

Top 12 Clutch & Brake Application Criteria

Take these into consideration early in the design cycle to save time/money and ensure proper performance.



Clutches and brakes are widely used to transfer rotary motion from one shaft to another or hold a load in place. It sounds simple, and all too often, the clutch or brake component is overlooked until later in the design cycle.

However, decades of experience demonstrate time and time again that taking clutch or brake considerations into account early on in the system design cycle can be a major contributor to meeting project budgets and scheduled targets. And, doing so will also ensure

that appropriate time and attention are provided to engineer the clutch or brake to the specific system requirements for best-fit maximum performance for the life of the unit.

As such, involving a clutch/brake expert, such as SEPAC, early in the design stage, will ensure that all necessary criteria are carefully thought through, planned and designed accordingly, and built to comply with the performance spec, budget and delivery schedule.

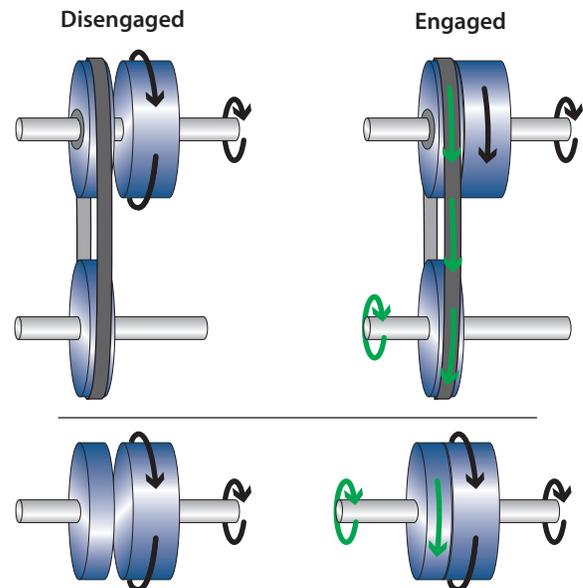
Top 12 Clutch & Brake Design Considerations

The following twelve most common criteria should all be taken into consideration for every clutch or brake design project. High-performance installations may involve additional application-specific criteria as well. Please contact us with any questions or concerns about any of these for your application. We can provide numerous alternative solutions if a “standard” solution is not sufficient.

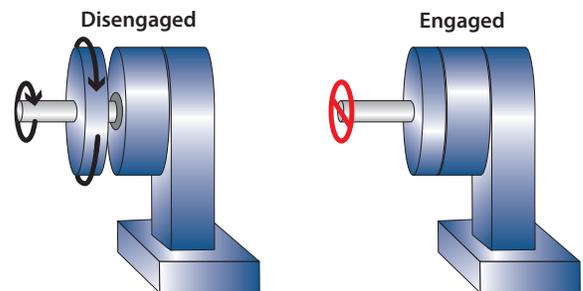
- Determine the function required for the application.**
- Evaluate voltage/current objectives.**
- Determine rotating inertia load.**
- Size the clutch or brake appropriately to the function: is it being used to stop/start or hold?**
- Confirm proper interface dimensions to ensure proper mounting and alignment.**
- Is heat self-generation an issue that needs to be addressed?**
- Is the “heat dissipation” capability of the unit (thermal capacity) sufficient for the specific application?**
- What is the response time of the clutch or brake unit, as well as other components in the system?**
- Does the application require burnishing or run-in before use?**
- Are any environmental effects at play with the unit in this particular application?**
- Is the life requirement of the system synchronized with that of the clutch or brake?**
- Look at the big picture: evaluate total cost versus price.**

1. Determine the Function Required for the Application

Does the application require a clutching action or a braking action? In the case of a clutch, the torque is transferred to an in-line or parallel shaft; in the case of a brake, the torque is transferred from a rotating shaft to a motor flange or ground in order to stop or hold the shaft.



A clutch is used when two rotating parts must be connected or disconnected to each other, whether two shafts in parallel or two in-line split shafts.



A brake is used when the load must be held statically, or stopped dynamically to a backstop, motor, or machine frame.

