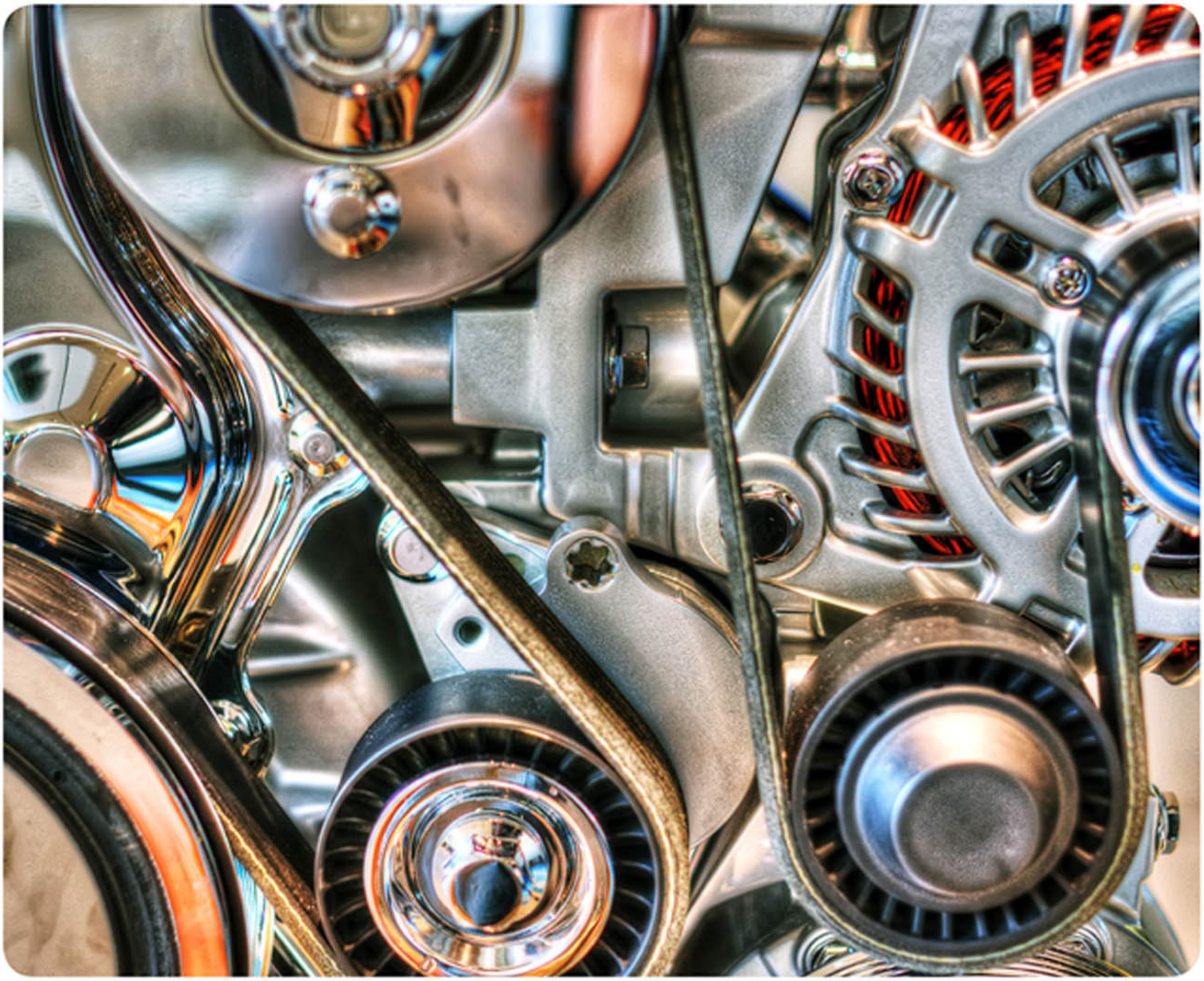
MOTORS for MAKERS

A Guide to Steppers, Servos, and Other Electrical Machines



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AC MOTORS

Remote-controlled vehicles and hobbyist devices generally rely on DC motors, but most household/industrial appliances rely on AC motors. The reason is simple—houses and other buildings provide electrical power as alternating current (AC). This is why electric fans and blenders, which have AC motors, can be plugged directly into electrical outlets.

The goal of this chapter is to introduce different types of AC motors and explain their advantages and disadvantages. Because AC motor technology is so old (the first practical AC motors were constructed in the 1880s), a wide range of AC motors is available. They can be categorized in a number of ways, but this chapter classifies motors according to two criteria:

- **Polyphase/single-phase**—The electrical content of the motor's incoming power
- **Synchronous/asynchronous**—The relationship between the motor's speed and the frequency of the incoming power

This chapter introduces polyphase motors first and then presents single-phase motors. The last part of the chapter discusses the fascinating topics of AC motor control and universal motors.

