1 Determination of Locomotive Performance Requirements

1.1 Introduction

Before a suitable motor and its associated gearing can be selected, it is necessary to establish the performance required from the locomotive or multiple unit in which it is to be installed. These vary widely and the object of this section is to provide information which will enable the modeller to determine the speed and tractive effort characteristics necessary to provide the desired performance. Subsequent sections will explain how these are used to select a suitable motor.

It is recognised that a large proportion of Guild members will have small layouts which limit train length. However, there are many test tracks on which their locomotives could occasionally haul prototype length trains at prototype speeds, which for the fortunate owners of large systems is normal. Therefore the Technical Sub-Committee recommends that irrespective of their normal duties model locomotives should, whenever practicable, be capable of a performance equivalent to that of their prototypes. The power output of modern motors is such that this can readily be achieved and it is far better to install such a motor than one which will not do so when the opportunity arises. Speed on a small layout can be reduced by means of the controller but mediocre performance on a test track or large railway is not so easily remedied.

1.2 Tractive Resistance

The tractive effort required to haul a train at constant speed, whether model or prototype, must equal its resistance to motion and therefore the first step in determining the performance required from a locomotive is to calculate the resistance to motion of the trains it is desired to haul. This is known as the tractive resistance and is the sum of the following components, which must be calculated individually.

1.2.1 Tractive Resistance on Level Straight Track.

This is the sum of frictional and wind resistance. For full size trains the latter is the major component whereas it is negligible on model ones.

The frictional resistance of different types of rolling stock has been measured and the results published in Data Sheet T2, but for most purposes it will be found adequate to assume the following average values;

Bogie coaches:
weight: 500gm, resistance: 10gm.

Four and six wheel coaches:
weight: 300gm, resistance: 6gm.

Empty four wheel wagons:
weight: 200gm, resistance: 4gm.

Loaded four wheel wagons:
weight: 300gm, resistance: 6gm.

Bogie wagons:
count as two four wheel ones

Large tender locomotives:
weight: 2500gm, resistance: 70gm.

Small tender locomotives:
weight: 2000gm, resistance: 55gm.

Tank engines:
weight: 1500gm, resistance: 45gm.

Diesel and electric locos
weight: 750gm on each driving axle.
resistance: 12gm x total no. of axles.

Note: Some types of 2-rail current collectors can greatly increase the locomotive frictional resistance, in extreme cases collector friction can be the major component of the total resistance of the locomotive and train.

1.2.2 Curve Resistance

When rounding a curve the frictional resistance increases due to flange contact and to one wheel having to slip or skid because of the different circumferences of the inner and outer rails of the curve. The coning of the tread compensates to some extent for the latter but there is not the full correction provided by the differential of a road vehicle. The increase in resistance over the value on straight track is a function of the curve radius and is known as the curve resistance.

Measurement of the tractive resistance on curved track gave a nearly constant increase over the value on straight track, 'soft' plastic wheels giving a larger increase than other types due to their higher flange and tread friction.

The table and graph show the curve resistance as a percentage of that on straight track.

Curve Resistance
(Percentage of Resistance on Straight Track)

Radius	Metal Wheels	'Soft' Plastic Wheels
2.4m (8ft)	10	15
1.8m (6ft)	17	22
1.4m (4ft 6in)	25	40
0.9m (3ft)	50	60
0.8m (2ft 8in)	55	65

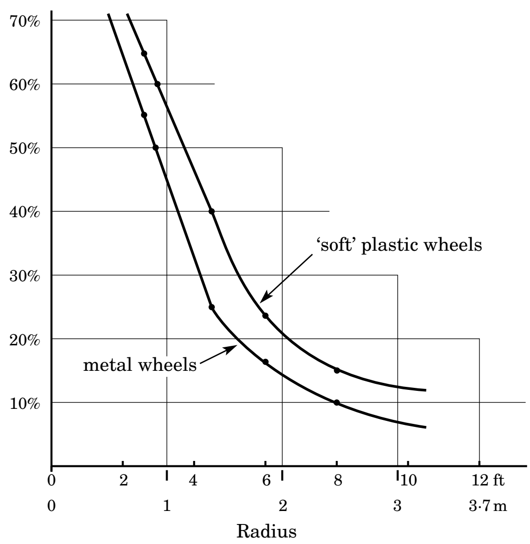

FIGURE 3-1
Curve Resistance
(Percentage of Resistance on Straight Track)

1.2.3 Gradient Resistance

This is an additional resistance dependent only on the vehicle weight and the steepness of the grade.

