Chapter VI. Motion Control: Clutches and Brakes

VI.1. Discussion Map

- A *brake* is a device used to bring a moving system to rest, to slow its speed, or to control its speed to a certain value under varying conditions.
- A *clutch* is a device used to connect or disconnect a driven component from the prime mover of the system.
- Brakes and clutches either add energy to a moving system or take energy from it. Analyzing the necessary energy changes is an important part of designing effective motion control components.

VI.2. Definitions

The machine elements most frequently used for motion control are the clutch and the brake, defined as follows:

- A *clutch* is a device used to connect or disconnect a driven component from the prime mover of the system. For example, in a machine that must cycle frequently, the driving motor is left running continuously, and a clutch is interposed between the motor and the driven machine. Then the clutch is cycled on and off to connect and disconnect the load. This permits the motor to operate at an efficient speed, and it also permits the system to cycle more rapidly because there is no need to accelerate the relatively heavy motor rotor with each cycle.
- A *brake* is a device used to bring a moving system to rest, to slow its speed, or to control its speed to a certain value under varying conditions.

VI.3. Objectives of the Chapter

After completing this chapter, you will be able to:

1. Define the terms *clutch* and *brake*.
2. Differentiate between a clutch and a *clutch coupling*.
3. Describe a fail-safe brake.
4. Describe a clutch-brake module.
5. Specify the required capacity of a clutch or a brake to drive a given system reliably.
6. Compute the time required to accelerate a system or to bring it to a stop with the application of a given torque.
7. Define the inertia of a system in terms of its *Wk*2 value.
8. Compute the energy-dissipation requirements of a clutch or a brake.
9. Determine the response time for a clutch-brake system.
10. Describe at least five types of clutches and brakes.
11. Name six actuation means used for clutches and brakes.
12. Perform the design and analysis of plate-type, caliper disc, cone, drum and shoe, and band brakes and clutches.
13. Name nine other types of clutches and brakes.

VI.4. Description of Clutches and Brakes

Several arrangements of clutches and brakes are shown in Figure VI–1. By convention, the term *clutch* is reserved for the application in which the connection is made to a shaft parallel to the motor shaft, as illustrated in Figure VI–1 (a). If the connection is to a shaft in-line with the motor, the term *clutch coupling* is used, as shown in Figure VI–1 (b).

Also by convention, a brake [Figure VI–1 (c)] is actuated by some overt action: the application of a fluid pressure, the switching on of an electric current, or the moving of a lever by hand. A brake that is spring-applied automatically in the absence of an overt action is called a *fail-safe brake* [Figure VI–1 (d)]: When the power goes off, the brake goes on.

When the functions of both a clutch and a brake are required in a system, they are frequently arranged in the same unit, the *clutch-brake module*. When the clutch is activated, the brake is deactivated, and vice versa [see Figure VI–1 (e)].

A *slip clutch* is a clutch that, by design, transmits only a limited torque; thus, it will slip at any higher torque. It is used to provide a controlled acceleration to a load that is smooth and that requires a smaller motor power. It is also used as a safety device, protecting expensive or sensitive components in the event that a system is jammed.

Most of the discussion in this chapter will concern clutches and brakes that transmit motion through friction at the interface between two rotating parts moving at different speeds. Other types are discussed briefly in the last section.

VI.5. Types of Friction Clutches and Brakes

Clutches and brakes that use friction surfaces as the means of transmitting the torque to start or stop a mechanism can be classified according to the general geometry of the friction surfaces and by the means used to actuate them. In some cases, the same basic geometry can be used as either a clutch or a brake by selectively attaching the friction elements to the driver, the driven machine, or the stationary frame of the machine.

The following types of clutches and brakes are sketched in Figure VI–2:

- ***Plate clutch or brake:*** Each friction surface is in the shape of an annulus on a flat plate. One or more friction plates move axially to contact a mating smooth plate, usually made of steel, to which the friction torque is transmitted.
- (b) ***Caliper disc brake:*** A disc-shaped rotor is attached to the machine to be controlled. Friction pads covering only a small portion of the disc are contained in a fixed assembly called a *caliper* and are forced against the disc by air pressure or hydraulic pressure.

