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### **Lesson Focus**

This lesson forms part of an interrelated set of four lessons, the others being "Basic Electricity and Magnetism", "Basic Direct Current Motors" and "Basic Electric Transformers". The general field of electric motors is unusually wide, covering as it does both direct current (DC) and alternating (AC) machines. While DC motors are comparatively simple, AC motors are much more complex and cover a much wider range of alternatives. They are therefore more suited to an older group of students. With this in mind, we have decided to cover this topic in two separate lessons. This present lesson covers AC motors only and is suited for students in the 12 to 17 age bracket. DC motors are covered in the lesson entitled "Basic Direct Current Motors & Generators" to be found elsewhere in this general series. AC generators are considered to be more suitable for first-year University and are not covered in this series.



It should also be understood that the principal objective of this lesson is simply to provide the students with the ability to identify the various types of AC motors available in everyday use, and to be aware of their principal characteristics and applications. There is no intention to provide instruction in the calculation of performance and other technical features.

### **Lesson Synopsis**

The lesson begins by outlining the work of some of the early experimenters and the sequence which eventually led to the realization of the tremendous advantages of an alternating current system, particularly for large scale and long distance applications.

A necessary preliminary to this lesson is the lesson entitled "Basic Direct Current Generators and Motors" to be found elsewhere in this series.

The lesson ends with a section in which the students are invited to discuss with the teacher, various ways in which they think these demonstrations could be improved.

### **Age Levels**

12-17

#### **Basic Alternating Current Motors**

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## Objectives

Students will:

- ◆ To provide a basic understanding of alternating currents.
  - ◆ Learn about how a rotating magnetic field, when interacting with suitably arranged coils of wire, can be made to produce a rotating mechanical force, i.e. an electric motor.
  - ◆ Learn that a rotating magnetic field, when driven by a mechanical force, can produce an electric voltage, i.e. a generator.
  - ◆ Learn that these two effects are generally speaking, equal and opposite.
  - ◆ Learn about how these two phenomena can be conveniently and safely controlled.
  - ◆ Learn about the importance of discipline and team work.
- 

## Anticipated Learner Outcomes

As a result of this activity, students should develop an understanding of:

- ◆ Basic alternating current motors
  - ◆ engineering history
  - ◆ problem solving
  - ◆ teamwork
- 

## Lesson Activities

At the end of this lesson there is a very simple hands-on demonstration of the working principle of an AC motor, which can be assembled in the classroom. Given that AC motors require a more complex power supply than DC motors, it is not considered reasonable to offer anything more sophisticated at this time.

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## Resources/Materials

- ◆ Teacher Resource Documents (attached).
  - ◆ Student Resource Sheets (attached)
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## Alignment to Curriculum Frameworks

- ◆ See attached curriculum alignment sheet.
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## Internet Connections

- ◆ TryEngineering ([www.tryengineering.org](http://www.tryengineering.org))
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## Recommended Reading

- ◆ Wikipedia "How Electric Motors are made".
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## Optional Writing Activity

- ◆ Having discussed the obvious limitations of this very simple demonstration unit, students should be asked to set out ways in which they think it could be improved.
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### Basic Alternating Current Motors

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***For Teachers:  
Teacher Resource***

**Materials and Costs**

The materials required for the hands-on activity associated with this lesson are listed at the end of this lesson. They total about \$85.00. However, since most hardware stores will offer a discount if told they will be part of a school exercise, they will usually offer a discount. Teachers are encouraged to ask. Similarly most of the components are re-usable. It is also suggested that the school may want to visit a local electrical repair shop and buy (or ask to be given) an assortment of scrap motors which could be cut up to show the internal structure. These items can also of course be kept available for demonstration purposes over and over again.

**Safety Note**

Since the hands-on activity associated with this lesson is very simple the safety requirements are minimal. The Bell Transformer and its enclosure must of course be assembled in accordance with the local electrical code. Since most schools limit classroom voltages to 12 volts, the 16 V terminal screw should be removed, as shown in Figure 12.

**Time Needed**

It is suggested that, for students in the 12-17 age bracket, three sessions of 45 minutes each should be sufficient.

**For Teachers:**  
**Teacher Resource**

**THE BASIC BASICS.**

The two companion lesson plans, "Basic Electricity and Magnetism" and "Basic Direct Current Generators and Motors" cover this material in some detail and will not be repeated here.

**WHY USE ALTERNATING CURRENTS?**

In the early years of the development of electric power systems, all operated on a direct current (DC) basis. However as these systems became larger and more powerful, several disadvantages became evident. One, of course, was the fact that the only way to send more power over longer distances was to increase the voltage. But it was soon found that higher voltages became more dangerous to handle, particularly for domestic applications. (E.g. 120 Volts is the standard in North America, while elsewhere the maximum is 240 Volts). The other problem encountered with large DC motors and generators was that the commutators became a frequent source of breakdown and repairs. In general, commutators are not seen very often today, except in steel mills. The unit shown in Figure 1 below is a medium size unit in a plant which is no longer in use and is not open to the public. Hence it is not very clean. If it were in regular use, the copper commutator segments would be kept shiny bright by the light rubbing pressure of the graphite brushes.

