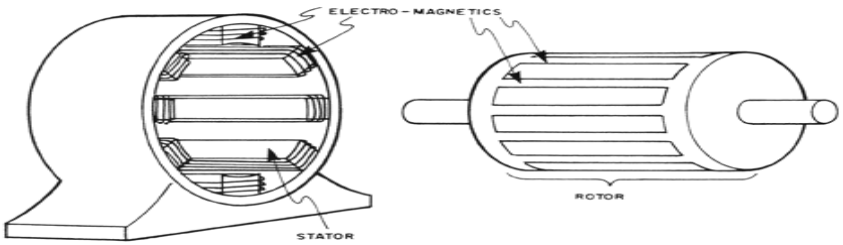


Figure 6

Single Phase AC

Single phase AC motors utilize single phase AC electricity.

Uses:

Residential or areas where only single phase wiring is available. Good performance up to 1.0 hp; can use 110V up to nearly 5 hp. Also, some are available for 220V single phase.

Three Phase AC

Three phase AC motors utilize three phase AC electricity (that must be wired in the outlet)

Uses:

Industrial or areas with appropriate wiring.

Advantages:

•Uses 1/3 the amount of current (increased efficiency)

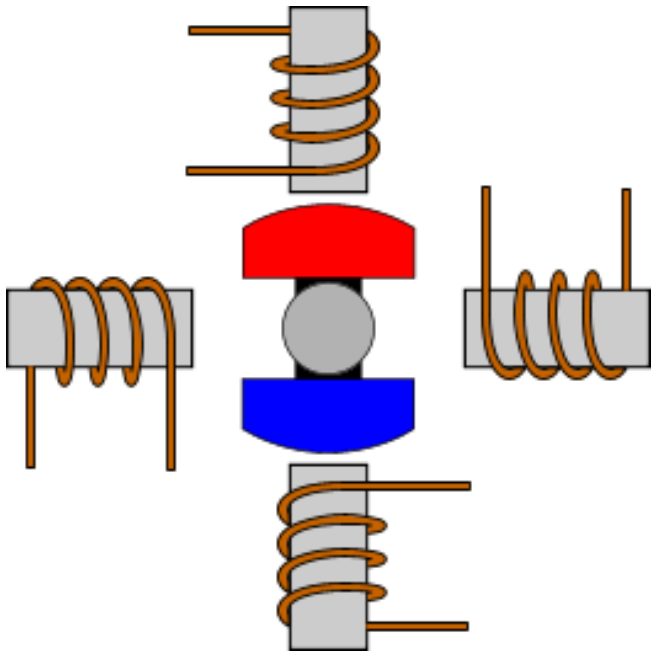
•More easily reversed

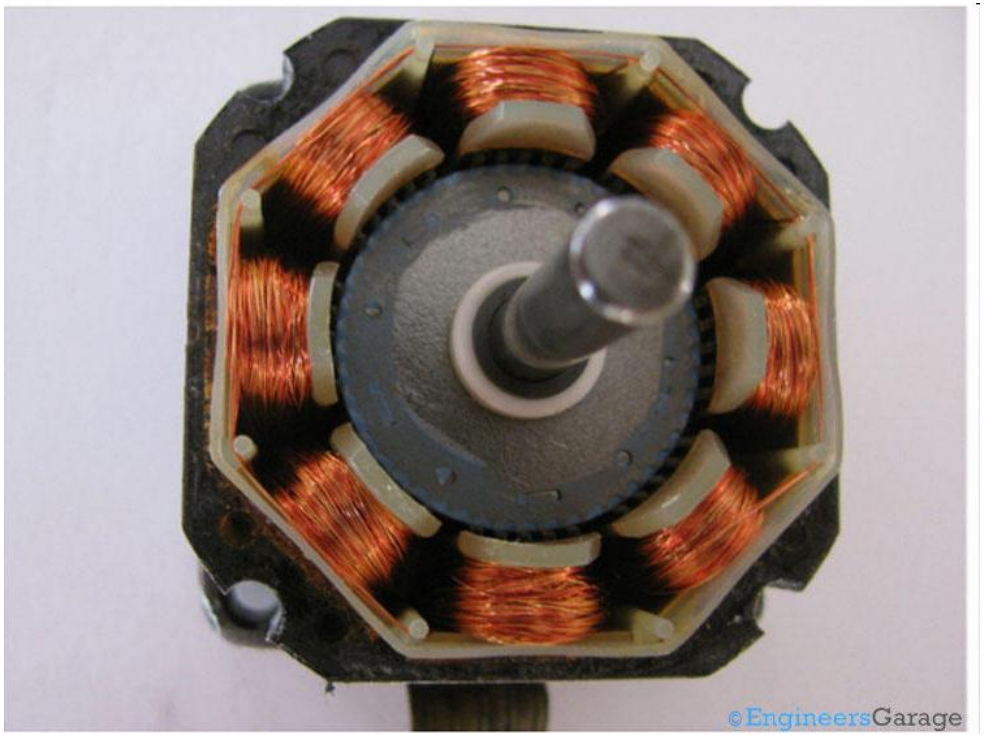
•Huge power capabilities

Stepper Motor

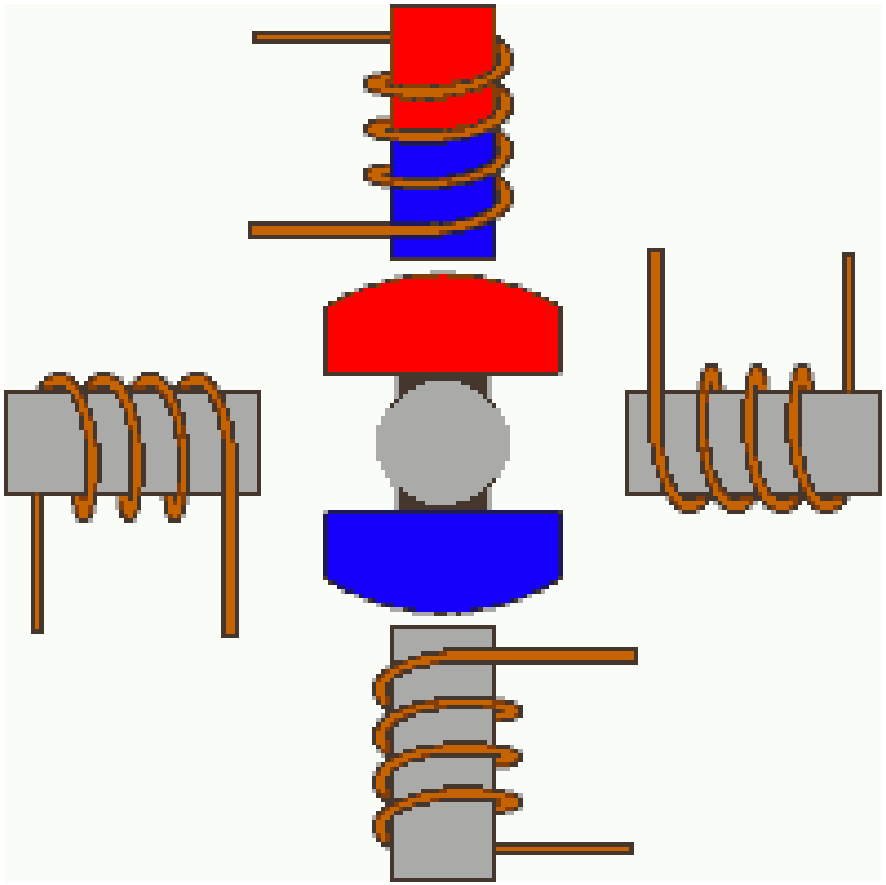
- Stepper motors rotate in steps
- Each step is a fraction of a full circle. This fraction depends mostly from the mechanical parts of the motor, and from the driving method.
- They are driven (usually) with pulses.
- Each pulse is translated into a degree of rotation.
- For example, an 1.8^{o} stepper motor, will revolve its shaft 1.8^{o} on every pulse that arrives.
- Due to this characteristic, stepper motors are called also digital motors.

