4 Calculation of Locomotive Performance Characteristics

4.1 Tractive Effort

Section 1.6 describes how to calculate the tractive effort which a locomotive has to develop in order to perform a specified duty. Section 2 describes the various types of motor used for Gauge O locomotives, including the basic theory of their application, and Section 3.2 describes the selection of suitable gearing to couple them to the driving wheels.

Having determined the gear ratio it is necessary to ascertain whether the locomotive tractive effort will be sufficient for the intended duty. For model purposes it is sufficiently accurate to regard the tractive effort characteristic curve with respect to speed as being a straight line rising from zero at a locomotive speed corresponding to the motor no-load speed to a maximum corresponding to the motor stalled torque. Both the no-load speed and the stalled torque, which are either obtained from the manufacturer's data sheet or determined by tests, are the values at the maximum motor voltage for the particular application.

The theoretical 'no-load' speed in scale MPH is given by:

Equation 1 $$\text{MPH} = \frac{\text{rpm x D}}{\text{336 x GR}}$$

Where: rpm = Motor no-load speed on full voltage
D = Prototype wheel diameter in inches
GR = Gear ratio

The stalled tractive effort in grams is given by:

Equation 2 $$\text{Tractive effort} = \frac{\text{Stalled torque (gm.cm) x 2 x GR x \% gear efficiency}}{\text{Model wheel diameter (mm) x 10}}$$

In this calculation the friction in the locomotive bearings and motion is not taken into account as it is included in the total tractive resistance of the train, (see Section 1.6).

4.2 Motor Current Limitations

Having determined the characteristic necessary to meet the performance requirements and selected a motor and gear ratio which seem suitable it is necessary to confirm that the motor can carry the load current without overheating.

Current is proportional to tractive effort and, if the stall or intermediate speed values are known, its value at any point on the characteristic can be derived from them. If, however, the no-load current is also known the following formula will give a more accurate result than simple proportioning.

If the current at tractive effort $T_1 = I_1$ amps and at no-load = I_0 amps then the current I_2 at tractive effort T_2 will be:

$$\frac{(I_1\text{-}I_0) \text{ x } T_2}{T_1} + I_0$$

Some motor data sheets give the limiting maximum and continuous currents which the motor can withstand and these should not be exceeded. If this information is not available a general guide is that the speed of the heaviest train when on full voltage should not fall below about 60% of the light locomotive speed at the same voltage except when accelerating or climbing short gradients. In order to meet this requirement it may be necessary in some cases to fit a motor which will give the locomotive a higher stalled tractive effort than at first calculated. It is particularly important to check the current capacity of coreless motors as they are easily damaged beyond repair by short-time overloads which other types can withstand without harm.

Note: The final stage in selecting a motor is to check that it will fit into the space available in the locomotive chassis and body. Although accommodating the older types of motor in small locomotives was sometimes a problem, the smaller size of present day motors has largely overcome this. However, if the motor first chosen is found to be too large for the available space it may be necessary to use an alternative requiring some compromise in the performance characteristic.

Motor mounting and drive arrangements are described in a later section.

4.3 Worked Example

Application: 4-6-0 mixed traffic locomotive capable of the performance specified in Section 1.		
Driving wheel diameter :		72 inches
Motor no-load speed :		6000 rpm
Stalled torque :		325 gm.cm
Suitable gear ratio as calculated in Section 3 (k = 0.75) :		12.9 to 1
Nearest available gear ratio :		12.5 to 1
Gear efficiency :		30%

From equation 1:

The theoretical 'no-load' track speed: $\frac{6000 \times 72}{336 \times 12.5}$ = 103 MPH

From equation 2:

The stalled tractive effort: $\frac{325 \times 2 \times 12.5 \times 30}{42 \times 10}$ = 580 grams

The following tractive effort requirements for this type of locomotive are derived in Section 1.

Tractive effort to haul a passenger train at 75 MPH on level track:	190 grams
Tractive effort to haul a passenger train on 1 in 70 + 2.4m curve :	330 grams
Tractive effort to haul a freight train at 45 MPH on level track :	270 grams
Tractive effort to haul a freight train on the grade and curve :	475 grams
Maximum starting tractive effort :	502 grams

Note: All the above are total values which include a locomotive frictional resistance of 70 grams. This should be deducted from the totals to obtain the tractive effort at the wheeltread.

