People use electromagnetic (EM) clutches and brakes every day and often don’t realize it. Anyone who switches on a lawn tractor, copy machine, or car air conditioner may be using an EM clutch — and EM brakes are just as common.

Electromagnetic clutches operate electrically but transmit torque mechanically. Engineers once referred to them as electromechanical clutches. Over the years EM came to stand for electromagnetic, referring to the way the units actuate, but their basic operation has not changed.

Electromagnetic clutches and brakes come in many forms, including tooth, multiple disc, hysteresis, and magnetic particle. However, the most widely used version is the single-face design.

Elements of EM

Both EM clutches and brakes share basic structural components: a coil in a shell, also referred to as a field; a hub; and an armature. A clutch also has a rotor, which connects to the moving part of the machine, such as a driveshaft.

The coil shell is usually carbon steel, which combines strength with magnetic properties. Copper wire forms the coil, although sometimes aluminum is used. A bobbin or epoxy adhesive holds the coil in the shell.

Activating the unit’s electric circuit energizes the coil. The current running through the coil generates a magnetic field. When magnetic flux overcomes the air gap between the armature and field, magnetic attraction pulls the armature — which connects to the hub — into contact with the rotor.

Magnetic and friction forces accelerate the armature and hub to match rotor speed. The rotor and armature slip past each other for the first 0.02 to 1.0 sec until the input and output speeds are the same. The matching of speeds is sometimes called 100% lockup.

Brakes lack a rotor, so magnetic flux acts directly between the armature and
The field usually bolts to the machine frame or on a torque arm that handles brake torque. When the armature contacts the field, braking torque transfers into the field housing and machine frame, decelerating the load. As in a clutch, speed changes quickly.

Most industrial applications use single-flux, two-pole clutches. These have one north-south flux path between the rotor and armature. However, mobile clutches and other specialty electromagnetics clutches can use a double or triple-flux rotor. These clutches have slots in both the rotor and armature that create additional air gaps between the two parts. These curved slots run parallel to the rotor or armature circumference, so they are often called banana slots.

Taking the path of least resistance, magnetic flux springs between the rotor and armature two or three times when the faces engage. This weaves produces multiple north-south pole pairs. Each pair can increase the torque in a clutch.

In theory, an additional set of poles at the same diameter as the first set would double the operating torque. In practice, however, each addition shrinks the diameter of all contact points. The serpentine path the magnetic flux takes also diminishes the available flux. But a double-flux design pushes up torque to 30 to 50%, and a triple-flux design can bring a 40 to 90% torque boost over a single-flux unit.

The ability to increase torque without a heavier or larger clutch is especially important in weight-sensitive applications, especially when the faces engage. This weaving produces multiple friction points on the mating faces. These cycles — 20 to over 100 of them, depending on the amount of torque required — should be short enough that they do not overheat the coil.

**All torque up**

So how much torque will a given brake or clutch supply? The main factor affecting the torque rating of a clutch or brake is the combination of voltage and current. The field of EM clutches and brakes can be constructed for almost any dc voltage. The torque the unit produces will be the same as long as it is supplied with the correct operating voltage and current.

Electrical current controls the change in magnetic field strength, $dl$, as shown by:

$$dl = rac{μI}{(4/π) \times \sin (a)^2}$$

where $I = \text{net current}$, $r = \text{displacement vector from the coil to the fluid}$, $μ = \text{magnetic permeability}$ of the fluid, $a = \text{angle between the vector and a current element}$, and $dl = \text{magnetic moment of the dipole}$.

Designers must also distinguish between the clutch or brake’s dynamic and static-torque ratings. Applications with relatively low rotational speed — 5 to 50 rpm depending upon the unit’s size — need not consider dynamic torque. The static torque rating is usually closest to the application’s conditions.

