

CLUTCHES AND BRAKES

Key to effective control and transmission of drive torque, speed, and power in many rotating drive systems are clutches and brakes. Their function is to either transfer torque from an input shaft to an output shaft (clutching) or to stop and hold a load (braking). Though offered as separate components, their functions are often combined into a single unit referred to as a clutch-brake.

Clutches and brakes can be categorized by the technique used to engage or stop the load (friction, electromagnetic, mechanical lockup), and by the method used to actuate them (mechanical, electric, pneumatic, hydraulic, self-activating).

FRICTION

The most popular type of clutch or brake uses the friction developed between two mating surfaces to engage

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or stop a load. One surface is metallic, generally cast iron and shaped into a disc, band, or drum. The other surface has a friction facing made from molded organic material, and held together by a heat-cured resin binder — usually a plate, shoe, or pad. Friction facings can be made from any of several types of material, depending on application requirements. Often, brass or aluminum chips are included to extend life and improve heat dissipation.

Disc

In simplest form, a disc-type clutch or brake has a single friction plate and disc. A clutch-brake combines

clutching and braking functions in one unit, Figure 1. It has a friction plate and disc combination for each function. As with many other types of clutch or brake, various mounting arrangements are possible for clutch-brake units, and so are various means of actuation.

In more complex designs, clutches and brakes use multiple discs and friction plates to increase the working (friction) surface, Figure 2. Often the discs are submersed in oil to extend friction component life and increase cooling efficiency.

Some disc brakes use calipers in place of a friction plate, Figure 3. An advantage to this design is that additional calipers can be added to increase braking torque. Also, brake pads are easily serviced.

Drum

Drum clutches and brakes, Figure

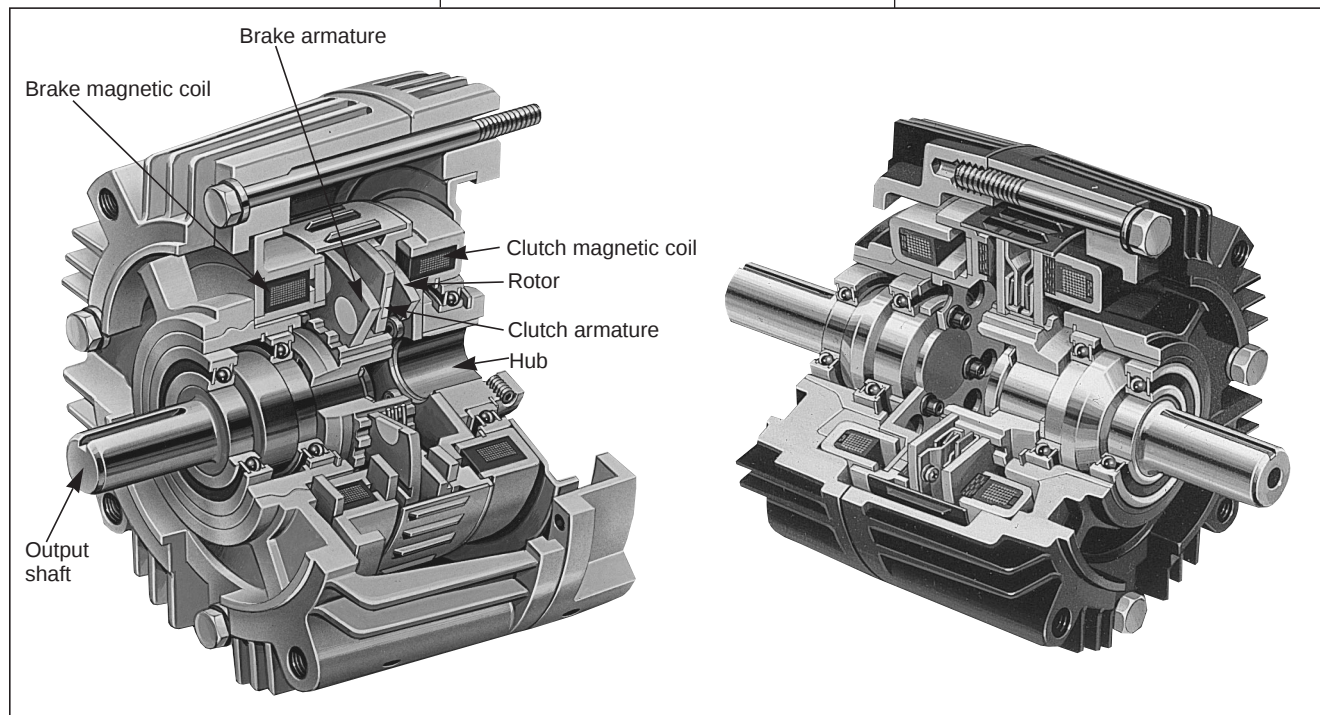


Figure 1 — NEMA C-face (left) and foot-mounted (right) electric clutch-brakes. To start, current applied to clutch coil generates magnetic flux that clamps armature to rotor, causing it to rotate along with attached hub and output shaft. To stop, current is removed from clutch coil and applied to brake coil. This clamps brake armature to magnet, which is fixed to housing, thereby stopping the load.

