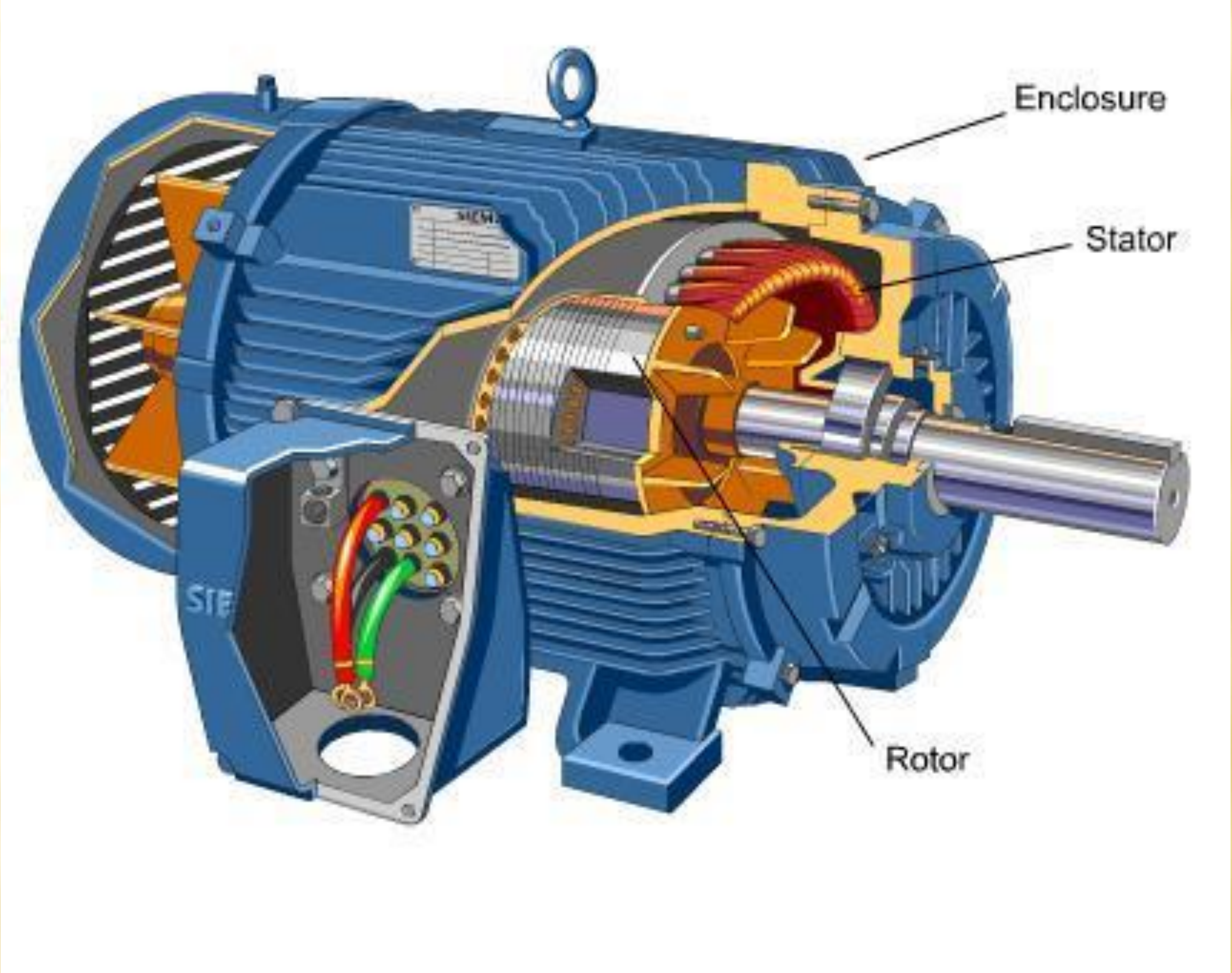
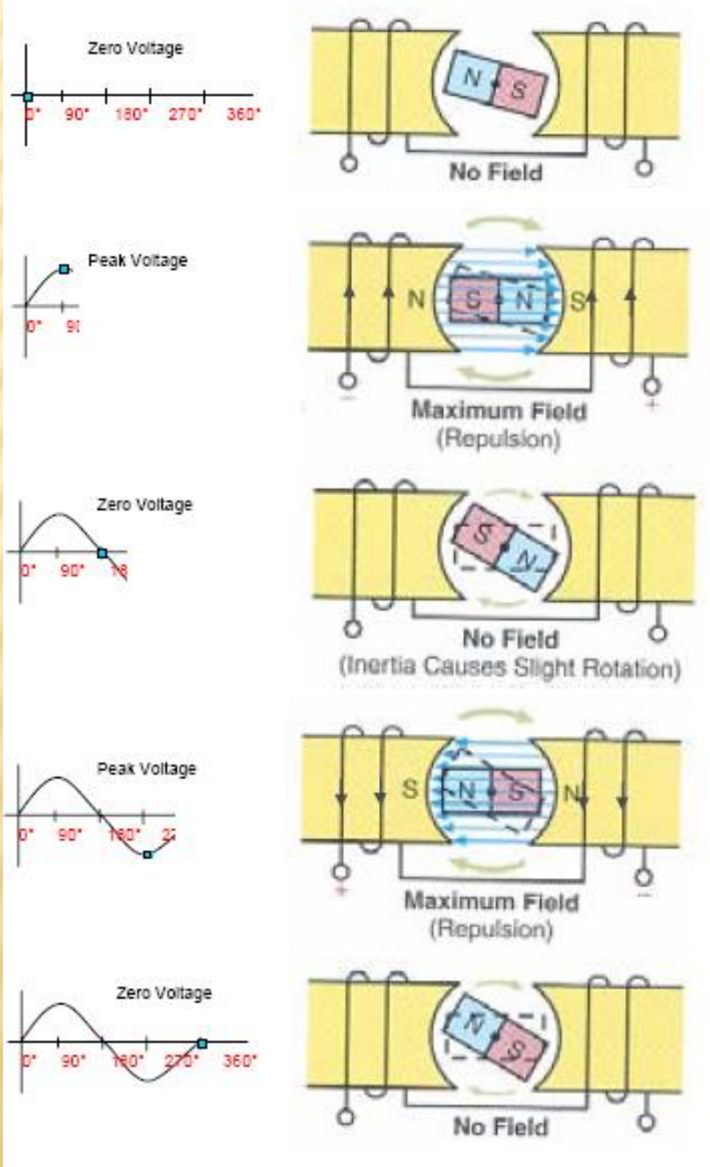
AC MOTORS

PARTS OF AC MOTOR



THE CYCLE



The armature of an AC Motor is a permanent magnet.
The stator of an AC Motor is an electromagnet.

At peak voltage, the magnetic field causes the rotor's magnet to line up.

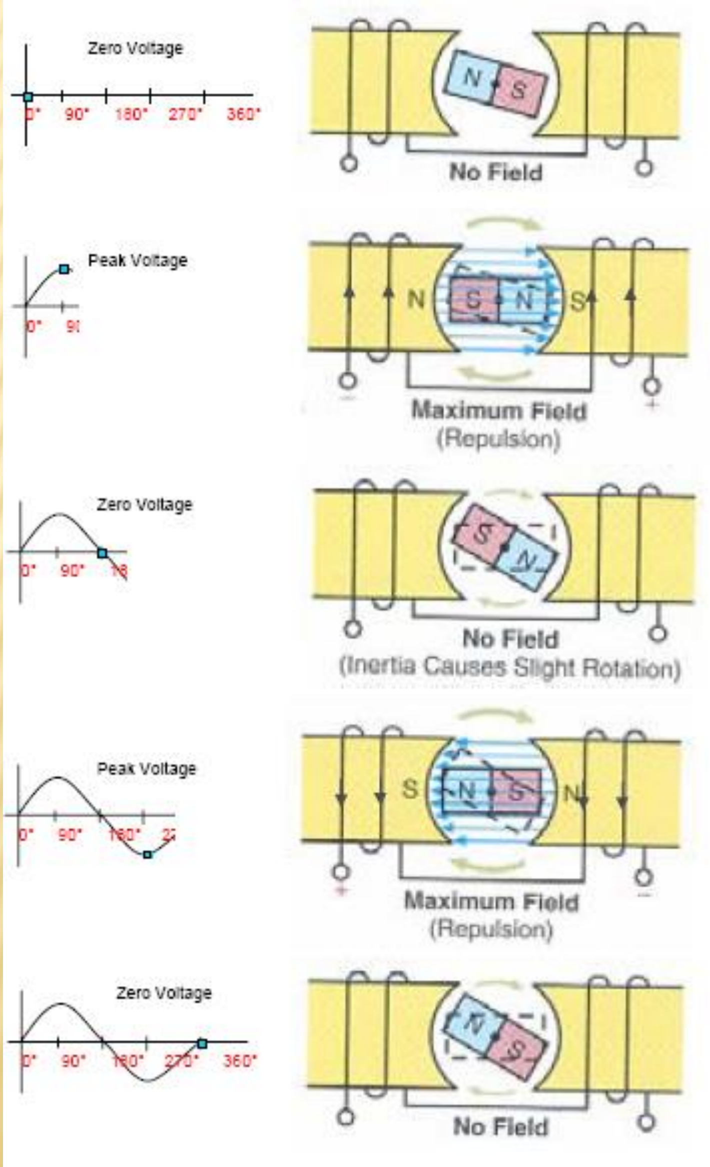
At zero voltage, the motor uses the angular momentum of the rotor to keep the rotor spinning.

Then we repeat the process.

You can think of the rotor frantically trying to "catch up" with the rotating magnetic field.

FYI, this magnetic field turning on/off with a sinusoid acts like a rotating magnetic field. This rotating magnetic field is known as "double revolving field theory."