2. Evaluate the Voltage/Current Objectives

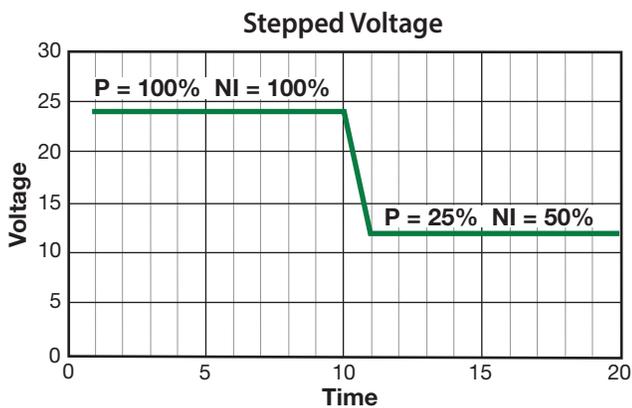
Whether it be a new electric car, a robot, an airplane, or just about anything else involving electricity, virtually every manufactured product today has a focus toward energy consumption/conservation.

Engineers are always looking for ways to save energy. With clutches and brakes there are many ways the current of the overall system can be reduced.

Over-Excitation or Stepped Voltage:

Full Voltage = Full Current = Full Magnetic Force

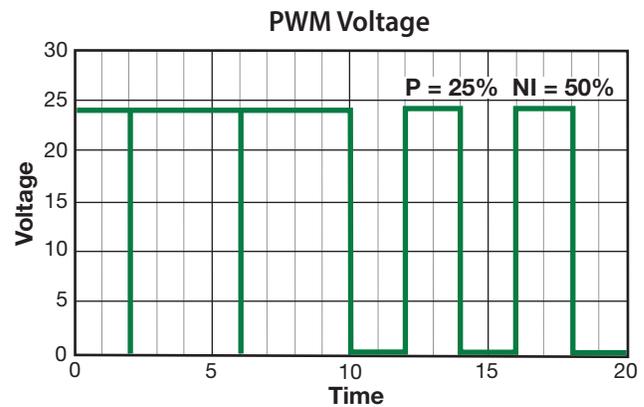
In many cases, such as a spring engaged brake (SEB Series), the full voltage or full current is only required for a very short period of time to dis-engage the brake. Once the brake is disengaged, it only requires about 25% of the power to remain disengaged.



In the case of a magnetically engaged or power on clutch or brake, an over-excitation is used to achieve a faster response time and higher torques for a short period of time. It's when a coil momentarily receives higher voltage until the load or drive is moved. Normally a standard clutch brake can withstand up to 4 times the current for a very short period of time (10-100 ms).

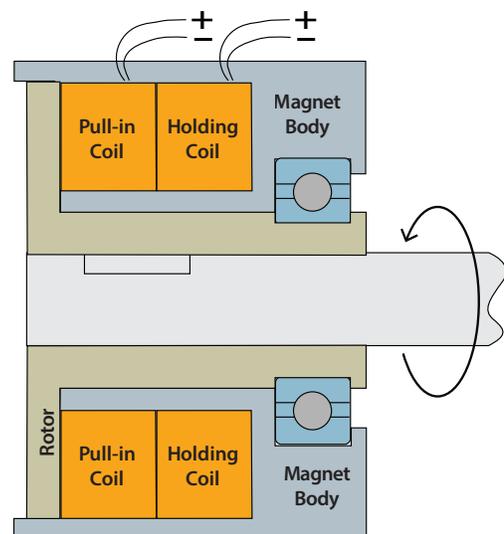
PWM (Pulse with modulation):

The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load. By using PWM after the initial voltage application, the power can be lowered to about 25% of full power and still operate the device with 50% NI (Enough to hold or drive steady state).



Dual Coils:

Using dual coils in a spring engaged Clutch or Brake will allow a high current "pull-in" coil to be used for a short period of time followed by a sustaining or holding coil. The holding coil only requires about 25% of the current used in the pull coil.

