

## Selecting and Applying Clutches and Brakes for Optimal Performance and Long Service Life

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Clutches and brakes are widely used to transfer rotary motion from one shaft to another. In the case of a clutch, the torque is transferred to an inline or parallel shaft. In the case of a brake, the torque is transferred from a rotating shaft to a motor flange or ground to stop or hold the shaft.

The two most widely used types of clutches and brakes are wrap spring and electromagnetic friction. Each has unique specifications that make one type more suitable for a specific application than the other. Clutches and brakes come in a variety of sizes, ranging in torque and speed from 3 to 5000 lb-in and 150 to over 20,000 rpm. Their specifications are spread over four modes of operation: start, index, slip and hold. The start and slip modes are rated exclusively for clutches, the hold mode for brakes and the index mode for both clutches and brakes.

### **Wrap spring clutches and brakes**

Wrap spring clutches and brakes are composed of three basic parts, an input hub, a wrap or coil spring and an output hub. They transmit torque through the interference between the wrap spring internal diameter and the outside diameters of the input and output hubs.

Wrap spring clutches and brakes excel in torque capacity, low power, positive engagement, stopping accuracy and choice of pneumatic or mechanical actuation. They are the best choice for single revolution operation and are equal to electromechanical clutches and brakes for rapid cycling capability. The primary limiting characteristics are uni-directional operation and speeds that are limited to about 1750 rpm. However, depending on the application and torque requirements wrap spring clutches and brakes can be designed for higher speeds.

### **Figure 1: Overrunning wrap spring clutch**

Wrap spring clutches come in overrunning, start-stop or random positioning and single revolution types. A fourth type is the clutch brake combination which uses two wrap springs. In the basic form of an overrunning clutch, when the input hub rotates, the spring wraps down to engage the two hubs. When the input stops or reverses, the spring unwraps to release the output hub and allows the load to overrun. These clutches also can be used for one-way indexing and backstopping.

The overrunning clutch may be modified to become a start-stop clutch by adding a control tang to the spring. The tang is used to engage and disengage the load by locking into position with the stop collar. When the tang is disengaged, the load coasts freely from the continuously running input.

A single revolution clutch can be made by securing a second tang to the output hub. When the control tang engages, the output hub cannot overrun because it is secured to the spring. Most single revolution clutches can stop only about 10% of their load capacity.

### Figure 2: Wrap spring clutch brake

Wrap spring clutch brake combinations use two control tangs to hold open the clutch or brake spring. When the clutch and brake control tangs rotate with the input hub, the clutch spring positively engages the input hub and the output shaft. When the stop collar locks the brake control tang, the brake spring wraps down to engage the output shaft to the stationary brake hub. Simultaneously, the clutch spring unwraps slightly and lets the input hub rotate freely.

When the load needs to come into synch rapidly, say, within a predictable time or travel, the wrap spring clutch is a better choice. A friction device slips under certain conditions but a wrap spring clutch or brake will not slip after the spring wraps down and locks the input and output hubs together. When the slip mode is not appropriate for the application, a wrap spring device should be considered. Wrap spring devices are quite cost effective due to their simple construction. When used properly, they are maintenance free and do not require periodic parts replacement or lubrication. They are easy to install and have long service life.

The torque capacity of a spring wrap clutch or brake is a direct function of the diameter of the hub and the tensile strength of the spring. The wrap spring clutch or brake will supply torque demanded up to the mechanical limitations of the spring. When the drive spring is allowed to wrap down to grip the hubs, the output hub typically accelerates to the input rpm in 0.003 second. When the brake spring is activated it stops the output shaft in 0.0015 sec.

The torque demand on the wrap spring clutch equals the system frictional torque of the load plus the dynamic torque of acceleration. When approaching the stop position of the cycle, enough energy must be available in the rotating mass of the load to enable the spring to unwind the drive spring off of the input hub. This means that when there is a large frictional load or a torque demand when the load comes up to the top of a cam, sufficient energy must be available in the rotating mass to open the drive spring. Without sufficient energy, the input hub could wear excessively and generate noise.

