

Chapter 2. General Principle of Electromagnetic Brakes

2.1. Introduction

Electromagnetic brakes have been used as supplementary retardation equipment in addition to the regular friction brakes on heavy vehicles. We outline the general principles of regular brakes and several alternative retardation techniques in this section. The working principle and characteristics of electromagnetic brakes are then highlighted.

2.2. General Principle of Brake System

The principle of braking in road vehicles involves the conversion of kinetic energy into thermal energy (heat). When stepping on the brakes, the driver commands a stopping force several times as powerful as the force that puts the car in motion and dissipates the associated kinetic energy as heat. Brakes must be able to arrest the speed of a vehicle in a short periods of time regardless how fast the speed is. As a result, the brakes are required to have the ability to generating high torque and absorbing energy at extremely high rates for short periods of time. Brakes may be applied for a prolonged periods of time in some applications such as a heavy vehicle descending a long gradient at high speed. Brakes have to have the mechanism to keep the heat absorption capability for prolonged periods of time.

2.3. Conventional Friction Brake

The conventional friction brake system is composed of the following basic components: the “master cylinder” which is located under the hood is directly connected to the brake pedal, and converts the drivers’ foot pressure into hydraulic pressure. Steel “brake hoses” connect the master cylinder to the “slave cylinders” located at each wheel. Brake fluid, specially designed to work in extreme temperature conditions, fills the system. “Shoes” or “pads” are pushed by the slave cylinders to contact the “drums” or “rotors,” thus causing drag, which slows the car. Two major kinds of friction brakes are disc brakes and drum brakes.

Disc brakes use a clamping action to produce friction between the “rotor” and the “pads” mounted in the “caliper” attached to the suspension members (see Figure 2.1). Disc brakes work using the same basic principle as the brakes on a bicycle: as the caliper pinches the wheel with pads on both sides, it slows the vehicle (Limpert 1992).

Drum brakes consist of a heavy flat-topped cylinder, which is sandwiched between the wheel rim and the wheel hub (see Figure 2.2). The inside surface of the drum is acted upon by the linings of the brake shoes. When the brakes are applied, the brake shoes are forced into contact with the inside surface of the brake drum to slow the rotation of the wheels (Limpert 1992).

Air brakes use standard hydraulic brake system components such as braking lines, wheel cylinders and a slave cylinder similar to a master cylinder to transmit the air-pressure-produced braking energy to the wheel brakes. Air brakes are used frequently when greater braking capacity is required.

2.4. “Brake Fading” Effect

The conventional friction brake can absorb and convert enormous energy values (25h.p. without self-destruction for an 5-axle truck, Reverdin 1974), but only if the temperature rise of the friction contact materials is controlled. This high energy conversion therefore demands an appropriate rate of heat dissipation if a reasonable temperature and performance stability are to be maintained. Unfortunately, design, construction, and location features all severely limit the heat dissipation function of the friction brake to short and intermittent periods of application. This could lead to a 'brake fade' problem (reduction of the coefficient of friction, less friction force generated) due to the high temperature caused by heavy brake demands. The main reasons why conventional friction brakes fail to dissipate heat rapidly are as follows:

- poor ventilation due to encapsulation in the road wheels,
- diameter restriction due to tire dimensions,
- width restrictions imposed by the vehicle spring designer;
- problems of drum distortion at widely varying temperatures.

It is common for friction-brake drums to exceed 500 °C surface temperatures when subject to heavy braking demands, and at temperatures of this order, a reduction in the coefficient of friction ('brake fade') suddenly occurs (Grimm, 1985). The potential hazard of tire deterioration and bursts is perhaps also serious due to the close proximity of overheated brake drums to the inner diameter of the tire.

2.5. Retarders

Retarders are means of overcoming the above problems by augmenting a vehicle's foundation brakes with a device capable of opposing vehicle motion at relatively low levels of power dissipation for long periods.

