2 Traction Motors

2.1 Types of Motor

Before describing how to select a motor to meet a locomotive performance specification it is appropriate to review the development of the various types of traction motor used in model locomotives.

Early types of motor had the armature set across the frames and drove the axles through spur gears. As more powerful motors were demanded the armature diameter was increased but its length was limited by the dimension between the frames. Turning the armature to run parallel to the frames avoided this limitation and the resulting increase in motor power led to this becoming the normal arrangement.

Figure 2-1 illustrates a Bassett-Lowke 'Permag' motor of this type. Similar motors were produced by Bonds, Leeds Model Co and Milbro. They were usually supplied as a unit complete with gears and locomotive driving wheels.

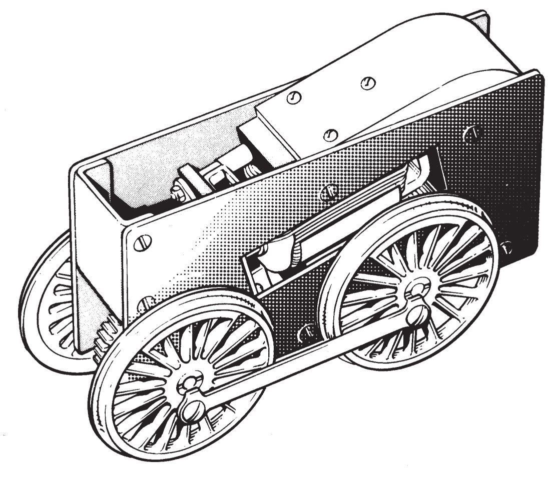

FIGURE 2-1
Bassett-Lowke 'Permag' motor.

Motors with transverse armatures continued to be manufactured, notably by Hornby, and their power was often increased by using wound field magnets in conjunction with reversing switches mounted on the locomotive. These are now generally found only in models of interest to collectors and are outside the scope of this publication. A recent exception is the Lima motor which has a transverse armature and a modern very powerful permanent magnet, a combination which gives adequate power for multiple units and small locomotives.

The motor illustrated in Figure 2-1 was fitted with a single piece permanent magnet but the development of improved magnet steels led to the use of block magnets with separate pole pieces, (Figure 2-2), the improved magnetic strength meant that a lower current was required to produce a given torque.

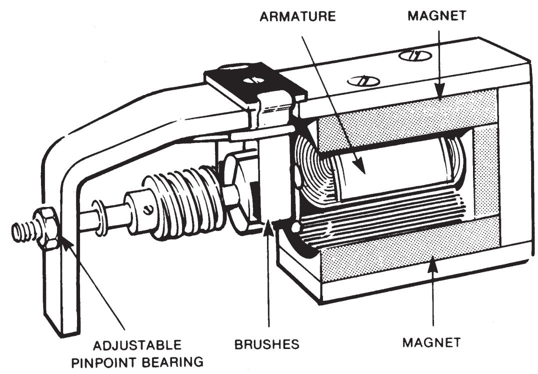

FIGURE 2-2
Romford motor.

After 1945 both solid magnets made from the improved magnet steels and block magnets with separate pole pieces were used but due to their better magnetic properties coupled with ease of manufacture the latter soon became the general practice, although they have now been largely superseded by magnets moulded from still better materials. The Bonds motor illustrated in Figure 2-3 is a post-war design using a block magnet, it was supplied with an integral gearbox which greatly simplified installation.

The development of many devices such as tape recorders and computer printers has enormously increased the demand for small electric motors, many of which are suitable for Gauge O locomotives. At the same time further development of permanent magnets resulted in the production of alloys which, although unmachinable by conventional methods, could be accurately moulded to form pole pieces for small motors.

Figure 2-4 illustrates a motor with this type of magnet. In addition it incorporates a number of

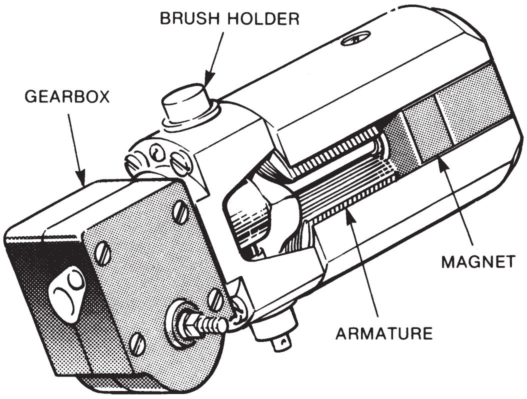

FIGURE 2-3
Bond's motor.