The dynamic torque of acceleration or deceleration is proportional to the RPM multiplied by the load inertia and divided by the acceleration time. This fact indicates that spring clutches and brakes are inertia sensitive—the more inertia, the higher the dynamic torque. The torque

demand of the spring clutch is equal to the system frictional torque of the load plus the dynamic torque of acceleration.

### **Selecting wrap spring clutches and brakes**

Three basic steps are required to select wrap-spring clutch/brakes: determine the clutch/brake function, determine the clutch/brake size, and then verify the design considerations.

#### **Determine the required function**

Wrap-spring clutches and clutch brakes can perform three functions: overrunning, start-stop and single revolution. Determine the function that provides the best control for the application. Select the series that best fits the application requirements from the manufacturer's selection charts.

#### **Determine the size**

A quick way to select the correct clutch or clutch brake model is from a manufacturer's catalog is to consult an RPM vs. shaft diameter selection chart. Start with the shaft diameter in the bore size column and shaft speed expressed in RPM. Select the correct model from the clutch size model while staying within the gray area. If the diameter of the shaft is outside of the gray area for the desired RPM, and no particular requirement for the shaft diameter is specified, consider selecting a shaft that would fit the chart selection criterion. However if the shaft is required to be larger or smaller than the selection chart suggests, consult the clutch/brake manufacturer for a possible custom device.

#### **Torque Requirement**

The following calculations verify that the clutch has sufficient torque to start the load and the load and shaft have enough inertia to activate the stop spring of the clutch/brake. Calculate the inertia,  $WR^2$ , of all rotating components, such as shafts, drums, pulleys, and so forth. Consult a reference table listing inertia of steel shafting per inch of their length of thickness. For materials other than steel use conversion multipliers usually included with the listing. For hollow components, calculate the inertia of a solid component of the same outside diameter then calculate the inertia of the hollow area as if it were a shaft. Subtract the inertia of the hollow area from the solid inertia and multiply the per inch number by the length or thickness of the component.

Determine the preliminary clutch/brake torque requirement to perform the function:

Overrunning and Random Start Stop

$$T = (WR^2 \times S)/(3700 \times t) - T_f$$

Where:

T = torque required to wrap down the spring, in.-lb

$WR^2$  = Load inertia determined above, lb-in.<sup>2</sup>

S = Shaft speed at clutch/brake, RPM

t = time to disengage (0.003 s for clutch), seconds

T<sub>f</sub> = friction torque (torque required to overcome static friction), in.-lb

For Model S – Single Revolution and Clutch Brakes

Consult the detailed product specifications and verify that the selected clutch/brake model exceeds the torque requirements. From the same specification, find the unit inertia (inertia of the rotating component of the selected clutch/brake) and calculate the torque requirement more accurately by adding it to the load inertia.

$$T_t = [(WR^2_{LOAD} + WR^2_{UNIT})S]/(3700 \times t) - T_f$$

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Where:

T<sub>t</sub> = total system torque, in.-lb

WR<sup>2</sup><sub>LOAD</sub> = load inertia, lb –in.<sup>2</sup>

WR<sup>2</sup><sub>UNIT</sub> = clutch/brake inertia, lb-in.<sup>2</sup>

S = shaft speed, RPM

T<sub>f</sub> = friction torque, in.-lb

T = .0015 for brake

#### Minimum Inertia

The second aspect to verify is whether the load has enough inertia to fully engage the stop brake spring and disengage the clutch spring in order to accurately stop the load. The minimum inertia can be found as follows:

$$I = [(t) (T_c + T_o) (3700)]/S - I_c$$

Where:

I = minimum inertia required to fully engage the stop spring and disengage the clutch spring, lb-in.<sup>2</sup>

t = time, seconds (see catalog factory chart for values)