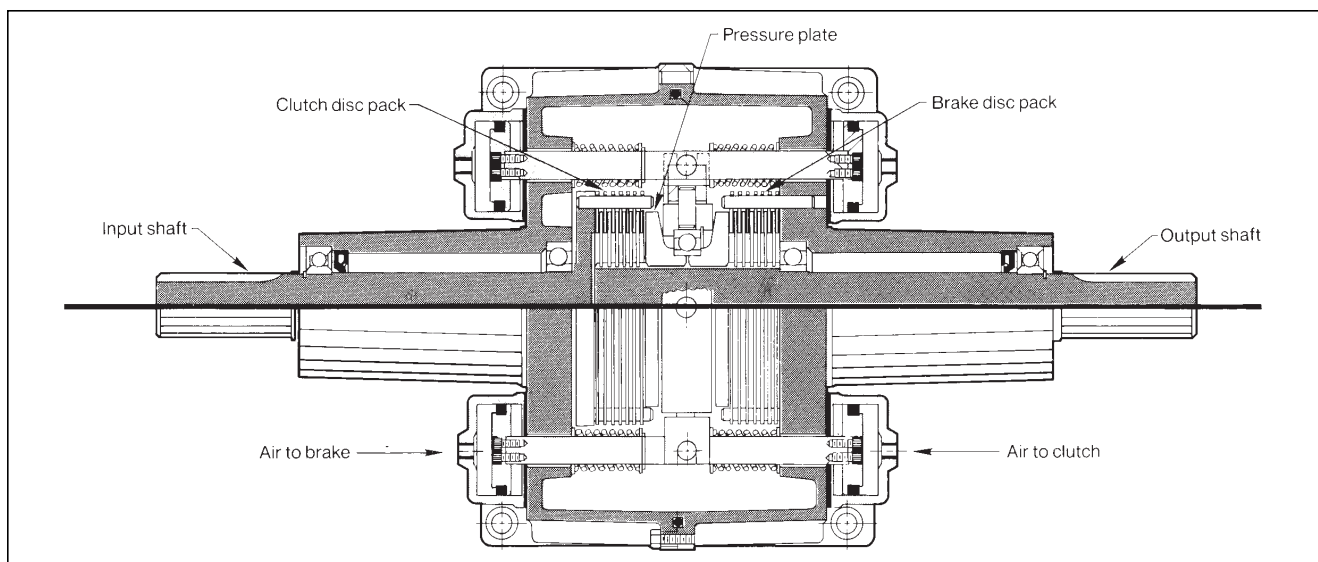


Figure 2 — Typical wet-disc clutch-brake with multiple discs.

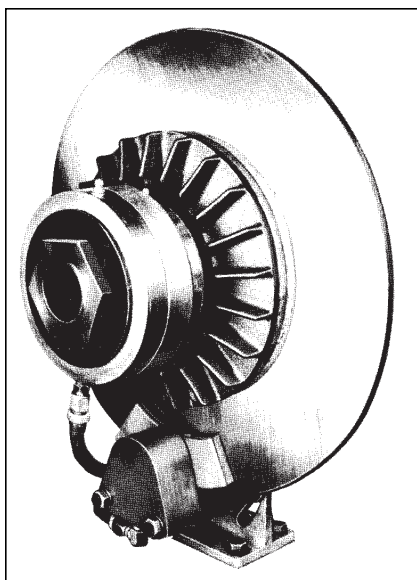


Figure 3 — Caliper type disc brake.

4, have cylindrical friction surfaces with a common axis (the shaft) on which the unit is mounted. Drum units are either constricting or expanding types; that is, the drum is contacted on either its outside or inside diameter to force engagement. Drum clutches and brakes wear evenly and transmit high torque. The contracting type responds especially fast because centrifugal force helps withdraw the shoes rapidly, thus making them well suited for high cyclic operations.

Cone

Cone clutches and brakes, Figure 5, have friction surfaces that are

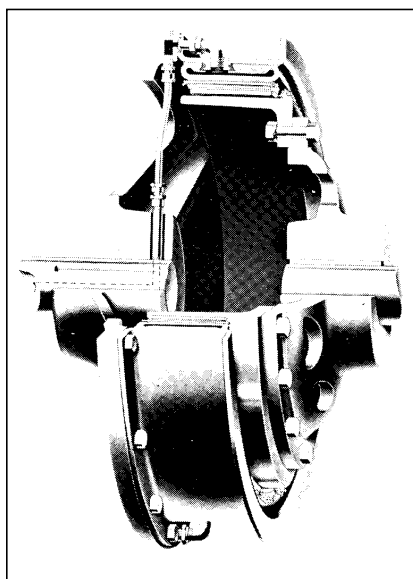


Figure 4 — Drum type clutch.

slightly tapered and coaxial with the shaft, and they are engaged in an axial direction. In this respect, they are a cross between drum and disc types.

Cone clutches have light engagement forces and high power transmitting capabilities, but are difficult to disengage. Cone units are not exten-

sively used in modern power transmission systems.

ELECTROMAGNETIC

Three types of nonfriction electric clutches and brakes are available: magnetic particle, eddy current, and hysteresis. Used primarily in applications that require variable slip, electromagnetic clutches and brakes use electromagnetic attraction rather than friction to perform their function.