Stepper Motor

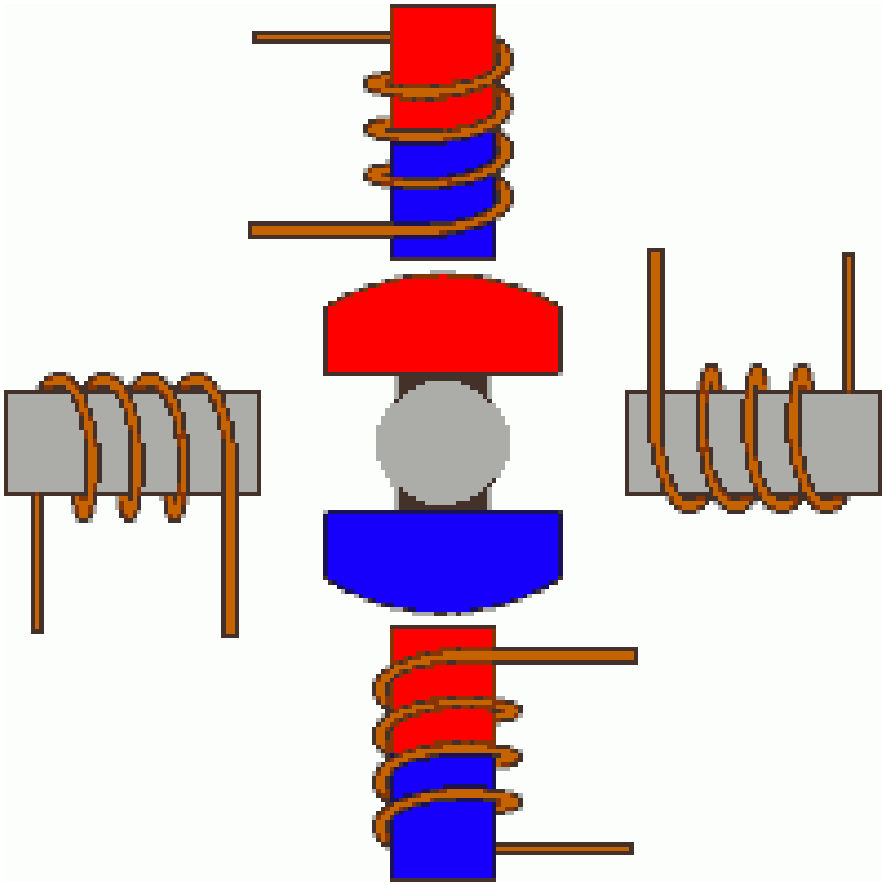




Single-Coil excitation Stepper Motor



Two-Coil excitation Stepper Motor

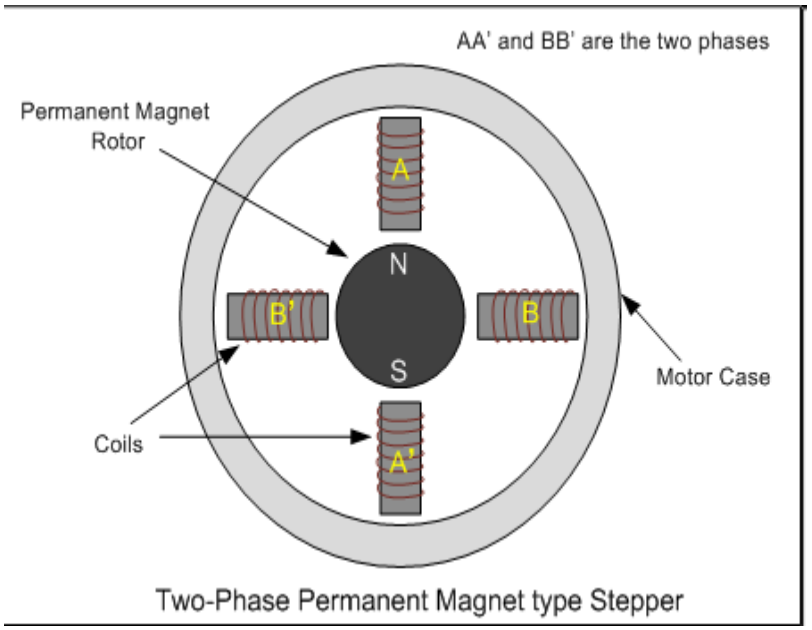


Stepper motor types

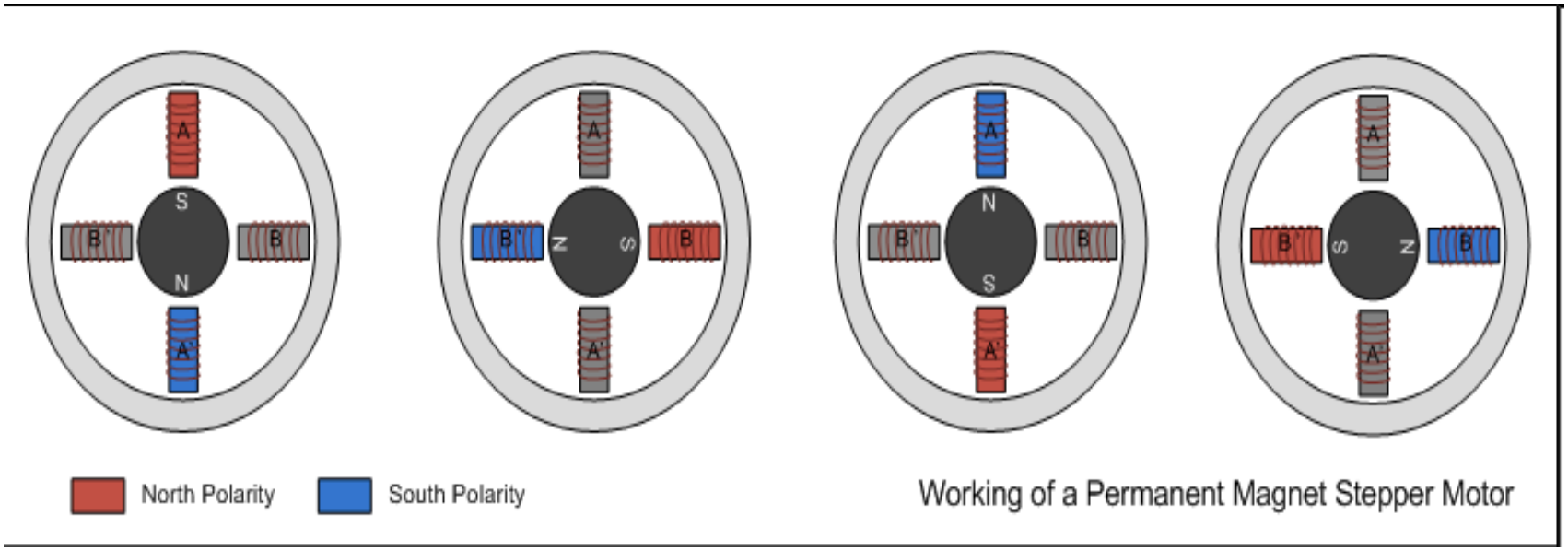
- Permanent Magnet Stepper Motor (**PM**)
- Variable Reluctance Stepper Motor (**VR**)
- Hybrid Stepper Motor