T<sub>c</sub> = torque specified to activate the selected clutch/brake, in.-lb

T<sub>o</sub> = drag torque, in.-lb S = shaft speed, RPM

I<sub>c</sub> = inertia of the clutch/brake output side, lb-in.<sup>2</sup>

If the result is zero or negative, the overall system has enough inertia for stopping within the specified accuracy. When the result is positive, the springs will not wrap down and release properly. Additional inertia equal to or greater than the calculated minimum inertia should be added to the system. Use the equation below to determine the maximum load inertia that a given clutch/brake model can handle without excessive wear or failure:

### Maximum Inertia

$$WR^2 = (T \times 3700 \times t)/S$$

Where:

T = clutch/brake torque, in.-lb

t = 0.0015 seconds

S = speed, RPM

### Verify the design considerations

Manufacturers' data sheets and catalogs provide a detailed list of options to help build a complete product part number. In order to fully specify the clutch/brake, review the design considerations and make selections. Choose clockwise or counter clockwise direction of rotation, and then select the stop collar. Stop collars with one or more stops (up to 24) sets either full or fractional rotation. Next, select the bore size. Finally, choose from the available activation methods, usually AC or DC solenoids (optional pneumatic).

### Electromagnetic friction clutches and brakes

#### Figure 3: Electromagnetic friction clutch

An electromagnetic friction clutch or brake has an input, typically a motor, connected to an input rotor-shaft assembly bore and a load connected to the armature of the clutch with a pulley or gear. In the power-on version of the electromagnetic clutch or brake, when the coil is not energized, a spring within the armature assembly separates the armature assembly from the input rotor shaft so the armature assembly does not rotate. When the coil is energized it attracts the armature plate which engages with the rotor assembly and drives the load.

#### Figure 4: Power-on electromagnetic brake

A power-on electromagnetic brake operates using the same principle as the clutch, but with only a single rotating component, the armature assembly. The brake is generally positioned on the load shaft with the armature assembly secured to the shaft while the field assembly is mounted to a non-rotating component or bulkhead. Until the coil is energized, the armature assembly will rotate freely. Upon energization, the field assembly becomes an electromagnet, attracting the armature plate, thus braking the load.

#### Figure 5: Power-off electromagnetic spring-set brake

A power-off electromagnetic spring-set brake operates on a slightly different principle. The actual braking force is applied by the use of compression springs within the field assembly. In normal power-off mode these springs apply pressure to the fixed armature plate which in-turn applies pressure to the rotor. This rotor has the ability to "float" back and forth when power or voltage is supplied. It is coupled to the load shaft by a spline or hex through a hub. Some

rotors are suspended between two diaphragm-like springs to achieve the “floating” state for “zero backlash” applications.

Electromagnetic friction clutches and brakes excel in random stop/start, power-on and power-off braking, soft start/stop, bi-directional rotation, and speeds exceeding 1750 rpm. Motion systems that require a soft start normally use electromagnetic friction clutches since the friction can be gradually reduced or increased by varying the voltage across the coil.

### **Selecting electromagnetic friction clutches or brakes**

#### **Static brake applications**

Determine if the application requires a static (holding) or a dynamic (stopping) brake. For static brake applications, determine the required static torque to hold the load under worst-case conditions, including system drag. Select a brake model from the manufacturer catalog with a static torque rating greater than the required torque. Verify that the selected brake fits into the available application envelope and mounting configuration.

#### **Dynamic brake applications**

For dynamic braking applications with a specific stopping time requirement, first calculate the dynamic torque (TD) necessary to decelerate the load using the inertia-time equation:

$$TD = (0.104(I\omega)/t) - D$$

Where:

I=total system inertia, lb-in.-sec<sup>2</sup>

$\omega$ = shaft speed. rpm

t=time to zero, sec

D=load drag, lb-in.

Multiply by 1.25 to convert to static torque.

When the inertia or engagement time of the clutch or brake initially selected represents more than 10% of the load inertia or acceleration time, use the inertia-time equation to solve for acceleration time. Use an inertia value equal to the sum of the load inertia and the clutch or brake inertia. Then verify that the sum of the acceleration and clutch or brake engagement time is still within the required acceleration time for the application.