- (c) ***Cone clutch or brake:*** A cone clutch or brake is similar to a plate clutch or brake except that the mating surfaces are on a portion of a cone instead of on a flat plate.
- (d) Band brake: Used only as a brake, the friction material is on a flexible band that nearly surrounds a cylindrical drum attached to the machine to be controlled. When braking is desired, the band is tightened on the drum, exerting a tangential force to stop the load.
- (e) and (f) Block or shoe brake: Curved, rigid pads faced with the friction material are forced against the surface of a drum, from either the outside or the inside, exerting a tangential force to stop the load. Some brake shoes are short and some are long as described later in this chapter.

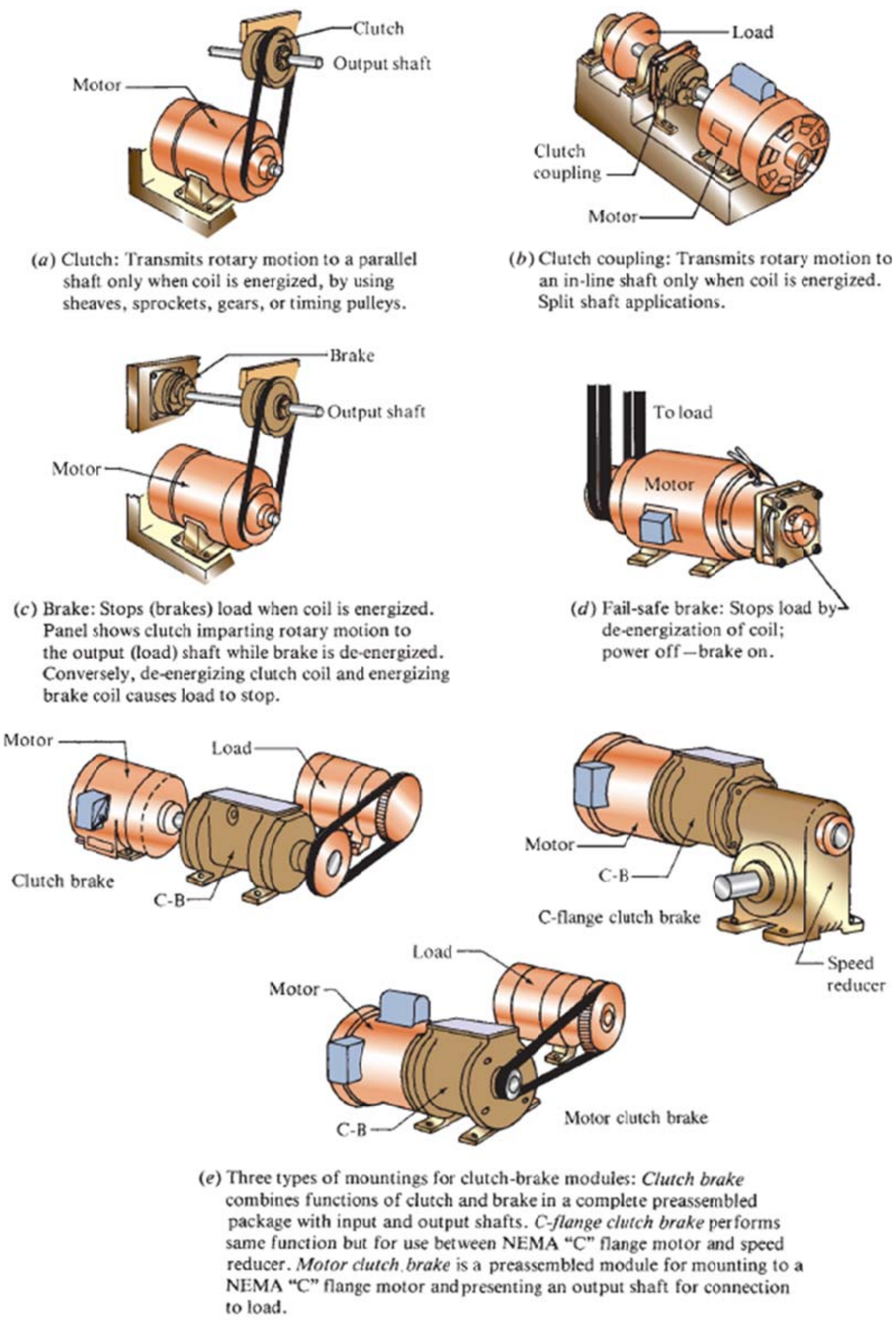

Fig. VI–1 Typical applications of clutches and brakes

VI.6. Actuation

The following are the means used to actuate clutches or brakes. Each may be applied to several of the types described. Figures VI–3 through VI– 9 show a variety of commercially available designs.

VI.6. 1. Manual. The operator provides the force, usually through a lever arrangement to achieve force multiplication. Figure V–3 shows a power take-off for agricultural or construction equipment where a manually operated clutch engages and disengages the driven shaft from the engine. The driven shaft drives accessory equipment such as a fertilizer spreader, concrete mixer, or wood chipper.

VI.6. 2. Spring-applied. Sometimes called a *fail-safe* design when applied to a brake, the brake is applied automatically by springs unless there is some opposing force present. Thus, if power fails, or if air pressure or hydraulic pressure is lost, or if the operator is unable to perform the function, the springs apply the brake and stop the load. The concept may also be used to engage or to disengage a clutch.

VI.6. 3. Centrifugal. A centrifugal clutch is sometimes employed to permit the driving system to accelerate without a connected load. Then, at a preselected speed, centrifugal force moves the clutch elements into contact to connect the load. As the system slows, the load will be automatically disconnected.

VI.6. 4. Pneumatic. Compressed air is introduced into a cylinder or some other chamber. The force produced by the pressure on a piston or a diaphragm brings the friction surfaces into contact with the members connected to the load.

VI.6. 5. Hydraulic. Hydraulic brakes are similar to the pneumatic type, except that they use oil hydraulic fluids instead of air. The hydraulic actuator is usually applied where high actuation forces are required.