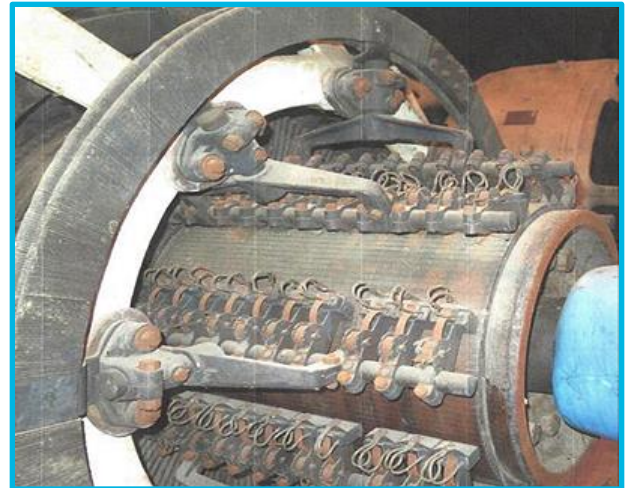


Fig. 1

The scientist generally credited with developing a better (AC) system was Nicola Tesla (1856-1943). In the early 1880's he became disenchanted with all the difficulties the industry was having with keeping commutators and brush gear clean and in good repair, that he applied himself to the development of what eventually became known as a wound-rotor induction motor. See Figure 2. But note that in this particular case, although the rotor is wound with wire, the ends of the wire are not brought out. The rotor winding is in fact one single continuous loop.

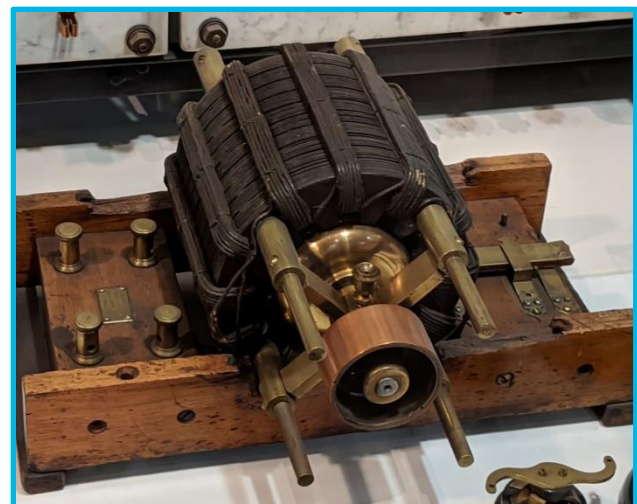


Fig. 2

**Basic Alternating Current Motors**

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### Interesting note about Tesla:

Tesla was amazingly intelligent. He was known for being able to visualize complicated schemes in his head, without making sketches or calculations. His first induction motor as above was an early example.

This was really very ingenious because, as you will see, there was no commutator at all. His early version, (which he patented and sold to George Westinghouse in 1888 for \$150,000, a huge sum in those days). An examination of Figure 2 will show several interesting features:

1. There is no commutator.
2. It only had two phases, in contrast to almost all modern systems, which have three phases. But nevertheless it worked well enough.
3. For an amusing account of early technology, see the article about the Telluride mine in Colorado, in the IEEE Magazine "Power & Energy" for January/February 2014, pp 82-98. Title: Telluride Power Co., Pioneering AC in the Rocky Mountains. Author Alan Drew.

The device shown in Figure 2 is actually a replica in a museum in Belgrade, the original having been lost. Tesla later patented a 3-phase system, but never seems to have developed it. See Figure 3.

### Some Basics

- AC systems almost always use either one "phase" or 3 "phases".
- The three phases are symmetrically disposed at  $120^\circ$  to each other.
- They are usually identified as "a, b and c", or "Red, Yellow and Blue" (aka R, Y & B).
- By convention, they are assumed to rotate in a **counter-clockwise** direction.
- Under normal conditions, each phase has the same voltage and current.
- They have no commutator. A minor exception to this is that some very small AC motors, such as vacuum cleaners etc, will run acceptably on an AC supply provided they are of the commutator type. They may however, spark a little.

### There are three main types of AC motor

- A "Squirrel Cage" induction motor". (Look at Figure 5 and you will see why.)
- A "Wound Rotor" induction motor, in which the solid bars of the squirrel cage are replaced by coils of insulated wire, the ends of which brought out to slip rings for speed control purposes, and
- A "Synchronous" motor.

Squirrel cage and wound rotor induction motors can be either single or three-phase, depending on the application. Synchronous motors are almost always three-phase.

Squirrel cage induction motors are the most common for small household use in fans etc., and have no speed control features. Wound rotor motors are used where some limited control of speed is required. Synchronous motors, by definition, can only run at one fixed speed, which is governed by the frequency of the power system (60 Hz in North America and 50 Hz in most other countries)

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## How does a 3-phase Motor Produce a Rotating Magnetic Field?

Refer to Figure 3 below. Here you will see a “Time Lapse” sequence of what happens, both outside and inside a three-phase motor frame. The rotor is excluded for clarity. In these diagrams the phases have been colored Red, Yellow and Blue, simply to coordinate with the hands-on demonstration at the end of this lesson. The magnetic flux in each phase is shown on the left-hand side. The diagram on the right hand side represents the cylindrical casing. Each of the three rectangles inside the casing represents one of the phase windings. This whole assembly is known as the stator, because it remains stationary. Note that these are also lettered R, Y & B, same as the phases of the power supply.

The students are encouraged to consider the four vector diagrams on the left hand side of Figure 3, overleaf. By inspection it will hopefully be evident that at all times, as the three vectors rotate in unison, they are always equally balanced – provided, of course, that their magnitudes are equal. In other words, if these conditions apply, the vector sum at the neutral point is always zero and no unbalanced current will flow in the neutral conductor. If the students have trouble with this concept, they should consult their math teacher.