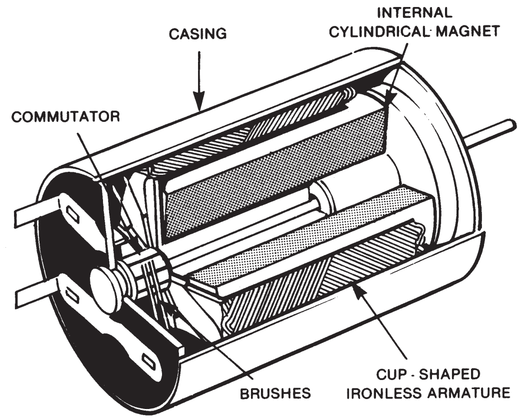

FIGURE 2-5
Typical coreless motor.

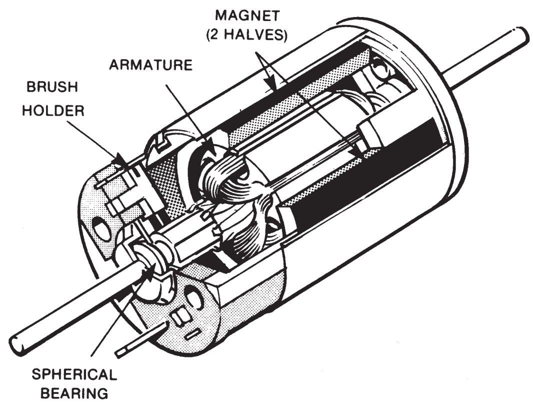

FIGURE 2-4
Typical modern motor with iron armature core.

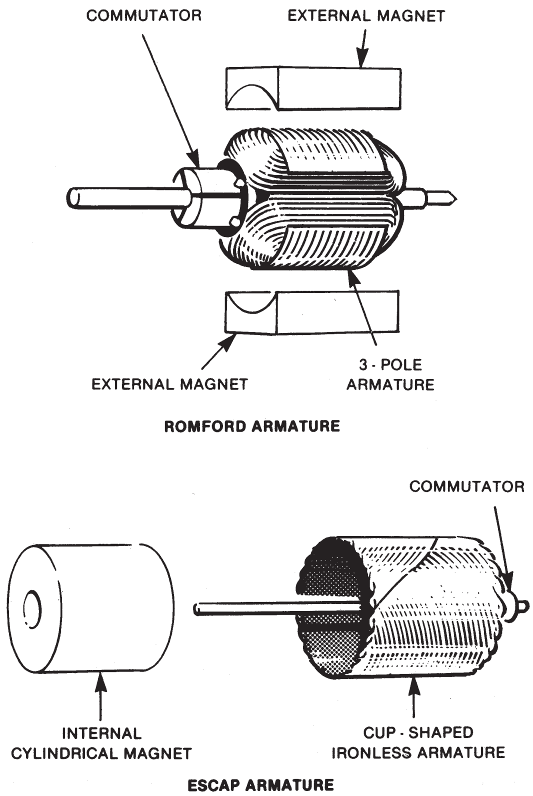

FIGURE 2-6
Comparison of iron cored and coreless armatures.

other features giving improved performance. The armature has an increased number of poles giving a smoother torque, particularly at low speed, and self aligning oil impregnated bearings give low friction at less cost than if ball bearings were fitted. The improved magnet results in a substantially lower current being required to produce a given torque and this in turn reduces the overall size of the motor, which is of considerable advantage to builders of smaller types of locomotive.

The most recent development is the coreless or, more correctly, the ironless armature motor which is rapidly becoming a very common type of miniature motor. Figure 2-5 is a sectional view of a typical coreless motor and Figure 2-6 compares its construction with that of a conventional motor in which the armature winding is mounted on an iron core. The coreless armature winding is produced on a former before being encapsulated in epoxy resin. The resin is then cured to solidify it after which the former is removed, leaving the cup shape shown in Figure 2-6. When the motor is assembled a stationary cylindrical magnet forms the armature core instead of the conventional rotating core built up from iron stampings. Coreless motors have the highest efficiency and therefore the smallest size of any of the types used by modellers but they have the disadvantage of being more liable to be damaged by overloading than other types. (This subject is dealt with in greater detail in the clauses covering motor theory and selection).

