# 3 Gearing

## 3.1 General

In order to transmit power from the motor to the driving wheels some form of transmission must connect the two, gears being the type most used on Gauge O locomotives. As driving wheels do not normally rotate at more than 750 rpm and motors run at at least 2500 rpm this must include a means of speed reduction.

Figure 3-1 illustrates simple spur gears as used on motors with transverse armatures. The number of stages used, usually two, is dependent on the motor speed. Some motors of this type have the axles coupled by the gearing, the coupling rods being purely ornamental. Gear ratios range from 8 to 1 up to 15 to 1. They are often expressed in terms of the number of teeth on the gears, e.g. 64/8 is a typical 8 to 1 ratio.

**Note:** There is often confusion regarding the meaning of high and low ratio. This probably arises from road vehicle practice which refers to a high gear ratio between engine and wheel speeds as being in 'low gear'. As an example of the nomenclature used throughout this manual 25 to 1 would be called a high ratio and 6 to 1 a low ratio.

Most motors now have the armature shaft at right angles to the axles, which involves using one of the various types of right angle drive, the simplest being a crown wheel and pinion. For a given crown wheel the gear ratio can be varied by altering the number of teeth on the pinion (as in Meccano gearing) but the mesh can never be perfect and therefore this type of gear is not extensively used on model locomotives. A pair of matched bevel wheels as in Figure 3-2 can be used to provide the right angle turn but it is seldom possible to obtain the desired ratio within the available space. They are therefore usually employed in conjunction with one or more stages of spur gears and provide a high efficiency, although sometimes noisy, drive. Leeds Model Company used this type of drive with 2 to 1 bevel gears followed by 12 to 30 and 13 to 33 spur gears to give an overall ratio of 12.7 to 1.

32/16 x 30/12 x 33/13 = 12.7 to 1

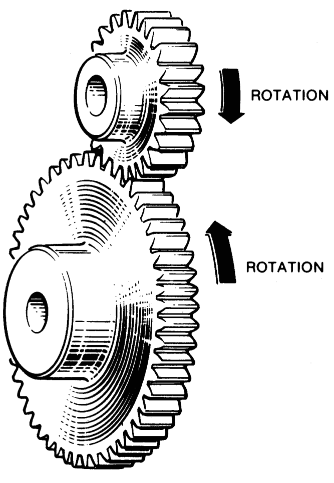


FIGURE 3-1
*Spur gears*

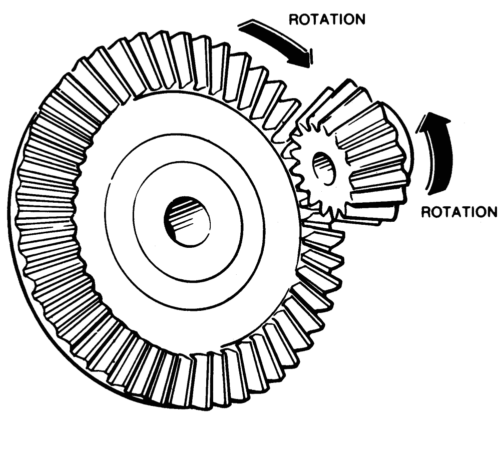


FIGURE 3-2
*Bevel gears*

Another type of high efficiency right angle drive, illustrated by Figure 3- 3, is crossed helical (or spiral bevel) gears but these also have limits on the ratio which can be fitted into the space available on model locomotives. They are being increasingly used in conjunction with spur gears for integral gearboxes fitted to high speed motors.

The most compact type of right angle drive for model locomotives is worm gearing mounted directly on the motor. This can usually provide the desired ratio in a single stage, although often with considerably lower efficiency than other types.