There are several retarder technologies currently available. Two major kinds are the hydrokinetic brake and the exhaust brake. Hydrokinetic brake

uses fluid as the working medium to oppose rotary motion and absorb energy (Packer 1974). Hydrodynamic brakes are often built into hydrodynamic transmissions (Foster, 1974). Exhaust brakes use a valve which is fitted into the exhaust pipe between the exhaust manifold and silencer. When this valve is closed air is compressed against it through the open exhaust valve by the piston rising on the exhaust stroke. In that way the engine becomes a low pressure single stage compressor driven by the vehicle's momentum, resulting in a retarding effect being transmitted through the transmission to the driving road wheels. The power-producing engine is converted into a power-absorbing air compressor (Smith, 1974). This approach could put a lot of stress on the cylinder and exhaust system. So it may require extra engineering efforts to implement this system. As a brake applied to the engine, exhaust brakes can only absorb as much power as the engine can deliver. But the power absorbed in braking is usually greater than the power absorbed in driving.

Compared with these retarders, electromagnetic brakes have greater power capability, simplicity of installation and controllability.

2.6. General Principle and Advantage of Electromagnetic Brakes (retarders)

2.6.1. Installation Location

Electromagnetic brakes work in a relatively cool condition and satisfy all the energy requirements of braking at high speeds, completely without the use of friction. Due to its specific installation location (transmission line of rigid vehicles), electromagnetic brakes have better heat dissipation capability to avoid problems that friction brakes face as we mentioned before. Typically, electromagnetic brakes have been mounted in the transmission line of vehicles, as shown in figure 2.2. The propeller shaft is divided and fitted with a sliding universal joint and is connected to the coupling flange on the brake.

The brake is fitted into the chassis of the vehicle by means of anti-vibration mounting.

The practical location of the retarder within the vehicle prevents the direct impingement of air on the retarder caused by the motion of the vehicle. Any air flow movement within the chassis of the vehicle is found to have a relatively insignificant effect on the air flow around tire areas and hence on the temperature of both front and rear discs. So the application of the retarder does not affect the temperature of the regular brakes. In that way, the retarders help to extend the life span of the regular brakes and keep the regular brakes cool for emergency situation.

2.6.2. Working Principle

The working principle of the electric retarder is based on the creation of eddy currents within a metal disc rotating between two electromagnets, which sets up a force opposing the rotation of the disc (see figure 2.3). If the electromagnet is not energized, the rotation of the disc is free and accelerates uniformly under the action of the weight to which its shaft is connected. When the electromagnet is energized, the rotation of the disc is retarded and the energy absorbed appears as heating of the disc. If the current exciting the electromagnet is varied by a rheostat, the braking torque varies in direct proportion to the value of the current. It was the Frenchman Raoul Sarazin who made the first vehicle application of eddy current brakes. The development of this invention began when the French company Telma, associated with Raoul Sarazin, developed and marketed several generations of electric brakes based on the functioning principles described above (Reverdin, 1974).

A typical retarder consists of stator and rotor. The stator holds 16 induction coils, energized separately in groups of four. The coils are made up of varnished aluminum wire moulded in epoxy resin. The stator assembly is

supported resiliently through anti-vibration mountings on the chassis frame of the vehicle. The rotor is made up of two discs, which provide the braking force when subject to the electromagnetic influence when the coils are excited. Careful design of the fins, which are integral to the disc, permit independent cooling of the arrangement.

2.6.3. Electric Control System

The electric wiring diagram of the installation is shown in figure 2.4. The energization of the retarder is operated by a hand control mounted on the steering column of the vehicle. This control has five positions: the first is 'off', and the four remaining positions increase the braking power in sequence. This hand-control system can be replaced by an automatic type that can operate mechanically through the brake pedal. In this case, the contacts are switched on successively over the slack movement of the brake pedal. The use of an automatic control must be coupled with a cut-off system operating at very low vehicle speed in order to prevent energization of the retarder while the vehicle is stationary with the driver maintaining pressure on the brake pedal. Both the manual control and the automatic control activate four solenoid contractors in the relay box, which in turn close the four groups of coil circuits within the electric brake at either 24 volts or 12 volts, as appropriate (Reverdin 1974 and Omega Technologies).