2.2 Motor Theory

When selecting a motor it is useful to have some knowledge of motor theory as statements are often made about amps, volts and magnets which are not necessarily wrong but are often over simplified and can lead to wrong conclusions.

The fundamental relationships which apply to all direct current motors, large and small, are:-

Torque is proportional to:-

Armature current x (magnetic field strength x number of armature conductors).

Note that voltage does not feature in this relationship.

No load speed is proportional to:-

Voltage ÷ (magnetic field strength x number of armature conductors).

There are constants in these relationships which depend on the type of armature winding but these are not relevant to these notes.

For permanent magnet motors as used on model locomotives the magnetic field is substantially constant and so for any given motor the relationships can be simplified to:-

Torque (and hence tractive effort) is proportional to current.
No load speed is proportional to voltage.

These relationships are strictly true only if there is no reduction in torque due to friction or magnetic losses and if no voltage is absorbed by the motor resistance. The major loss in the small motors used in model locomotives is that arising from the armature resistance, magnetic (iron) losses are negligible but friction losses may be significant at high speed or if the brush pressure is too high. Friction in the gear train can have a major effect on the suitability of a motor for a given application but it does not affect the torque at the motor shaft. (Gear friction is dealt with in Section 3).

The torque produced by a motor can be increased simply by forcing more current through it by raising the voltage, but in so doing the resistance losses are increased in proportion to the square of the current. These losses produce heat and if excessive current flows the insulation of the winding is destroyed and the soldered joints, and in extreme cases the wire itself, are melted. This is what is meant by 'burning out' the winding.

Unlike their full size counterparts most model locomotive motors can be stalled at full voltage for a few seconds without damage but this is in no way a practical operating condition and if it occurs the motor is being seriously overloaded. It can, however, arise from a derailment and some motors. particularly the coreless armature type, require the provision of fuses or other means of protection to prevent serious damage under these circumstances.

CAUTION: Cut-outs on power units are provided to protect the power unit from damage due to overloading, they do NOT protect the locomotive motors.

The great improvement in the performance of small motors in recent years has been due to the development of permanent magnets which can create a much stronger magnetic field than was previously possible. Consequently there has been a dramatic reduction in the current required to produce a given torque and as resistances losses are proportional to the square of the current motor efficiency has greatly increased. (This is often attributed to the 'efficiency' of the magnet but this is a misnomer as it does not consume any power, 'effectiveness' is therefore a better term).

This improvement is demonstrated by comparing the performance of the motors given in the table below, from which it will be seen that although both have almost the same top speed motor B produces 50% more stalled torque for only 38% of the current taken by the earlier design.

Comparison of Two Designs of Small Motor

Motor	No Load Speed rpm	Stalled Torque gm cm	Stalled Current amps
A	4800	150	2.1
B	4570	225	0.8

2.3 Flywheels

Due to better magnetic circuit design minimising the variation in torque during each revolution, the ability of small motors to run smoothly at slow speed is now greatly improved compared with earlier types. In some cases the variation was so great that stalling occurred at certain armature positions, a considerable increase in voltage being necessary to re-start rotation. This is termed ‘cogging’ or ‘magnetic locking’. Older motors with three pole armatures and weak magnets were particularly prone to it, which probably led to high gear ratios and flywheels becoming fashionable.

A flywheel increases the inertia of the drive system and thus minimises the effect of torque variations. As its effect is proportional to the square of its speed it should run at motor speed and consequently is usually most conveniently mounted on an unused shaft extension of a double ended motor. To be most effective the wheel should have the largest diameter which can be accommodated in the body and have its weight concentrated in the rim. Accurate balancing is essential to prevent vibration.

With older types of motor the benefit of fitting a flywheel can be significant, but with modern motors used in conjunction with a good supply system the improvement resulting from fitting a practical size of flywheel is likely to be only marginal.

A well designed and correctly applied modern motor will propel a locomotive at scale walking pace without recourse to a flywheel, but fitting one to motors which drive the wheels through an irreversible worm gear will prevent abrupt stops when power is shut off and will give smoother running if the electrical contact between wheel and rail becomes intermittent. The increased drive inertia will give slower acceleration but the overrun on switching off power will make precise stopping more difficult.

2.4 Motor Voltage

It is customary to refer to motors as ‘12 volt’ or some other value. This is somewhat of a misnomer because it means only that the motor will give the stated speed and torque at that voltage and does not necessarily mean that it cannot be used on other voltages.