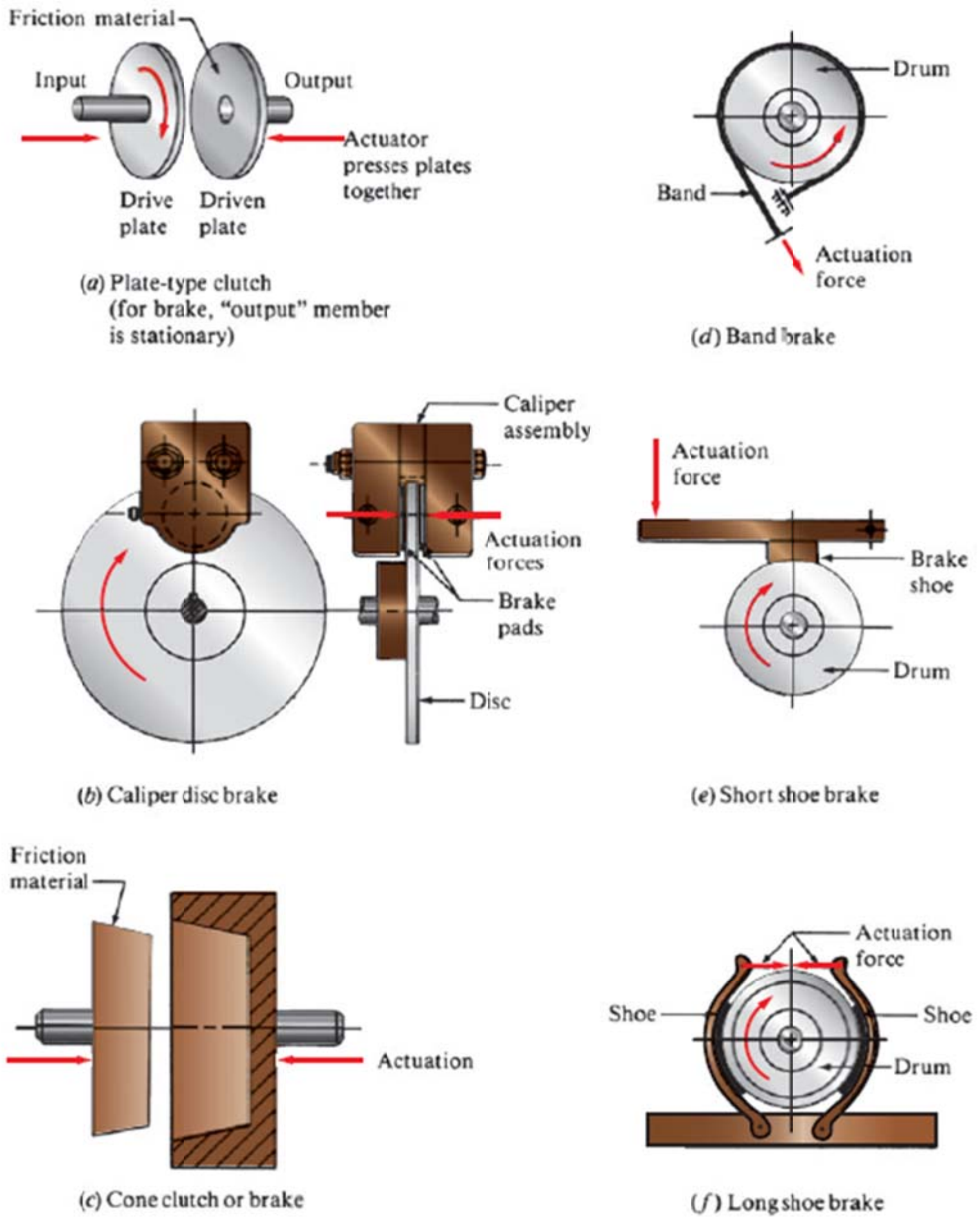

Fig. VI–2 Types of friction clutches and brakes

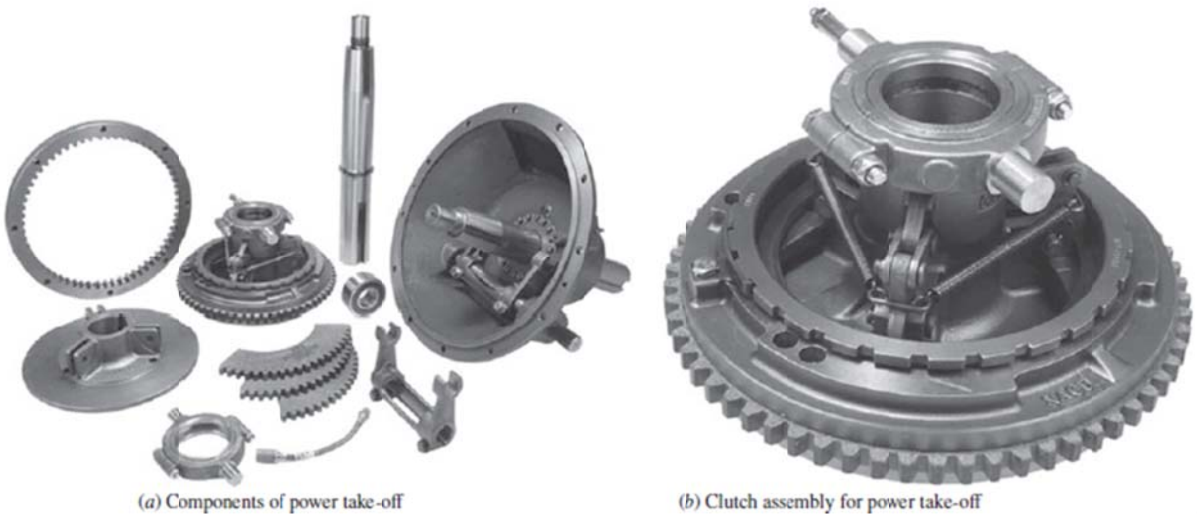

Fig. VP–3 Power take-off with manual clutch

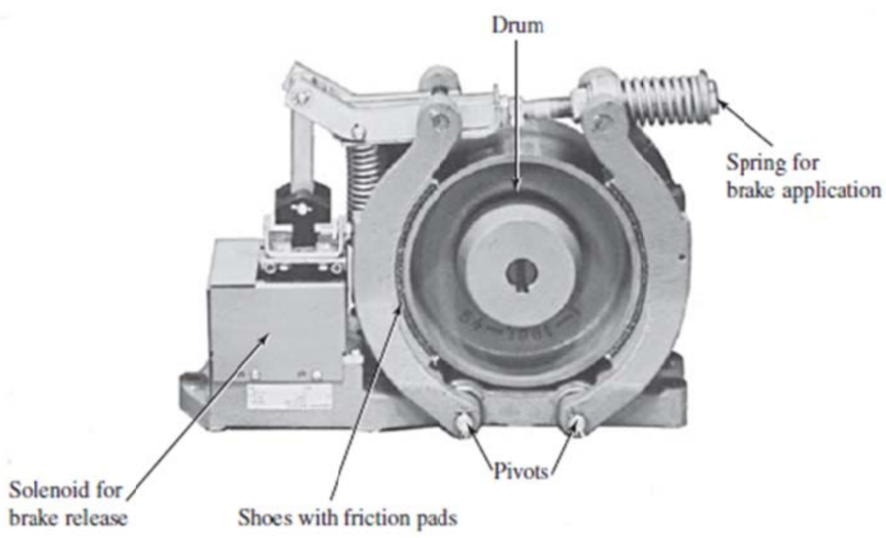