Before I start discussing rotors and stators, I'd like to review the concepts underlying AC power. The better you grasp this topic, the better you'll be able to understand the motors that make use of alternating current.

6.1 Alternating Current (AC)

The fundamental difference between AC motors and DC motors is that the power delivered to an AC motor is sinusoidal. AC power has a number of advantages over DC power, and one major advantage is that AC voltage can be increased and decreased (that is, stepped up and stepped down) with transformers. This makes it possible to transmit AC power over long distances at high voltage and low current. This low current guarantees that the I^2R losses in transmission lines will be as low as possible.

6.1.1 Single-Phase Power

The power provided by residential electrical outlets is single-phase, which means the power is received in a single sinusoid. Figure 6.1 shows what single-phase power looks like.

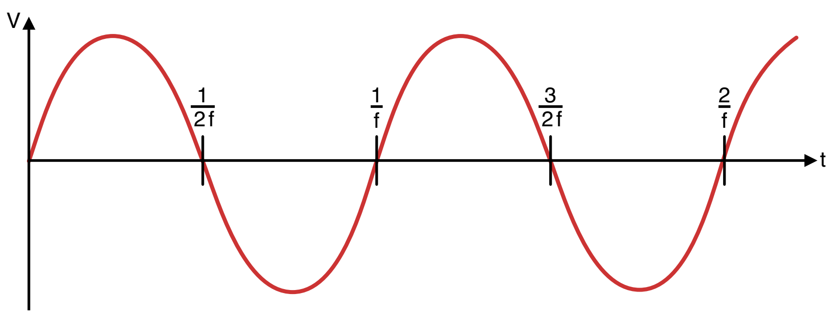


Figure 6.1 Single-phase AC power

In this figure, the sinusoid's frequency is denoted f, which means it completes a cycle in 1/f seconds. In the USA and Canada, f equals 60 Hz and the sinusoid's amplitude is 168 V, which is equivalent to 120 V RMS (root-mean-square). In other nations, it's common to see line power provided at higher voltage (230–250 V RMS) and frequencies of 50 Hz.

6.1.2 Three-Phase Power

Single-phase power is fine for households, but it's insufficient for industrial machines. To meet the greater need, power is delivered with three sinusoids. This is called three-phase power, and Figure 6.2 depicts sinusoidal power provided in three phases, labeled A (solid line), B (dashed line), and C (dotted line).

When you're selecting an AC motor for an application, it's crucial to know what type of power the motor requires. Motors designed for three-phase power won't function properly when given single-phase power, and single-phase motors will likely break when three-phase power is delivered.

Because of their usage in industry, three-phase motors are more common than single-phase motors. But if you're building a product to run on household power, you should take a close look at single-phase motors.

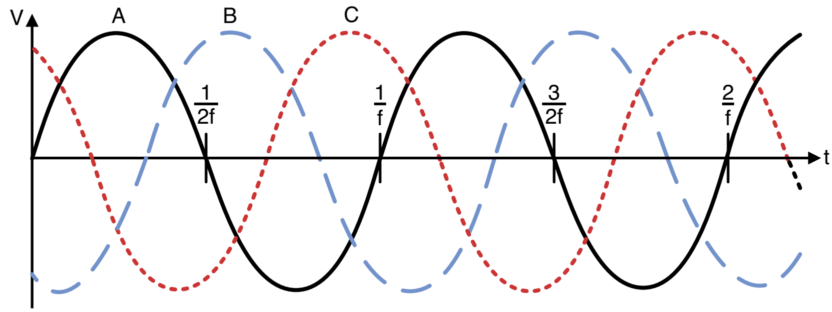


Figure 6.2 Three-phase AC power

6.2 Overview of Polyphase Motors

Polyphase motors are the workhorses of industry. Cranes, drills, and electric trains all rely on large-scale polyphase motors. These motors come in different types to serve different needs, but their stators all have the same general structure.

The stator of a polyphase motor contains windings (electromagnets) that produce a rotating magnetic field. This rotating field causes the rotor to turn. To understand how polyphase motors work, it helps to understand this rotating field and how it relates to the rotor's speed.

6.2.1 Stators

As discussed in Chapter 1, "Introduction to Electric Motors," an electric motor is the union of two parts: the rotor (which rotates when power is delivered) and the stator (which stays in place). In an AC motor, the structure of the rotor changes according to the motor's type. For example, the rotor of an induction motor is markedly different from the rotor of a permanent magnet synchronous motor.

However, every polyphase AC motor discussed in this chapter has the same stator structure. The stator is always positioned outside the rotor, and its windings receive AC power.

If a motor is intended to receive polyphase power, its windings are grouped into sets called *phases*. The stator has one phase for each phase of input power, and windings in the same phase receive power from the same phase. Figure 6.3 shows what a stator of a three-phase AC motor looks like.