Worms can have one or more 'starts'. A single start worm advances the driven worm wheel by one tooth and its appearance is similar to a threaded screw. Increasing the angle of the thread (the lead angle) permits a number of parallel threads to be

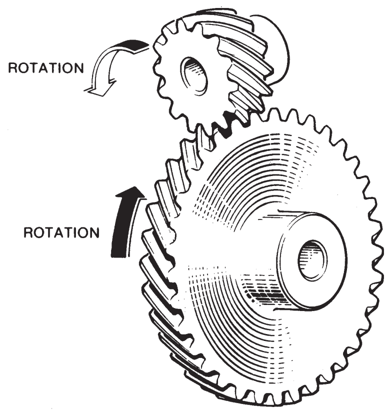


FIGURE 3-3
*Crossed-helical gears*

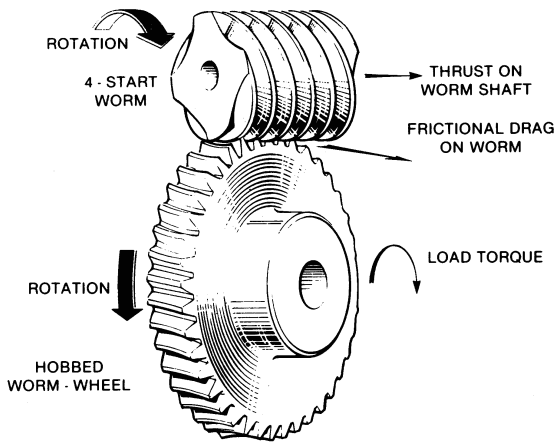


FIGURE 3-4
*Worm gears*

cut so that one revolution of the worm advances the wheel by a number of teeth equal to the number of threads, the gear ratio being the number of teeth on the worm wheel divided by the number of starts. Figure 3-4 shows a four start worm and 48 tooth wheel giving a 12 to 1 ratio.

Despite the development of more efficient arrangements the simplicity and compactness of this type of gearing result in its still being extensively used.

## 3.2 Determination of Gear Ratio

Once the performance requirements of a locomotive have been established the next step in determining the suitability of a motor is to decide on the gear ratio necessary to meet these requirements. The optimum ratio is calculated from the no-load speed of the motor by means of the following formula.

$$\text{Gear Ratio} = \frac{\text{rpm} \times K \times D}{336 \times \text{MPH}}$$

Where: rpm = No-load motor speed on nominal voltage.

D = Prototype wheel diameter in inches. (If D is in mm 336 becomes 8534).

MPH = Desired maximum train speed.

K is a factor to take account of the fall in speed of the motor when loaded. Its value depends on the slope of the particular motor characteristic but 0.75 is sufficiently accurate for the initial stage of motor selection. It can be corrected later if this is found to be necessary.

Taking a typical mixed traffic locomotive as an example, if the driving wheel diameter is 6ft, the desired train speed 75mph and the no-load speed of the proposed motor 6000 rpm, the optimum gear ratio will be:

$$\frac{6000 \times 0.75 \times 72}{336 \times 75} = 12.9 \text{ to } 1$$

(This will give a theoretical 'no-load' speed of 100 MPH)

It is unlikely that the exact gear ratio will be obtainable and therefore the nearest suitable one will have to be used.

## 3.3 Gear Efficiency

Most model locomotives drive through one stage of worm gearing and it is important to appreciate that, for given diameters of worm and wheel, tooth friction causes the efficiency of the drive to fall rapidly as the ratio increases, particularly if the lubrication is inadequate. Failure to appreciate this has resulted in many disappointments.

It can be proved mathematically that if a worm gear is not reversible, i.e. the motor cannot be driven by turning the locomotive wheels, the efficiency is below 50% and, conversely, in order to be reversible the efficiency must exceed 50%. Efficiency of worm gearing can be greatly improved by increasing the lead angle of the teeth, but this may result in the diameter of the worm being reduced to such an extent that it can no longer be mounted directly on the motor shaft and so a separate gearbox must be employed. This subject is referred to in greater detail in a later section.