Fig. VI–4 Spring-applied, electrically released, long shoe brake

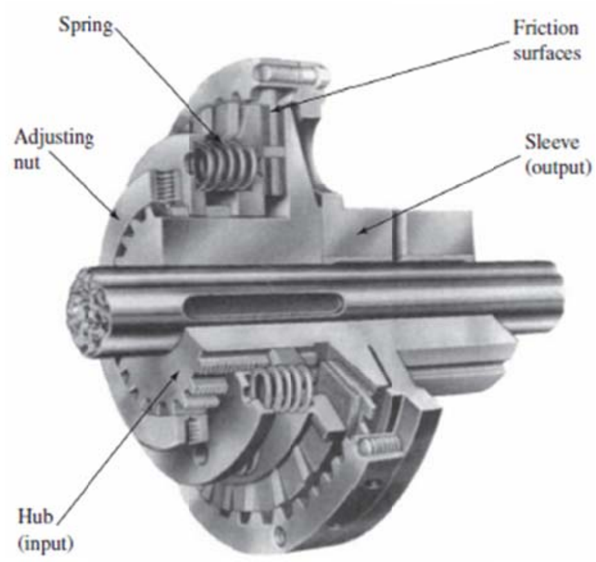

Fig. VI–5 Slip clutch. Springs apply normal pressure on the friction plates. The spring force is adjustable to vary the torque level at which clutch will slip