2.6.4. Characteristic of Electromagnetic Brakes

It was found that electromagnetic brakes can develop a negative power which represents nearly twice the maximum power output of a typical engine, and at least three times the braking power of an exhaust brake (Reverdin 1974). These performance of electromagnetic brakes make them much more competitive candidate for alternative retardation equipments compared with other retarders. By using the electromagnetic brake as supplementary

retardation equipment, the friction brakes can be used less frequently, and therefore practically never reach high temperatures. The brake linings would last considerably longer before requiring maintenance, and the potentially “brake fade” problem could be avoided. In research conducted by a truck manufacturer, it was proved that the electromagnetic brake assumed 80 percent of the duty which would otherwise have been demanded of the regular service brake (Reverdin 1974). Furthermore, the electromagnetic brake prevents the dangers that can arise from the prolonged use of brakes beyond their capability to dissipate heat. This is most likely to occur while a vehicle descending a long gradient at high speed. In a study with a vehicle with 5 axles and weighing 40 tons powered by an engine of 310 b.h.p traveling down a gradient of 6 percent at a steady speed between 35 and 40 m.p.h, it can be calculated that the braking power necessary to maintain this speed is the order of 450 h.p. The braking effect of the engine even with a fitted exhaust brake is approximately 150 h.p. The brakes, therefore, would have to absorb 300 h.p, meaning that each brake in the 5 axles must absorb 30 h.p, which is beyond the limit of 25 h.p. that a friction brake can normally absorb without self-destruction. The electromagnetic brake is well suited to such conditions since it will independently absorb more than 300 h.p (Reverdin 1974). It therefore can exceed the requirements of continuous uninterrupted braking, leaving the friction brakes cool and ready for emergency braking in total safety.

The installation of an electromagnetic brake is not very difficult if there is enough space between the gearbox and the rear axle. It does not need a subsidiary cooling system. It does not rely on the efficiency of engine components for its use, as do exhaust and hydrokinetic brakes. The electromagnetic brake also has better controllability. The exhaust brake is an on/off device and hydrokinetic brakes have very complex control system. The electromagnetic brake control system is an electric switching system which gives it superior controllability.

From the foregoing, it is apparent that the electromagnetic brake is an attractive complement to the safe braking of heavy vehicles.

2.6.5. Thermal Dynamics

Thermal stability of the electromagnetic brakes is achieved by means of the convection and radiation of the heat energy at high temperature. The major part of the heat energy is imparted to the ventilating air which is circulating vigorously through the fan of the heated disc.

The value of the energy dissipated by the fan can be calculated by the following expression:

$$Q = MC_p \quad (2.1)$$

where:

M = Mass of air circulated;

C_p = Calorific value of air;

= Difference in temperature between the air entering
and the air leaving the fan;

The electromagnetic brakes has excellent heat dissipation efficiency owing to the high temperature of the surface of the disc which is being cooled and also because the flow of air through the centrifugal fan is very rapid. Therefore, the curie temperature of the disc material could never been reached (Reverdin 1974).

The practical location of the electromagnetic brakes prevents the direct impingement of air on the brakes caused by the motion of the vehicle. Any air flow movement within the chassis of the vehicle is found to have a relatively

insignificant effect on the air flow and hence temperature of both front and rear discs.

Due to its special mounting location and heat dissipation mechanism, electromagnetic brakes have better thermal dynamic performance than regular friction brakes.

2.7. Summary

With all the advantages of electromagnetic brakes over friction brakes, they have been widely used on heavy vehicles where the 'brake fading' problem is serious. The same concept is being developed for application on lighter vehicles.