STARTUP DIRECTION

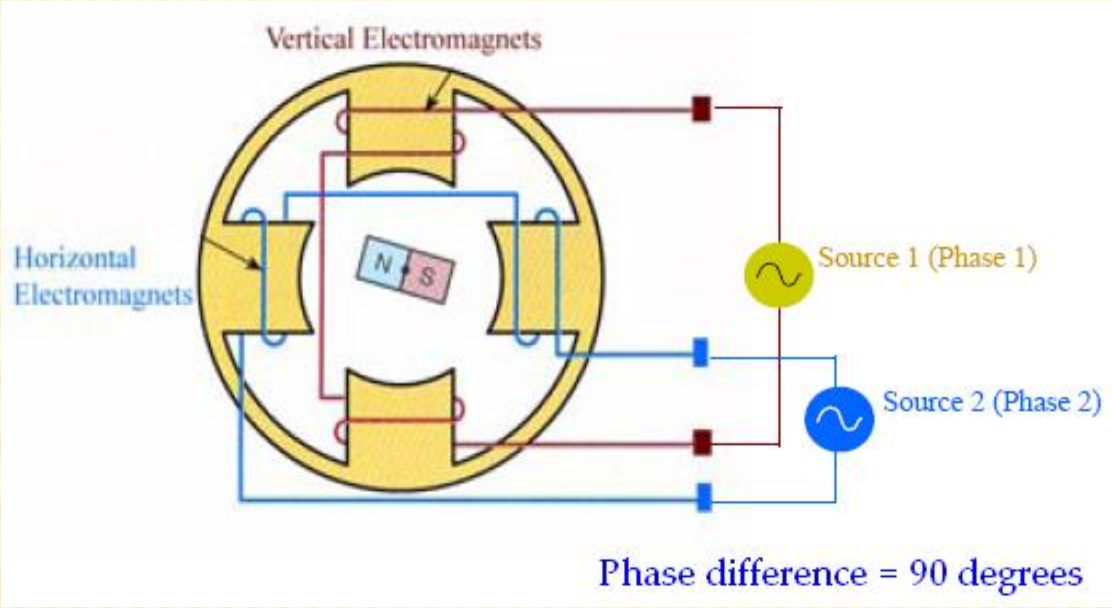


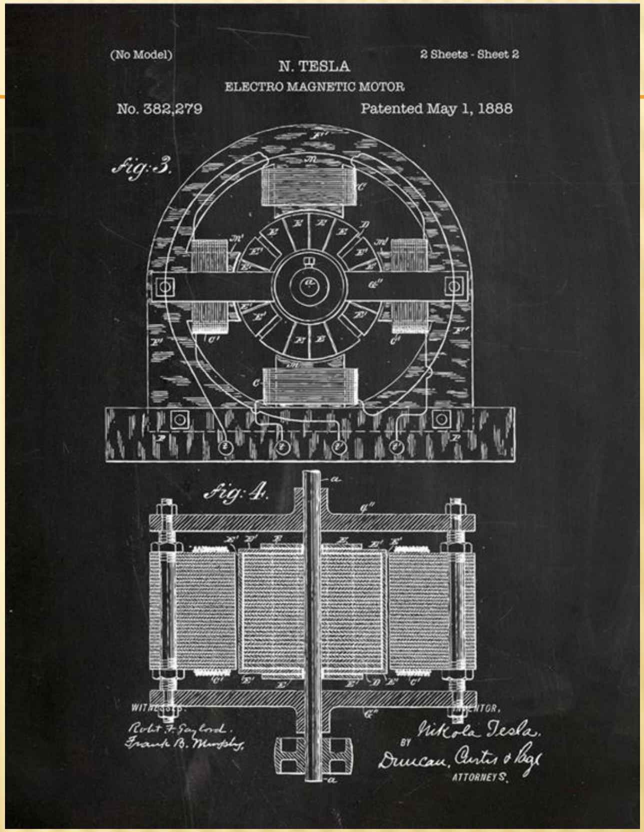
Notice that this rotor turns clockwise since the rotor was oriented (slanted downward slightly) in a way that would cause the N-S attraction to turn that way. If the rotor's magnet's position was slanted upward, then the rotor would have turned counter-clockwise.

This is less than ideal since most motors need to turn in the same direction each time (such as a vacuum cleaner)!

We may need a startup push.

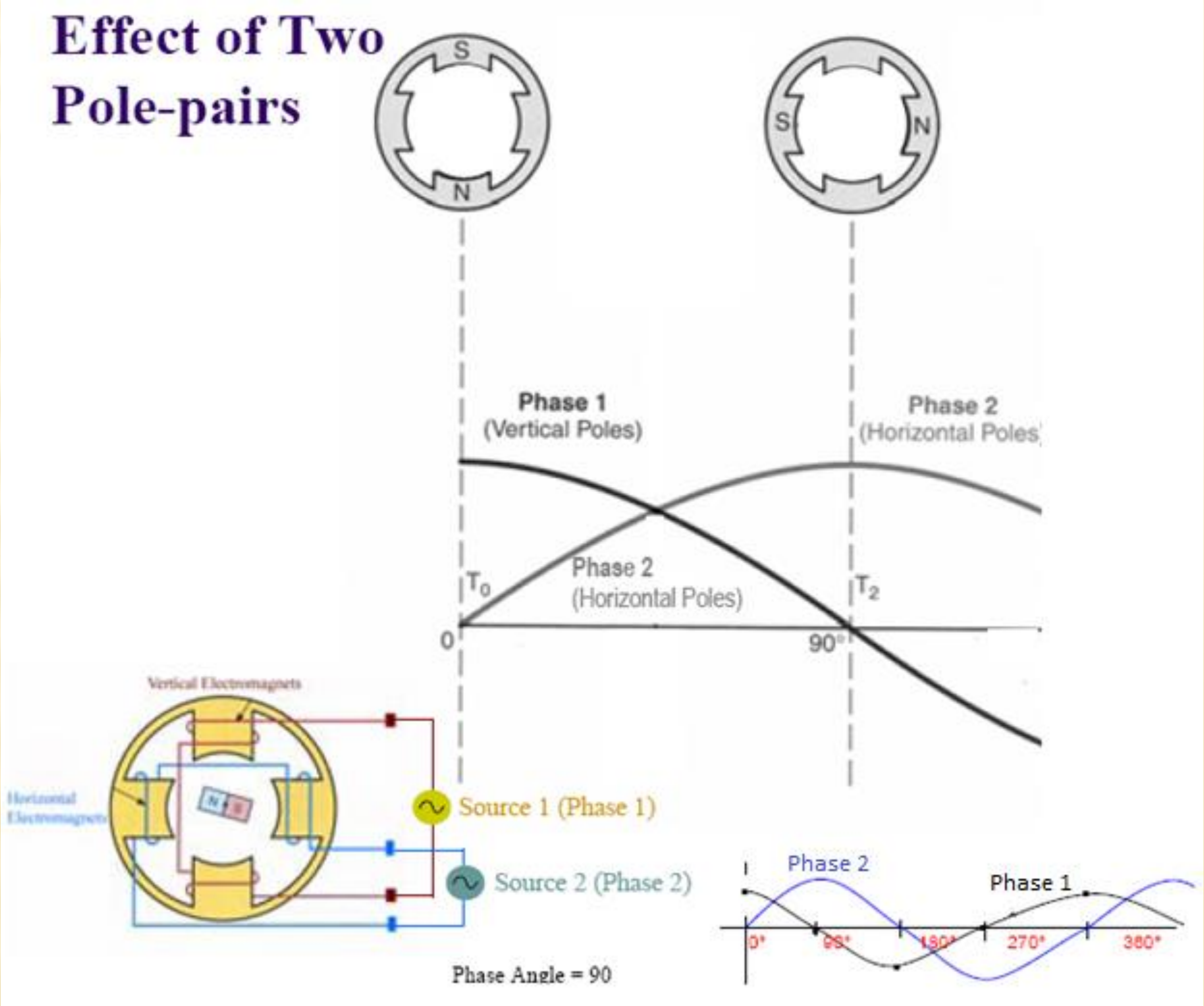
TWO POLE PAIRS





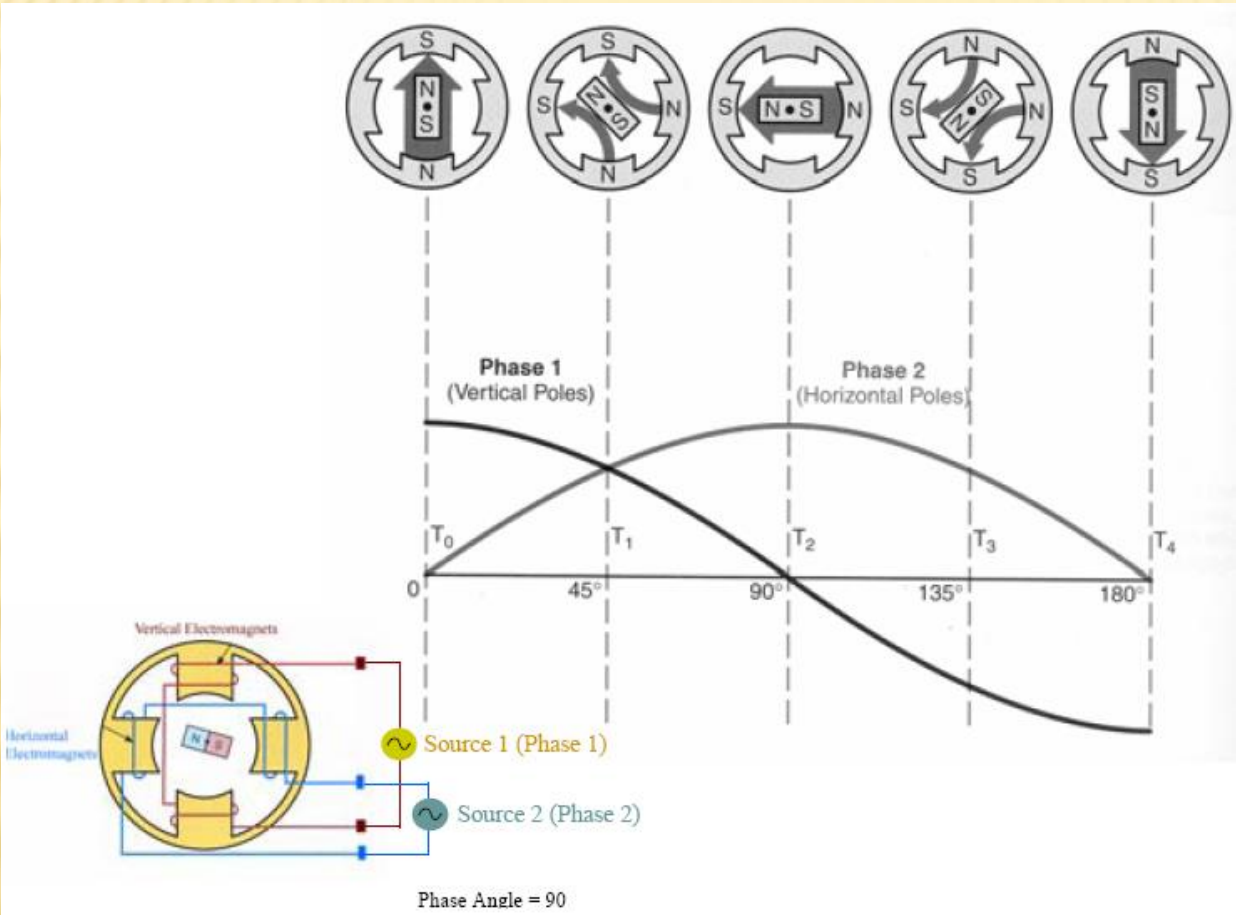
By adding another pole, we can ensure that the motor turns in the same direction each time.

TWO POLE PAIRS



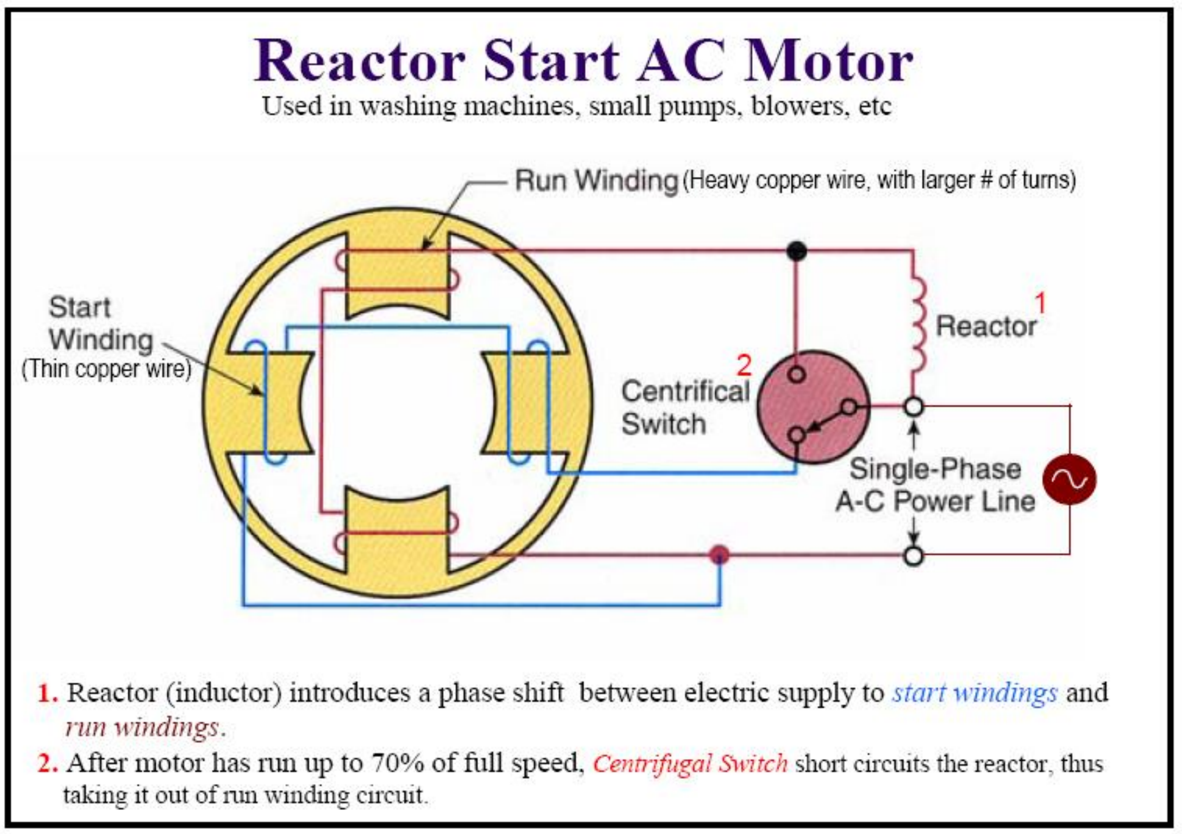
By having the two poles out of phase (90 degrees) from one another, the rotor is always attracted in a counter-clockwise fashion.