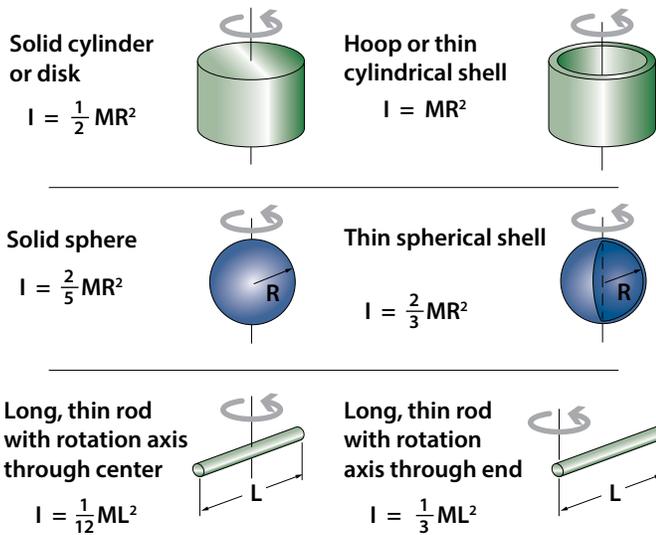


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3. Determine Rotating Moment of Inertia

When starting or stopping a load in a machine member, be aware of the total inertia of the system reflected back to the clutch or brake shaft to properly size the clutch and/or brake:

- Critical to the calculation is using the proper "Units of Measure" to define the correct torque required.
- Mass moments of inertia have units of dimension: mass × length². It is the rotational analogue to mass. NOTE: The axis of rotation is taken to be through the center of mass, unless otherwise specified.



Clutch or Brake 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-sec²
ω = 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

4. Are you Stopping/Starting or Holding?

Most spring engaged brake applications typically use a brake to hold equipment (shaft) in place when the motor or drive is de-energized, similar to using the parking brake on a car. When a car is in motion, brakes are applied (via the foot pedal), to slow down and stop the car (dynamic braking), as opposed to when the car is stopped, and the parking brake is applied (static braking).

With dynamic stopping or starting (apply brake/clutch while load is spinning, deceleration/acceleration of rotating machine members), the brake/clutch must absorb the kinetic energy built up by the inertial loads. In such instances the brake transfers that energy causing heat buildup and wear on the surfaces of the rotating components (friction discs, plates).

With static holding, all rotating components come to a rest and the brake/clutch when activated simply holds the load. As a result, there's little to no wear and no heat buildup. These are an ideal situation for a tooth clutch or brake.

There can be some dynamic engagement even in applications that need only a holding brake/clutch. Most spring engaged brakes or clutches are designed to absorb that energy. For example, if a brake responds in about 100 msec and motor response time is 20 msec, the brake can be dynamically engaged for 80 msec.

To size a brake/clutch for dynamic stopping or a clutch for starting, first estimate the torque needed to stop the system inertia within the available time (or chosen time). See the inertia section above. At this point the only known parameter is the load inertia. Later, once you've chosen a particular brake, you'll need to account for the inertia of the brake friction disc (or rotor), and hub. A general rule of thumb is to add 25% to the load inertia to estimate the brake rotor inertia.

The equations for dynamic starting or stopping (shown at left) are the same.