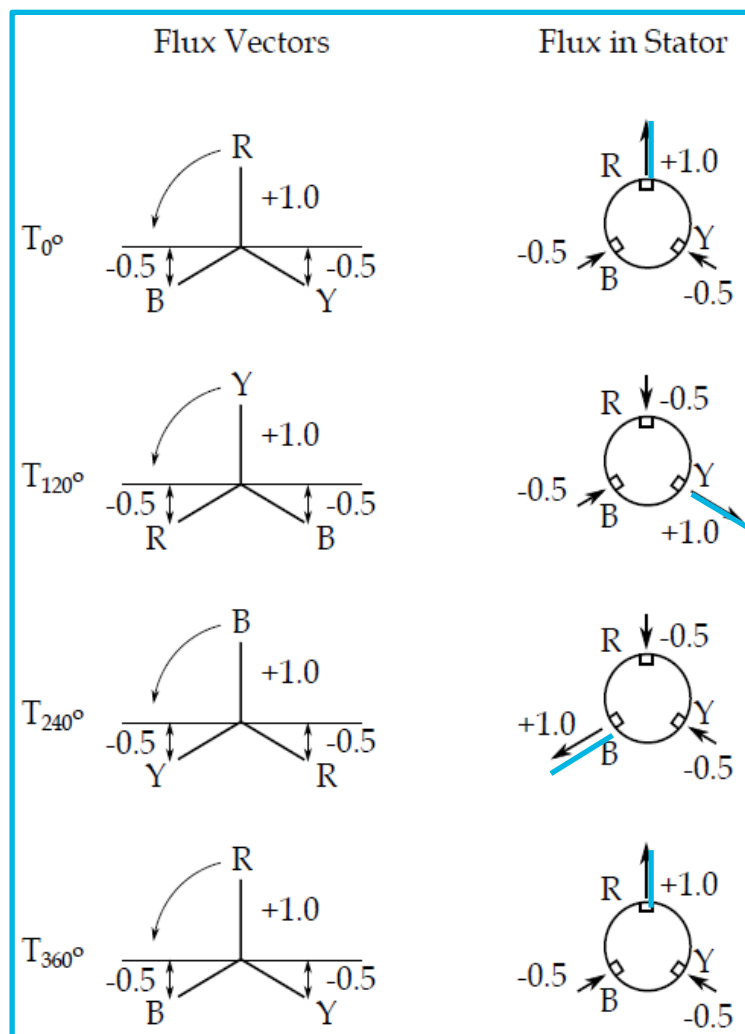


Fig. 3

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1. At time  $T = 0$  the three flux vectors are as shown, in which Red is at its' vertical component of 1.0. Yellow is down and to the right, with a vertical component of 0.5 downwards. Blue is down and to the left, also with a vertical component of 0.5. Note: The units here do not matter. Only their relative size matters. If we then transfer these components to their respective poles, we will see that the flux in R is at a maximum of 1 unit, and pointing outwards (for the sake of argument). Similarly, both Y and B are at a value of 0.5 units and pointing in the opposite direction (inwards in this example). Note also that the sum of all three flux vectors is zero.
2. At time  $T = 120^\circ$  all three vectors will have rotated counter clockwise  $120^\circ$ . At this point Yellow have a vertical component of 0.5 units negative (pointing inwards). Note once again that the vector sum of these components is zero.
3. At time  $T = 240^\circ$ , the three vectors have rotated another  $120^\circ$  counter clockwise, and it is now Red which is at its' maximum positive of 1.0 units (pointing outwards). And once again the vector sum of the fluxes is zero.

### So, What Do We Conclude?

1. If we look just at the sequence in which the flux vectors reach their maximum outward position, we will see that it has progressed smoothly from the Red pole, to the Yellow pole, to the Blue pole, and then back to Red again. Note here that it is only the flux which moves. The poles themselves are fixed to the stator and do not move.
2. But it is interesting to note that the sequence of rotation inside the stator frame can easily be reversed i.e. to a clockwise direction, by switching any two of the phase wires. In other words, if we switch any two wires, we get a rotation which becomes R, B, Y, or even B, Y, R. This is one of the big advantages of a 3-phase AC system it is so easy to reverse direction.
3. Note also that at all times, the sum of the flux vectors inside the stator is zero. This means that there is virtually no unbalance, and the motor will operate without vibration. That us the other big advantage of a 3-phase system.
4. However one disadvantage of an AC motor is that speed control is more difficult.

### The Squirrel Cage Rotor

So far we have not considered the rotor in the above sequence. Figure 4 shows a side view a so-called squirrel cage rotor. Note that it is very compact and simple, with no coils visible. Figure 5 shows an end view, in which the only thing visible is a disc of aluminum. However, Figure 6 in which the aluminum disc has been cut away to show the internal structure, in which the coils (called rotor bars in the case of a Squirrel Cage Motor) can be seen. A squirrel cage motor is one of the simplest, crudest, but most robust pieces of electrical equipment available. The components are:

The rotor, which is a series of circular laminations each with a series of radial slots punched in them. The laminations are not insulated from each other.