However, a designer specifying a clutch or brake for a machine that runs at 3,000 rpm must determine the unit’s dynamic torque. Almost all manufacturers list products by static-torque rating, but dynamic torque can be less than half the static rating. Most manufacturers publish torque curves showing the relationship between dynamic and static torque for a given series of clutch or brake. (A sample curve is shown in the accompanying graphic.)

**Timely torque**

Torque is probably the designer’s first consideration when specifying EM clutches or brakes, but engagement time is important, too. There are actually two engagement times. The first is the time it takes the coil to develop a magnetic field strong enough to pull in the armature. The second, the time-speed or time-to-stop for clutches and brakes, respectively, relates to the unit’s inertia.

Inertia depends on the mass and geometry of the rotating system. Web sites like inertia-calc.com can help designers determine a system’s inertia and the torque needed to accelerate or decelerate that load in a given time.

Most CAD systems can calculate component inertia, but the key to sizing clutches is calculating how much inertia is reflected back to the clutch or brake. To do this, engineers use the formula:

$$T = \frac{(W2 \times \Delta N)}{308 \times t}$$

where $T = \text{required torque (lb-ft)}$, $W2 = \text{total inertia (lb-ft)}$, $\Delta N = \text{change in rotational speed (rpm)}$, and $t = \text{time during which the acceleration or deceleration must take place}$. The inertia term accounts for rotational considerations, where $V$ is the velocity, $W$ is the weight, and $r$ is the radius of gyration ($r = \text{component\’s weights} \times \text{radius of gyration} / \text{component\’s weights}$).

Designers sizing a clutch or brake must first determine this inertia to calculate how much torque the unit can handle. Compared to inertial considerations, the time needed to develop a sufficient magnetic field to actuate the brake or clutch is short.

**Magnetic field strength**

Magnetic field strength depends on the number of turns in the coil. The air gap between the armature and clutch rotor or brake face is a resistance the magnetic field must overcome. Magnetic lines of flux diminish quickly in air, so the greater the gap, the longer it takes the armature to develop enough magnetic attraction.

High-cycle applications often use floating armatures that rest against the rotor or brake face, making the air gap zero. With zero air gap, the voltage required to actuate a small clutch or brake will be higher than in a fixed-armature design. The time to engage a small clutch or brake will be less than that required for a fixed-armature design.

In fixed-armature designs, engineers must consider the air gap in new units as well as the gap in the future as contact surfaces wear and the gap grows. In high-cycle applications where accuracy is important, even a difference of 10 to 15 msc can affect performance. And in normal-cycle applications, a new machine with accurate timing can eventually actuate with $t = 1$ msc due to wear.

Consider a cut-to-length application where a photo-eye reads a mark on the material to determine where to stop the machine. These cycles — 20 to over 100 of them, depending on the amount of torque required — should be lower in inertia, speed, or both, than the end application.

For some designs, like bearing-mounted clutches with the same armature connected and held in place by a bearing, users can complete the burningish on a bench top or burningish station instead of on the machine. On the other hand, two-piece clutches or brakes, which have separate armatures, burnish better after installation. That’s because armature alignment and, hence, burningish lines can shift slightly when the unit moves.

**The benefits of burningish**

Although armatures, rotors, and brake faces are machined or even lapped as flat as possible at manufacture, peaks and valleys remain on the surfaces. When a new clutch or brake engages, the contact area is initially compensated for the mating surfaces. This smaller contact area means torque can be as much as 50% less than the unit’s static torque rating.

To get the full torque, users need to burnish mating surfaces. Burningish cycles the unit, letting those initial peaks wear down so there is more surface contact between the mating faces. These cycles — 20 to over 100 of them, depending on the amount of torque required — should be lower in inertia, speed, or both, than the end application.

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To find the best alignment shifts may produce small torque reductions that would only be noticed in torque-sensing applications. Other applications may not need burningish at all.
Flexible flux
Coil
Rotor
Armature
Banana slots

If the system needs less torque than the clutch or brake provides out of the box, users can skip the burnishing step. In general, burnishing is more critical on higher torque devices.