5. Check Alignment

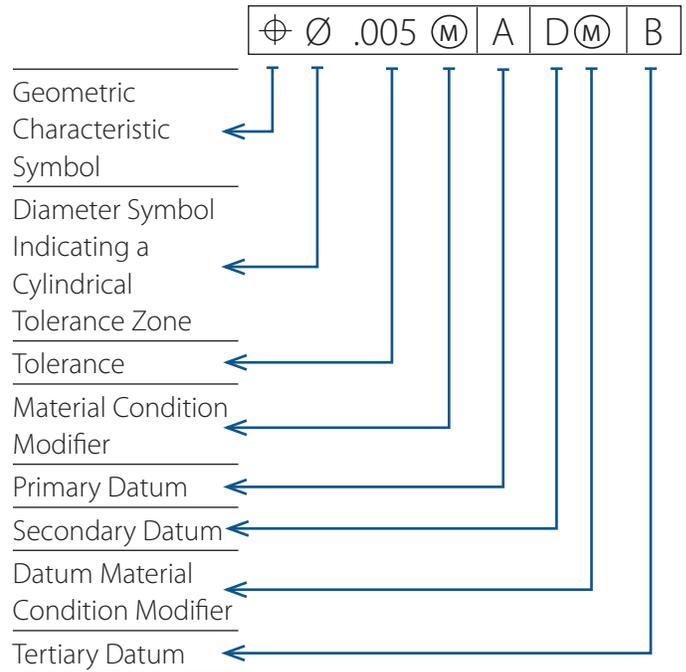
Concentricity, True Position, Run-Out

When installing a clutch or brake into a machine or piece of equipment, the alignment of the shaft to the rotating members of the clutch or brake is critical. Recalling geometric dimensioning and tolerances from high school and college classrooms, the symbols below are used to insure proper “fit”. The machined parts that interface with the clutch or brake need to be held to close tolerances.

With tooth clutches and brakes, the maximum allowable deviation is 0.003” to 0.005” total; for friction clutches and brakes, maximum deviation is 0.004”- 0.008”.

Misalignment of the shaft will cause poor performance or premature failure to the component or your machine.

Shaft End-play – Clutches and brakes that have fixed air gaps cannot handle any shaft end-play. Note that some motors have shaft movement, or end-play, sometimes up to 0.03” when the motor is powered.

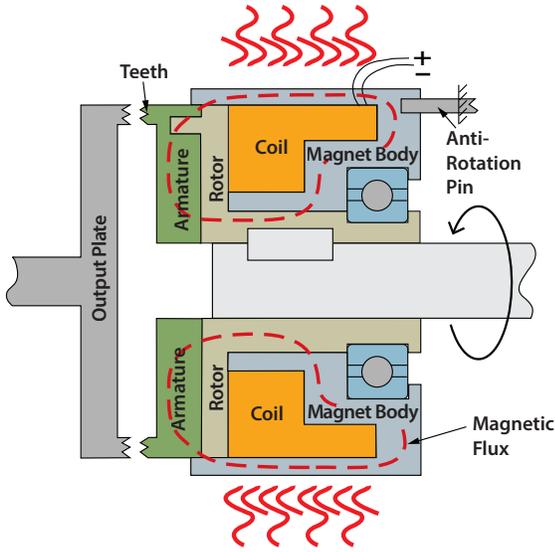


Symbol	Characteristics	Category
—	Straightness	Form
	Flatness	
○	Circularity	
	Cylindricity	
	Profile of a Line	Profile
	Profile of Surface	
	Angularity	Orientation
	Perpendicularity	
	Parallelism	
	Position	Location
	Concentricity	
	Symmetry	
	Circular Run-out	Runout
	Total Run-out	

Symbol	Term
(M)	At Maximum Material Condition
(S)	Regardless of Feature Size
(L)	At Least Material Condition
(P)	Projected Tolerance Zone
∅	Diameter
S∅	Spherical Diameter
R	Radius
SR	Spherical Radius
()	Reference
	Arc Length

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6. Heat Self-Generation



Electric coils generate heat, friction surfaces generate heat – the environment the clutch or brake is in generates heat. When applying clutches and brakes, this heat must be taken into consideration.

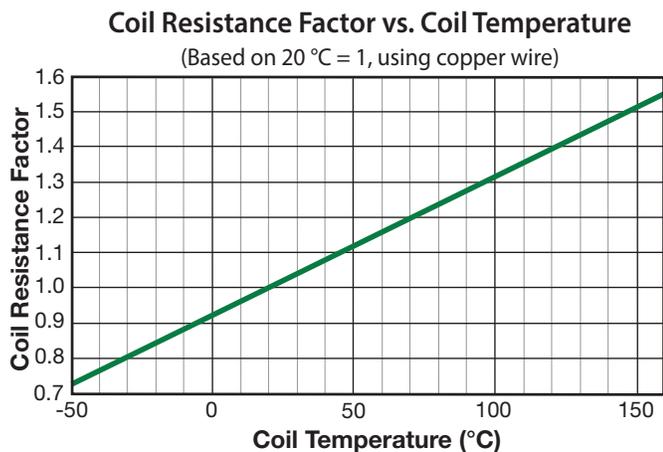
Physics of copper or any wire dictates when the wire is “heated” the resistance changes. Clutches and brakes operate with “magnetic force” or “flux lines through the steel”. The strength of the magnet is a result of “Ampere Turns” or NI (N = number of turns of the coil wire $\times I$ = Current).