Permanent Magnet Stepper Motor (**PM**)

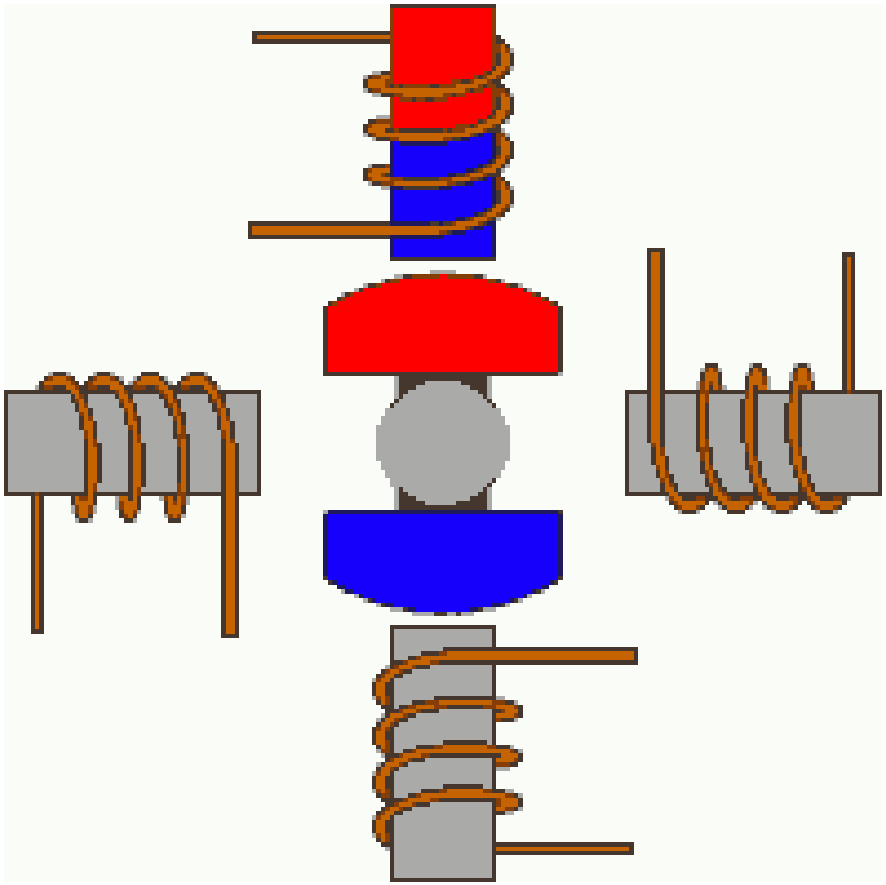
- The rotor of the PM motor carries a permanent magnet with 2 or more poles, in a shape of disk.
- The stator coils will attract or repulse the permanent magnet on the rotor and will generate the torque. Here is a sketch of a PM motor:
- PM stepper motors have usually step angle from 45^{o} to 90^{o}.



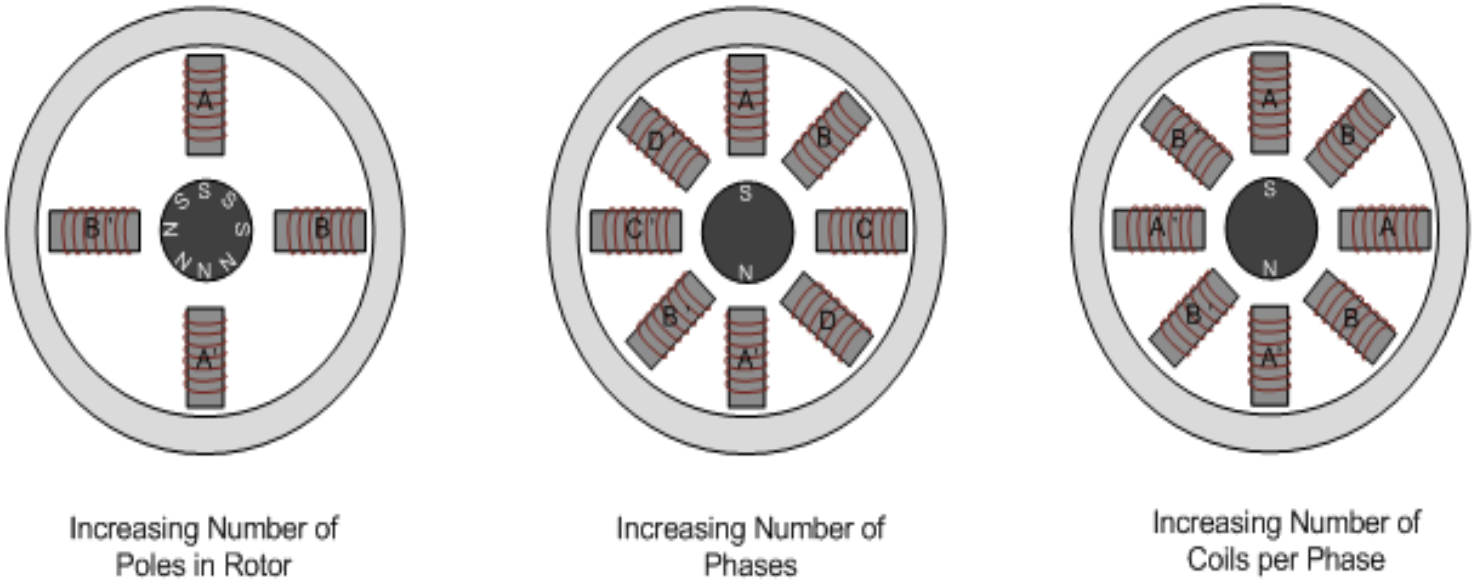
Working of permanent magnet stepper



Permanent Magnet Stepper Motor (**PM**)



The resolution of a permanent magnet stepper can be increased by increasing number of poles in the rotor or increasing the number of phases.