Magnetic particle

The operating principles of magnetic particle clutches are illustrated in Figure 6. The space between the input and output members is filled with a mixture of dry iron particles. When the coil is energized, the magnetic flux lines span this space and line up the particles on the magnetic flux lines. This results in the magnetic particle chains locking the input and output members together, causing them to rotate as a single unit. The amount of particle bonding determines the amount of torque that can be transmitted and is directly proportional to the current flowing to the rotor. Torque can, therefore, be adjusted by varying the amount of current flowing to the coil. Magnetic par-

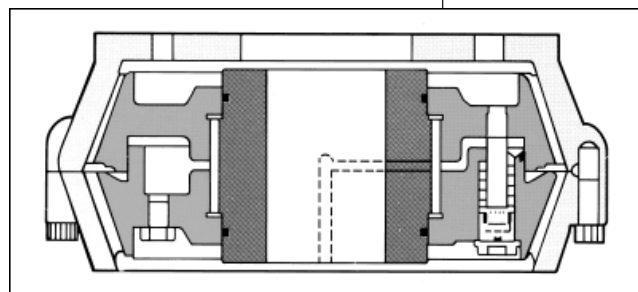


Figure 5 — Cone type clutch.

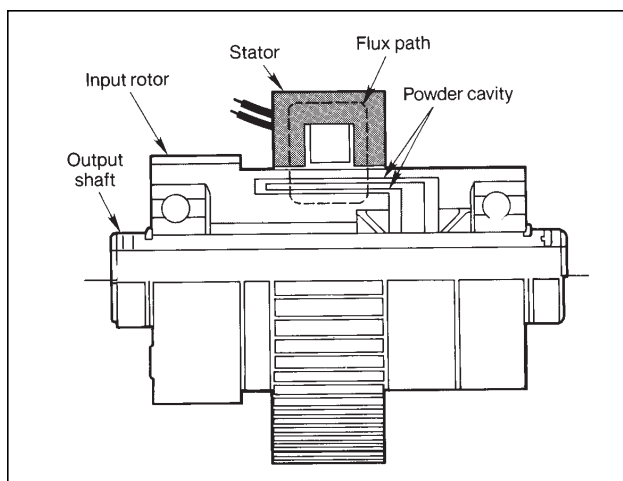


Figure 6 — Magnetic particle clutch.

ticle clutches and brakes are useful in tensioning and positioning applications where continuous changes of speed are required.

Eddy current

Primarily used in variable speed devices, these clutches and brakes cannot be operated at zero slip. They consist primarily of an input drum, stationary field coil, and a coupling pole assembly that acts as an output rotor, Figure 7. When the field coil is energized, magnetic flux links the input drum with the coupling pole assembly. Eddy currents, developed when the input drum rotates, create a new magnetic field that interacts with the field in the pole assembly, creating coupling torque proportional to coil current.

At zero slip, the eddy current brake has no torque, thus it cannot be used where holding a load is required. They are useful for providing drag loads needed in applications such as tensioning.

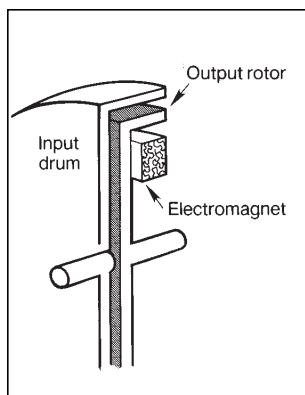


Figure 7 — Eddy current clutch.

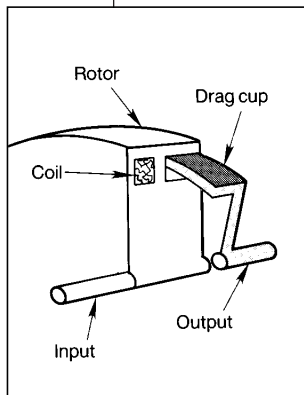


Figure 8 — Hysteresis clutch.

provide any amount of slip, as long as heat dissipation capacity of the unit is not exceeded. Hysteresis losses transmit torque in this type of clutch. A coil on the input rotor generates a magnetic field in the rotor and drag cup, Figure 8. The hysteresis losses in the drag cup cause the flux to change more slowly through the cup than the rotor; thus torque is transmitted through the drag cup. Hysteresis brakes provide constant torque for a given control current. Torque is independent of speed up to high speeds. Used primarily in fractional horsepower applications, these brakes exhibit virtually no wear and almost unlimited life.