TWO POLE PAIRS



This demonstrates how the rotor is attracted in a counter-clockwise fashion.

ONE POLE WITH INDUCTION STARTUP



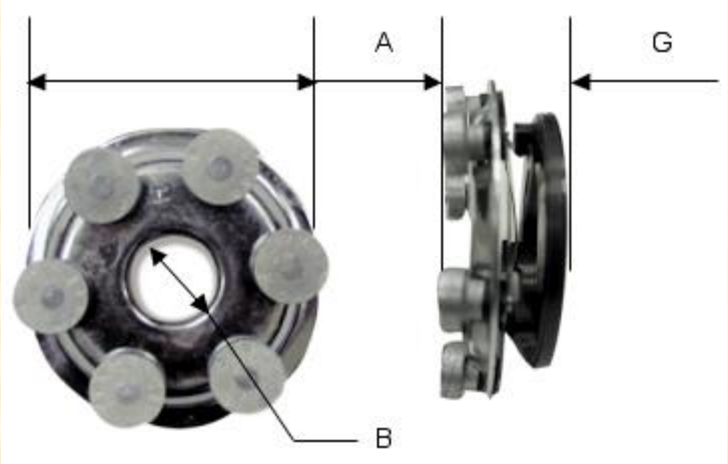
Suppose we wanted to run single phase and we wanted the startup to turn the motor in a particular direction each time.

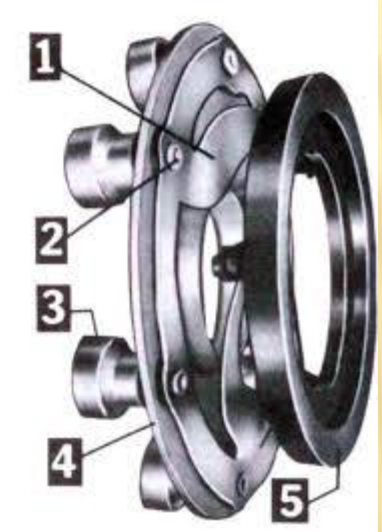
You could do this by adding an inductor to make the two poles 90 degrees out of phase.

Once the motor gets going, the inertia of the centrifugal switch switches in the upward position and turns off the startup coils (blue) and bypasses the inductor. Then the motor runs in normal single phase operation in the correct direction.

Note: This type of motor is sometimes called a “split-phase” motor.

CENTRIFUGAL SWITCH





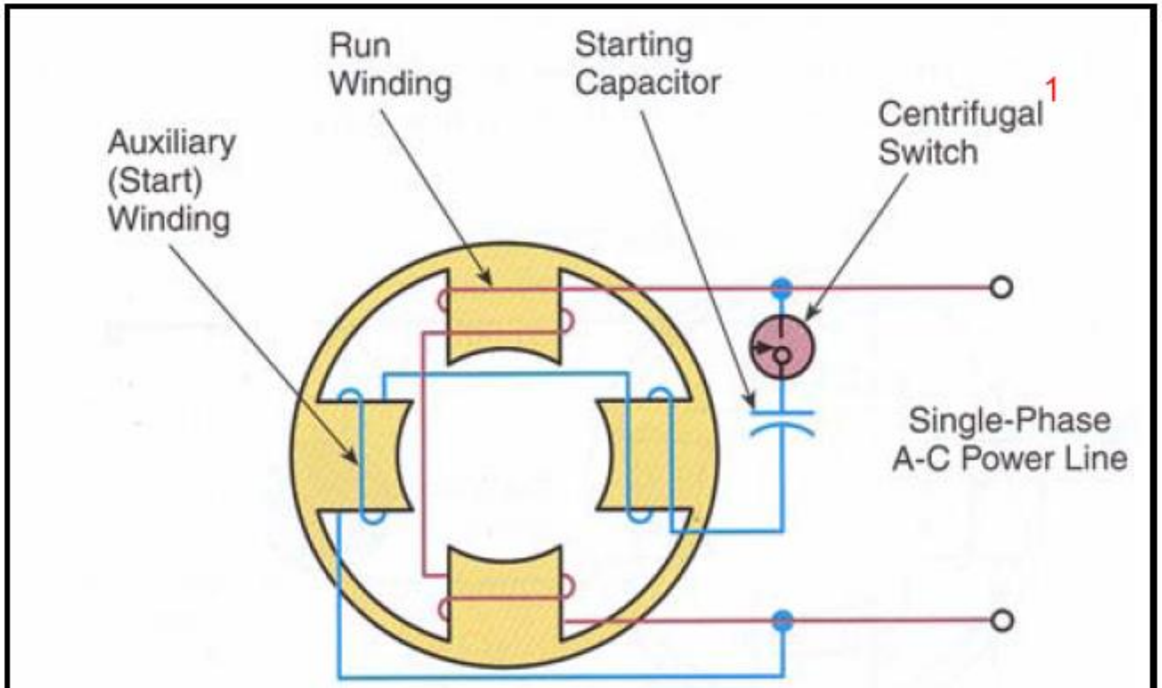
#1 in the diagram is the spring and it makes contact initially. #3 are the calibrated weights. As the shaft rotates, the inertia of these weights causes the weights to want to travel outward which causes the switch to snap away from the metal ring and break the contact.

It's important for the spring to have a snapping action so that once it disconnects, it happens quickly. This is kind of like debouncing a mechanical switch.

CENTRIFUGAL SWITCH

Example: https://www.youtube.com/watch?v=QUfLM4o2mDU

ONE POLE WITH CAPACITOR STARTUP



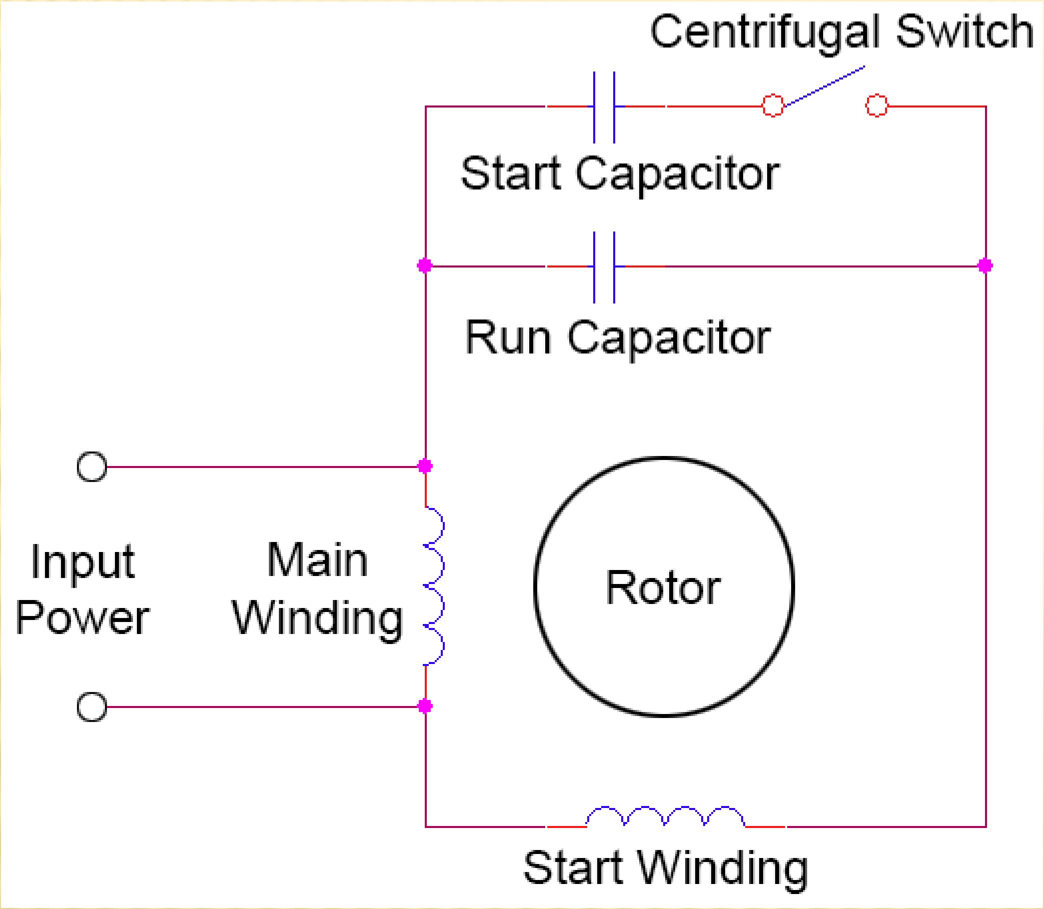
1. After motor has run up to 70% of full speed, *Centrifugal Switch* disconnects the *start windings* from the electric supply.
2. Typically phase split is 30 degrees.

You can achieve the same thing with a capacitor.

Nikola Tesla came up with this idea.

Start capacitors are usually above 70 uF and have voltage ratings between 125 and 330 V.

RUN CAPACITORS



Run capacitors are different than start capacitors because they are used even after the motor gets up to speed to create the rotating magnetic field to insure that the rotor always spins one way.

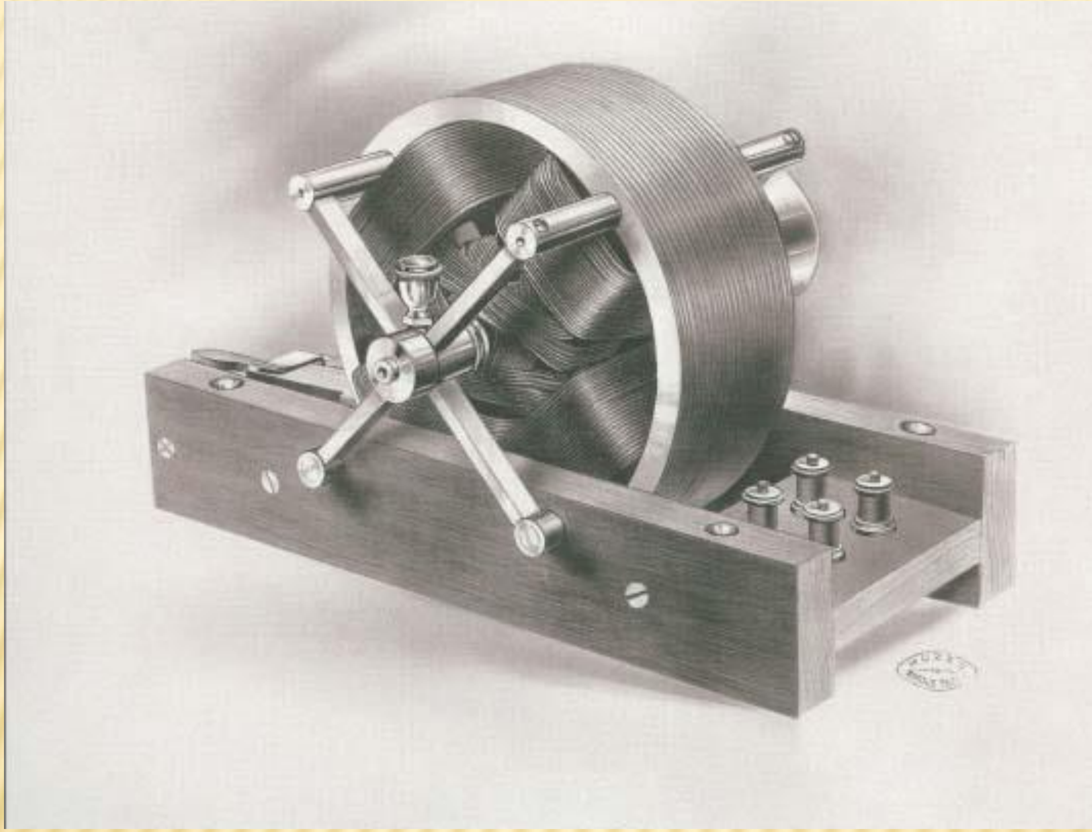
These capacitors range from 1.5 to 100 uF with voltage ratings from 370 to 440V.