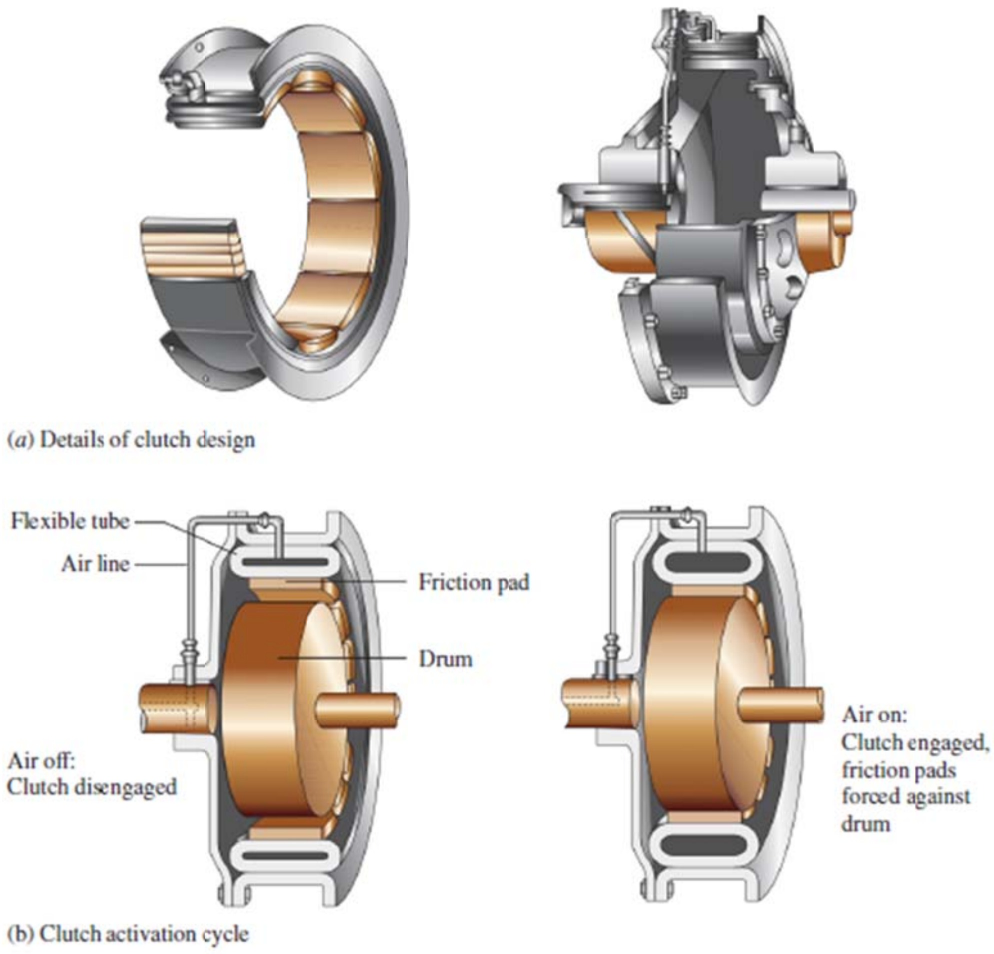

Fig. VI–6 Air-actuated clutch or brake

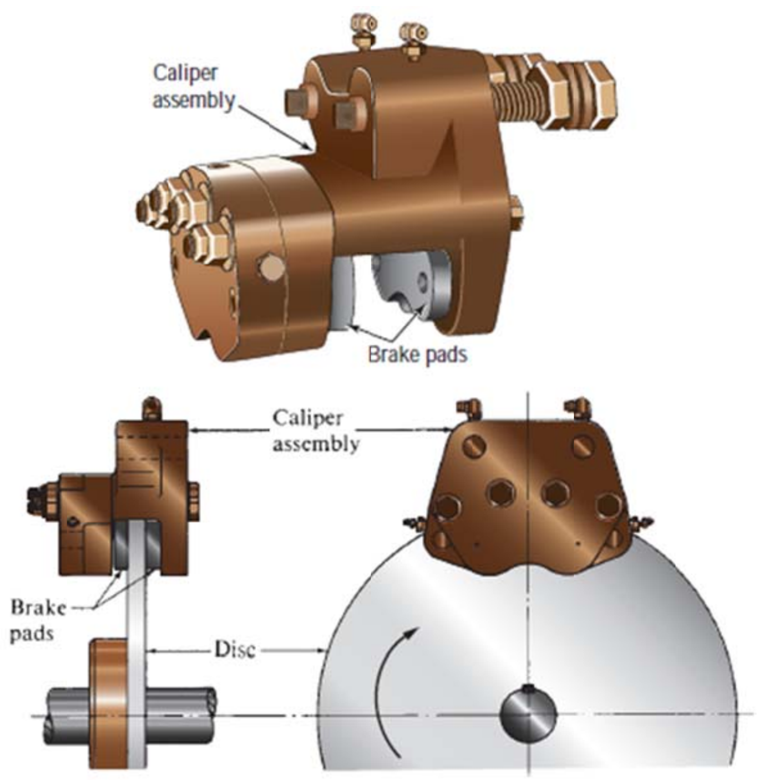

Fig. VL–7 Hydraulically actuated disc brake assembly

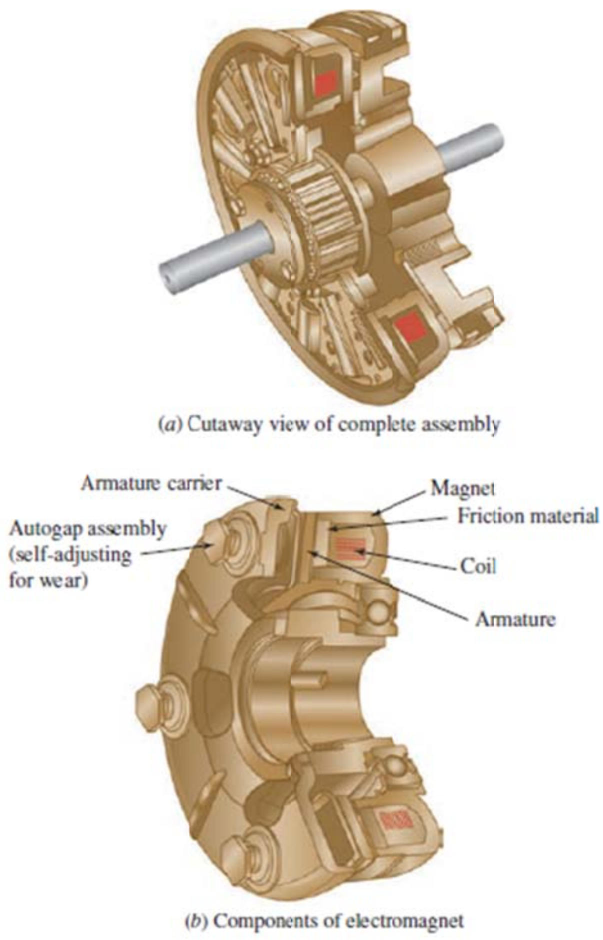

Fig. VI–8 Electrically actuated plate-type clutch or brake

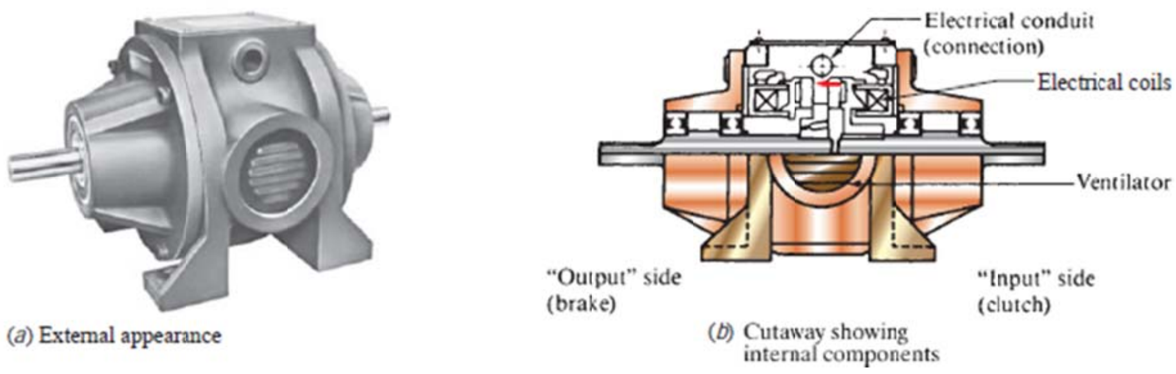

Fig. VI–9 Electrically operated clutch-brake module

VI.7. Friction Materials and Coefficient of friction

Many of the types of clutches and brakes discussed in this chapter employ mating surfaces driven through friction materials. The function of these materials is to develop a substantial friction force when a normal force is created by the brake actuation means. The friction force produces a force or a torque that retards existing motion if applied as a brake or that accelerates a member at rest or moving at a slower speed if applied as a clutch. The desirable properties of friction materials are as follows:

1. They should have a relatively high coefficient of friction when operating against the mating materials in the system. The highest coefficient of friction is not always the best choice, because smooth engagement is often aided by a more moderate frictional force or torque.
2. The coefficient of friction should be relatively constant over the range of operating pressures and temperatures so that reliable, predictable performance can be expected.
3. The materials should have good resistance to wear.
4. The materials must be chemically compatible with mating components.