The efficiency of a particular set of gears is greatly influenced by the tooth accuracy and finish, the accuracy of mounting, the material from which the gears are made, the type of thrust bearing and the quality of the lubrication. Although efficiencies exceeding 50% are obtainable with high quality worm gears mounted in separate enclosed gearboxes with proper lubrication, the efficiency of 'standard model quality' open worm drives becomes very low at ratios above about 20:1 and the use of a two-stage worm and spur drive or high efficiency gearing will give greater haulage capacity at the desired speed. If the best use is to be made of the motor power the fitting of the latter may well be considered justified for all ratios.

### 3.3.1 Efficiency Graph

The efficiency graph (Figure 3-5) shows average efficiency curves for a range of worm gear combinations. The efficiency of a particular gear ratio can be read off and used in the performance calculations which are described in Part 3, Section 4.

As a general guide, the efficiency of properly mounted worm gears should fall within a band 5% above or below the average efficiency curve illustrated. If a particular gearing combination efficiency falls below that band it needs to be inspected to discover where the fault lies. It is very important to ensure that slight backlash is present in a worm drive and that the gearbox frame does not distort under load. In extreme cases distortion of the box can cause total lock-up of the drive.

The efficiency of spur and crossed helical gears can vary considerably, from the low 90s down to 80% for spur gears and 70% for helical gears in the worst cases. For the purposes of calculation, nominal values of 85% and 75% respectively should be adopted. The percentage efficiency of multi-stage gearing is the efficiency of the first stage multiplied by the efficiency of the subsequent stages expressed as a decimal.

As an example, a three stage gearbox having two spur stages and a helical gear stage would have an nominal efficiency of 85 x 0.85 x 0.75 = 37%. With careful construction and lubrication this figure can be exceeded.

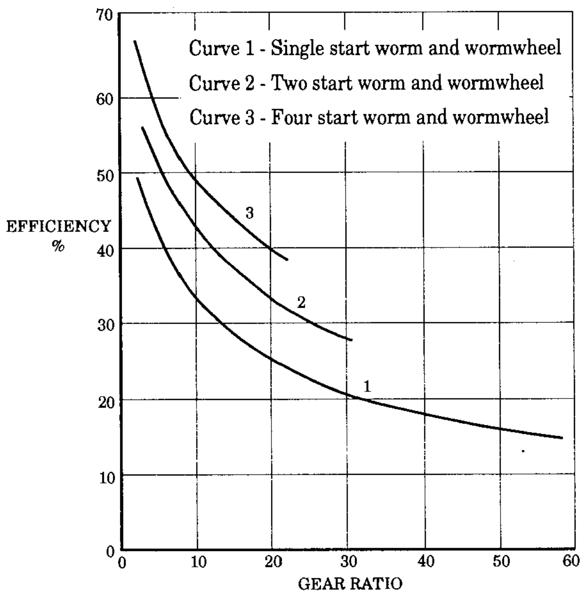


Figure 3-5 - *Typical Gear Efficiencies for Model Quality Wormgear Sets*

## 3.4 Gear Ratio Tables

Most gearset suppliers have more than one combination of gears on their lists. To select the most suitable ratio for a particular duty decide on an appropriate maximum scale speed for the model. In Table 1 use the nearest speed and driving wheel diameter to find the driving axle rpm.

In Table 2 use the driving axle rpm obtained from Table 1 and the motor rpm, which can be obtained from either the motor data sheets or manufacturer's data, to find the gear ratio. The final figure is an approximation but is suitable for model purposes.

**Note:** The gear ratios shown in the table have been calculated to take account of the loss of speed in a loaded motor. (see Section 3.2)

## 3.5 Gear Materials, Quality and Cost

Commercially produced gearing falls into three broad types. The decision to select a particular type would be influenced by the duty to be performed and the cost.