THE 2 TYPES OF AC MOTORS

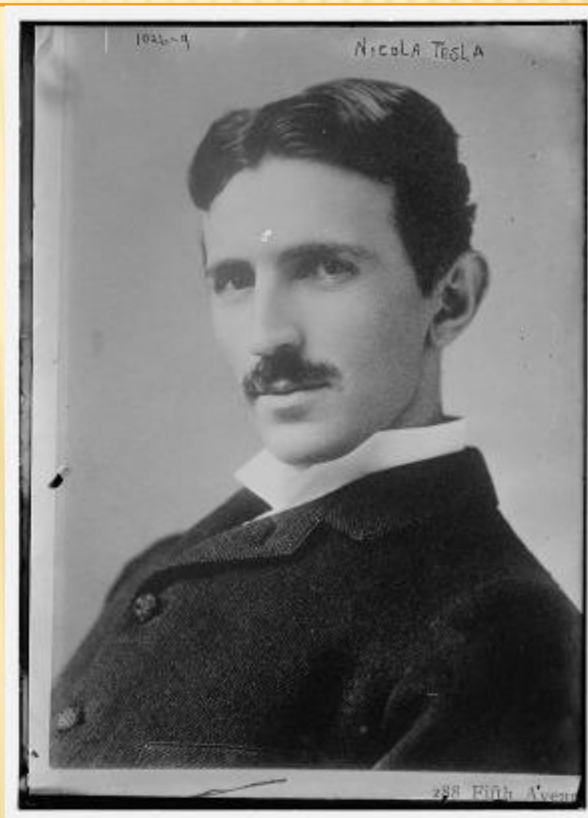
AC motors have two types . . .

1. Asynchronous – which are typically called induction motors
2. Synchronous

I. ASYNCHRONOUS AC MOTORS (AKA "INDUCTION MOTORS")



www.zmescience.com



Smithsonian Magazine

The induction motor was invented by Nikola Tesla around 1888 and is considered one of the greatest discoveries of all time because this design is still the main motor used in industry and household appliances.

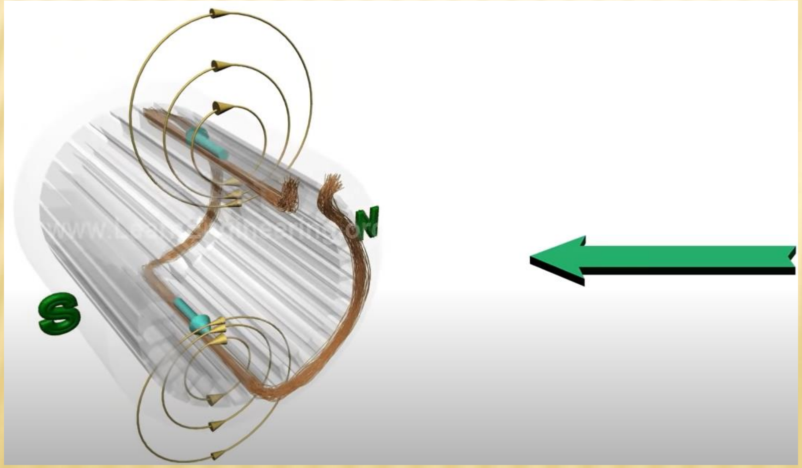
HOW INDUCTION MOTORS WORK

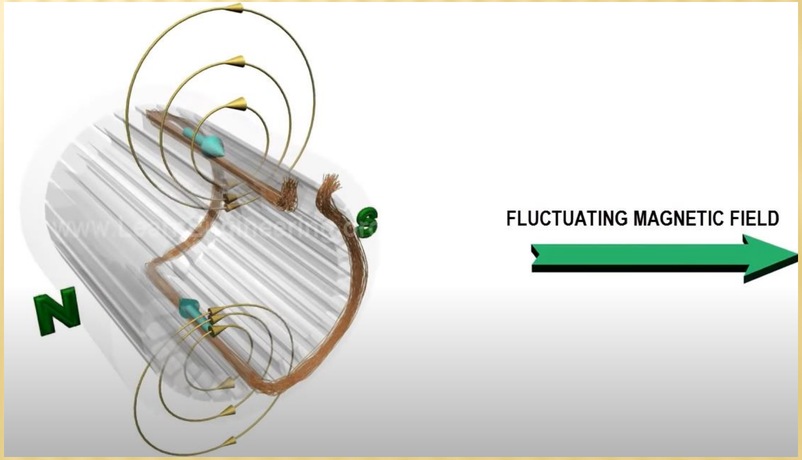
An induction motor consists of an electromagnet in the stator (coils) and a rotor that has conductive bars *(images shown in future slides)*. The stator coils are parallel to the conductive bars so that the electromagnetic stator coils can **induce** a current within the conductive bars of the rotor. The rotor's conductive bars do not have a their own current supply.

Stator Electromagnetic Coils

Induction motors always use alternating current so the stator coils (electromagnet) is constantly changing from N to S to N to S and so on as the voltage goes from positive to negative to positive and so forth as shown below.

The N to S to N to S changing magnetic field generates a rotating magnetic field (RMF).





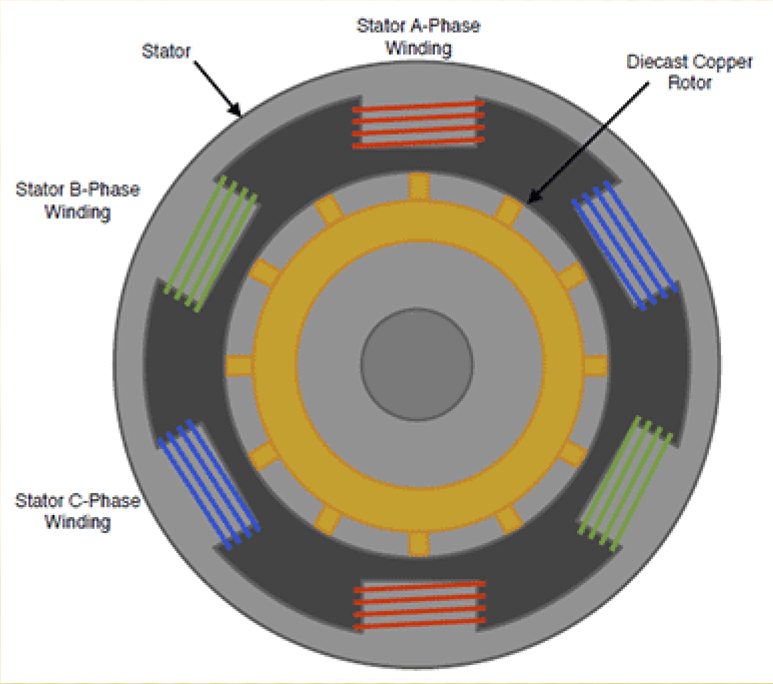
One phase motors will have another pair of coils

As mentioned in the beginning of this lecture, one phase motors will have an additional pair of coils to force the RMF to flow in a rotating direction instead of back and forth.

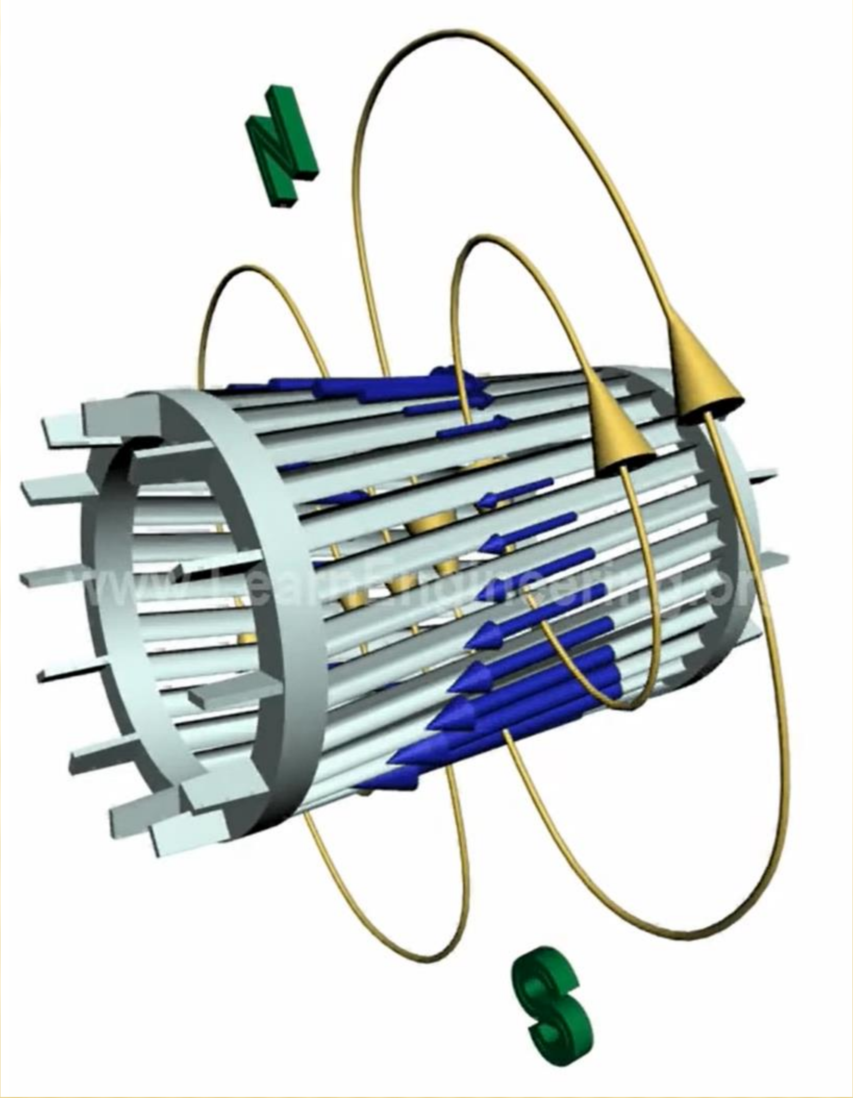
The motor below is a single phase induction motor that runs a fan. One can see the 4 stator coils.

Side Note: RMF from Three Phase Supply

Rotating magnetic field can also be created if one has access to a 3 phase supply. A 3 phase supply actually makes generating an RMF easier. With 3 phases, the phases are 120 degrees out of phase so they naturally make a RMF *(more on this at the end of this lecture)*.