5. Environmental hazards must be minimized.

Several materials are used for friction elements in clutches and brakes, and many are proprietary to a particular manufacturer. Common in the past were various asbestos-based compounds having coefficients of friction in the range of 0.35 to 0.50. Asbestos has been shown to be a health hazard and has been replaced by molded compounds of polymers and rubber. Where flexibility is required, as in band brakes, the base material is woven into a fabric, sometimes strengthened with metal wire, saturated with a resin, and cured. Cork and wood are also used sometimes. Paper-based materials are used in some oil-filled clutches. In severe environments, cast iron, sintered iron or other metals, or graphite materials are employed. Table VI–1 gives approximate ranges of coefficients of friction and the pressure that the materials can withstand.

For automotive applications, standards are set by SAE International. In SAE J866, a set of codes is defined to classify friction materials according to the coefficient of friction, regardless of the material used. Table VI–2 lists these codes.

In problems in this book that require a coefficient of friction, we will use a value of 0.25 unless otherwise stated. Based on the values reported here, this is a relatively low value that should yield conservative designs.

Table VI-1 Coefficients of Friction

Friction material	Dynamic friction coefficient: Dry	Dynamic friction coefficient: In oil	Pressure range (psi)	Pressure range (kPa)
Molded compounds	0.25–0.45	0.06–0.10	150–300	1035–2070
Woven materials	0.25–0.45	0.08–0.10	50–100	345–690
Sintered metal	0.15–0.45	0.05–0.08	150–300	1035–2070
Cork	0.30–0.50	0.15–0.25	8–15	55–100
Wood	0.20–0.45	0.12–0.16	50–90	345–620
Cast iron	0.15–0.25	0.03–0.06	100–250	690–1725
Paper-based		0.10–0.15		
Graphite/resin		0.10–0.14		

Table VI-2 Coefficient of Friction Classification Codes of the Society of Automotive Engineers

Code letter	Coefficient of friction
C	Not over 0.15
D	Over 0.15 but not over 0.25
E	Over 0.25 but not over 0.35
F	Over 0.35 but not over 0.45
G	Over 0.45 but not over 0.55
H	Over 0.55
Z	Unclassified

V.7.1. Materials for Discs and Drums

A variety of metals are applied in the manufacture of brake and clutch discs and drums. The material must have sufficient strength, ductility, and stiffness to withstand the applied forces while maintaining a precise geometry. It must also be able to absorb heat from the friction surface and dissipate it to the environment.

Some of the popular choices are gray cast iron, ductile iron, carbon steel, and copper alloys. Many discs and drums are cast for cost reasons and to obtain near net shape of the parts that require little machining after casting. Cast iron has low cost and high thermal conductivity as compared with ductile iron. However, ductile iron is better able to withstand shock or impact loading. Copper alloys have far higher thermal conductivity than the other materials, but they have poorer wear performance.