**Table 1 - *Driving axle rpm (to nearest 5rpm)***

| | Driving wheel diameter | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Speed mph | 2ft 10in 850mm | 3ft 6in 1070mm | 4ft 1220mm | 4ft 6in 1370mm | 5ft 1520mm | 5ft 6in 1680mm | 6ft 1830mm | 6ft 6in 1980mm | 7ft 2130mm |
| 20 | | 160 | 140 | 125 | 110 | 100 | | | |
| 30 | | 240 | 210 | 185 | 170 | 155 | 140 | | |
| 40 | | 320 | 280 | 250 | 220 | 200 | 185 | 170 | |
| 50 | | 400 | 350 | 310 | 280 | 255 | 235 | 215 | 200 |
| 60 | | 480 | 420 | 375 | 335 | 305 | 280 | 260 | 240 |
| 70 | 700 ● | 560 | 490 | 435 | 390 | 355 | 325 | 300 | 280 |
| 80 | 800 ● | 640 | 560 | 500 | 450 | 410 | 375 | 345 | 320 |
| 90 | 950 ● | 720 ● | 630 ● | 560 ● | 505 | 460 | 420 | 390 | 360 |
| 100 | 1050 ● | 840 ● | 700 ● | 620 ● | | | | | |
| 125 | 1320 ● | 1050 ● | 875 ● | 780 ● | | | | | |

● Modern diesel and electric locomotive and MU classes.

**Table 2 - *Gear ratio to nearest whole number***

| | Axle RPM | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No-load Motor RPM | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 700 | 800 | 900 | 1000 | 1100 | 1200 | 1300 | 1400 |
| 6000 | 30 | 23 | 18 | 15 | 13 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 5 | 4 | 4 | 4 | 3 | 3 |
| 7000 | 35 | 27 | 21 | 18 | 15 | 13 | 12 | 11 | 10 | 9 | 7 | 6 | 6 | 5 | 5 | 4 | 4 | 4 |
| 8000 | 40 | 30 | 24 | 20 | 17 | 15 | 13 | 12 | 11 | 10 | 8 | 7 | 7 | 6 | 5 | 5 | 5 | 4 |
| 9000 | 45 | 34 | 27 | 23 | 19 | 17 | 15 | 13 | 12 | 11 | 9 | 8 | 7 | 7 | 6 | 6 | 5 | 5 |
| 10000 | 50 | 38 | 30 | 25 | 21 | 19 | 17 | 15 | 14 | 12 | 10 | 9 | 8 | 7 | 7 | 6 | 6 | 5 |
| 11000 | 55 | 42 | 33 | 28 | 24 | 21 | 18 | 17 | 15 | 14 | 12 | 10 | 9 | 8 | 7 | 7 | 6 | 6 |
| 12000 | 60 | 45 | 36 | 30 | 26 | 22 | 20 | 18 | 16 | 15 | 13 | 11 | 10 | 9 | 8 | 7 | 7 | 6 |
| 13000 | 65 | 49 | 39 | 33 | 28 | 24 | 22 | 20 | 18 | 16 | 14 | 12 | 11 | 10 | 9 | 8 | 7 | 7 |

For ratios greater than 20:1 a two stage reduction will give improved gear train efficiency

The least expensive type are those gears made for general use in construction models, the best known being Meccano. They are mainly produced in brass or delrin and have a fairly simple tooth form. These gears are suitable for light duties. The main drawback is that where a large gear ratio is required involving the use of a worm there are no proper wormwheels. In the Meccano range a single start worm drives any standard spur gear which has a suitable number of teeth to give the required ratio. As the spur gears have their teeth cut parallel to the shaft the contact area between them and the worm is a point contact. If the lubrication is poor or the power delivered quite high this can create rapid tooth wear. Therefore they cannot be recommended for use in large locomotives required to haul heavy trains regularly.

Most gears supplied by model shops fall into the middle price range and are satisfactory for all but the most onerous duties. They are usually cut to a correct involute tooth form from suitable materials, i.e., steel worm and hard brass wormwheels or steel pinions and hard brass spur gears. They are available in a range of sizes and pitches so that almost any ratio can be made up.

The most expensive gears are those supplied for light industrial purposes and are of high quality. Worms are of hardened and polished steel, often stainless steel, and wormwheels of phosphor bronze; spur gears are available in similar materials. The cost of these gears is between 1½ and 2 times that of the average model gear sets but correctly fitted they will last a lifetime. Gears of this quality are fitted into enclosed gearboxes available from several specialist suppliers.