Rotor Conducting Bars

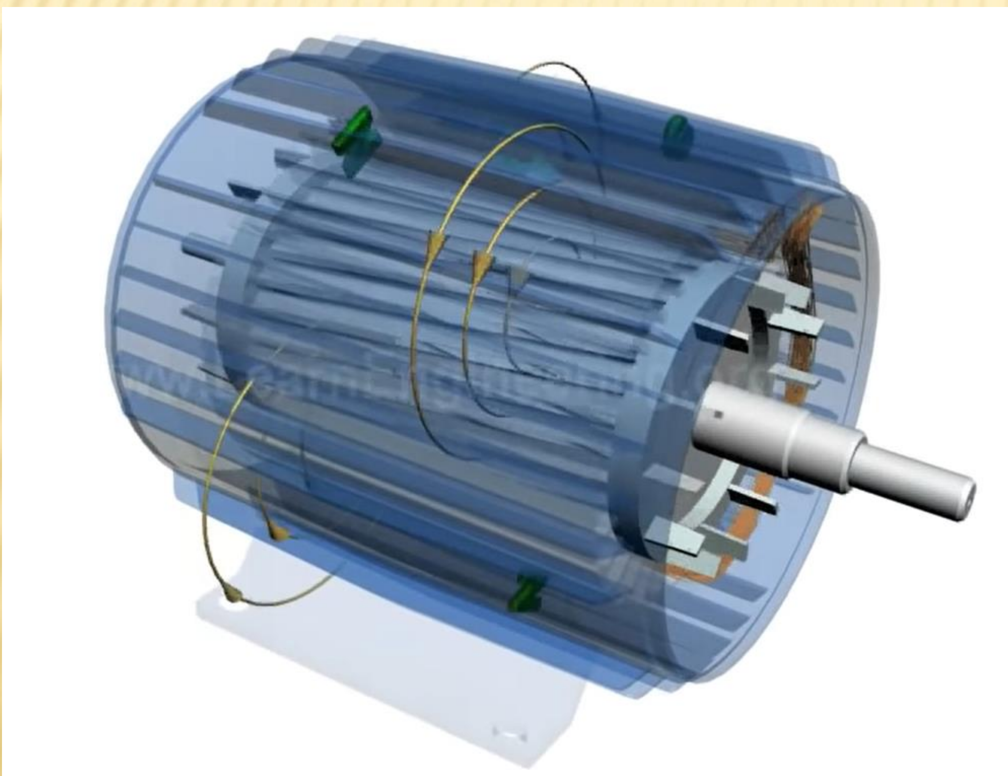


Since the magnetic field of the stator coils is always changing, this induces an electric current on the conductive bars of the rotor as shown by the blue arrows of the image.

This induced current in the rotor where you can see that the current is maximum on the top and bottom of the conductive bars. This current creates its own magnetic field as shown to the left as depicted by the gold arrow loops.

Stator and Rotor Combined

The induced current (in the rotor coils) is opposite to the current in the stator coils *(similar to how the coils in a transformer behave)*. This means that the magnetic fields in the stator are opposite to the magnetic field in the rotor which **creates an attraction between the stator coils and the induced magnetic field created in the rotor cage**. The rotor is always frantically trying to catch up to the rotating magnetic field (RMF).



INDUCTION MOTORS ARE ASYNCHRONOUS

One interesting fact is that if the rotor were to spin as fast as the RMF, then the RMF is no longer changing with respect to the moving rotor which means that no current is induced on the rotor coils and therefore the rotor stops being a magnet and has to slow down. Once the rotor slows down, then the RMF is changing compared to the rotor and current is once again induced. This concludes that the rotor will never be as fast as the RMF (which is also known as the synchronous speed) and hence as to why induction motors are also called **asynchronous motors**.

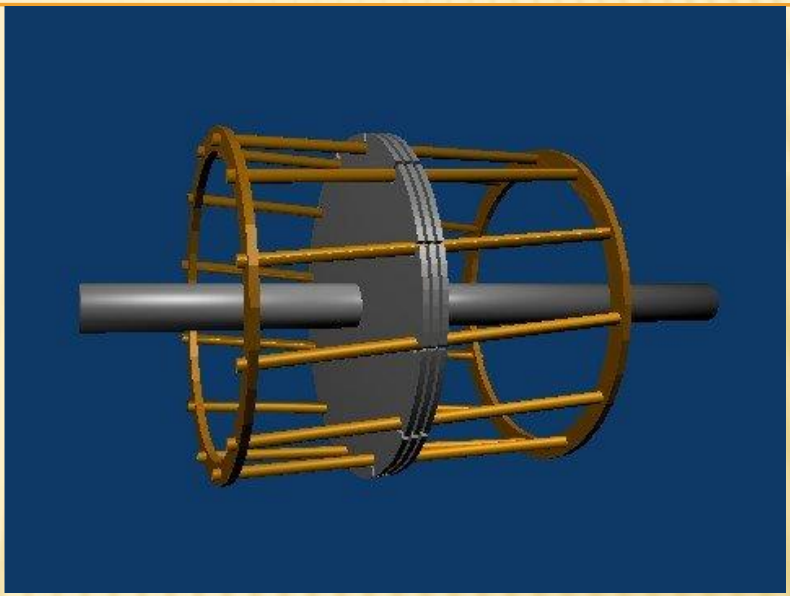
This difference in speed between the RMF and rotor is known as slip. Slip increases with load size. The slip value is typically around 2-6%.

One may think that the maximum torque on the rotor is when the rotor is not spinning. This would be true, except the RMF is rotating so fast that the rotor doesn't have enough time to respond (spin up) which unfortunately causes a lower starting torque (note that this starting torque is still better than synchronous motors).

TWO TYPES OF ROTORS

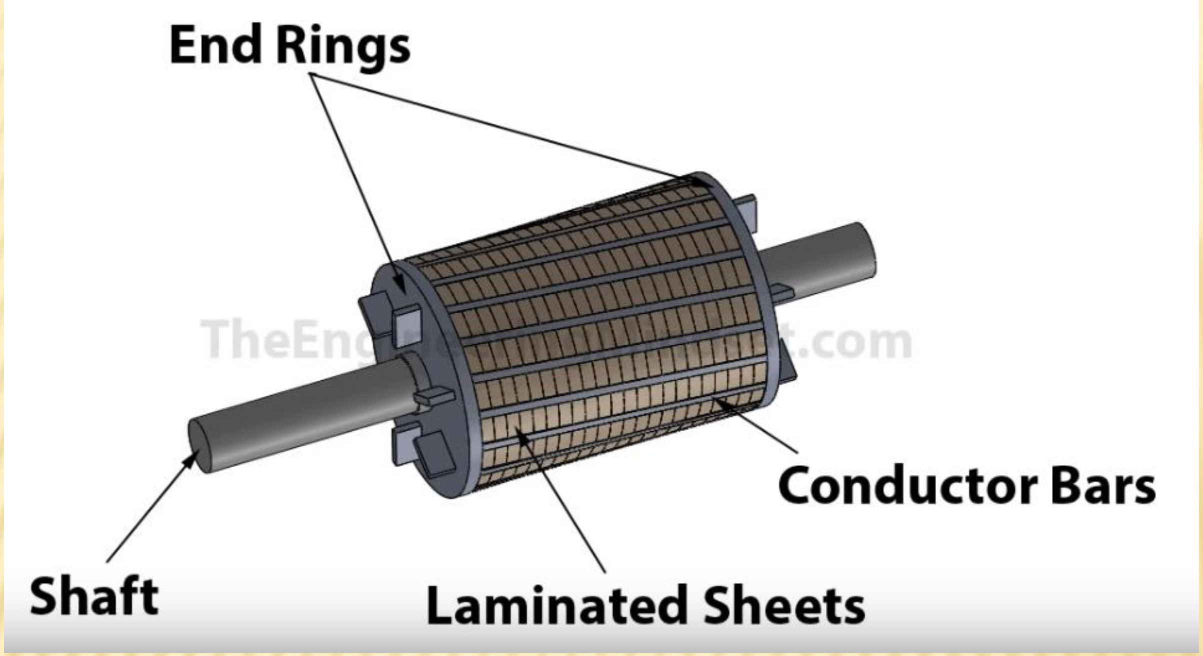
1. Squirrel Cage
2. Slip Ring

A. SQUIRREL CAGE ROTOR



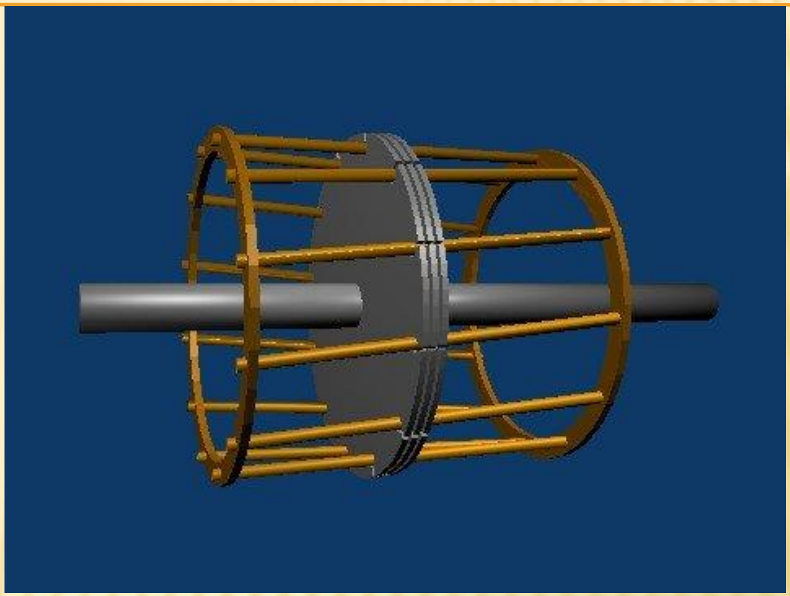
Squirrel cage rotors are named this because they look like the cages for squirrels or hamsters. 95% of induction motors use squirrel cage rotors *(the other 5% uses slip rings, which have the advantage of having a larger startup torque)*. The bars are used to conduct electricity to create current loops and consist of copper or aluminum.

A. SQUIRREL CAGE ROTOR



The conductive bars that have AC current induced on them create a magnetic field which is transferred to the laminations creating a large electromagnet where one half of the cylinder is North and the other half is South.

A. SQUIRREL CAGE ROTOR

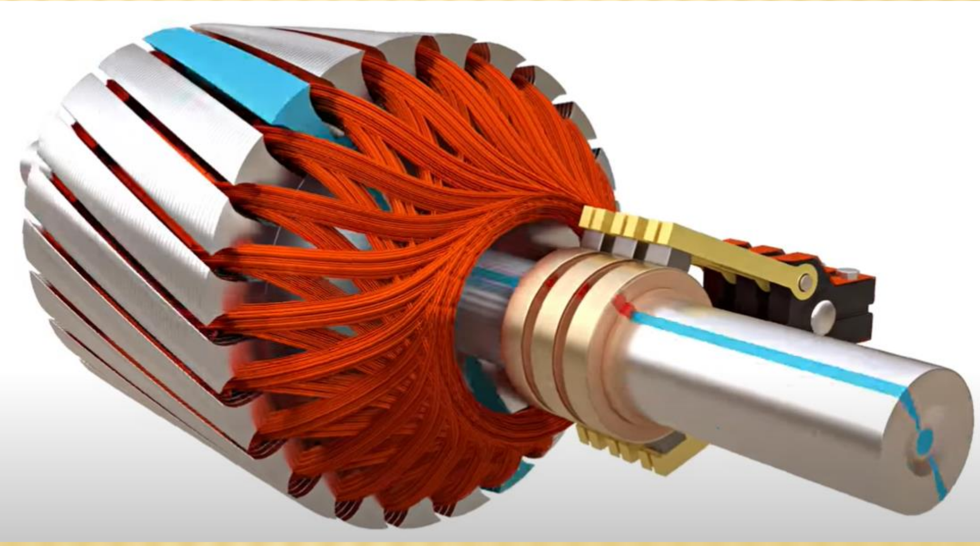


The bars being skewed produces a more uniform torque curve which reduces humming and noise. It also helps to keep the rotor from locking up.

B. SLIP RING ROTOR

The ring rotor is similar to the coils in the DC motor, except they exists using three phases. The coils are wired in a parallel fashion to the axis of rotation.