It has already been stated that the applied voltage determines the speed at which a motor will run or, if it is stalled, the current which will flow through it. Thus increasing the voltage will either increase the speed or start it if it is stalled. Hence regulation by various means of the voltage at the motor terminals is the basis of all speed control.

It is permissible to increase the performance of a motor by increasing the voltage provided that **both** the following conditions are complied with:-

a) The current taken is not increased to a value which will cause overheating. This is only likely to occur if the motor is loaded so that it either runs at a very slow speed or even stalls. Warning of overheating is given by a smell of hot insulation or the emission of smoke, in which case either the duty should be reduced or a more powerful motor fitted. It is stressed that motors can be burnt out at any voltage if they are loaded so that the designed current is exceeded except for short periods when accelerating or climbing gradients.

b) The no-load speed is not increased to a value which will cause damage.

Note: ‘Ironless’ or ‘coreless’ motors, which are being increasingly used on model locomotives, have less heat capacity than motors with iron cored armatures and so are more likely to suffer damage from short-time overloads. In some cases it is necessary to fit fuses or other current limiting devices to the locomotive to prevent burn out due to overload or lock up arising from derailment.

2.5 Operation of ‘12 volt’ Motors on Higher Voltage.

As will be seen from the data sheets many nominally 12 volt motor and gearbox units develop more than adequate starting tractive effort but are deficient in top speed. If the no-load motor speed on 12 volts is below the mechanical limit this deficiency can be reduced without harming the motor by increasing the voltage. (If motor speed is at the limit a higher supply voltage can still be used if the locomotive is fitted with a voltage limiting device. Details of a suitable circuit are given in 2.8).

Even if a motor has an acceptable performance on the nominal 12 volts increasing the voltage can be beneficial if the gear ratio is changed to give the same train speed on the higher voltage as on the lower one, as is illustrated by the following example.

If a current of 1 amp is taken when hauling a train with the motor supplied at 12 volts the power consumed is 12 watts. Provided there is no significant change in the efficiency of the motor and gearing this power will remain constant whatever the supply voltage.

The motor speed is approximately proportional to the voltage and if the latter is doubled the motor speed will also double. Therefore in order to maintain the same train speed the gear ratio will have to be doubled.

As the power remains constant at 12 watts the current will fall in inverse proportion to the increase in voltage, i.e., to a close approximation doubling the voltage and the gear ratio will maintain the same train speed at half the current.

It is stressed that this is only permissible if the motor design allows the no-load speed to be increased.

2.6 Supply Voltage

The voltage of a motor is the value at its terminals. In the case of locomotive motors there is a voltage drop between the wheel and the rail and at other contacts. There may also be a significant voltage drop in the feeder system which could be as high as 3 Volts on the long feeders of an outdoor line. Thus the power unit should supply at least 1 and preferably 3 volts above the nominal motor voltage and this value should be maintained up to the full load current of the unit.

This is not always the case as the voltage output of some power units falls with load to an extent which significantly affects motor performance. (See also Part 8, Section 1).

There are considerable advantages to be gained by increasing the voltage to as much as 24 volts especially on large systems. These are as follows:

a) A higher voltage increases the reliability of electrical contact between wheel and rail to such an extent that track cleaning is greatly reduced. With series resistance controllers interruption of the current due to track conditions when running slowly causes the full supply voltage to appear between the wheel and rail and it is obvious that the higher is this voltage the better is the chance of restoring contact before the train comes to a standstill.

b) This effect is particularly advantageous on outdoor railways on which track conditions are rarely as good as on indoor lines. Even if the motor performance on 12 Volts is adequate it is worth obtaining this improvement by using a higher voltage supply and reducing the voltage by electronic means on the locomotive. (As stated above voltage limitation on the locomotive may also be necessary to avoid damaging some types of motor).

A further advantage of a higher voltage supply is that the lower current for a given power will reduce both the actual volt drop in the feeder system and its proportion of the supply voltage.

2.7 Motor Speed/Torque Characteristics

A number of bench tests have been carried out to provide data which locomotive builders can use to select a suitable motor. In addition some motor suppliers have published similar data. Whilst the tests were sufficiently accurate and consistent for their purpose, they were not intended to be regarded as precision laboratory checks on manufacturer's data and must not be used as such. However, considering the relatively simple test methods the consistency and accuracy of the results was remarkable and higher than was at first expected.