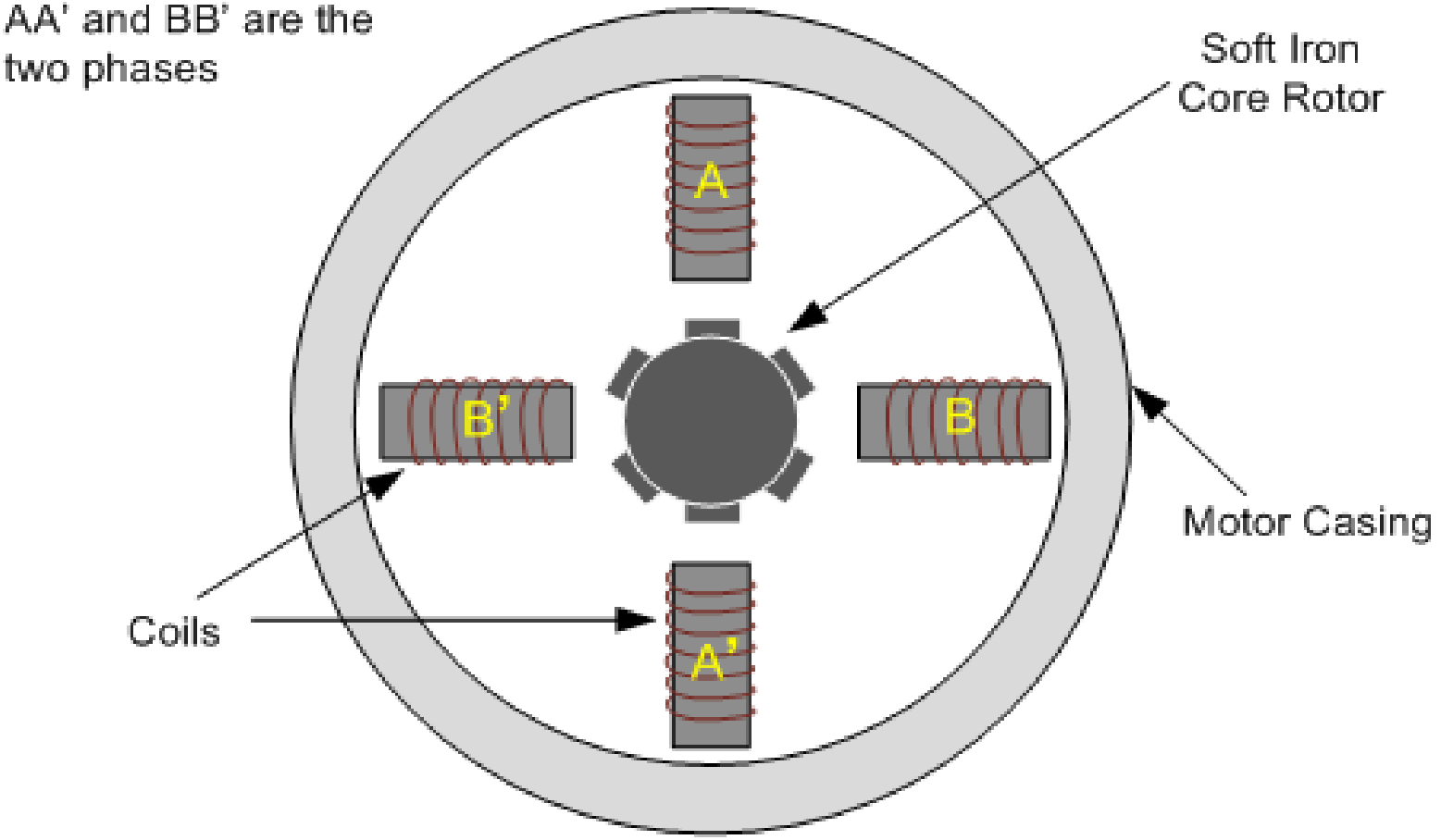


Methods to increase resolution of a Permanent Magnet Stepper

Variable Reluctance Stepper Motor (**VR**)

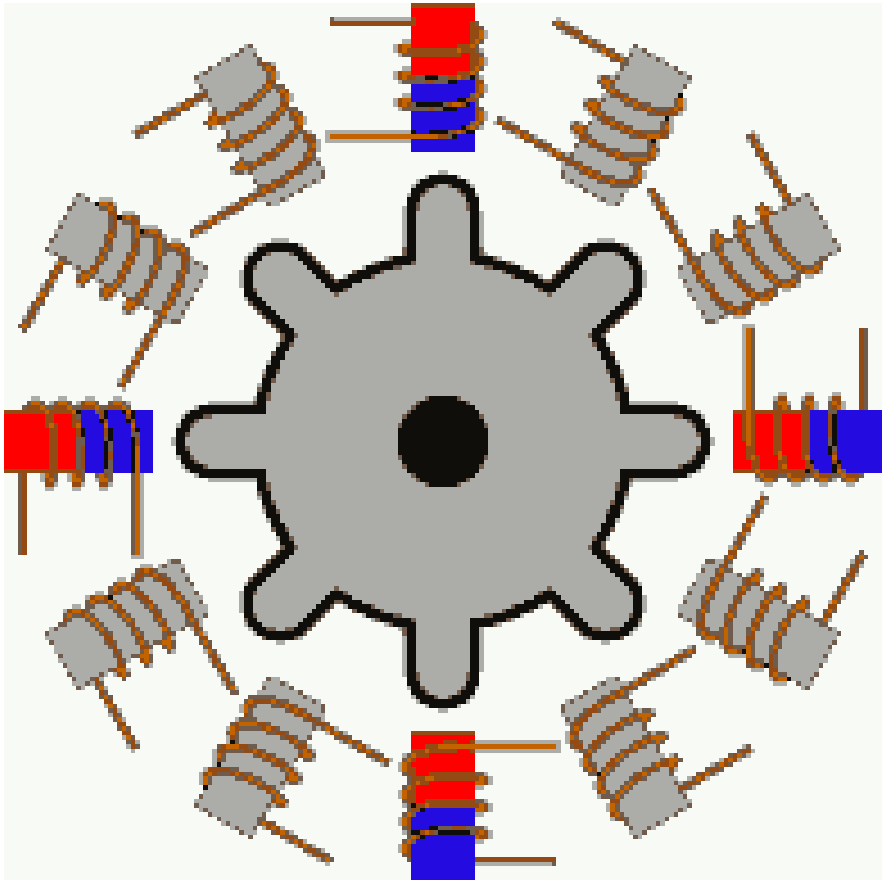
- The VR motor does not have a permanent magnet on the rotor
- Instead, the rotor is made of soft iron, and performs a teethed disk like a gear.
- The stator has more than 4 coils. The coils are energized in opposite pairs, and will attract the rotor.
- When the stator coil is energized the rotor moves to have a minimum gap between the stator and its teeth.
- VR stepper motors have usually step angle from 5^{o} to 15^{o}.