Fig. 4



Fig. 5



Fig. 6

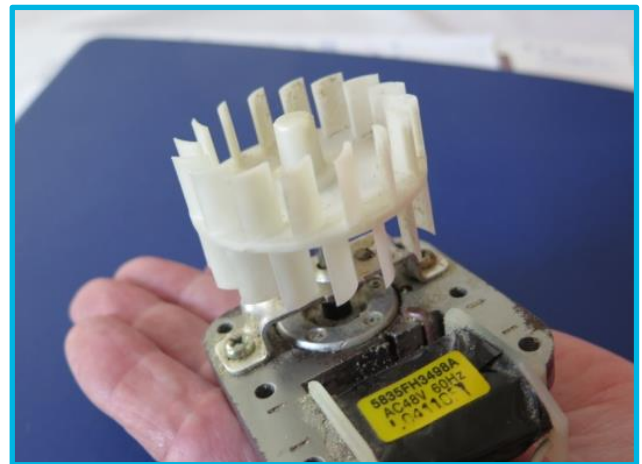


Fig. 7

There are no coils as such. What you see in the end view is a series of aluminum bars. These are as crude as they look, and are simply put in place by pouring molten aluminum into the slots, and capping them with an aluminum disc, also poured at both ends from a molten state. This is a very small rotor from a bathroom fan, but the principle is exactly the same for much larger motors.

1. There is no commutator and no brushes. A big advantage.
2. There is no insulation between rotor laminations and none between the aluminum bars and the rotor steel.
3. Figure 7 shows an assembled squirrel cage motor from a hair dryer.
4. In summary, these motors are crude, robust and cheap. Everything can be made by machine. Since it is for light intermittent duty, efficiency is not an issue.

### Basic Alternating Current Motors

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## How does it work?

We have already seen that a 3-phase power supply will produce a rotating magnetic field inside the stator. Now if we place a squirrel cage rotor inside the stator, at the instant the power is turned on, the rotating magnetic field in the stator will, by transformer action, induce a corresponding rotating current in the aluminum bars of the rotor. At the instant the power is turned on, and only for that instant, the flux in the stator will induce a flux in the rotor which will rotate at the system frequency of 60 Hz (cycles per second) or 3,600 times per minute, or 3,600 rpm. And this is the interesting part. At the instant of starting, the speed of the rotor is zero. Thus the speed of flux in the rotor will also be 3,600 rpm. But then, as the speed of the rotor starts to catch up with that in the stator, the speed difference between the two decreases, and consequently the magnetic flux and current in the rotor bars also decreases. It would be nice to think that eventually the two would match up exactly so the rotor would also be spinning at 3,600 rpm. But like the carrot and the donkey, the two never do quite catch up. Friction in the bearings (extremely small) and what is known as "wind resistance" as the rotor spins, mean that the rotor always has to revolve just a little bit slower than the stator, in order for the "transformer action" to provide just enough power to overcome these losses. But it does mean that an induction motor never does quite run at the same speed as the power system. This difference is known as "Slip".

## Slip

The speed difference between rotor and stator is known as "slip". In most cases, the slip at NO LOAD is about 1% of synchronous speed. In other words, for a 3,600 rpm motor, 1% slip is about 36 rpm, and the maximum attainable motor speed is about  $(3,600 - 36) = 3,564$  rpm, at what is known as "speed no-load". And then, as the load on the motor is increased, the slip will automatically increase in order for the transformer action between stator and rotor to provide enough torque to meet that load. At full load, slip is usually about 5% or 180 rpm, and rotor speed will be about  $(3,600 - 180) = 3,420$  rpm. Much beyond that, and the rotor speed will drop to a point where it can no longer produce enough torque to keep up with the stator, and the motor will stall and eventually stop. It will also get extremely hot unless it is switched off. This is a bad situation for the motor because everything will overheat. Motors usually have a heat-sensitive cut-out to switch off the power before damage is done. <sup>1</sup>

## Starting a Single-Phase Induction Motor

From Figure 2 above, which demonstrates how a three-phase motor produces a rotating magnetic flux in the stator, it should be an easy step to realize that a single phase also requires a rotating magnetic field, at least to get it started. But a single phase current in the stator simply produces a flux which merely pulses but does not rotate. Fortunately this can be overcome with a little ingenuity. See Figure 8.

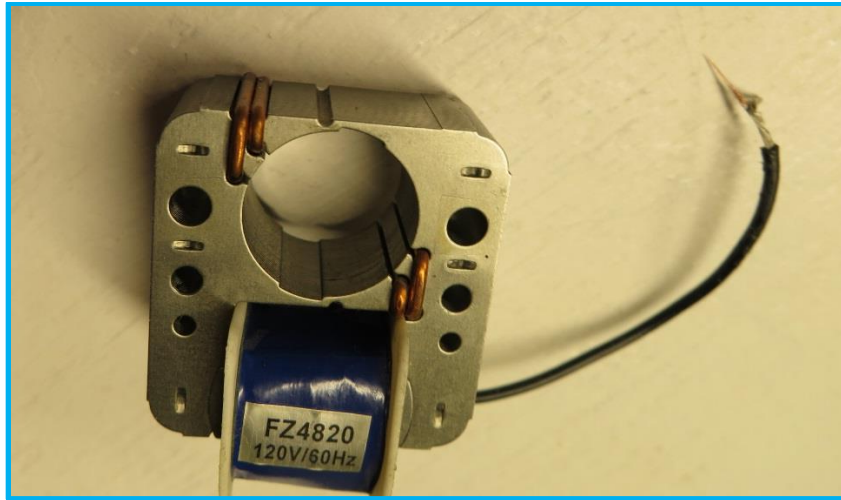


Fig. 8

From this it will be seen that there are two very small but thick loops of copper right in the air gap between the rotor and the stator. These two loops produce a very small flux which is offset by about 15 or 20 degrees from the main stator coil. This small flux creates the impression of a rotating effect, just enough to get the rotor moving, and up to close to but not quite synchronous speed, as explained above. It is worth noting that the two loops of copper are both in fact full short circuits. Hence the current in them is relatively high. But since they are small in size, the losses they represent are quite small.