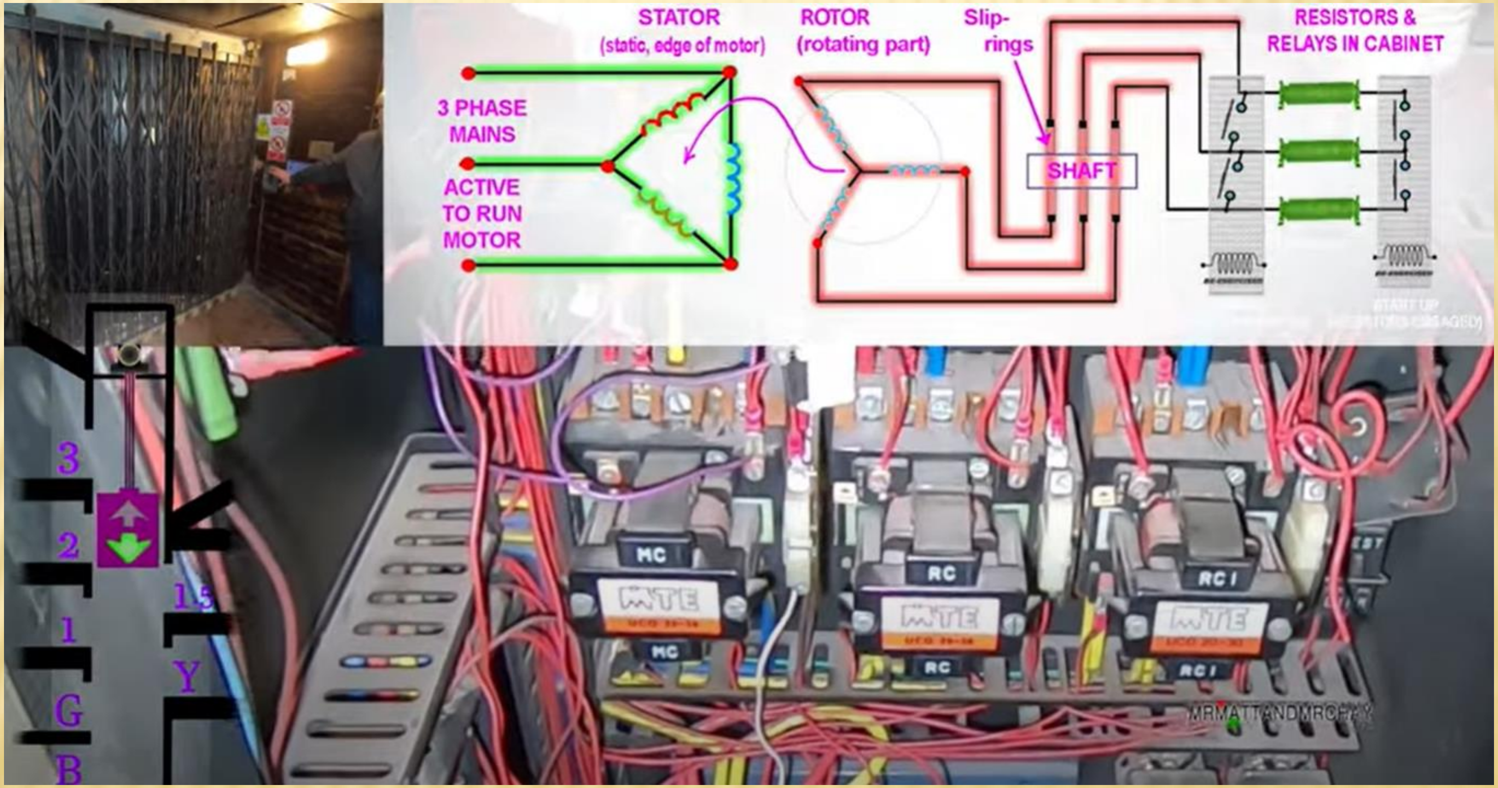
There exist 3 brushes on the shaft wired in series with a power resistor that can be turned on or off by a controller. So it’s just like the squirrel cage except the current can be controlled by turning on/off resistance in each loop. The controller controls the resistance by using relays or by using a variable power resistor. By controlling the resistance, the induced electromagnet rotating field can be slowed down which enables a larger starting torque. The resistance reduces current which can reduce rotor damage (from the wire insulation melting). Once the rotor reaches full speed, the resistances are discarded (shorted) and the rotor acts identically to the squirrel cage rotor.



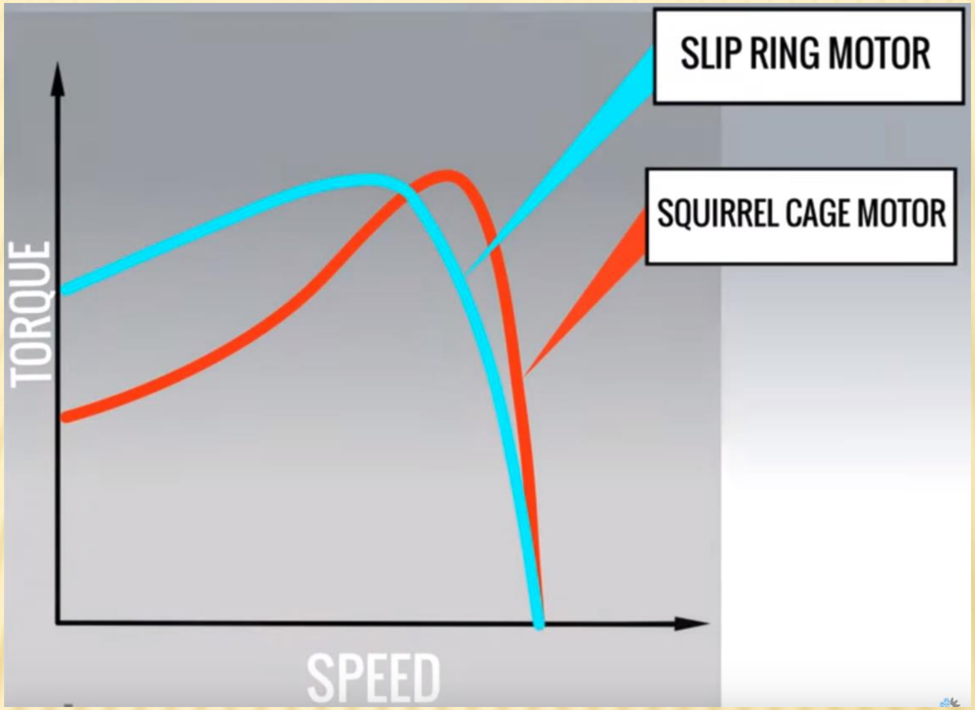
Controller of Slip Ring Induction Motor

Watch the first minute of this video just to show the controller controlling relays to the resistors.

https://youtu.be/W1mee2uNFiE?t=281



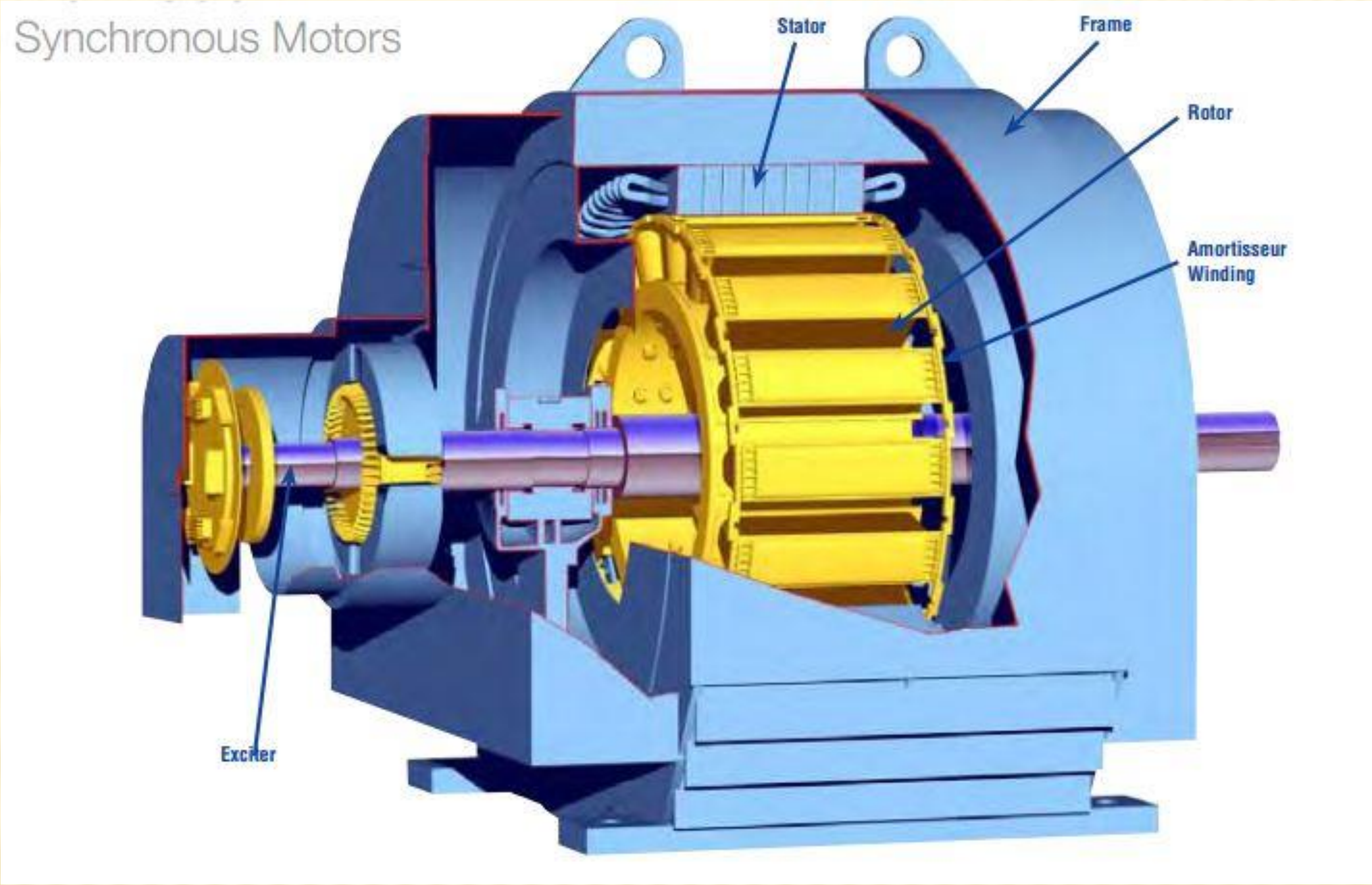
SLIP RING VS SQUIRREL CAGE ROTOR



The squirrel cage rotors are easier to manufacturer which makes them cheaper and have less maintenance and repair especially without the brushes. These are more common.

The main advantage of slip ring rotors is their higher starting torque and smoother acceleration. Used in elevators and hoists (such as in cranes) among other places.

II. SYNCHRONOUS AC MOTORS



SYNCHRONOUS AC MOTORS

In synchronous AC motors, the rotor consists of either a permanent magnet or a electromagnet. If an electromagnet is used, then the electromagnet must have a separate DC supply to drive DC current through the coil so that it maintains a constant magnetic field (just like a permanent magnet).

Synchronous Motors have an attractive force between the rotor and the stator.

As the rotating magnetic field (RMF) of the stator rotates, the rotor's magnet synchronizes with this field and spins at the same speed as the RMF.
RPM = 120*f/P where f is the frequency of electricity in Hz, and P is the number of poles (for example: At 60 Hz and with one pole pair (2 poles), the rotor spins 120*60/2 = 3600 RPM). *Note that the 120 comes from 60 s in 1 min and poles are in pairs (60*2=120).*

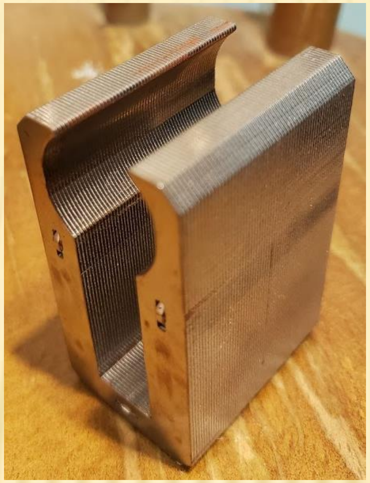
SYNCHRONOUS AC MOTORS

In synchronous AC motors, the rotor consists of either a permanent magnet or a electromagnet. If an electromagnet is used, then the electromagnet must have a separate DC supply to drive DC current through the coil so that it maintains a constant magnetic field (just like a permanent magnet).

