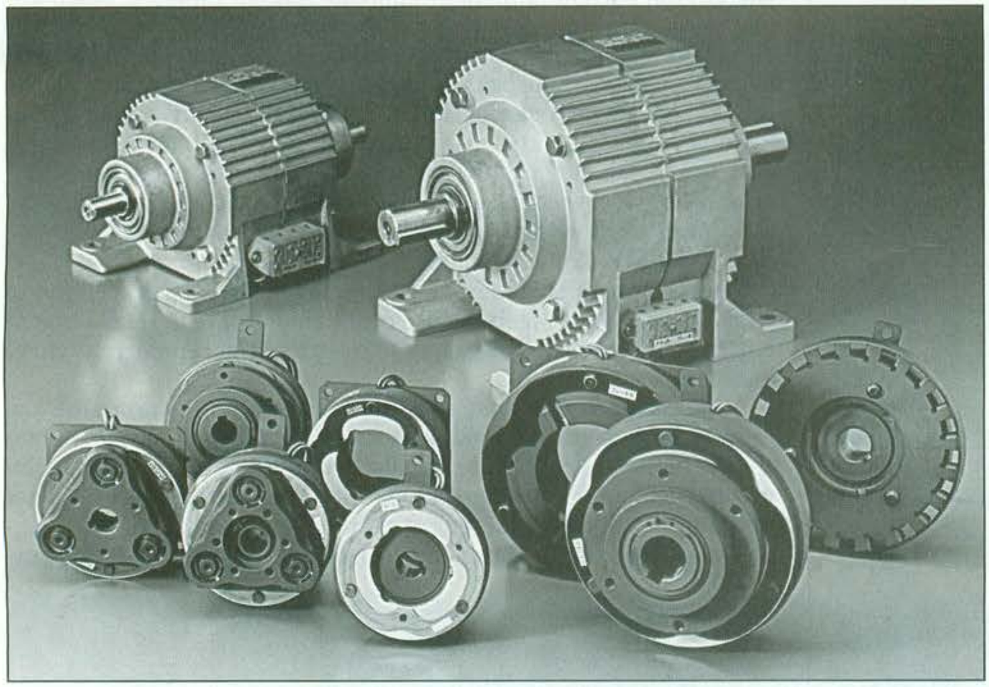
GETTING A GRIP ON CLUTCH AND BRAKE SELECTION



Learn the basic steps for picking the best clutch or brake instead of waiting to learn them when a component fails.

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Tell a junior engineer to pick an electromagnetic friction clutch for a new application and all you may get is a look of confusion. But choosing the right clutch is easier than most people think. And the same simple steps that apply to picking a clutch can just as easily be applied to brake selection. Once designers learn these steps, they can save time and money up front and end up with the right component for the job.

Electromagnetic friction clutches (EMFC) are used to control rotary motion without shutting down a motor, such as in automobiles, copiers, packaging equipment, and machine tools. Although these clutches are found everywhere, few engineers learn anything about them in college. It is only when designers face a specific problem in controlling rotary motion that EMFCs come to mind. Then the task of selecting and specifying the right unit begins.

KEY DESIGN FACTORS

Fortunately there are only a few steps involved in clutch selection. One of them is determining what response time is needed. In fact, the majority of calls from designers in search of a clutch start with the question, "What is the response time of a unit with X lb-ft torque at Y rpm?" When designers talk about response time, they typically mean how long it takes a clutch to bring the load to a certain speed.

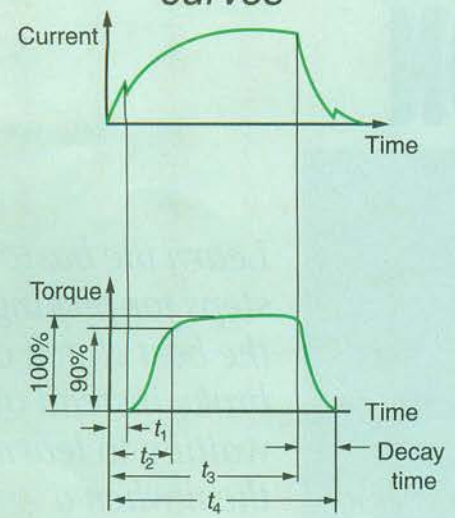
Clutch makers generally quote response times for *unloaded* clutches. The response times for unloaded clutches, however, are important only for evaluation purposes. *Actual* response times depend on the inertia of the load that the clutch "sees" and the required load speed. You can use clutch manufacturers' quoted response times to make initial ball-park selections, then make more specific calculations to determine whether or not the clutch meets your requirements.