In the heated condition, since the resistance rises performance at the elevated temperatures will be “de-rated” by the change in temperature. The Temperature effect can be “calculated by using the following formula:

Coil resistance change over temperature:

$$R_f = R_i [(T_f + 234.5) / (T_i + 234.5)]$$

(Shown graphically below)



Operate voltage corrected for temperature change:

$$V_f = V_o(R_f/R_i)$$

Actual coil temperature by change-of-resistance method:

$$T_f = T_i + R_f/R_i(k+T_{ri}) - (k+T_{rt})$$

[k = 234.5 for copper wire]

Using these formulas and basic algebra, one can:

- Calculate the expected resistance change over temperature (be sure to include not only ambient temperature but the effect of self-heating within the coil and the heating due to internal load-carrying components as well).
- Calculate the expected change in operating voltage
- Calculate the increase in actual coil temperature - and so coil resistance from one condition to another (i.e. - room ambient temperature unpowered, no-load to elevated ambient temperature with coil powered and contacts fully loaded).

Nomenclature definition for above formulas:

R_i = Coil resistance at initial coil temperature

R_f = Coil resistance at final coil temperature

T_i = Initial coil temperature

T_f = Final coil temperature

T_{ri} = Ambient temperature at start of test

T_{rt} = Ambient temperature at end of test

V_o = Original “operate” voltage

V_f = Final operate voltage (corrected for coil temperature change).

Notes:

- “Ambient” temperature is the temperature in the vicinity of the clutch/brake - this is not the same as the temperature in the vicinity of the assembly or enclosure containing the clutch/brake.
- Similarly, “initial coil temperature” and “initial ambient temperature” may not be exactly the same at the start of the test unless sufficient time has elapsed to stabilize both temperatures.
- Because coils and other components have thermal mass, sufficient time must be allowed for all temperatures to stabilize before measurements are recorded.

7. Heat Dissipation Capacity

Friction clutches and/or brakes are not designed to slip continuously. They can be used for soft starting/stopping for downline equipment protection. With more slippage, more heat is generated.

When cycling a friction clutch or brake, be aware of the "Thermal Capacity" of the unit. Most clutch/brake manufacturers publish Heat Dissipation graphs showing the heat input capacity of the individual clutch or brake, and provide formulas to help calculate the maximum cycle rate, based on heat input and the thermal capacity.

SEPAC Thermal Capacity:

$$E \times C \leq Q \times K_1 K_2$$

where:

E = BTU/Engagement calculated from the formulas (#9, #10 or #11) in the SEPAC Application and Selection Guide.

C = Number of engagements per minute.

Q = Thermal Capacity (BTU/minute) for the model selected.

K₁ = Wet (with oil spray) 1.00

(Factors as high as 2.00 can be obtained by forcing oil through the discs)

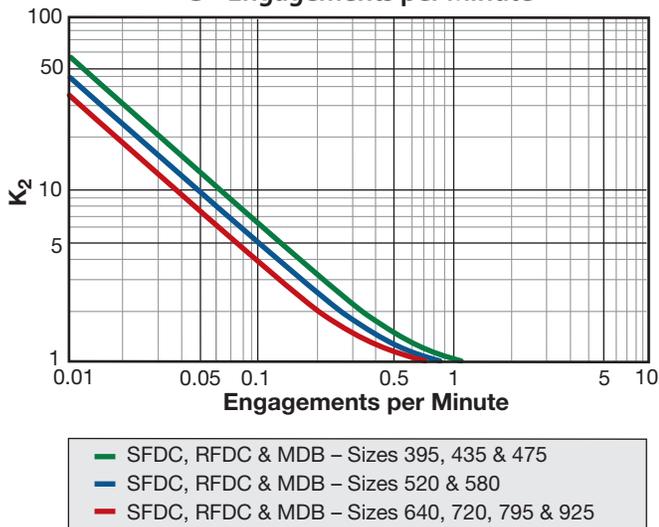
Wet (10-20% submerged) 0.86

Dry (fan cooled) 0.74

Dry (no cooling) 0.53

K₂ = From chart below

C – Engagements per Minute



NOTE: For thermal capacity of dry application, non-asbestos or bronze disc stacks, consult SEPAC Engineering.