Below is a washing machine drain motor (synchronous). First picture is it all put together. Second picture is plastic housing taken off.

SYNCHRONOUS AC MOTORS

The first picture is all the parts put together (w/o the plastic housing) The second picture shows the laminated steel to conduct the RMF. The third pictures shows the coil windings with the electrical connectors. It also has a thermal switch to turn off the motor in case it overheats. The last picture



shows the permanent magnet rotor where one half of the cylinder is N and the other half is S. This rotor broke because the plastic blades decoupled from the permanent magnet.

SYNCHRONOUS AC MOTORS

One major disadvantage to synchronous motors is most need a startup push.

The reason for this is that the RMF moves so fast that the rotor switches from attraction to repulsion back to attraction and so on causing the motor to never start spinning. Fancier synchronous motors will use a squirrel cage rotor to essentially create an induction motor at startup by turning off the rotor electromagnet *(note: this cannot be done if using a permanent magnet for the rotor)*. Once the motor spins up, the rotor energizes its coils and the motor switches to a synchronous motor. Eventually, the motor will spin as fast as the RMF and this prevents the squirrel cage rotor from having any effect on the motor's operation.

The washing machine drain motor evidently didn't have a large enough load on it to require a startup push.

INDUCTION VS. SYNCHRONOUS MOTORS

Induction Motor Advantages

- Cheaper
- Doesn't require a starting mechanism
- Doesn't require DC power source for rotor (and no brushes)
- Doesn't require rotor windings since it typically uses a squirrel cage rotor with laminations

Synchronous Motor Advantages

- Higher efficiency
- Better power factor
- Rotor speed is independent of the load (no slip)
- Can use a permanent magnet in the rotor (eliminates the need for brushes and windings, but this means it must have some mechanical startup mechanism)

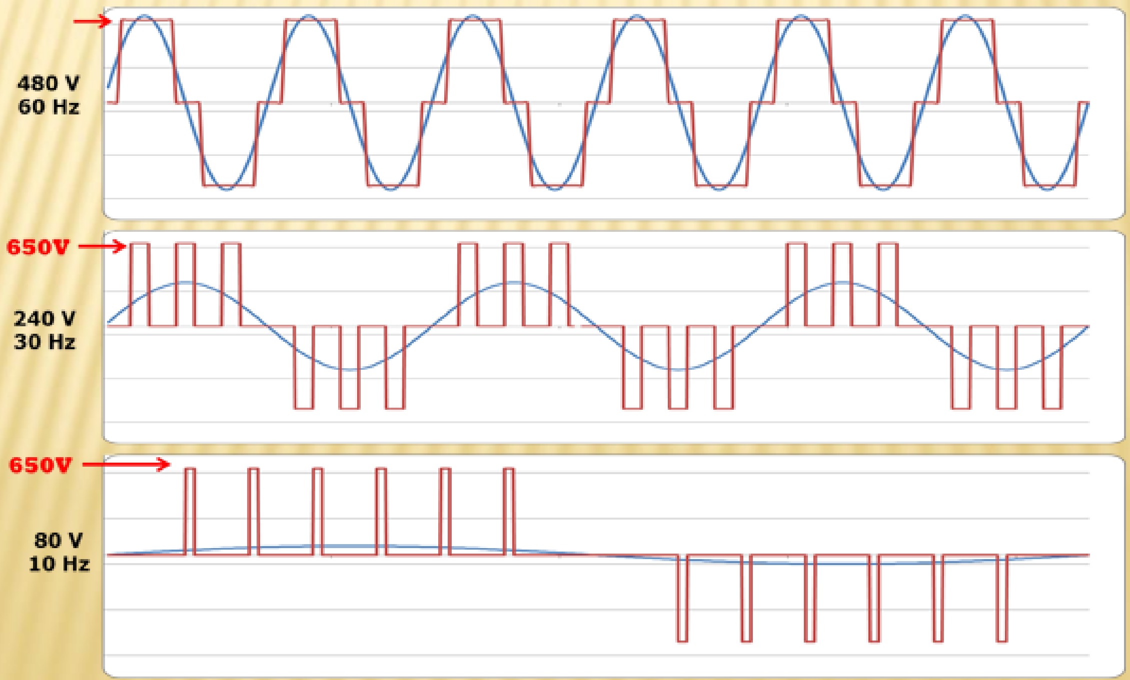
VARIABLE-FREQUENCY DRIVE

To control the speed of the AC motor, we have to control the frequency and voltage of the AC drive using what is called a variable-frequency drive.

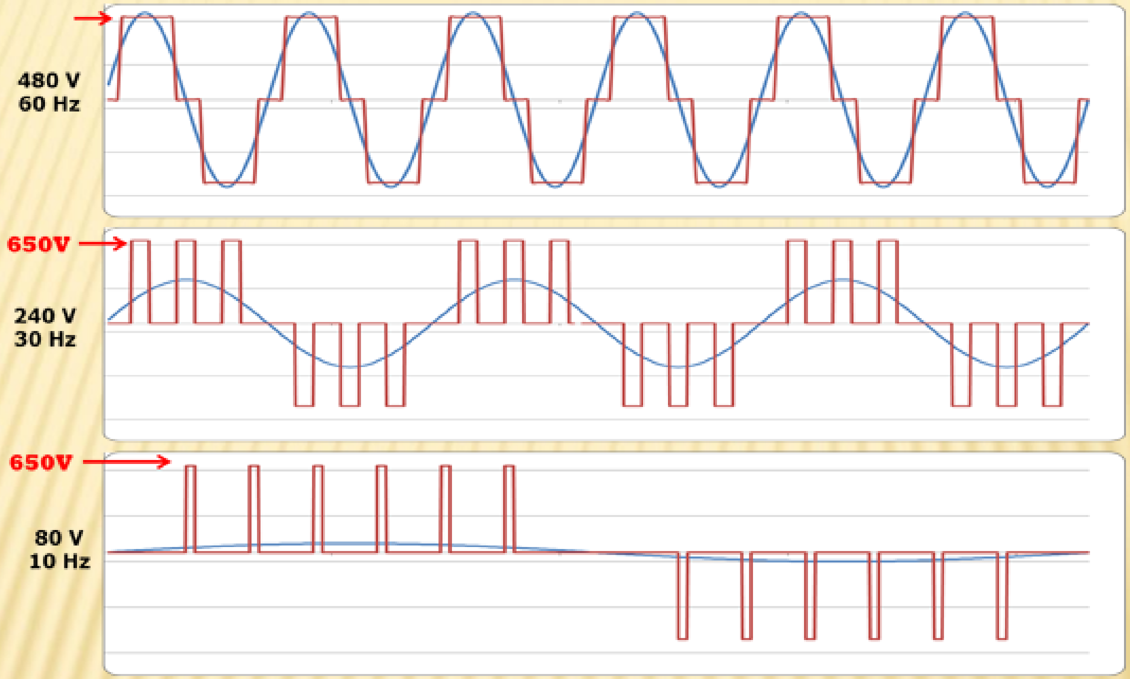
Variable-Frequency Drive (VFD) is sometimes termed “adjustable-frequency drive,” “variable-speed drive,” “AC drive,” “micro drive,” or “inverter drive.”

VFD controls the frequency and voltage of the motor input. It is typically used with 3-phase motors *(we’ll talk about 3 phase in a future slide).* However, it can be used with 1 phase motors.

It works by using square waves to make a modified sine wave.



VARIABLE-FREQUENCY DRIVE



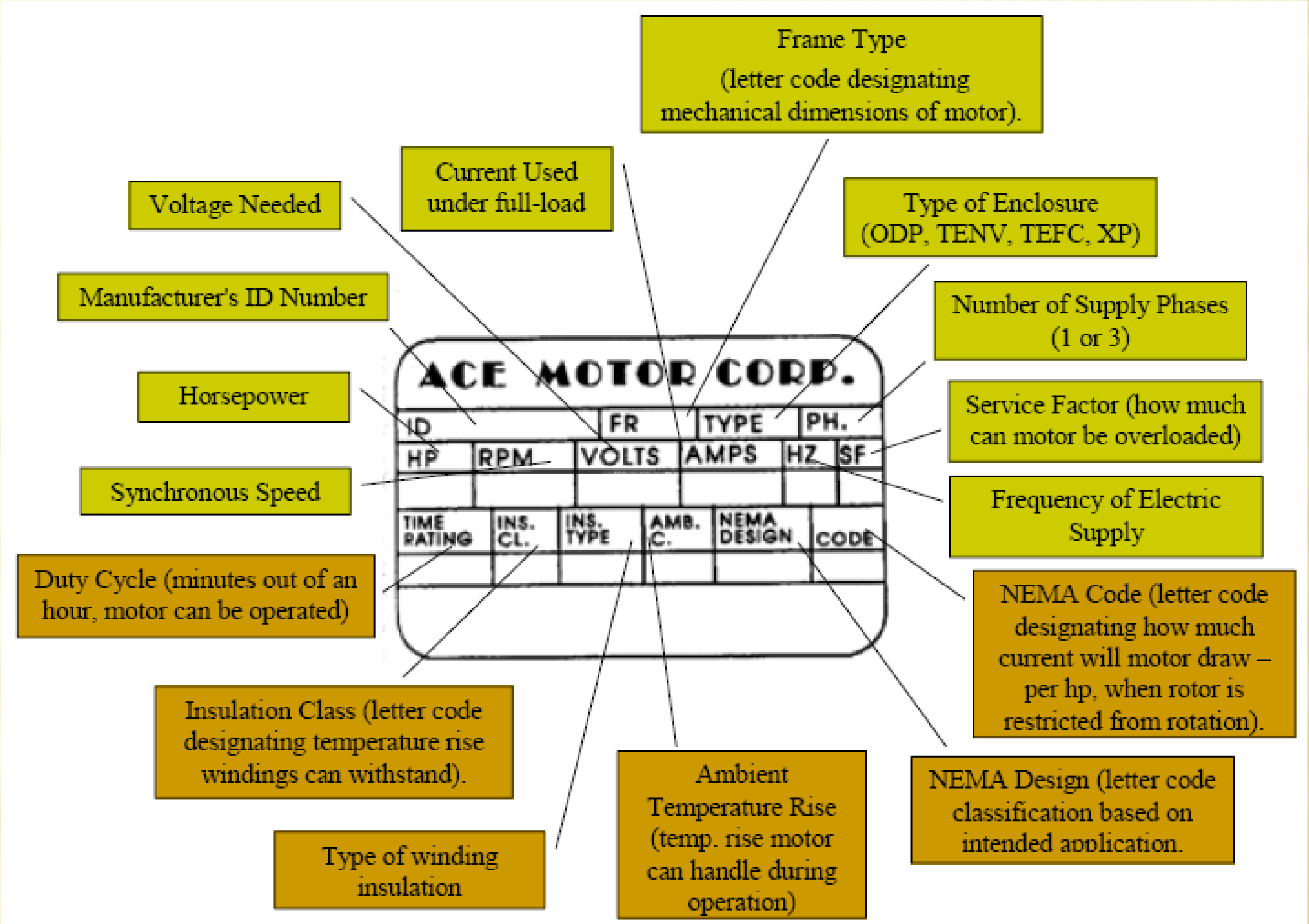
Notice that you can change the amplitude by decreasing the pulse widths. And you can change the frequency by deciding when the pulses are positive and negative.

Many times, VFDs are built in with the motor.