**How long does it last?**

Normal operations wear down contact surfaces, just as burnishing does. Every time a clutch or brake engages during rotation, a certain amount of energy is transferred as heat. This transfer wears both the armature and the opposing contact surface.

Wear rates depend on size, speed, and inertia. For example, if workers changed pulleys on a machine from 1:1 to 2:1 so that it ran at 1,000 rpm instead of its previous speed of 500 rpm, the change would quadruple its clutch’s wear rate. That’s because reflected inertia increases with the square of the speed ratio. That is:

\[
(\frac{WK^2}{r})r = WK^2 \times \Delta N^2.
\]

In such situations, a fixed armature stops engaging when the air gap gets too large for the magnetic field to overcome. Zero-gap or auto-wear armatures can wear to less than one-half of their original thickness before failing.

Designers can estimate life from the energy transferred each time the brake or clutch engages.

\[
E_e = \frac{m \times v^2 \times \tau_f}{182 \times (\tau_f + \tau_l)}
\]

where \(E_e\) = energy per engagement, \(m\) = inertia, \(v\) = speed, \(\tau_f\) = dynamic torque, and \(\tau_l\) = load torque. Knowing the energy per engagement lets designers calculate the number of engagement cycles the clutch or brake will last:

\[
L = \frac{V}{(E_e \times w)}
\]

where \(L\) = unit life in number of cycles, \(V\) = total engagement area, and \(w\) = wear rate.

Clutches subject to low speed, low side loads, or infrequent operation often use bushings on rotating parts. Although less expensive than bearings, bushings tend to fail before the air gap grows to the point of failure. At higher loads and speeds, bearing-mounted fields, rotors, and hubs are better options. Unless bearings are stressed beyond their physical limitations or become contaminated, they tend to have a long life and are usually the next area to fail after the air gap.

It is rare for a coil to stop working in an EM clutch or brake. Coil failures are usually due to heat-induced breakdown of the coil-wire’s insulation. Causes include high ambient temperature, high cycle rates, excessive slipping between the armature and contact surface, and the application of higher voltage than the coil rating permits.

**Figuring on friction**

The torque between an armature and clutch rotor or brake field is derived from the steel-to-steel coefficient of friction and magnetic force, but most industrial designs add friction material to change torque or wear characteristics.

The friction material is recessed between the inner and outer poles in both brakes and clutches. This ensures magnetic metal-to-metal contact between the armature and coil shell or rotor but expands the contact surface area. The larger area slows wear and extends cycle life. In some applications, materials such as ceramics have greatly extended life in clutches and brakes to 25 or 50 million cycles.

Clutches in automobiles, agricultural equipment, and construction gear tend not to use friction material because they have lower cycle requirements than industrial clutches. In addition, mobile equipment is often exposed to wet weather that can swell friction materials and cut available torque.

While most friction materials primarily slow wear, they can also be used to alter the relatively high coefficient of friction of steel-to-steel contact. An engineer who needs a clutch or brake with extended slip time might specify a material with a lower coefficient of friction. Conversely, for slightly higher torque, common in low-rpm applications, designers might use high-coefficient-of-friction materials such as cork.

No matter what material designers choose, the wearing action creates particulates. Where particulates are problematic, such as in clean-room and food-handling applications, units should be enclosed to keep particles from contaminating the surroundings.

However, a more-common scenario is that the clutch or brake becomes contaminated by something in the environment. Oil or grease should be kept away from clutches or brakes because they reduce friction between contact surfaces, lowering available torque. The same is true for oil mists and airborne lubricant particles in the work area.

Dust and other contaminants that fall between contact surfaces can also reduce torque. Designers who know their clutch or brake will be in a contaminant-prone environment may choose to add a shield to protect contact surfaces.

Clutches and brakes that have not been used in a while can rust on the contact surfaces. This is generally not a major concern because the rust wears away within a few cycles, leaving no lasting impact on torque. **MD**