It was found that an adequate assessment of motor performance could be obtained from the results of the following two tests.

1 Stalled torque with respect to current.
2 No-load speed at full voltage.

The results enabled the speed/torque characteristic of the motor to be drawn with sufficient accuracy for the purpose, typical results for two motors being shown by Figure 2-7.

The motors tested had a range of no-load speeds from over 8000 rpm down to 2600 rpm and torques from 35 to 700 gram centimetres, but before this data can be put to practical use it must be converted to track speed and tractive effort. This conversion is the subject of the following Sections on Gearing and Locomotive Characteristics.

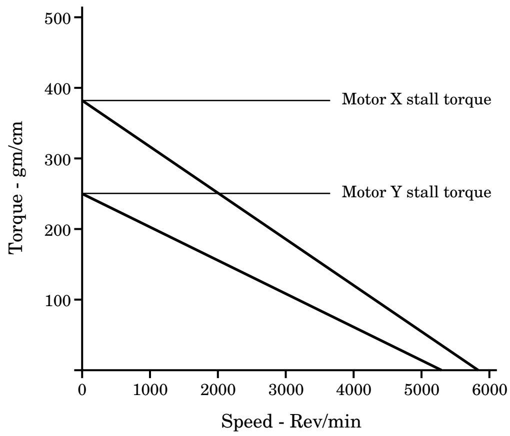

FIGURE 2-7
Typical motor speed/torque characteristics.

2.8 Motor Voltage Limiting Circuit

Although the majority of nominally 12 Volt model traction motors are suitable for operation on up to at least 24 volts some are not, and if they are to be run on a supply above their designed maximum voltage a voltage limitation device must be fitted in the locomotive.

This can be either a simple series resistance or an electronic circuit. The former method is inevitably a compromise because if the resistance value is such that the motor voltage is limited to 12 on light load it will be lower on full load. Most motors which require voltage limitation will be high efficiency types with no-load speeds at their nominal voltage of over 10,000 rpm and full load currents of the order of 0.25A. A 56 Ohm 7 Watt standard resistor will mount easily between the frames of a locomotive and will drop 14 volts at 0.25A but the best compromise will depend on the characteristic of the particular motor. A better means of voltage limitation is to use an electronic voltage divider, a typical circuit which will provide a voltage proportional to the supply voltage being shown in Figure 2-8.

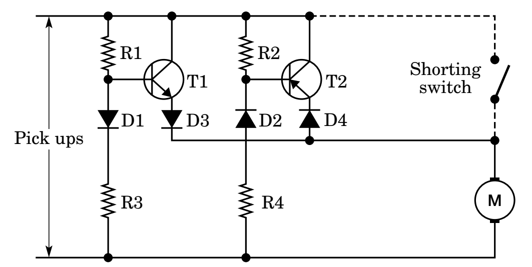

FIGURE 2-8
Motor voltage divider circuit.

This will supply the types of Gauge O motor likely to need a voltage divider providing transistors T1 and T2 have heatsinks which allow them to pass the full motor current without overheating.

To give approximately half the supply voltage to the motor the ratio of R1 to R3 and R2 to R4 should be approximately 2 to 5, suitable standard values for R1 and R2 being 2kΩ and for R3 and R4 4.7kΩ or 5.1kΩ, all rated at 0.25W.

The rating of diodes D1 and D2 is not critical but D3 and D4 must be able to carry the maximum motor current, type IN5401 is suitable.

T1 and T2 are Darlington transistors with heatsinks, types TIP 120 or TIP 121 being suitable for T1 and types TIP 125 or TIP 126 for T2. For low power applications types BD 679 and BD 680 can be used.

If desired R1 and R2 can be variable so that the proportion of the supply voltage fed to the motor can be adjusted.

An optional shorting switch is shown. This allows the motor to be fed with the full supply voltage if this facility is required.

2.9 Reversal of Wound Field Motors

On this type of motor the field magnetism is produced by current flowing through a coil surrounding the magnetic circuit instead of by a magnet made from special material which, when once magnetised, retains this property, hence the term permanent magnet.

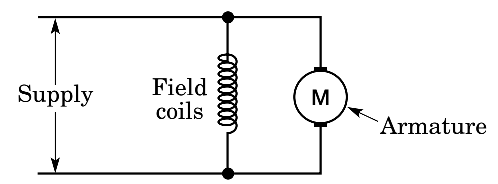

FIGURE 2-9A
Shunt wound motor.