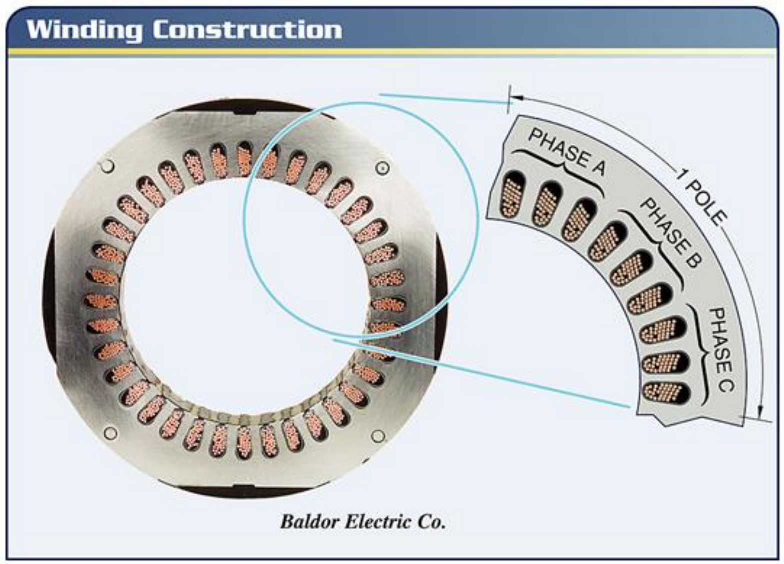
VFDs can improve the efficiency of the motor by ramping up the motor so that it doesn't slip.

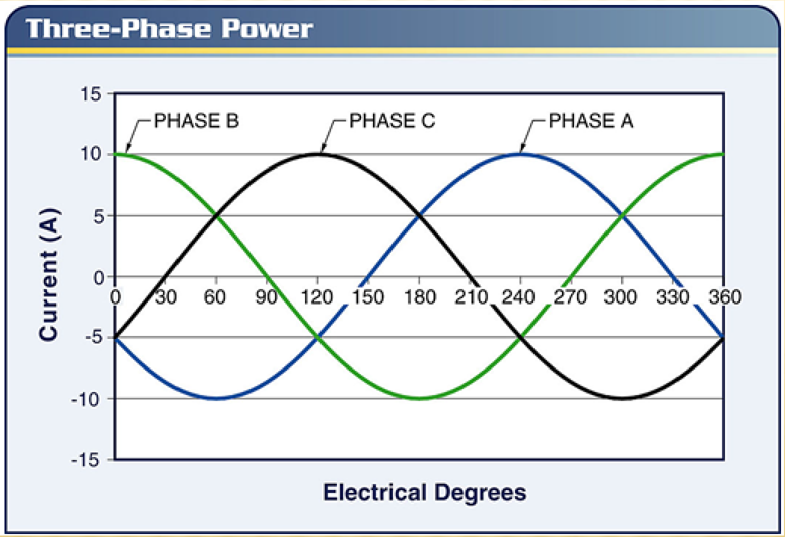
MOTOR SPECIFICATIONS STAMP

Most AC motors have a stamp on it that tells some of the specifications of the motor.



THREE PHASE



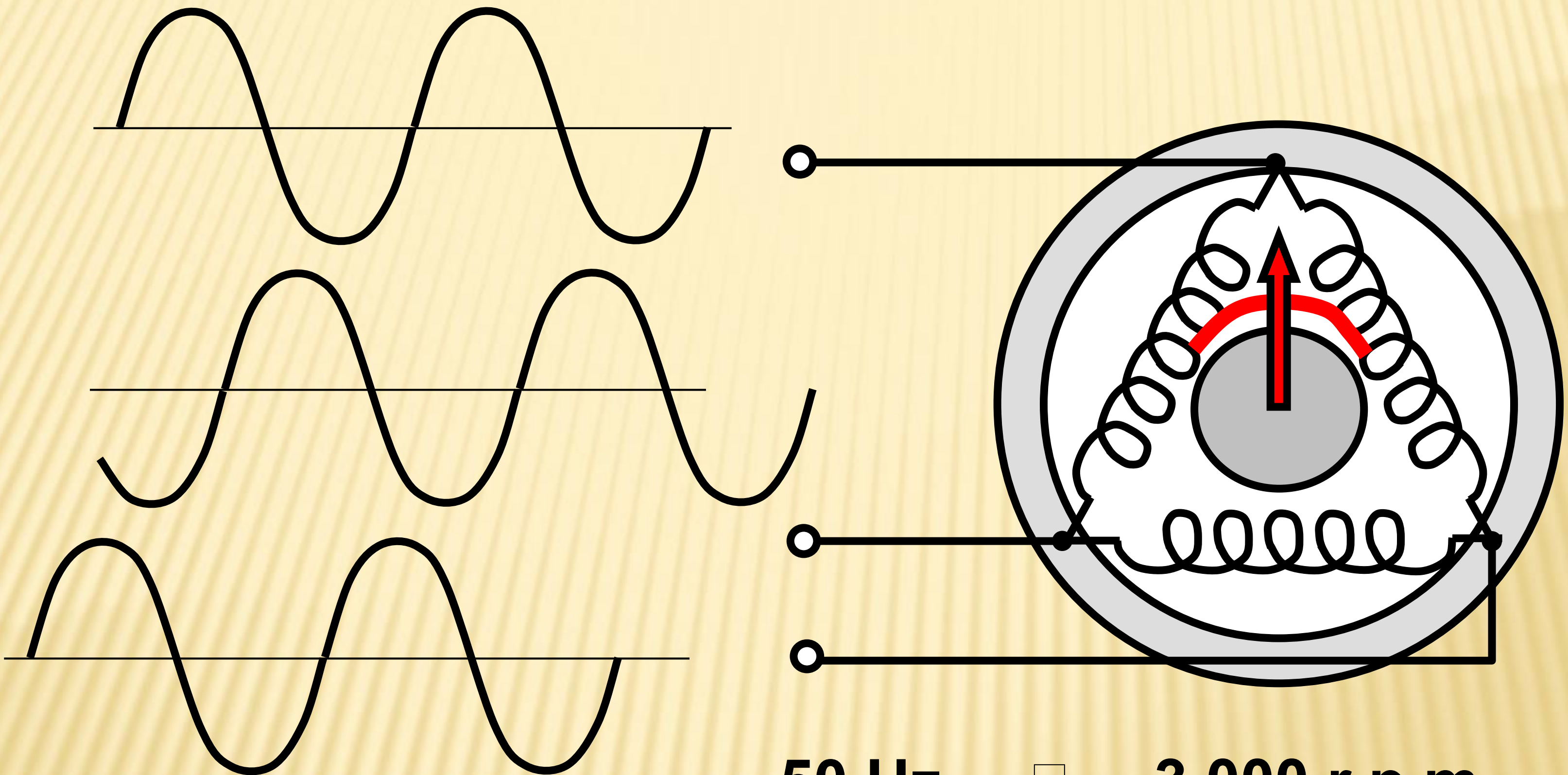


Some AC Motors are wired in three phase because these motors are typically 2 to 4 times more efficient.

Many milling machines and lathes require 3 phase.

Most homes do not have 3 phase power, but fortunately there are single phase to three phase converters that you can purchase if you happen to need 3 phase power.

A.C. Motors.

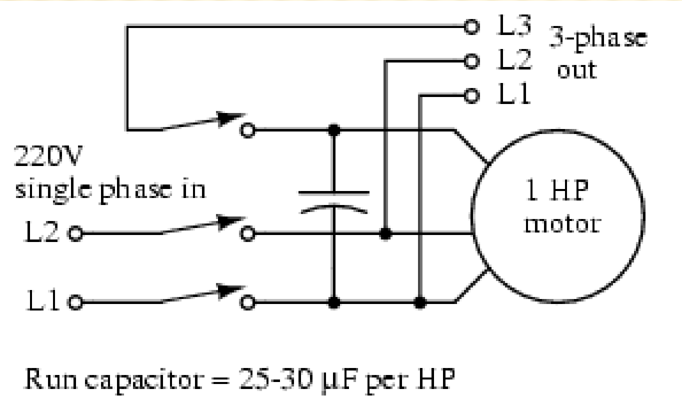


50 Hz. □ 3.000 r.p.m.

50 Hz. = 50 r.p.s x 60 = 3.000 r.p.m.

Triphasic voltage produces a rotator magnetic field that steers the magnetic rotor.

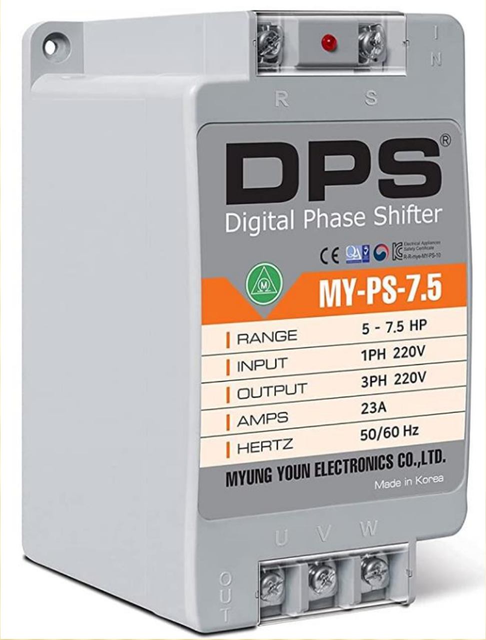
SINGLE PHASE TO THREE PHASE CONVERTER

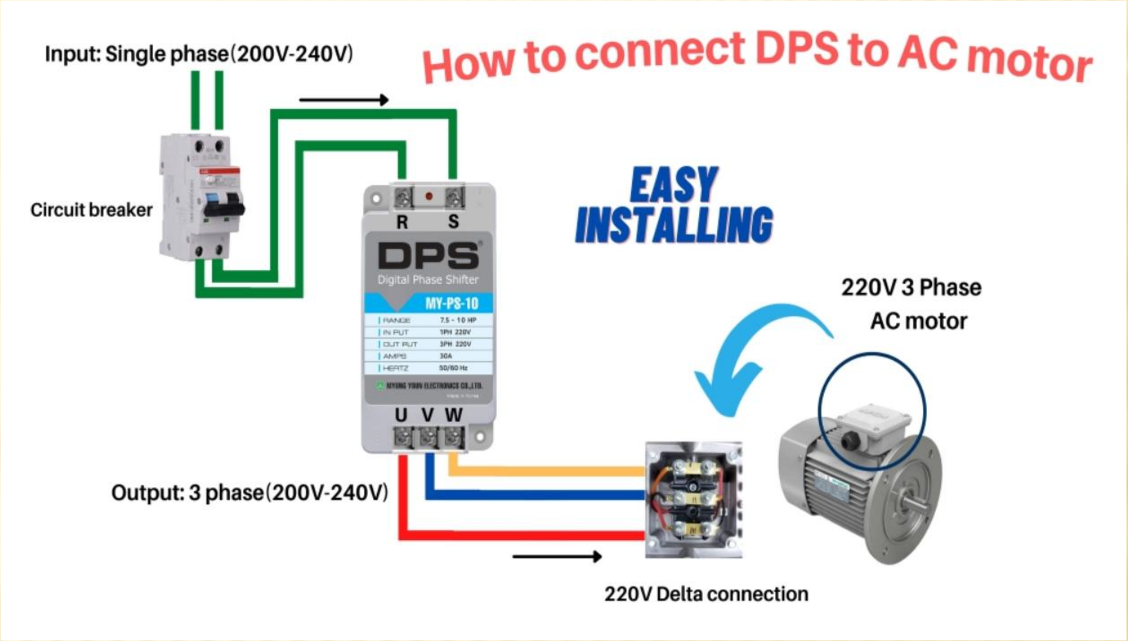


OLD!

Single phase to 3 phase works because the motor becomes a generator.

SINGLE PHASE TO THREE PHASE CONVERTER





NEW!

Digital phase shifters are replacing the rotary phase shifters. These are smaller and efficient. You can buy this one on Amazon for around $230.