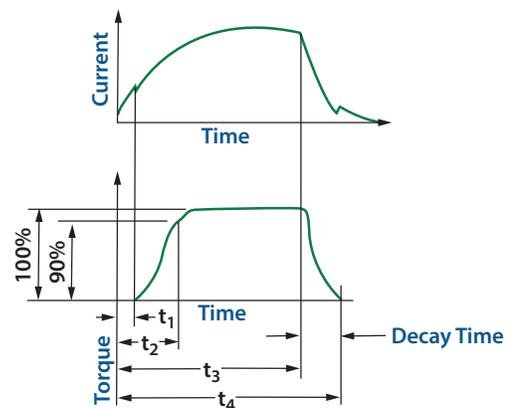
8. Response Time

There are two response time considerations when sizing a clutch or brake:

- Electrical response time (coil build up and decay)
- Starting or stopping time

The electrical response time is easily measured and usually catalog data is available. However, the stopping or starting times need to be calculated using the inertia-time equation from Section 1: Rotating Moment of Inertia.

Current and Torque Curves



Pull-in time, denoted as **t₁**, is the time it takes for the clutch to close the air gap. After coil-current buildup, the armature makes contact and the coil-current curve dips slightly at **t₁**.

Time-to-speed response time occurs at **t₂**. After the armature and rotor surfaces mate at **t₁**, both coil current and torque continue to increase. Torque reaches 90% of its full-rated value (at time **t₂**) and continues to rise to full torque. Most users call **t₂** 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 (**t₃**). Coil current and torque begin to decrease, with torque reaching zero at **t₄**. Decay time is the time required for torque to reach zero after coil current is turned off (**t₄ - t₃**).

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.

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9. **Burnishing Friction Clutches and Brakes**

When friction surfaces are new they are flat and smooth. The surfaces must be broken-in before the full torque capacity is reached. This process is commonly referred to as burnishing (Run-In or “bedding-in”). Burnishing is the wearing or mating of opposing surfaces.

Years ago, when the auto mechanic installed a new set of brake pads on your car, you were told not to slam on the brakes, but gently apply them for the first few miles. This allowed the brake pads to be run-in or burnish.

If clutches and brakes are not burnished properly, they may not deliver rated torque. Most applications allow the clutch or brake to run-in under normal operating conditions.

Likewise, most clutch/brake units are designed to burnish or run-in quickly with normal use. Others may be factory pre-burnished or available with optional pre-burnishing. With the pre-burnishing option, be sure to keep the friction surfaces together as a matched set. In the case of a power-on type brake, clutch or clutch coupling, the potential to miss-match the components is greater because the mating surfaces are physically not held together.

In most cases burnishing will increase the performance of the clutch or brake by 15 to 30% depending on the design.

Consult the factory for proper run-in or burnishing procedure.



The friction disc on the left is in its natural, unburnished state while the sample on the right has been fully burnished.

10. **Environmental Effects**

Environmental issues that commonly impact a clutch or brake performance include the following. Contact SEPAC to discuss your application to evaluate alternative solutions.

Altitude — Thinner air reduces heat dissipation

Shock and Vibration — Can cause structural degradation, and possibly unintentional release or re-engagement. Compression springs have a certain retention frequency. If the vibration exceeds this, the spring engaged unit may disengage.

Coatings — Increase the effective air gap and effects friction, thereby effecting engagement and release (magnetically). If proper coatings are not used, then steel members will corrode creating additional issues.

Shaft Material — External magnetic effects. Internal to the clutch or brake effects.

Water/Moisture/Salt — Need to protect the coil and provide non-corrosive coatings to mild steel. If the unit is exposed to salt, which is highly corrosive, extra precautions will be necessary.