There are several ways to optimize response times. For instance, always switch coil current on the dc side of your power supply. This eliminates time delays associated with filtering networks in the ac section of the coil's power-supply circuitry.

Cycle of operation must also be considered. A clutch cycle can roughly be separated into four

You can find related information at: http://www.machinedesign.com/bde/mechanical/index.html/bde/mechanical/driveline/clutch.html

Current and torque curves



These graphs show two curves drawn to the same time scale. The curves represent clutch-torque buildup time and coil-current buildup time.

time segments with variations in the coil current marking the boundaries of each segment. If you graph torque and coil current versus time, you get a set of curves similar to the ones displayed in *Current and torque curves*. As the curves show, the clutch torque follows a path corresponding to the coil-current path.

Coil-current buildup begins the instant you turn on the coil current, at t_0. During initial current buildup the torque will remain at zero while the armature travels toward the rotor. Designers can shorten coil-current buildup by applying spiking voltages, which are increased initial voltages applied to the coil.

Spiking voltages can cut response times in half and may also allow using a smaller, less-expensive clutch. This is because startup places the highest demand on the clutch. Spiking gives clutches an initial burst of power to get the load moving. Although spiking voltages are typically three times a clutch's rated value, the coil is not damaged because overvoltages only last for short time periods. After startup the clutch can work within its rated limits. Without spiking, a bigger clutch would be required to move the load from rest.

Pull-in time, denoted as t_1, is the time it takes for the clutch to close the air gap between the armature and rotor. After coil-current buildup, the armature contacts the rotor and the coil-current curve dips slightly at t_1.

Time-to-speed response time occurs at t_2. After the armature and rotor surfaces mate at t_1, both coil current and torque continue to increase. Torque reaches 90% of its full-rated value (at time t_2) and continues to rise to full torque. Most users call t_2 the time-to-speed response time because the load is rotating at nearly the speed of the rotor.

Decay time begins the moment current is turned off (t_3). Coil cur-

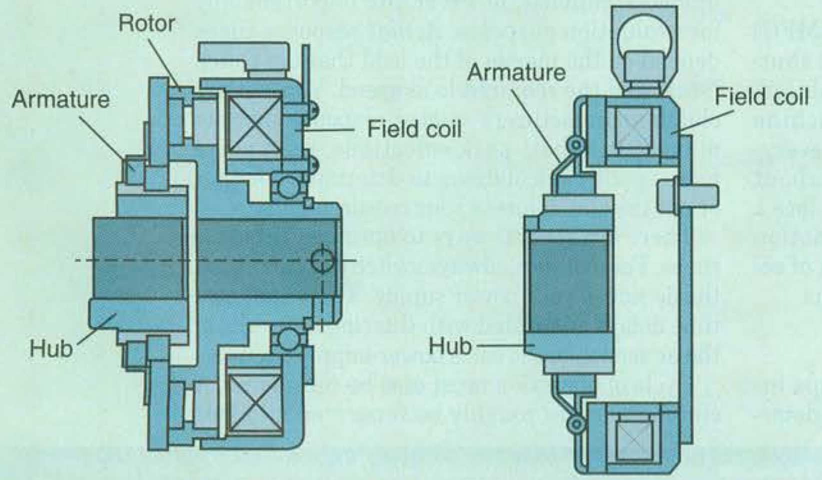
THE ABCs OF CLUTCHES

The basic EMFC with a single-plate friction surface has three main parts, an armature, rotor, and field coil. The armature and rotor-mating faces are covered with friction material and separated by a small air gap. The rotor is usually mounted on an input, or prime mover, shaft while the armature is mounted to a hub on an output, or load, shaft. In most applications, the rotor constantly rotates. A basic brake is similar to a clutch but the armature rotates with the load.

In a clutch, the rotor body is magnetized whenever an electric current is applied to the field coil. The magnetic field pulls the armature against the rotor and the mating surfaces meet, producing friction. The output shaft begins spinning and quickly accelerates to match the rotor speed. A properly sized EMFC is 100% efficient, meaning it transmits all the prime mover's torque to the load. The armature and rotor essentially become one assembly after engagement, without any slippage.

Turning off current to the field coil disengages the clutch and the armature is no longer held against the rotor. In most designs, springs hold the armature away from the rotor surface when coil power is turned off. This maintains a small air gap. When electric current is applied to a brake coil, the armature contacts a stationary plate and the load stops.