This type of motor is known as a “Shaded Pole” induction motor. There are other means of starting small single phase motors, but that is a subject better left for another day.

### Wound-Rotor Induction Motors

A wound-rotor induction motor, as its name implies, is an induction motor in which the solid aluminum bars in the rotor are replaced by a single continuous coil of insulated copper wire, the turns of which are evenly distributed among all the slots in the face of the rotor. The two tag ends of the coil are brought out to two slip-rings. To some extent, it looks a little like a DC motor, except that in place of a commutator, there are two slip-rings. While slip rings are much simpler to make than a commutator, they do nevertheless cost a little more than a squirrel cage rotor. So it is a compromise depending on what you want to do. The main advantage of this type is that if a rheostat is placed in the external part of the rotor circuit, the amount of current in the rotor can be smoothly varied. It also permits a smoother and more gradual start from rest. But the same limitation as to maximum speed applies. Like all induction motors, the torque developed is dependent on a certain amount of slip, and with about 5% slip being the minimum, this means that the maximum speed is limited to about 3,420 rpm (on a 60 Hz system). Large induction motors, such as the one shown in Figure 9 are commonly used in industry for driving pumps and air compressors etc.

### Synchronous Motors

These motors are one stage again more complex than a wound rotor induction motor. The stator may look much the same. But the rotor design and its’ external circuitry are quite different.

- The rotor is wound with two (or sometimes four or more) clearly defined magnetic poles. These may be embedded in slots<sup>2</sup>, but their configuration is such that when a DC (note that it is DC, and not AC) current is passed through it, there will be a series of distinct magnetic North and South poles around the rotor.
- The other major difference is that, instead of relying on “transformer action” to induce a current in the rotor winding, an external DC source is required to force a substantial current thru the rotor winding.

### **So Then What Happens?**

The fact that there is a strong DC current circulating in the magnetic poles of the rotor, means that, once it is up to speed, the strong magnetic flux in the rotor will engage strongly with the rotating flux in the stator, and hence the rotor will be carried round with it at exactly synchronous speed. There is no slip in a synchronous motor. This is a big advantage in industrial processes, where an exact and constant speed is required. And of course, a synchronous motor will only run at one set speed and no other.

Unfortunately however, there is one big, and perhaps surprising, disadvantage involved, and that is that a synchronous motor will not start itself from rest. It requires a small “pony motor” or some rather complex additional windings to bring it up to speed. This is of course an added expense and limits such motors only to large industrial processes. A small exception to this are the very small synchronous motors used in analog clocks. In these motors, the rotor is so small and light that as soon as the power is switched on, it can accelerate in just one or two cycles up to synchronous speed. But in almost all other cases, the method of starting has to be considered. And in any case, analog clocks are no longer seen very often. This is an outdated technology and most clocks today are digital.

### **Motor Efficiency**

AC motors are generally very efficient, reaching figures between 95% and 97%, depending on size. The very small sizes, such as that shown in Figure 8 are probably much less efficient, but for intermittent use, efficiency is not important.

### **External Appearance**

The various photographs and diagrams given above have dealt only with the internal features of the various types of motor. To a first approximation, it is usually not easy to tell by looking at the external casing, what type of motor is inside. But Figure 9 shows a 20 HP, 600 Volt, 3-phase, squirrel cage induction motor. For use in dry indoor locations, the motor will have an open frame to allow cooling air to circulate freely. But in the instance shown, the motor is fully weatherproof and can be used outdoors in any weather. It is also very heavy and weighs about 400 lbs (175 kg). But apart from that, one has to look at the nameplate for further details.

### **Speed Control of AC Motors (It's not easy!)**

For all of the motors outlined above, the maximum speed which can be obtained is governed by the speed at which the flux in the stator rotates. Since it is not possible to have less than one pair of poles (one north and one south) the speed at which the flux will rotate on a 60 Hz system, will be  $(60 \text{ Hz} \times 60 \text{ seconds}) = 3,600 \text{ rpm}$ . Similarly, on a

<sup>2</sup> Some larger synchronous motors may have separate poles bolted to the rotor shaft.

50 Hz system, the **maximum** rotation will be 50 Hz x 60 seconds) = 3,000 rpm. These are maximum speeds because it is not possible to have less than one pair of poles.

So as we have seen, 60 Hz **induction** motors will have a speed range of between 3,550 rpm at no-load down to about 3,400 at full load (between 2,900 and 2,700 rpm for 50 Hz systems). And it is not easy to get more precise figures.

If these speeds are way too high, it is always possible to add more poles to the stator. These of course, have to go in twos (4, 6, 8 etc.) because it is not possible to have a North pole without also having a corresponding South pole. A simple table here will suffice.

Poles	Synchronous speed	
	60 Hz system	50 Hz system
	<b>RPM</b>	<b>RPM</b>
2	3,600	3,000
4	1,800	1,500
6	1,200	1,000
8	900	750

And so on, as required.