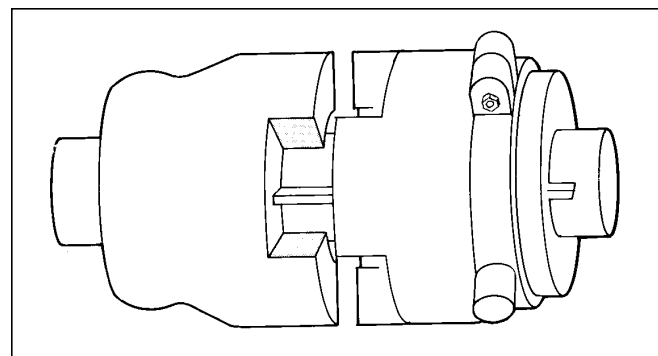
MECHANICAL LOCKUP

A direct mechanical connection between input and output components is used by mechanical lockup clutches to transmit torque. Many use centrifugal force, a wedging action, or wrapping action to lock the input component to the output component, and are often referred to as self-activating types. Speed, difference in speed between input and

output members, or direction of rotation are used to engage the torque transmitting components. Another type of mechanical lockup clutch, the multi-tooth design, uses electric, pneumatic, or hydraulic actuation.

Square jaw

The square jaw clutch, Figure 9,



Hysteresis

These are constant torque devices that can be used to

Figure 9 — Square jaw clutch.

consists of square teeth that lock into mating recesses in facing members. It provides positive lockup, but because it cannot slip, running engagement is limited to speeds under 10 rpm. Sizes accommodating from 1 to 260 hp per 100 rpm are available.

Spiral jaw

Spiral jaw clutches use sloping engagement surfaces to overcome the limited engagement speeds of square jaw types. Though the smooth, sloped engagement surfaces allow for engagement speeds of up to 150 rpm, they can operate in only one direction, and have a tendency to freewheel.

Multi-tooth

These clutches offer the advantages of mechanical lockup clutches combined with the advantages of electric, pneumatic, or hydraulic actuation. Running engagement speeds of up to 300 rpm are possible. They are available in capacities to 300 hp per 100 rpm, Figure 10.

Sprag

The typical sprag type clutch has cylindrical inner and outer races, with sprags filling the space in between, Figure 11. The sprags are sized, shaped, and mounted in a manner that assures they will wedge between the two races when rotation occurs in the correct direction.

Wrap spring

In wrap spring clutches, the input shaft and output shaft are connected by a coiled spring whose inside diameter is smaller than the outside diameter of the two shaft hubs, Figure 12.

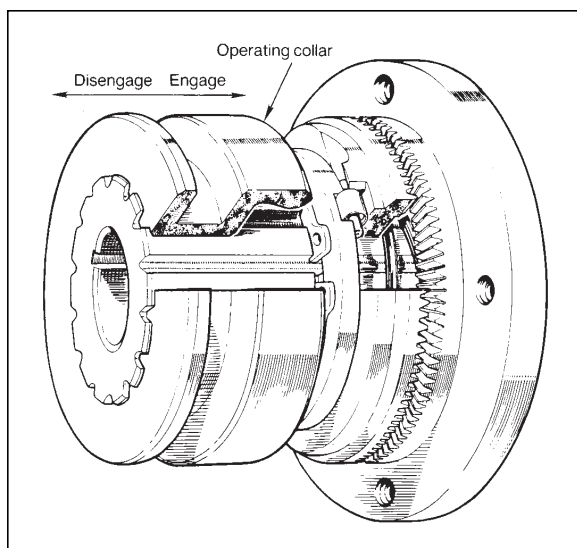


Figure 10 — Multi-tooth clutch.

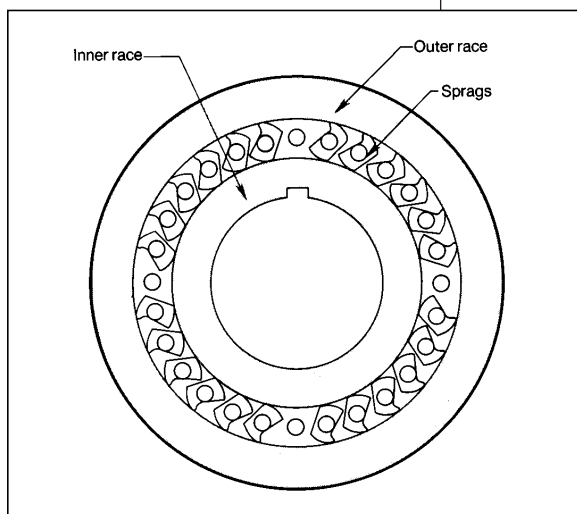


Figure 11 — Sprag clutch.

Rotation in one direction tightens the spring to transmit torque. Rotation in the opposite direction loosens the spring and disengages the unit.

Roller ramp

Roller-ramp type clutches transmit torque through rollers that ride on the ramped surface of a hub, Figure 13. When the clutch is engaged, a roll cage positions the rolls at the top of the ramps and torque is transmitted from the continuously rotating

sleeve to the intermittently driven hub. When the clutch is disengaged, the roll cage forces the rolls down the ramps away from the sleeve. Roll-cage position is controlled by an external trip cam and trip lever, which may be actuated manually or by electric, hydraulic, or pneumatic solenoid.

OIL-SHEAR CLUTCHES AND BRAKES

ment. Wear is greatly reduced by the oil film, which lubricates while transmitting most of the dynamic torque of engagement.

The heat of engagement is generated in the oil film rather than on working surfaces of the rotating elements, so the heat can be readily removed and the drive's thermal capacity is high. Also, the oil absorbs the shock of engagement as the film is squeezed between discs and plates, thus reducing drive-train stress. Small-diameter, multiple-disc designs produce high torque-to-inertia ratios.