Two-Phase Variable Reluctance Stepper Motor



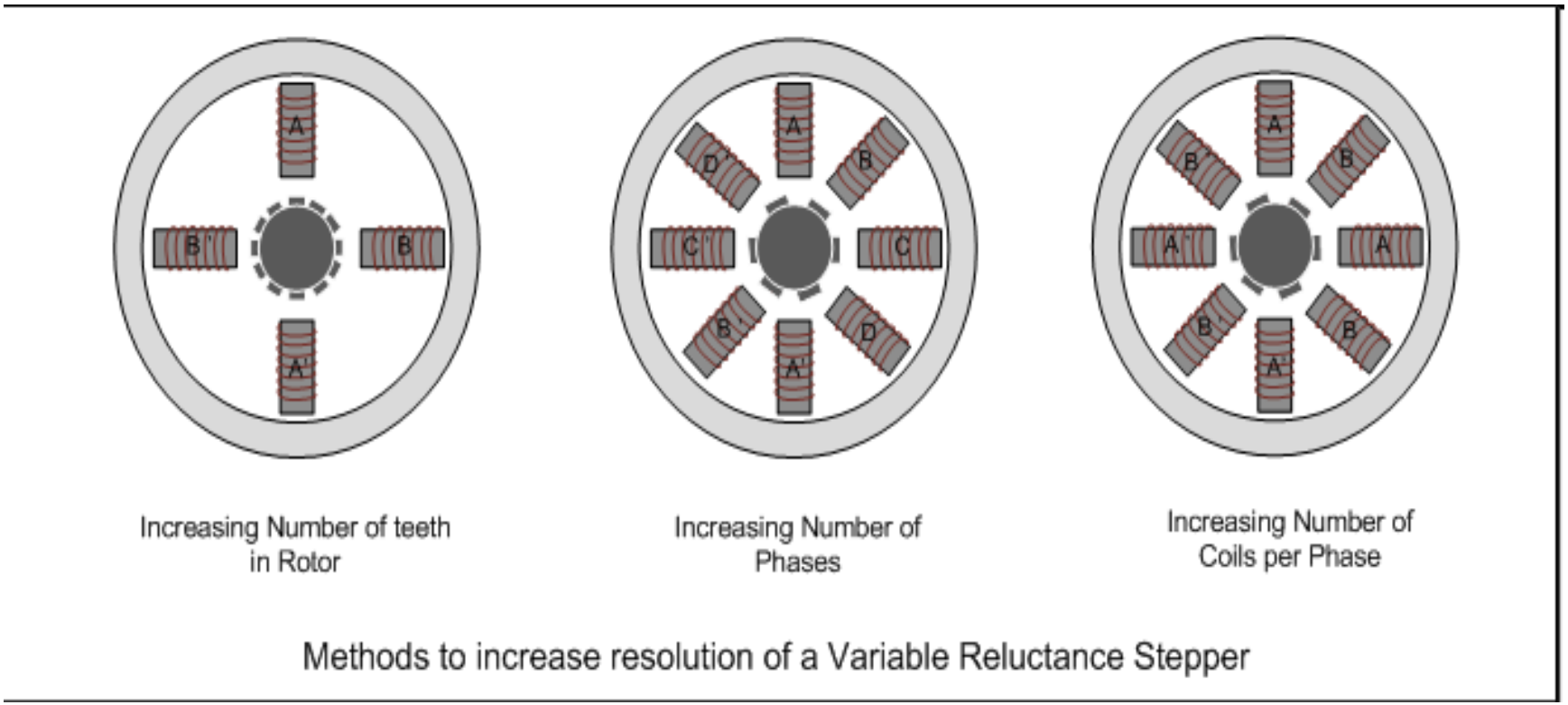
Notice that the teeth of the Rotor are so designed that when they are aligned to one phase, they get misaligned to the other

Variable Reluctance Stepper Motor (**VR**)



VR stepper motors have usually step angle from 5º to 15º.

The resolution of a variable reluctance stepper can be increased by increasing the number of teeth in the rotor and by increasing the number of phases.