**Note 1:** These are synchronous speeds as determined by the system. Induction motors will operate at slightly lower speeds depending on slip. Synchronous motors will run at these speeds exactly, and no other.

**Note 2:** If speeds higher than 3,600 rpm (3,000 rpm) are required, a speed increasing gearbox would be required, but these are very expensive and significantly reduce efficiency.

### Supplementary Information

For the benefit of those interested, the two figures below are included to show the general appearance of electric generators and motors of a larger size than seen in this lesson. Figure 9 shows a 20 HP, 600 Volt, squirrel cage induction motor, which is driving an irrigation pump for which exact speed control is not important. This motor is totally enclosed and weatherproof. It weighs about 400 lbs.





Fig. 9

Figure 10 below shows a (comparatively) small AC generator, rated at about 3,000 kW (4,000 HP) at 50 Hz and 5,000 Volts (5 kV). It is being driven by a hydraulic turbine, which is actually bigger than the generator. This illustrates the general efficiency of electrical equipment. This generator may look much like a motor, but the controls are much more complex and not discussed in the lesson. However, one last comment may be of interest. The small cylindrical object closest to the camera is actually the “Exciter”. This is a small DC generator which supplies DC current to the **rotor** of the main AC Generator, just as in a synchronous motor described above. As one last point, it is worth noting that by varying the DC voltage produced by the exciter, it is possible to vary the AC voltage of the main AC generator. Simple when you know how – isn’t it?



Fig. 10

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***For Teachers:***  
***Teacher Resource***  
***Hands-On Activities***

## A Simple Hands-on Demonstration

This is a simple and inexpensive demonstration of a single phase AC motor which can be assembled in the classroom. Figure 11 shows a birds-eye view of the simple materials required. In Annex 1 there is a bill of materials with approximate costs. Note that although the total cost is roughly \$90, most of the items can be re-used many times. Furthermore, the hardware store will probably offer a discount if told it is for a school project.

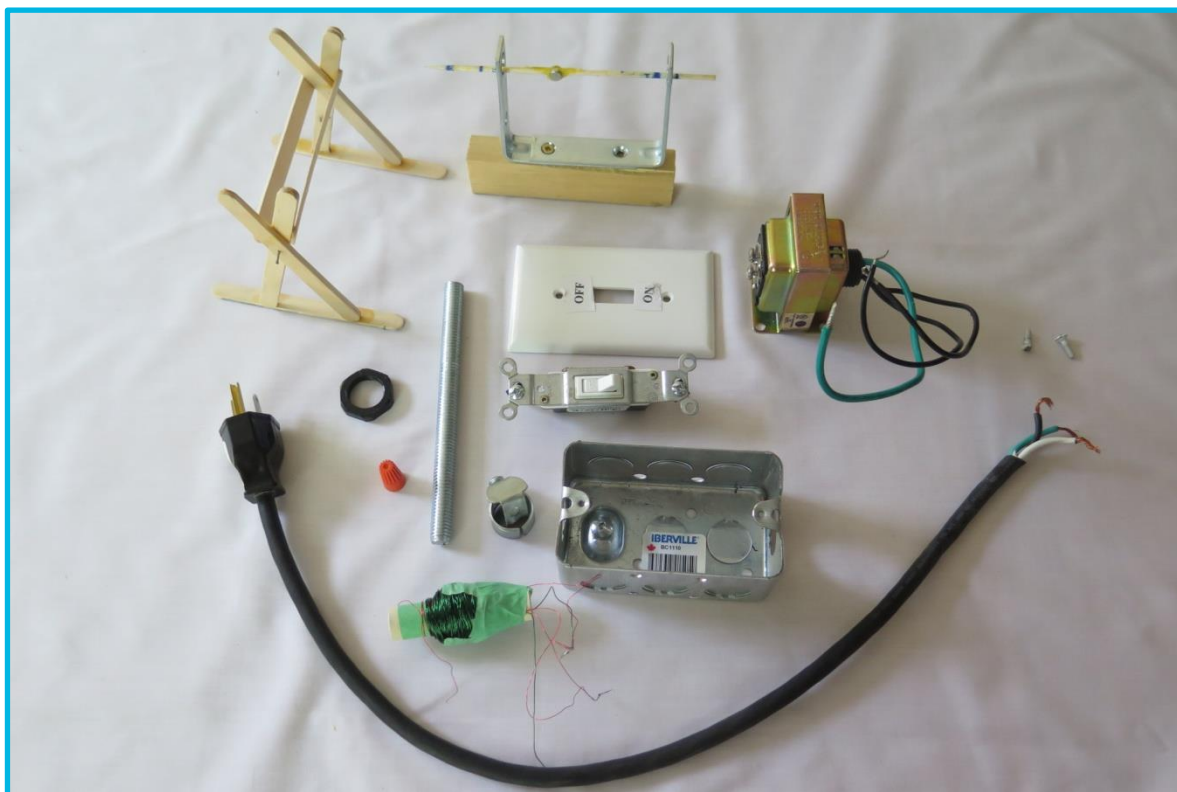


Fig. 11

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The list can be broken down into two main components, the “Bell Transformer” and “Motor”. Figures 12 and 13 show close-ups of the Bell Transformer. Since this item contains items at 120 Volts, it must be in accordance with the local electrical code. It should therefore be assembled either by the teacher or the school maintenance staff. Note also that since most school jurisdictions do not allow more than 12 Volts in the classroom. Hence in Figure 12, it will be seen that the 16 Volt terminal screw has been removed.