These characteristics suit oil-shear drives to applications ranging from high inertia to high cycle. With ordinary control logic, drives handle 50 to 100 cycles/min constant duty easily. You can raise that significantly with various valve and manifold arrangements.

Common applications include indexing and reciprocating drives, conveyors, hoists, shuttles, packaging machines, palletizers, welders, and machine tools. Oil-shear units serve in glass, wood products, steel, automotive, textile, building material, food-packaging, and other industries. They are well-suited for constant-slip tension uses and adjustable-speed drives.

It can be shown that output torque is directly proportional to viscosity, relative surface velocity, and area in contact; inversely proportional to oil-film thickness.

Clutch or brake output torque is proportional to the disc diameter as

well as contact area. For a given disc diameter, you can increase torque capacity by increasing the number of discs. The modern oil-shear clutch-brake has 6 to 36 working surfaces. Actuation may be by pneumatic, hydraulic, or spring pressure.

Figure 14 shows such a clutch-brake. Compressed air or hydraulic fluid pressure introduced in the clutch makes the nonrotating, centrally located piston exert clamping pressure on the clutch disc pack. The pack consists of steel discs (drive plates) keyed to the input shaft, and alternate friction-material-faced discs splined to the output shaft. During acceleration, torque transfers from the input to the output shaft through viscous shear in the oil between friction surfaces.

For braking, compressed air, hy-

In a basic oil-shear drive, torque is transmitted through shearing of an oil film between two discs. As the rotating input disc moves toward the stationary output disc, the shearing allows the output disc to begin rotating. There is no friction-material-to-metal contact until input and output disc speeds are nearly equal. Then the oil film breaks down, allowing full static engage-

Figure 13 — Roller-ramp type clutch.

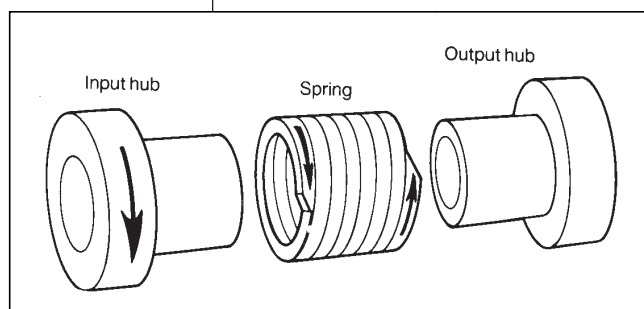
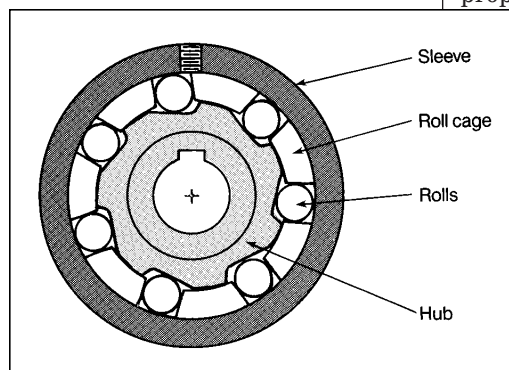


Figure 12 — Wrap spring clutch.

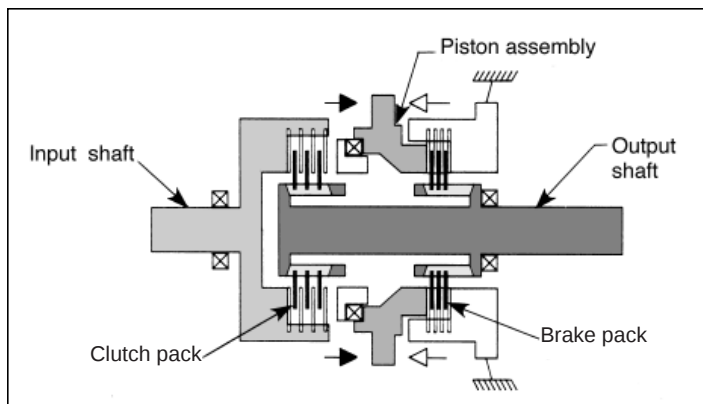


Figure 14 — Typical oil-shear clutch-brake unit has multiple-disc clutch and brake packs.

draulic fluid, or springs force the piston toward the brake end of the unit, as air or hydraulic fluid exhausts from the clutch piston chamber. The piston clamps the brake disc pack, which is similar to the clutch pack except that the steel plates are keyed to the housing.

For units that use external actuation of the brake, light-duty return springs are often used to move the piston. In a spring-applied safety-brake setup, heavy-duty springs replace the light-duty springs. Loss of electric power or actuating pressure automatically releases the clutch and sets the brake. Clutch-and-brake overlap is mechanically impossible.

Oil-shear performance requires positive oil circulation through the disc packs, Figure 15, to cool and lubricate friction surfaces and bearings. Typically, transmission fluid is dispersed radially across the faces of the friction surfaces. The fluid then flows to a sump where heat dissipates through the housing. An internal water-to-oil heat exchanger can increase thermal capacity.