Components of a basic electromagnetic friction clutch



rent and torque begin to decrease, with torque reaching zero at t_4. Decay time is the time required for torque to reach zero after coil current is turned off ($t_4 - t_3$).

In cycling applications the decay time becomes important (in addition to response time) because it is a part of the overall cycle. After optimizing response time, designers can shorten decay times by providing a convenient path for the coil current to dissipate after turning the coil off.

SELECTING A CLUTCH

Consider a common problem of cutting web-fed material as shown in the sketch at below. The motor is running the shaft at 500 rpm using a clutch. The clutch and brake are mounted on the same shaft and cycle at a relatively high rate of 100 milliseconds (0.1 sec). System inertia seen by either the clutch or brake is the same.

To calculate the required clutch and brake torque, first compute the total system inertia as seen by the clutch and brake. The accompanying table summarizes the parameters of the inertia components in the system.

We can determine the main drive shaft inertia using:

$$w_k^2 = 0.000681\rho LD^4$$
$$= (0.000681)(0.269)(14)(0.5)^4$$
$$= 0.00016 \text{ lb-ft}^2$$

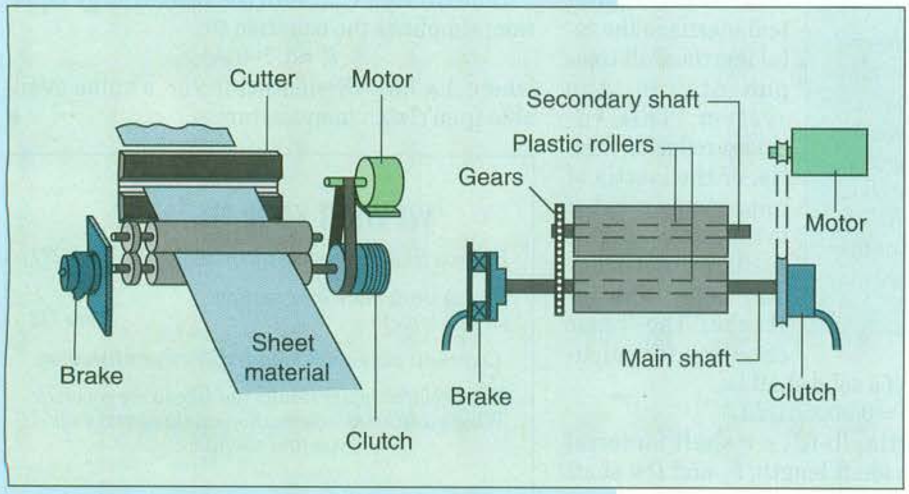
Calculations for the remaining components produce the following values:

Secondary shaft inertia = 0.000083 lb-ft^2
Gear inertias = 0.0077 lb-ft^2
Roller inertias = 0.013 lb-ft^2

Thus, total system inertia is 0.042 lb-ft^2. Directly obtain the required torque as follows:

$$T = (w_k^2 {}_s\Delta_s)/308t$$
$$= [(0.042)(500)] / [(308)(0.1)]$$
$$= 6.81 \text{ lb-ft}$$

A quick look in a manufacturer's catalog will locate a clutch and brake to handle this torque. In the Ogura catalog, for instance, a VCEH-1.2 clutch and VBEH-1.2 brake, both rated at 10.8 lb-ft, can do the job.



System inertia data

COMPONENT	DESCRIPTION
Main clutch/brake shaft	14-in. long × 0.5-in. diameter, steel
Secondary roll shaft	7-in. long × 0.5 diameter, steel
Gear on main shaft	3-in. diameter × 0.5-in. wide × 0.5-in. bore
Gear on secondary shaft	Same as gear on main shaft
Roller on main shaft	3-in. diameter × 6-in. long × 0.5-in. bore
Roller on secondary shaft	Same as roller on main shaft

CLUTCH EQUATIONS

The function of a clutch is to transmit torque without slippage, which occurs when the clutch doesn't completely carry the load it's trying to move. Slippage shortens the life of clutches. Thus, any clutch being considered must be able to transmit the required torque. To check for this, designers can use:

$$T = (5{,}252hK)/n$$

where T = torque, lb-ft; h = horsepower; K = service, or safety, factor; and n = speed, rpm.