Increasing Number of teeth in Rotor

Increasing Number of Phases

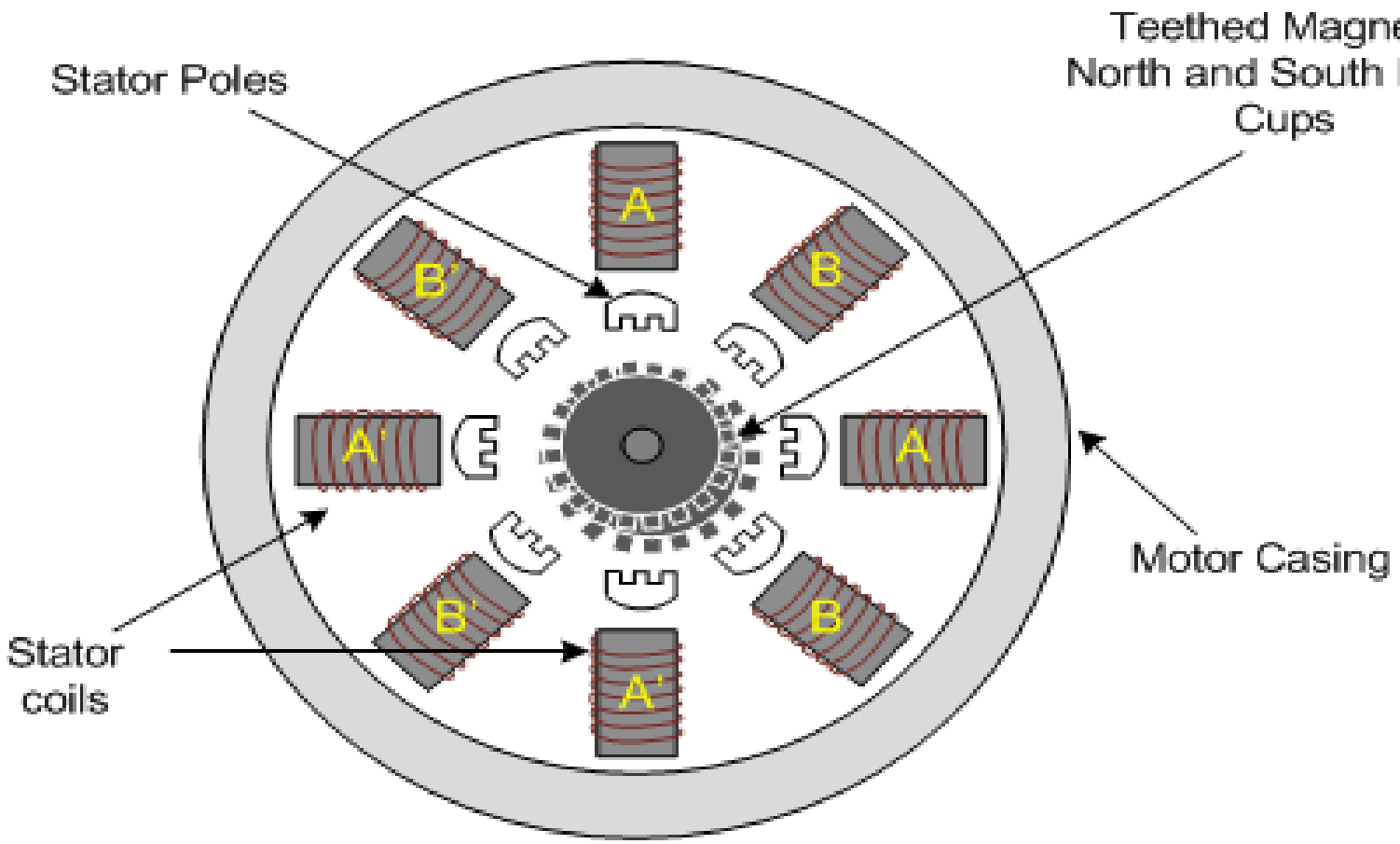
Increasing Number of Coils per Phase

Methods to increase resolution of a Variable Reluctance Stepper

Hybrid Stepper Motor

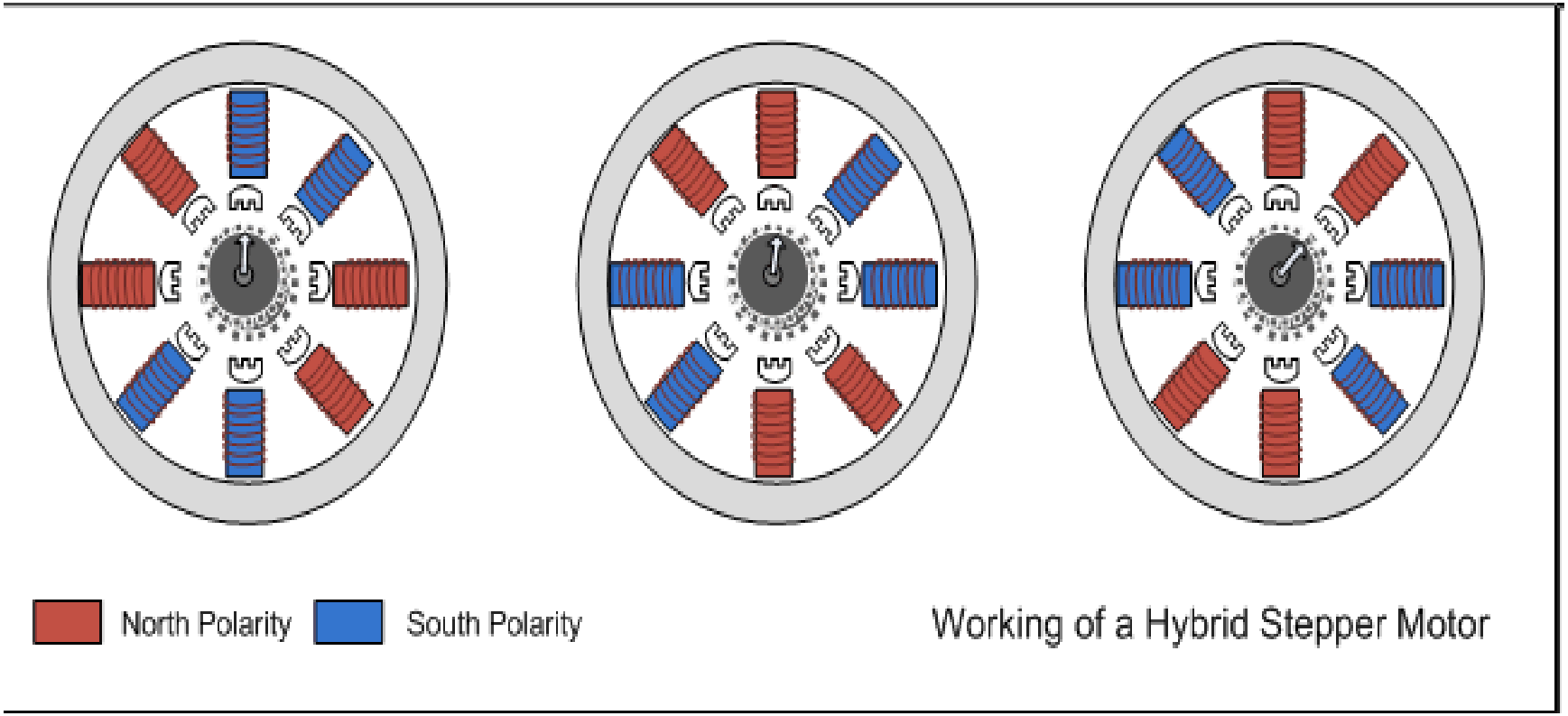
- The hybrid stepper motors are named so, because they combine the characteristics from both VR and PM stepper motors.
- They have excellent hold and dynamic torque, and very small step angles, from 0.9^{o} to 5^{o}, giving them A+ in accuracy.
- Their mechanical parts can rotate at high speeds relatively to the other stepper motor types.
- This is the type of motor used for high end CNC and robots.
- The major disadvantage is the cost.

Two-Phase Hybrid Motor construction

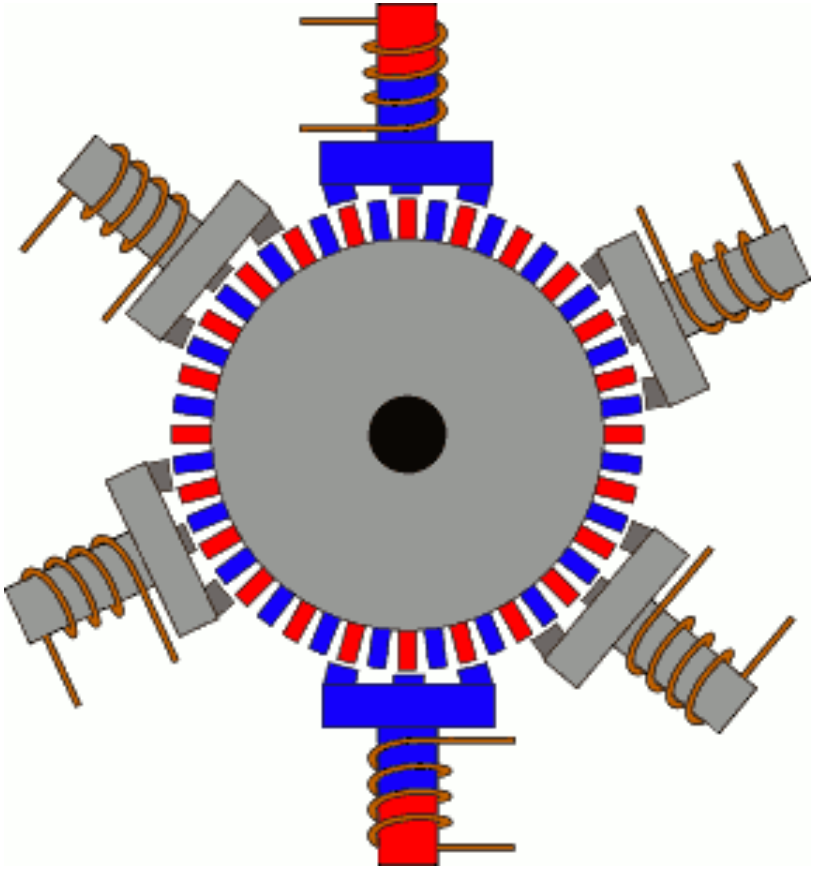


Notice the separate North and South Rotor Cup

The Hybrid motor rotates on same principle of energizing the stator coils in a sequence.