Not all wet clutches are oil-shear units. In some friction-type drives, oil may be used to cool the friction surfaces. Unless the clutch-brake maintains an oil film between surfaces, it behaves like a friction-type clutch-brake. Torque transfers mechanically from one friction surface to another, and heat will build up in the working surfaces, which must then be cooled.

Besides the low wear and cushioned engagement inherent in oil-shear drives, engagement time can be set as needed. Depending on control logic and methods of actuation and cooling, engagement times may be as

short as 50 milliseconds or as long as several minutes.

Also, the dynamic torque rating of an oil-shear unit can be modified with different combinations of oil and friction materials. And, because output torque varies inversely with film thickness, control of clamping pressure allows easy control of torque.

In a drive with a speed reducer, load inertia referred to the drive is reduced by the square of the reduction ratio. There, 50% or more of the motor output may go to accelerating the drive; 50% or more of the heat generated comes from starting and stopping the cyclic parts of the clutch-brake — important in high-cycling work. Because inertia increases by the fourth power of diameter, and torque increases proportionally to diameter or number of discs, the small-diameter, multiple-disc design can deliver high torque with minimum inertia. Drive rating increases almost in proportion to the number of working surfaces, with no derating for multiple-disc construction. You can get many torque ratings from one brake size by adjusting the number of discs and springs, or adjusting clamping pressure.

The totally enclosed, sealed housing prevents contamination from the outside. Also, normal maintenance requires only maintaining oil level.

In general, dynamic coefficient of friction can vary even at seemingly constant speed conditions, and even more so with varying speed and temperature. The coefficient for a wetted surface tends to be more constant than that for a dry surface. That consistency extends to oil-shear drives.

With a clutch or brake disengaged, the oil film, which is always present, continues to transmit some torque. This can be a limitation in high-speed, constant-slip applications. The

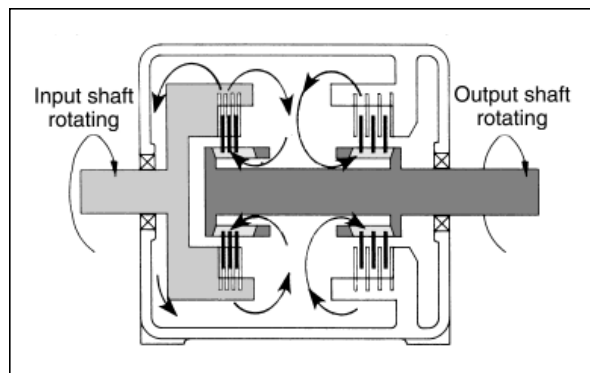


Figure 15 — In an oil-shear unit, oil flows through the hollow barrel of clutch or brake hub, then to the friction discs. Here the clutch is engaged, and fluid flows in the brake stack in preparation for brake engagement.

amount of drag is a function of viscosity, disc size, relative slip speed, and running clearance. Where residual drag may be a problem, steps can be taken to minimize it.

Most often, oil-shear drives are applied in cycling applications where frequent stopping and starting can quickly burn up a dry-friction unit or make it lose positioning accuracy. Conversion to an oil-shear drive is simplified, because the self-contained unit has its own bearings, housing, and input and output shafts.

Many oil-shear drives serve constant-slip applications. In start-stop uses, the objective is to accelerate or decelerate the load with full engagement of the clutch or brake. But in constant-slip applications, the objective is to slip continuously without full engagement. Typical uses include unwind brakes, rewind clutches, dynamometer absorbers, tension-control brakes, constant-tension drives, and adjustable-speed drives.

Unwind brakes, for example, maintain fairly constant tension in a material web even though the moment arm, and thus the torque required, changes as roll size diminishes. Torque in the oil-shear drive can be controlled by manual adjustment of clamping air pressure. You can get accuracy of $\pm 10\%$. Better accuracy with open-loop control is impossible; torque varies also with oil viscosity and slip speed. Closed-loop control with load-cell feedback to a suitable PID set-point controller can produce $\pm 0.25\%$ accuracy.

Oil-shear drives make excellent dynamometer absorbers because they

can develop high and low torque over a wide speed range, with low inertia. In particular, they can develop high torque, without chatter, at speeds below 1 rpm, where other absorbers can't function.

METHODS OF ACTUATION

You must consider several factors when selecting a clutch or brake for a given application:

- How much torque must the unit accommodate?
- What engagement methods are available?
- Does the job need remote or electronic control?
- What is the response-time requirement?
- What are the environmental conditions?
- What thermal capacity is needed?
- Are there space or weight restrictions?
- What is the maximum operating speed?
- What is acceptable service life for the unit or its friction elements?
- How much routine maintenance will be needed?

Most clutch and brake types are available for applications from fractional to 50-hp capacity. Thus, you must consider the method of actuation and operational characteristics typical of that method in order to optimize selection.

Mechanical

This is the simplest, least costly way to engage a clutch or brake. Actuation is by rods, cables, levers, or cams.

Besides cost, a major advantage of this type of actuation is the "feel" of engagement that the operator gets through a pedal or lever, and the ability to judge the amount of braking force or slip needed.