For dynamic braking applications that require the ability to only stall a load, calculate the appropriate static torque ( $T_s$ ) using the horsepower-rpm equation:

$$T_s = (1.25)(63000)(PK)/\omega$$

Where:

P = horsepower, hp

K = service factor

$\omega$  = speed, rpm

Select a brake model from the manufacturer catalog with a static torque rating greater than the required torque. Verify that the selected brake fits into the available application envelope and mounting configuration.

### **Electromagnetic friction clutch selection**

For applications with a specific acceleration time requirement, first calculate the dynamic torque (TD) required to accelerate the load using the inertia-time equation:

$$TD = 0.104(I \omega)/t + D$$

Where:

I = rotational load inertia, lb-in.-sec<sup>2</sup>

$\omega$  = Differential slip speed, rpm

t = time to speed, sec

D = load drag torque reflected to the clutch, lb-in.

Convert to static torque by multiplying by 1.25

For applications requiring only the ability to accelerate a load, calculate the static torque using the horsepower-rpm equation:

$$Ts = (1.25)(63000)(Pk)/\omega$$

Where:

P = horsepower, hp

k = service factor

$\omega$  = differential slip speed, rpm

Select a clutch model from the manufacturer's catalog with a static torque rating greater than the required torque. Verify that the selected clutch fits into the available application envelope and mounting configuration.

When engaging a clutch dynamically, carefully consider the proper energy dissipation. Calculate the total energy dissipated per minute:

$$E = (E_k + E_s)N$$

Where:

$E_k$  = kinetic energy, ft-lb/min

$E_s$  = slip energy, ft-lb/min

N = cycle rate, cpm

If the total energy dissipation is more than allowable, then consider using a larger series clutch.

In some applications it may be necessary to consider clutch or brake inertia and engagement time in calculating load acceleration. If the inertia or engagement time of the clutch or brake selected represents more than 10% of the load inertia or acceleration time, use the above mentioned inertia-time equation to solve for acceleration time (t), using an inertia equivalent to the sum of the load inertia and the clutch or brake inertia. Then verify that the sum of the acceleration and clutch or brake engagement times is still within the required acceleration time for the application.

### Figure 6: Brake arm example

In some applications the brake must mount on an arm to keep a load from falling when the power is removed. Simply calculate the torque needed to hold the load the weight of the arm plus the load (force X distance). Add a service factor (multiply by 1.5), then select the appropriate brake.

### **Bidirectional no-back wrap spring brake design**

The bidirectional no-back (BDNB) design is for applications requiring automatic position holding and rotary driven capability. The BDNB design can be turned only when torque is applied to the input shaft. The input shaft may be driven either direction with torque being transmitted directly to the output shaft. When there is no torque on the input, the output shaft is locked and cannot be rotated in either direction. Any torque applied to the output shaft is transmitted directly to the clutch body and will not be reflected to the input.

### **Torque feedback device**

A critical consideration in moving to electronic steering is that operators are used to the tactile response, or “feel,” provided by both direct mechanical and hydraulic steering systems. A unique torque feedback device works much like a brake by using a magnetic actuation system to apply force to a friction disc that impinges upon a rotor. The friction disc utilizes an innovative material whose static-to-dynamic-friction performance is not subject to the slip-stick effect that in a conventional brake generates a higher level of friction when the shaft is stationary. The new material generates a consistent frictional force over its life and does not generate any frictional force when current is turned off. The torque feedback device also provides faster response to very small changes in current.

### **Conclusion**

A wide variety of motion control applications require brakes and clutches for holding, stopping, indexing, or releasing a mechanical load. Wrap spring or electromagnetic friction clutches and brakes are the optimal choice for the vast majority of cases. Clutches and brakes are selected to match dynamic and static characteristics including torque, speed, accuracy and other specifications. This article has provided basic selection and application information. In addition, clutch and brake manufacturers provide extensive technical assistance in selecting a clutch or brake for optimal performance and long service life.