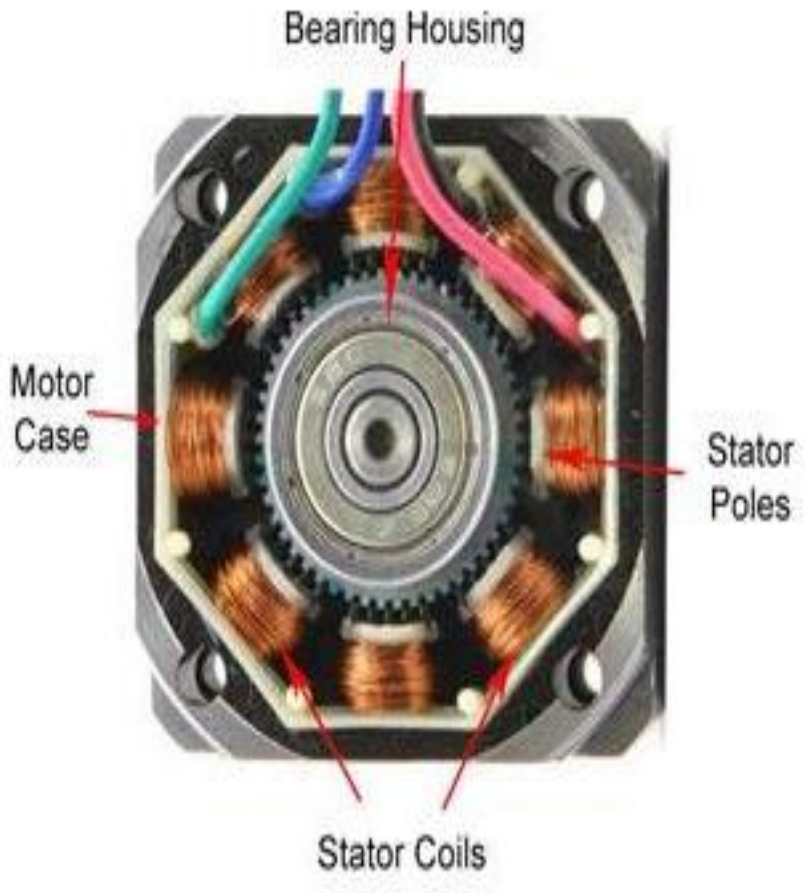


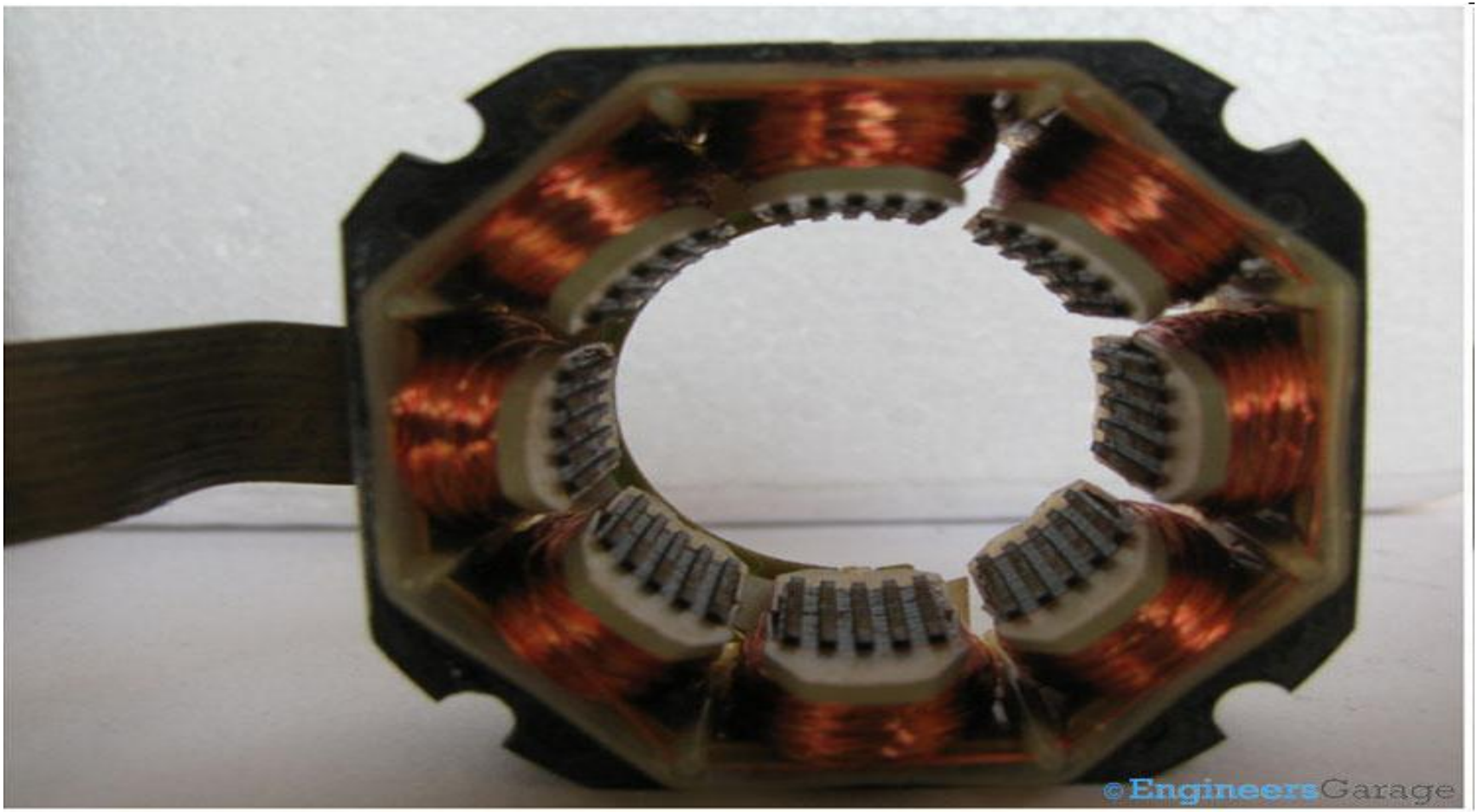
Hybrid Stepper Motor



75 steps per cycle (5^{o} per step)