Because mechanical actuation depends on human strength, actuation force is limited to about 75 lb. This low clamping force limits response times and cycling rates. Normally, mechanically actuated clutches cannot be cycled more than a few times per minute without wearing out clutch elements or tiring the operator. As a result, mechanically actuated clutches are restricted to vehicles and small industrial equipment such as hoists.

Electric

Electrically actuated clutches and brakes permit extremely fast cycling rates (to 1,600 cpm in some uses). However, they do not provide the torque range of pneumatic or hydraulic units. Electric clutches and brakes are more convenient for much automatic machinery, where control commands are electric. Electric actuation also works better in remote applications where piping would be cumbersome or costly.

Some types of electric clutches and brakes provide closely controlled actuation rates that would quickly wear out other types. Conversely, they do not provide the "feel" of engagement possible with other types.

An electromagnetic clutch or brake has two basic parts: an annular electromagnet and an armature. The electromagnet is a wound copper coil embedded in a donut-shaped iron shell, and fitted with lining material to retard wear. When voltage is applied to the coil, the magnetic field formed by the electromagnet shell and armature engages the two friction surfaces and locks them together as a rotating unit, Figure 16. If the armature is allowed to rotate, and the electromagnet is held stationary, the unit works as a brake.

Electromagnetic clutches and brakes can have rotating or stationary coils. Rotating coil types are commutated with slip rings and brushes, and cannot be used in explosive atmospheres. In the stationary field clutch, the magnetic coil is fixed and, thus, does not need rings.

The simplest type of clutch or brake control consists of a plug-in module that converts ac line voltage to dc voltage and provides for on-off switching.

More complex controls include solid-state input modules with integral 0, 50, and 100-msec time delay

outputs for smooth transitions between clutch and brake engagement in combination units. A control with a potentiometer permits torque adjustment for the clutch-brake and is often used to soften starts and stops of sensitive loads.

Though 60 cpm is a routine cycle rate for electrically actuated clutches and brakes, rates 10 times as high are often encountered. One special solid-state control, the overexcitation (OEX) control, increases cycle rate performance by reducing the magnetic field buildup time of the electromagnet coil. The OEX control operates initially by applying over-voltage to the coil, then reducing the voltage until rated voltage is reached. Sufficient voltage is applied to the coil for a few millisecond, after which the coil has reached flux saturation point. The overexcitation time is too brief to harm clutch-brake life.

Pneumatic

Air actuation is the most common method for industrial equipment. Most factories have compressed air that can serve clutches and brakes. Pressures to 200 psi are used to inflate tubes or act on pistons to engage or disengage friction surfaces. Some are air-engaged and spring-disengaged; others, spring-engaged and air-disengaged. Some combination clutch-brakes use air pressure to engage the clutch, and spring pressure to disengage the clutch while simultaneously engaging the brake.

Though some pneumatically actuated clutches and brakes operate at rates to 80 cpm, they usually serve in applications needing 20 cpm or less.

Perhaps the greatest asset of an air-actuated clutch or brake is low heat generation in the actuator. Unlike an electric unit, there is no heat

generation during a long period of engagement. Static pressure stays constant after the piston chamber is filled, so the power needed to sustain

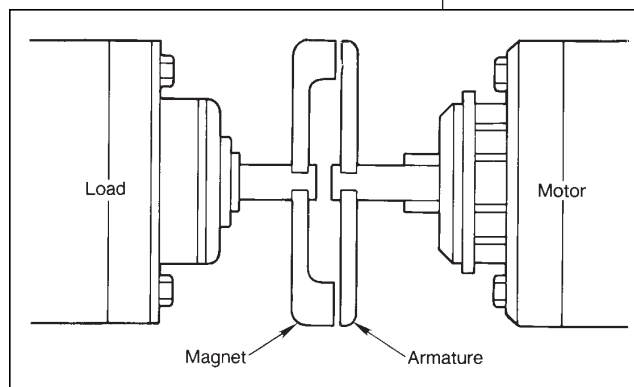


Figure 16 — Basic elements in a disc-type electric clutch.

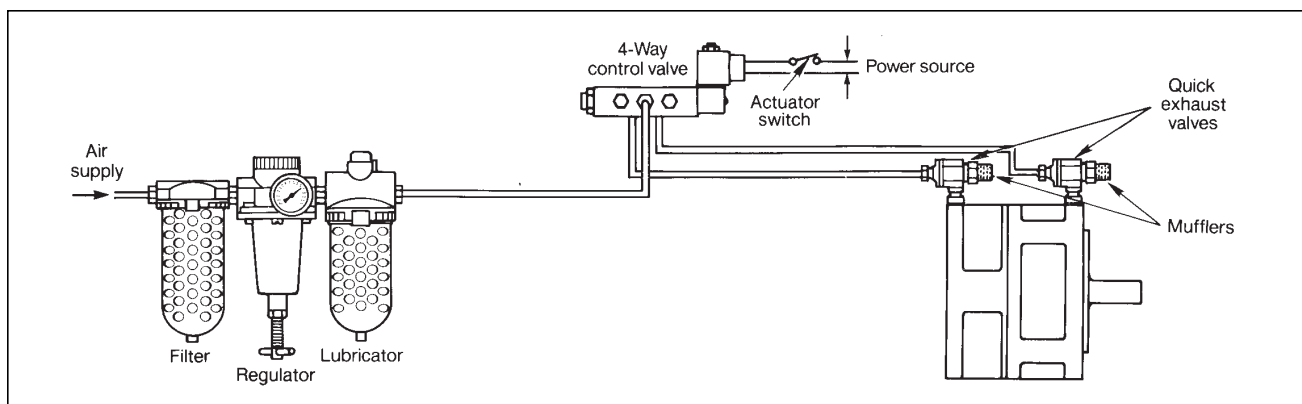


Figure 17 — Typical pneumatic clutch installation.

torque is almost nothing.