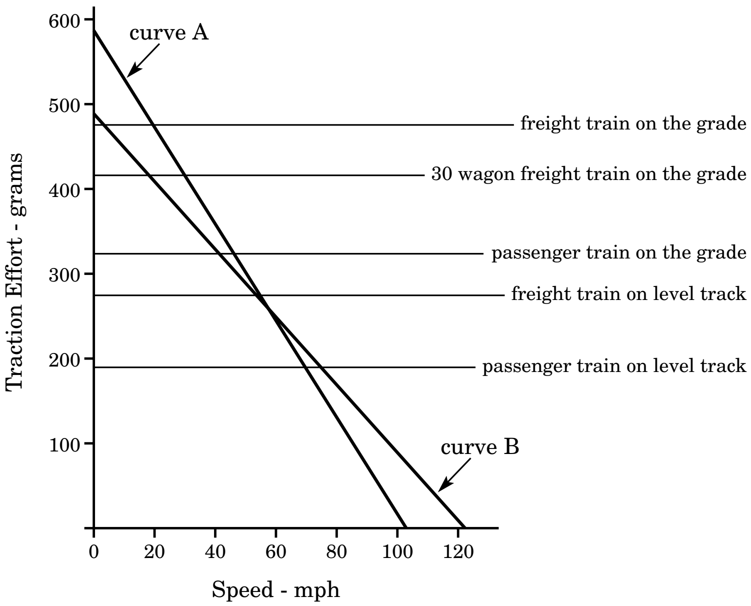

FIGURE 4-1.
Typical Locomotive Performance Characteristic

Figure 4-1 shows the locomotive tractive effort characteristic with the above requirements marked on it.

Curve A is with a 12.5 to 1 gear ratio selected as described in Section 3, in accordance with which the passenger train speed on level track was assumed to be 0.75 of the track speed corresponding to the no- load speed of the motor. Whilst this assumption would be valid in the majority of cases, it gives too low a speed for the heavy passenger train used as an example. Consequently, either the load would have to be reduced to 9 coaches or the gear ratio lowered to 10 to 1 (curve B), but with this lower ratio the freight train load would have to be reduced to no more than 30 wagons.

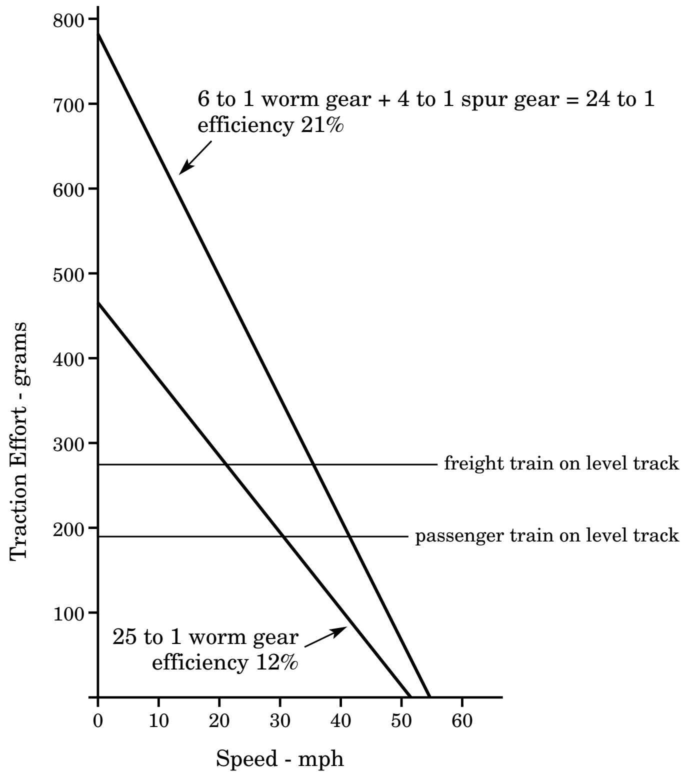

FIGURE 4-2
Effect of High Gear Ratios

4.4 Effect of High Gear Ratios.

Figure 4-2 shows the effect of using too high a gear ratio. If, in the previous example, a single stage low efficiency, (12%), 25 to 1 worm drive was chosen with the intention of sacrificing maximum speed in order to obtain smoother slow running, the no-load speed would be only 51 MPH and, from equation 1, the stalled tractive effort would be:

$$\frac{325 \times 2 \times 25 \times 12}{42 \times 10} = 464 \text{ grams}$$

i.e. because of the low gear efficiency there is **less** tractive effort than with the original lower ratio.

If a higher ratio is desired it is preferable to use either more expensive high efficiency worm gearing or a low ratio standard worm (e.g. 6 to 1) in conjunction with spur gears. A combination of a 6 to 1 worm and 4 to 1 spur gears would have an efficiency of 21% and would give a no-load speed of 54 MPH and a stalled tractive effort of 780 grams.

Comparing these two higher ratio characteristics with Figure 4-1 shows that the speed of the passenger train on level track is reduced to 30 or 40 MPH and that of the freight train to 21 or 35 MPH respectively, which are both considerably lower than the desired speeds.

Locomotives capable of prototype maximum speed will start and run smoothly at slow speed provided the control system is adequate and the motor design is such that the torque is sensibly constant as the armature rotates, which is the case with most modern motors.

The ratios of some of the motor and gearbox units tested by the Guild were found to be too high to allow locomotives fitted with them to reach prototype top speeds, this was despite the motor torques being sufficient to give adequate tractive efforts if used with gear ratios permitting such speeds to be attained. In many cases this can be remedied by increasing the supply voltage as explained in Section 2.