Sand/Dust — The clutch or brake has small air gaps that can be filled with debris causing malfunction. Clutches and brakes need to be sealed from sand and dust infiltration.

Oil/Other Fluids — Oil will reduce the holding force in most cases. Some fluids will also have an effect on friction materials. Be aware of the fluids that can come in contact with the clutch or brake.

11. Life Requirement

When applying clutches and brakes, the life required from the system is essential to the life of the product the clutches and brakes are used on.

Life can be compromised by all the issues in the preceding sections, which include

- Heat/wear
- Friction/wear
- Coil life (MTBF rates are commonly available)
- Spring life
- Environment
- Temperature
- Vibration
- Shock
- Mounting

Any calculation of service life will always theoretical, but in reality, there is often a huge difference between theory and practice. A huge number of factors come into play when calculating the service life. Because of the many variables if the life of the system is critical, a life test should be performed.

Frictional Materials

Asbestos was used almost universally for decades as the basis of brake/clutch friction material. The health hazards of asbestos led to its removal from most linings. Today, most friction materials are semi-metallic, rubber, or organic compounds. All have different coefficients of friction and wear rates. No single material has been able to replace asbestos for its best coefficient of friction and wear rate.

Frictional Property Examples:

- Coefficient of Friction (SAE J661)
Normal: 0.44
Hot: 0.40
- Wear Rate (SAE J661)
(inch³/hp-hr) : 0.005 max
- Friction Code : FF
- Rubbing Speed: 7500 fpm
- Pressure: 2000 psi
- Drum Temperature for constant Operation: 650

Once the energy transferred into the material (against steel) is calculated (see thermal capacity), the wear rate can be calculated using the 0.005max inch³/hp-hr.

12. Cost vs Price Considerations

It's important to consider the total cost of the clutch/brake application in addition to the purchase price of the component itself.

Starting with the price of the component, recognizing and understanding the pricing structures involved with your system and design is essential. For example, designing a basic actuator for an automotive application is a radically different project than designing a test fixture actuator used to evaluate those basic automotive actuators.

Engineers, more so than ever before, are becoming a necessary facet in the process of pricing products and services due to: the increasingly sophisticated performance requirements of the application; the advanced and oftentimes expensive materials of construction, and; the complex and strategic design for manufacturability issues involved. Even if these engineers completely understand their customer's needs, many struggle with the pricing process of what to charge for their products and services — simply because they do not have complete familiarity and knowledge of everything involved in making the call (cost of materials, accurate estimate of design time, etc.) As a result, cost-overruns, work change orders, schedule delays, shifting performance capabilities can result.

Bottom line on pricing: when evaluating clutch/brake components and the likely vendors that are providing them, it can be very difficult and challenging to make the evaluation an accurate apples-to-apples assessment. But, doing so can be vital to the project's success. Therefore, careful and thorough examination is important to ensure that the price does in fact reflect the "real price".

This apples-to-apples assessment brings up the need to evaluate total cost considerations of the component and the vendor that will provide it. For example, in the design phase, a number of questions will arise based on the complexity of the project: will in-house design team resources be sufficient; does the team have the time and talent to meet the project's objectives; is there a genuine cost-savings versus applying the expertise of a 3rd party design team; will an outside resource expedite the project and free in-house staff for more important issues; can a 3rd party provide an opportunity to actually improve the design of the project?

Looking at design for manufacturability issues: does the in-house design team, or the 3rd party vendor for that matter, have the experience and expertise to create a best-fit solution within budget and schedule guidelines; what is the impact of design complexity on development lead time; is there a simpler solution available?

And finally, there are cost-evaluation considerations for the end-result product itself and the vendor that supplies it, including:

- Ease of installation
- Serviceability
- Customer support and service from the manufacturer
- Any potential for reduced performance issues
- Replacement time/cost
- Loss of productivity due to downtime
- Any potential safety/liability issues

In conclusion, sizing up and selecting the right clutch/brake vendor to meet the performance, budget and scheduling objectives should be considered of equal importance to sizing and selecting the right clutch/brake unit itself.



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