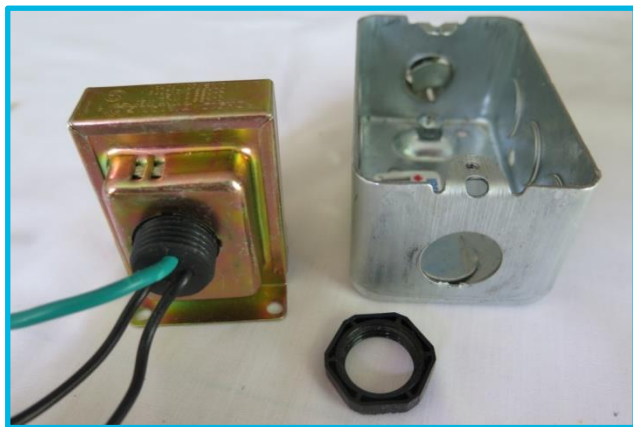


Fig. 12



Fig. 13

The components representing the “motor” are shown in Figure 14 and need not be described in detail, except to say that the initial gap between the “Stator Pole” and the “Rotor” should be about  $\frac{1}{2}$ ” (1.5 cm). Even the very small  $\frac{1}{4}$ ” button magnets are surprisingly strong and will stick firmly to any iron object which is brought too close. They are then quite hard to separate. The steel rod representing the “Stator Pole” should then be gently advanced towards the “rotor”, which will first vibrate slightly and then start to rotate. If you get too close, the magnet will suddenly jump at the stator pole and you will have to shut down and start over.

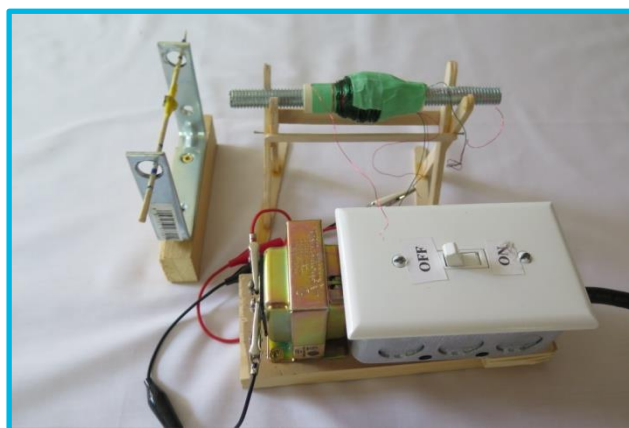


Fig. 14

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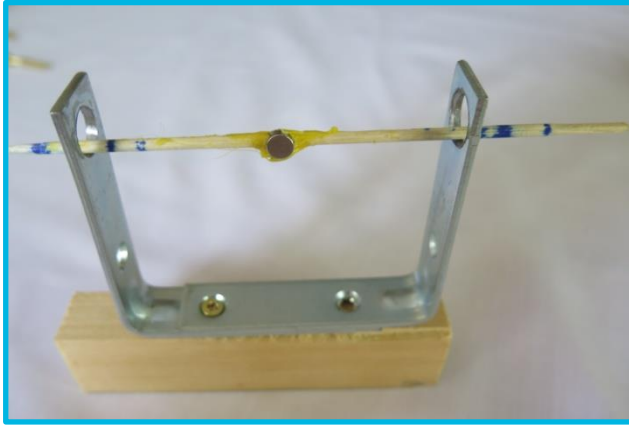


Fig. 15

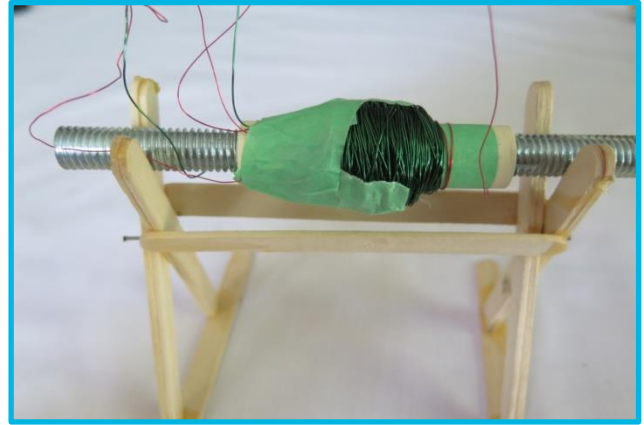


Fig. 16

Figure 15 shows the “rotor”. Note that the two ¼” magnets are stuck onto the bamboo skewer with yellow cement which is used with plastic piping. It is necessary to apply one magnet initially and set it aside for the glue to harden overnight. Then apply the other magnet next day and let it harden also. It is not easy to do this because the magnets are so strong and have a tendency to flip over to the other side. In other words, you will then have 2 magnets on the same side and nothing on the other.

Magnets of ½” or bigger are simply too strong for this demonstration and will lock everything up firmly.

The “stator coil” is shown in Figure 15 and outlined in Annex 1, and can be made with 500 turns of #26 awg insulated magnet wire. (#26 awg is usually green in color).

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**For Students:**  
**Student Worksheet**

**Reflection**

Complete the reflection questions below:

1. What is the principal material in a commutator?
2. Name three types of AC motor.
3. What is the approximate efficiency of an electric motor?
4. List some typical synchronous speeds of a 60 Hz motor.
5. What is the normal diet of the squirrel in a squirrel cage motor?