The value of K usually falls between 1.5 and 3, depending on how light or heavy the application is. Light applications typically do not require full-rated torque during acceleration and, therefore, can accept lower K values than heavy applications. Machine tools, for instance, are considered light duty because they do

SURFING FOR A CLUTCH

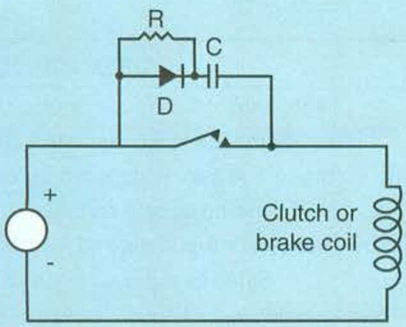
The equations derived in this article offer a starting point in a typical clutch or brake selection procedure. The Internet provides a wealth of information to the arsenal of product selection tools. Unlike printed catalogs that can become obsolete the minute they are printed, information on the Web can be constantly updated.

Clutch and brake manufacturers often classify their products in several ways, such as by application, type, or function. And each clutch or brake has a variety of sizes, mounting arrangements, and other parameters. It should be clear that a thorough study, including a visit to a Web site, must be the first step in selecting a clutch or brake. In fact, examining a Web site or catalog may give designers new ideas to solve their problem.

Let's assume your in-house clutch and brake expert has examined a few catalogs, magazine articles, Web sites, and even visited potential vendors. What's next?

Now is the time to go through some calculations and take additional advantage of the Internet. The Ogura Web site (www.ogura-clutch.com) provides several online calculators, including those that convert units or calculate moments of inertia and torque. To use these, simply plug in your numbers and print out the answer. Or better yet, flow charts let users select the right components by simply clicking suitable choices.

Shorter decay times



This circuit shortens decay time. When the coil is turned off, the current continues to flow and goes into the capacitor extremely fast. This is because the only resistance the current "sees" in its path is the small dc resistance of the coil and the smaller forward resistance of the diode. The value of the resistor connected in parallel with the diode is much higher than that of the diode's forward resistance so current flows into the diode and dissipates quickly.

not use full torque at the cutter until it reaches full speed. Conveyor belts, on the other hand, need full torque during acceleration and thus fall into the heavy-duty category.

The next step, calculating the system inertia, is fundamental to clutch and brake selection. System inertia is the total inertia of all components in the system. This includes reflected inertia, or the inertia of components coupled to the motor, such as shafts, gears, chains, and belts. For instance, the basic equation for calculating the inertia of a solid shaft is:

$$w_k^2 = 0.000681\rho L D^4$$

where w_k^2 = inertia, lb-ft^2; ρ = shaft material density, lb/ft^3; L = shaft length, ft; and D = shaft diameter, ft.

The inertia of a hollow shaft can be calculated by treating the shaft as solid and subtracting the inertia of the hollow portion.

The reflected inertia of the load is:

$$w_k{}^2{}_R = w_k{}^2{}_L / r^2$$

where $w_k{}^2{}_R$ = reflected inertia, lb-ft^2; $w_k{}^2{}_L$ = load inertia, lb-ft^2; and r = speed ratio.

If system inertia is known, the required torque is obtained from:

$$T = [(w_k{}^2{}_s)\Delta_s] / 308t$$

where T = torque, lb-ft; $w_k{}^2{}_s$= system inertia, lb-ft^2; Δ_s = change in speed or rpm; and t = time to speed (for clutch) or time to stop (for brake).

Finally, designers should make sure the clutch will dissipate heat quickly enough. Any clutch-application engineer will tell you that too much heat can fry clutches and brakes. In other words, a typical clutch or brake would last a long time if it were not subjected to excessive energy per cycle, which is typically due to an improperly sized clutch or brake.

Heat considerations are especially important in start-stop, or cycling, applications because slippage occurs every time the clutch engages. The amount of heat generated during acceleration and deceleration can be calculated from:

$$E = 1.7 w_k{}^2{}_s C (N/100)^2$$

where E = heat energy, lb-ft/min; lb-ft^2; C = number of starts or stops per minute, or cycling rate; and N = rotational speed, rpm.

Manufacturers provide curves to determine whether or not a clutch can perform its job based on heat dissipation. To use these curves, calculate the amount of generated heat, or heat energy, from the previous equation and, using the speed of the load and the selected unit, check whether or not the clutch meets the requirements.

The heat-energy equation can also be rearranged to determine the maximum number of cycles that can be produced by a clutch:

$$C_{max} = (40A / w_k{}^2{}_s)(100/N^2)$$

Substituting C_{max} into the heat-energy equation, simplifies the equation to:

$$E = 1.7(40A)$$

where A = heat-dissipation factor, a value available from clutch manufacturers. ■

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