As with mechanical actuation, a degree of touch control or “feel” can be gained with air clutches and brakes by channeling pressure through hand or foot-operated throttles. Where remote control is desired, electrically actuated solenoid control valves may be used to pressurize a clutch or brake, Figure 17.

To operate efficiently, air-actuated clutches and brakes need several supporting components:

- **Pressure regulators** — Selected in accordance with their flow capabilities, these valves set pressure ranges so that clutches and brakes deliver correct torque.

- **Filters** — Installed ahead of the pressure regulator, a filter needs at least 5-micron filtration capability.

- **Lubricators** — Located between the pressure regulator and control valve, a lubricator injects oil into the air when pressure drops.

- **Control valves** — Depending on the clutch or brake configuration, the control valve may be 3, 4, or 5-way solenoid type. A 3-way valve controls either a clutch or brake. A 4-way valve controls a combination clutch-brake, providing air to either component. A 5-way valve is used where clutch and brake require different pressures. Generally, a control valve is located as close to its clutch or brake as possible to assure least lag time.

- **Quick-exhaust valves** — Installed at the clutch or brake inlet port and used where long lines are necessary, these valves improve response time because air need not travel back to the control to be exhausted. Instead, it exhausts at the quick-exhaust valve whenever supply pressure drops by, say, 3 to 5 psi.

- **Exhaust mufflers** — To quiet noisy exhaust valves, they typically reduce sound pressure levels by up to 16 dB.

A disadvantage of air-actuated clutches and brakes is the support equipment needed and the maintenance costs that go with it. The clutches and brakes themselves, however, use actuators that are typically no more complex than a cylinder and piston sealed with O-rings or U-cups. Thus, no special skills are needed to maintain them.

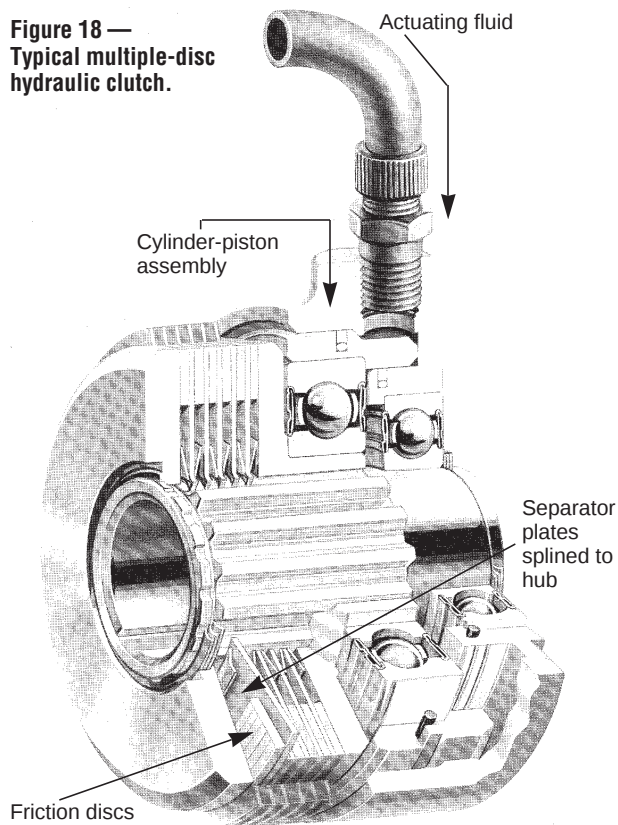
Hydraulic

Principles of operation for hydraulically actuated clutches and brakes are similar to those of pneumatically operated units. Oil pressure as high as 500 psi is used in conjunction with a mechanical friction brake or clutch. In these applications, oil pressure is delivered to a piston that acts against a rod, lever, or cam to engage or disengage the clutch or brake.

Hydraulic actuation usually provides fast response, and you can get smooth engagement by controlling the rate of pressure buildup with a pressure control valve.

As with pneumatic actuation, the main disadvantage of hydraulic actuation is maintenance of support equipment.

Figure 18 — Typical multiple-disc hydraulic clutch.



Self-actuating

These clutches rely on centrifugal, wedging, or wrapping action to lock input and output members together to transmit torque. (See “Mechanical Lockup.”) They are automatic, needing no external control. Actuation or release occurs due to speed, difference in speed between input and output members, or change in direction of rotation.

Self-actuating clutches are best applied to applications where motor speed is an adequate clutch control parameter, gentle starting with slip is desirable or tolerable, and energy savings are important. ■