This figure doesn't show the connections between the windings, but A and A' are connected together, B and B' are connected together, and C and C' are connected together. The number of windings per phase is called the number of *poles*, and it's always an even number. The motor displayed in the figure has six windings divided evenly into three phases. Therefore, it has two poles (6/3 = 2).

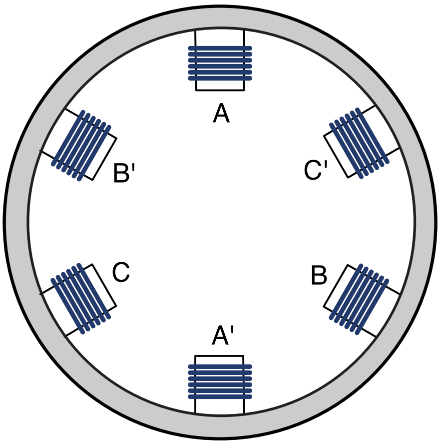


Figure 6.3
Stator of a three-phase AC motor with two poles

6.2.2 Rotating Magnetic Field

Each phase of the input power (A, B, and C) is delivered to the corresponding phase in the stator (A/A', B/B', and C/C'). In Figure 6.3, the three phases are separated from one another in space by 120°. In Figure 6.2, the three voltages are separated in time by an interval that corresponds to 120°. This isn't a coincidence. The alignment of winding position and voltage phase produces a crucial result: a rotating magnetic field in the stator.

The stator's rotating field is vital to the functioning of polyphase motors. To see how it's generated, we can examine the effect of the three-phase voltage on the windings. Figure 6.4 depicts one cycle of power, with markings at times t_0, t_1, t_2, and t_3.

> **note**
> The following discussion explains how the stator's magnetic field is created. It's not important to understand every detail so long as you're satisfied that the stator of a polyphase motor produces a rotating field.

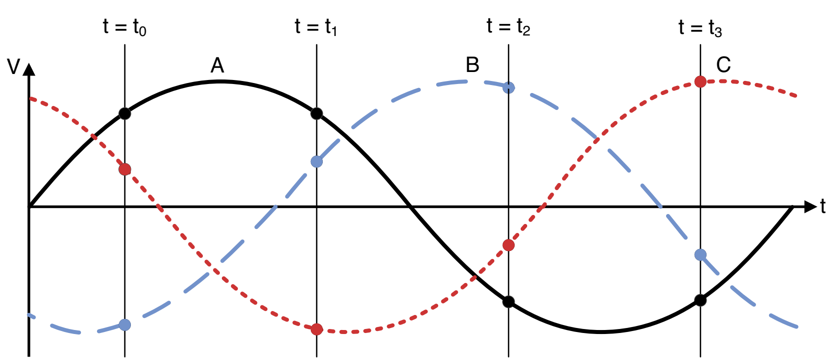


Figure 6.4
Single cycle of three-phase power

The magnetic field produced by a winding is proportional to the current flowing through it, which is proportional to the applied voltage. Therefore, we can gauge the relative strengths of the magnetic fields by comparing their relative voltages.

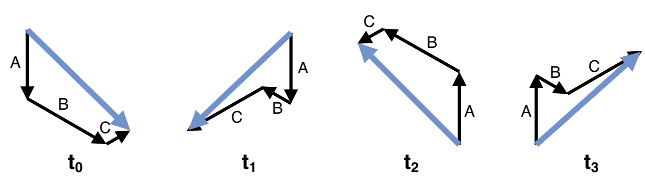
To determine the windings' magnetic fields at t_0, t_1, t_2, and t_3, we need to find their voltages at these times for each of the three phases. With the maximum voltage set equal to 1, these values are listed in Table 6.1.

Table 6.1 Voltages in Three-Phase Power

	A	B	C
t_0	0.738	–0.952	0.286
t_1	0.738	0.357	–0.976
t_2	–0.762	0.952	–0.310
t_3	–0.738	–0.381	1.0

We can visualize the relative magnetic field produced by each winding by drawing an arrow whose direction is determined by the winding's orientation (0° for A, 120° for B, or 240° for C) and whose length is determined by the winding's voltage. Figure 6.5 depicts these arrows at times t_0, t_1, t_2, and t_3.

Figure 6.5
Magnetic fields at times t_0, t_1, t_2, and t_3



The small arrows represent the field of each winding, and the large gray arrow represents the total magnetic field at the given time. This total field is obtained by arranging the small arrows in sequence. That is, Arrow B starts at the endpoint of Arrow A, and Arrow C starts at the end of Arrow B.

Figure 6.6 presents the same three-phase, two-pole stator as in Figure 6.3, but shows how the magnetic field behaves from t_0 to t_4. The field's direction changes over time, but its strength (represented by the length of the arrow) remains constant.

As depicted in this figure, the magnetic field performs a complete rotation for each cycle of the incoming three-phase power.