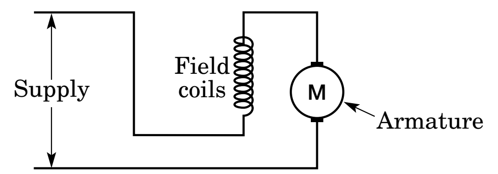

FIGURE 2-9B
Series wound motor.

The field coil can either be connected in shunt across the armature and the supply, Figure 2-9a, or in series with the armature, Figure 2-9b, the latter being by far the most common. Shunt wound motors will only operate on direct current but, series wound ones will work on either direct or alternating current and are often referred to as universal motors; they are extensively used in power tools and domestic appliances. Series connection is essential for alternating current because the current in the field and armature must reverse at the same instant. This is not the case with a shunt connection because the inductance of the field circuit causes its current to lag behind that in the armature.

Wound field motors have been used in model locomotives for two reasons, firstly because when electrically driven models were first introduced permanent magnets were very much weaker than they are today, and secondly because some model manufacturers decided to use alternating current which, as already stated, made wound field series motors obligatory. The development of stronger permanent magnets, combined with the availability of cheap rectifiers to produce direct current, has made the wound field motor obsolescent although there are many 'collectors' models still in service fitted with one.

The great disadvantage of a wound field motor is that normally it cannot be reversed by changing the polarity of the track supply. This is because doing so changes the direction of the current in both the armature and field and so does not alter the direction of rotation. To operate on ac, the relative direction of current in the armature and field windings must be altered by a switch on the locomotive. See Figures 2-10a and 2-10b.

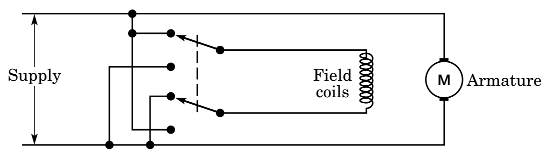

FIGURE 2-10A
Reversing a shunt wound motor.

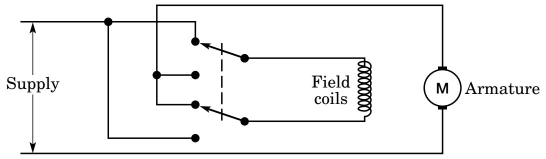

FIGURE 2-10B
Reversing a series wound motor.

This can either be hand operated or a sequence reverser which operates each time the current is switched on. Neither method is an ideal solution, but when rectifiers were relatively very much more expensive than they are today they did allow a cheap supply system to be employed, 6 and 20 volt ac series motors being fairly widely used, particularly by 'train set' manufacturers such as Hornby.

For operation on dc only, and as an alternative to using a reversing switch as described above, the availability of small diodes (which are electronic devices which pass current in one direction only) makes possible a very simple and cheap method of reversing a wound field motor by changing the polarity of the supply, but it is stressed that a motor so modified will not work on ac.

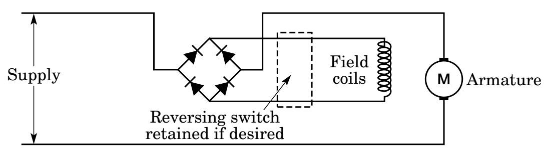

FIGURE 2-11A
Reversing a shunt wound motor using individual diodes.

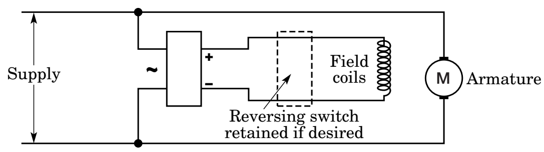

FIGURE 2-11B
Reversing a shunt wound motor using a full wave rectifier.

The method consists of supplying either the field winding or the armature through diodes connected in such a way that the current flows through the chosen winding in the same direction irrespective of the polarity of the supply. The diodes, which as a general rule should be able to carry at least 3 amps and withstand not less than 50 volts reverse voltage can be either four separate ones (Figure 2-11a) or a single bridge rectifier (Figure 2-11b). The latter will usually be the better arrangement. A number of suitable types small enough to be mounted between the frames of 'steam' locomotives are readily available from electronic component dealers. There is no need to remove the original reversing switches, retention of which can be an advantage on three rail systems because it allows locomotives to run 'nose to tail', which would not normally be possible.