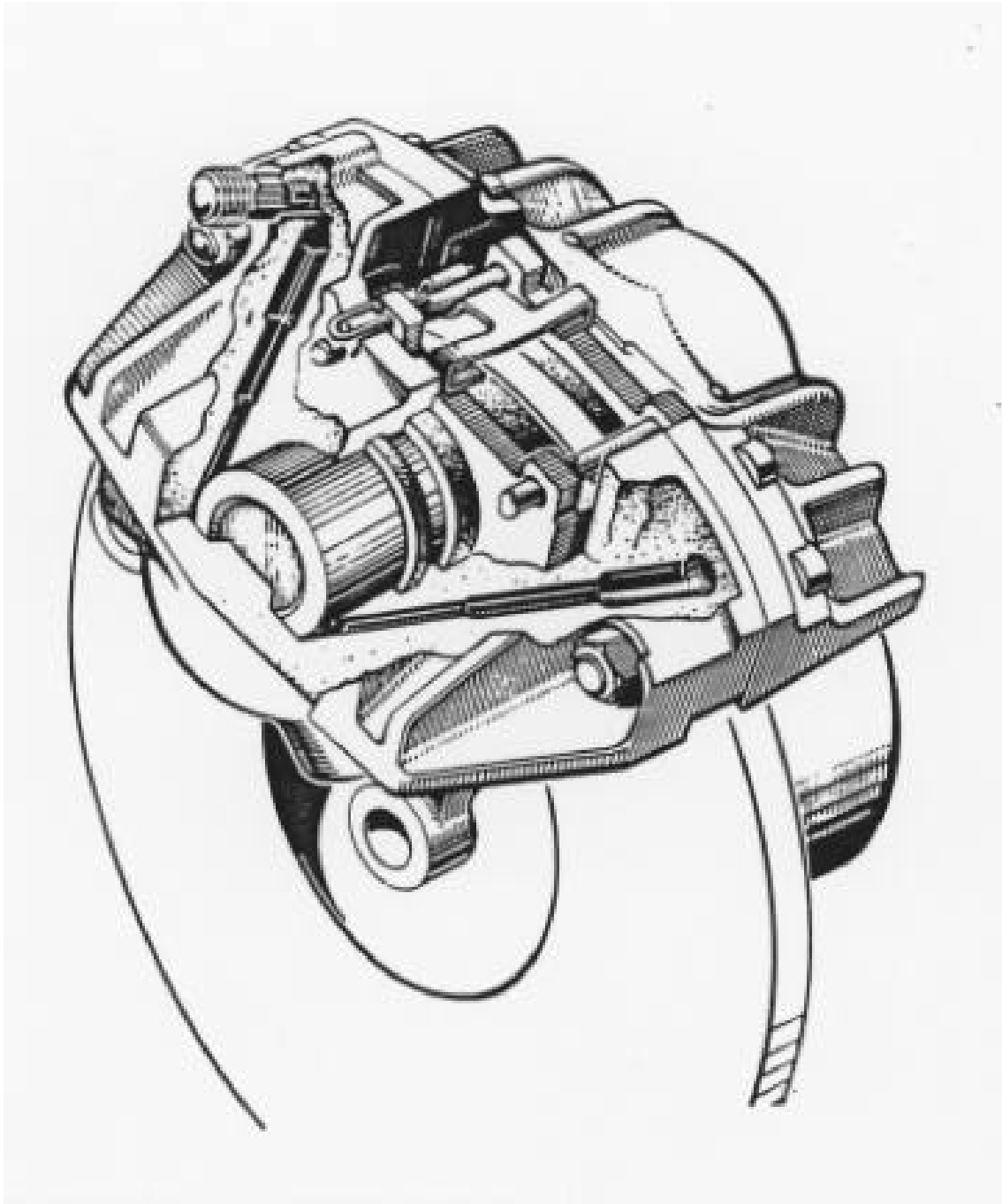
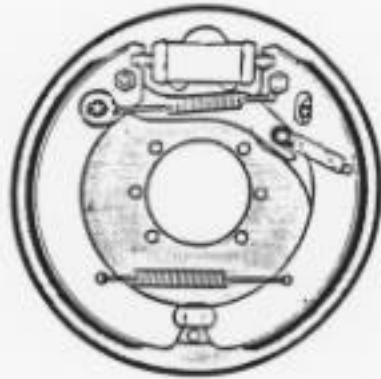
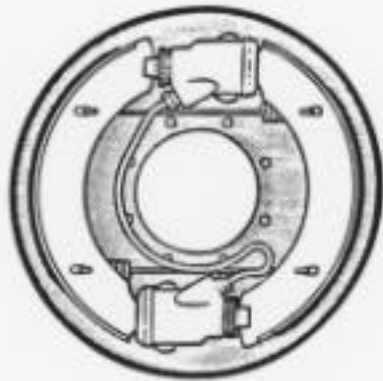


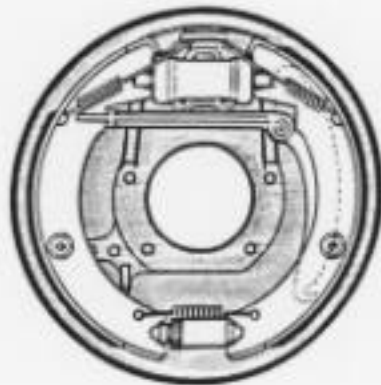
Figure 2.1. Disc Brake (Limpert 1992)



Leading-Trailing Shoe Brake



Two-Leading Shoe Brake



Duo-Servo Brake

Figure 2.2 Drum Brakes (Limpert 1992)