## For Teachers:

### Alignment to Curriculum Frameworks

**Note:** Lesson plans in this series are aligned to one or more of the following sets of standards:

- U.S. Science Education Standards ([http://www.nap.edu/catalog.php?record\\_id=4962](http://www.nap.edu/catalog.php?record_id=4962))
- U.S. Next Generation Science Standards (<http://www.nextgenscience.org/>)
- International Technology Education Association's Standards for Technological Literacy (<http://www.iteea.org/TAA/PDFs/xstnd.pdf>)
- U.S. National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (<http://www.nctm.org/standards/content.aspx?id=16909>)
- U.S. Common Core State Standards for Mathematics (<http://www.corestandards.org/Math>)
- Computer Science Teachers Association K-12 Computer Science Standards (<http://csta.acm.org/Curriculum/sub/K12Standards.html>)

## ◆ National Science Education Standards Grades K-4 (ages 4 - 9)

### CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ◆ Abilities necessary to do scientific inquiry
- ◆ Understanding about scientific inquiry

### CONTENT STANDARD B: Physical Science

As a result of the activities, all students should develop an understanding of

- ◆ Light, heat, electricity, and magnetism

### CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

- ◆ Understanding about science and technology

## ◆ National Science Education Standards Grades 5-8 (ages 10 - 14)

### CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop an understanding of

- ◆ Motions and forces
- ◆ Transfer of energy

### CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- ◆ Science and technology in society

### CONTENT STANDARD G: History and Nature of Science

As a result of activities, all students should develop understanding of

- ◆ History of science



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**◆Next Generation Science Standards Grades 3-5 (Ages 8-11)**

**Motion and Forces: Stability and Interaction**

Students who demonstrate understanding can:

- ◆ 3-PS2-3. Ask questions to determine cause and effect relationships of electric or magnetic interactions between two objects not in contact with each other.
- ◆ 3-PS2-4. Define a simple design problem that can be solved by applying scientific ideas about magnets.

**Energy**

Students who demonstrate understanding can:

- ◆ 4-PS3-4. Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

**◆Next Generation Science Standards – Grades 6-8 (Ages 11-14)**

**Motion and Stability: Forces and Interactions**

- ◆ MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

**Energy**

- ◆ MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.

**◆Standards for Technological Literacy - All Ages**

**Technology and Society**

- ◆ Standard 7: Students will develop an understanding of the influence of technology on history.

**Design**

- ◆ Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

**The Designed World**

- ◆ Standard 16: Students will develop an understanding of and be able to select and use energy and power technologies.

## Annex 1

### AC MOTORS

DATE OF ISSUE SEPT 26, 2015

#### ANNEX 1

#### BILL OF MATERIALS

Item	Unit Cost	Qty	Total Cost	INCL TAX
BELL TRANSFORMER	\$ 21.00	1	\$ 21.00	MUST ALL BE TO THE CODE. REMOVE 16 V TERMINAL
2 POLE SWITCH	\$ 2.25	1	\$ 2.25	"
METAL BOX	\$ 3.00	1	\$ 3.00	"
CABLE CLAMP	\$ 0.50	1	\$ 0.50	"
FACE PLATE	\$ 0.45	1	\$ 0.45	"
MARR CONNECTORS	\$ 2.20	1	\$ 2.20	BOX OF 20
CABLE - 3 cond.	\$ 1.00	3 FT	\$ 3.00	"
PLUG	\$ 6.50	1	\$ 6.50	"
<b>TOTAL FOR TRANSFORMER UNIT</b>			<b>\$ 38.90</b>	Say <b>\$ 45.00</b>
STEEL BRACKETS 3"X3"	\$ 1.69	2	\$ 3.38	
1/4" MAGNETS	\$ 11.95	2	\$ 11.95	BOX OF 20
SMALL BLOCK OF WOOD	\$ -	1	\$ -	
BAMBOO SKEWER	\$ -	1	\$ -	
POPSICLE STICKS	\$ 2.50	12	\$ 1.00	BOX OF 50
MISC SCREWS ETC.			\$ 1.00	
GLUE			\$ -	
WIRE			\$ 16.95	
FOR 40 FT OF #22. 75 FT OF #26, AND 220 FT OF #30. NOT REAL COPPER.				
PLASTIC PIPE.	\$ 5.00	2-3/4"	\$ 5.00	FOR 10 FT
1/2" ID, 9/16" OD, 2-3/4" LG				
STEEL CORE. 7/16" DIA, 6" LONG	\$ 2.50		\$ 1.25	PER COIL
<b>BALANCE OF EQUIPMENT</b>			<b>\$ 40.53</b>	Say <b>\$ 45.80</b>
<b><u>OVERALL TOTAL</u></b>			<b>\$ 79.43</b>	Say <b>\$ 90.00</b>

**Note. If you tell hardware store it is for school demo, they will probably give discount.**

#### COIL CALCULATIONS:-

OD OF PIPE	0.5625	INCH		
CIRCUM	1.76625	INCH		
SAY AVERAGE =	1.85	INCH		
GREEN TURNS. #26 awg	500		925	INCH
			77.1	FT
40 mOHM/ft	0.04	OHM/FT	3.1	OHMS

### Basic Alternating Current Motors

Provided by IEEE as part of TryEngineering [www.tryengineering.org](http://www.tryengineering.org)

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