Hybrid Stepper Motor





Hybrid Stepper Motor

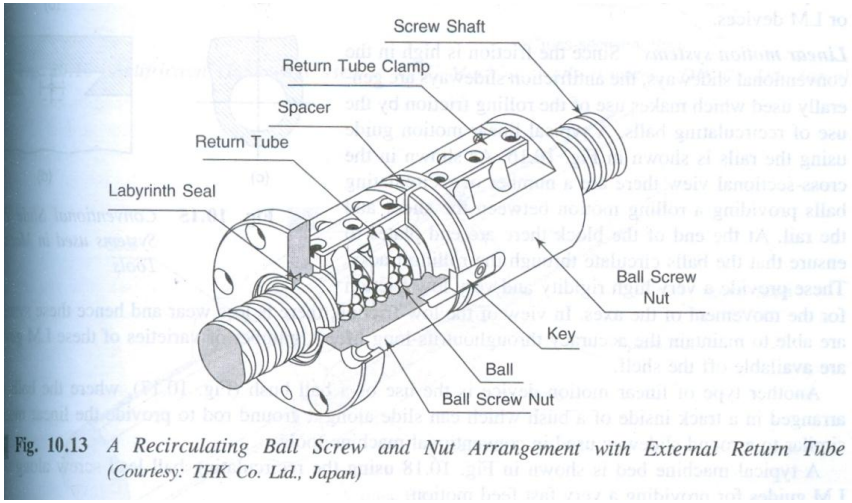
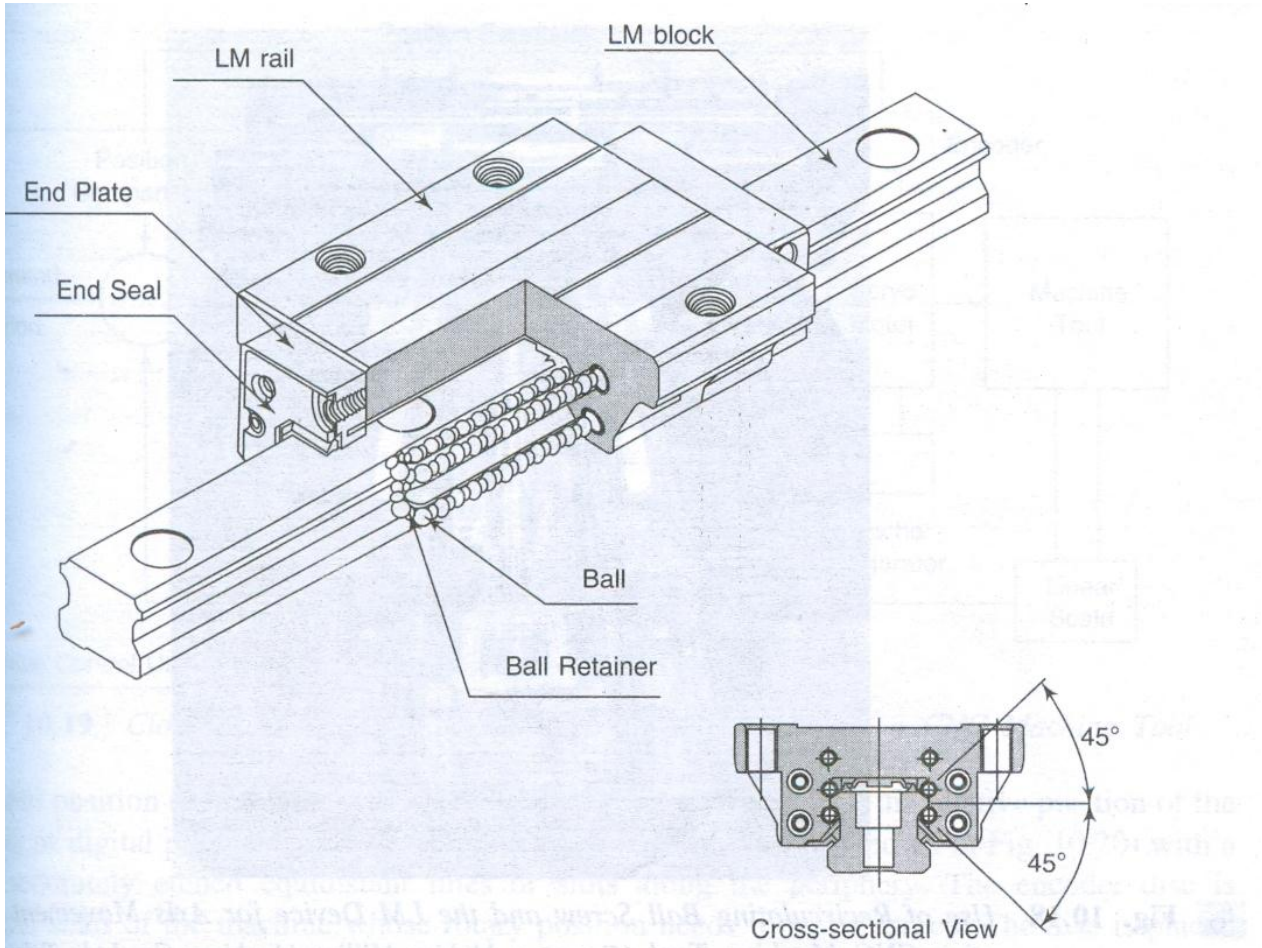


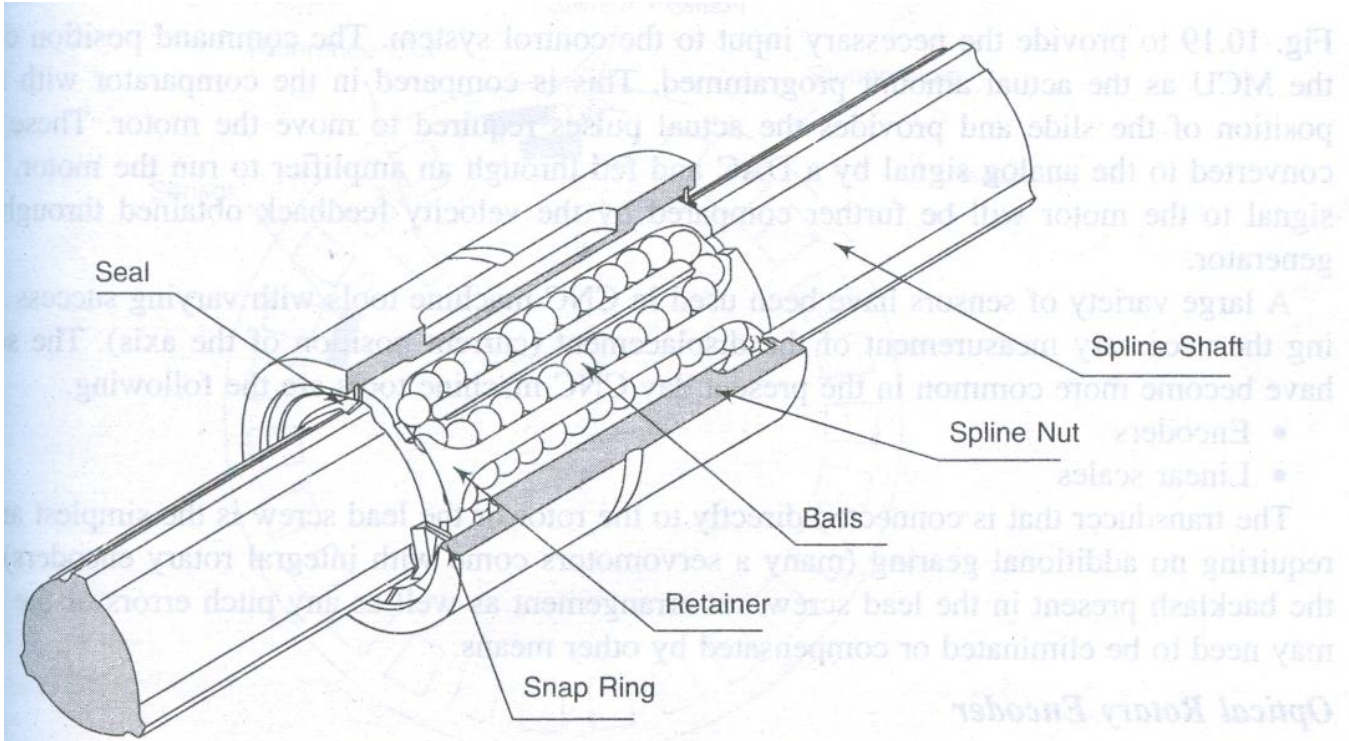
Fig. 10.13 *A Recirculating Ball Screw and Nut Arrangement with External Return Tube (Courtesy: THK Co. Ltd., Japan)*

Guideways



10.16 *Antifriction Guideways used in CNC Machine Tools (Courtesy: THK Co. Ltd., Japan)*

Guideways



10.17 *Ball Bush used for Linear Movement in CNC Machine Tools (Courtesy: THK Co. Ltd., Japan)*