If G is the distance along the slope measured in the same units as the rise (or fall), the gradient can be expressed in two ways, either as 1 in G, or as a percentage obtained by dividing 100 by G, e.g. a gradient of 1 in 50 is 2% and 1 in 100 1%.

The resistance on a grade of 1 in G is vehicle weight divided by G. If the gradient is expressed as a percentage the resistance is vehicle weight multiplied by % grade divided by 100.

Example
The Grade Resistance of a model coach weighing 500 grams on a grade of 1 in 50 (or 2%)

$$= \frac{500}{50} \quad \left(\text{or } \frac{500 \times 2}{100}\right) = 10 \text{ grams.}$$

1.3 Acceleration Force

In addition to overcoming frictional and grade resistance the tractive effort developed by a locomotive must be sufficient to counter the inertia of the train and accelerate it at the desired rate. Despite model acceleration and braking rates being much higher than those of full size trains the effect of scale makes inertia of little importance for model trains although it is very significant in the case of real ones. This makes it difficult to carry out realistic loose or hump shunting in model yards but it also allows model trains to be operated without any form of braking other than their own friction.

For model purposes the acceleration force can be taken as 1.1 grams per kilogram of train weight (including the locomotive) multiplied by the prototype acceleration rate expressed in miles per hour per second. Thus the tractive effort to accelerate a twelve coach passenger train weighing 6kg (12 x 500 grams), hauled by a locomotive weighing 2.5 kg, from standstill to a speed equivalent to 60 mph (1.38 mph actual speed) in 20 seconds is

$$\frac{1.1 \times (6.0 + 2.5) \times 60}{20} = 28 \text{ grams.}$$

i.e. approximately 23% of the tractive resistance on level track. (An actual locomotive hauled train takes much longer to reach 60 mph and most models accelerate more rapidly than the train used for this example).

1.4 Adhesion

Because it greatly reduces the danger of motor damage due to overloading it is recommended that any motor used in a locomotive can develop a stalled torque sufficient to slip the driving wheels at standstill. It follows that the maximum tractive effort which can be developed by a locomotive will be determined by the factor of adhesion between the driving wheels and the rails. Tests on typical model locomotives have shown the average value to be between 20 and 23%, although, as with their prototypes, much higher values can be attained under ideal conditions or with special design. In other words, the maximum tractive effort which can be exerted at the wheel tread should be assumed to be between 20 and 23% of the weight on the driving wheels, (not the total weight of the locomotive). It is recommended that the lower value be used for performance calculations.

Note: The frictional resistance of the locomotive must be deducted from the calculated total tractive resistance to obtain the tractive effort required at the wheel tread. (Theoretically, only the proportion attributable to the driving axles should be deducted, but in practice it is sufficiently accurate to deduct the total for the locomotive and tender on straight track).

Example
If a tractive effort of 400 grams is required to start a train, the weight on the locomotive driving wheels should be taken as 400 x 5 = 2000grams or 2kg. (The calculated value should not be greatly exceeded as this would increase the possibility of overloading the motor).

The total locomotive weight is the sum of the weights carried by the driving and non-driving axles. A gauge O steam outline locomotive should weigh between 1.0 and 2.5kg depending on the prototype and the duty required.

1.5 Maximum Speed

To have a performance equivalent to its prototype a 4-6-0 mixed traffic locomotive should be able to reach a scale 75 mph on level track with a train of up to 12 coaches, proportionally higher speeds being attained by express passenger locomotives and models of electric and diesel prototypes. These are the ultimate requirements which can be reduced for locomotives intended to operate only on layouts which are not suitable for high speeds or heavy trains.

1.6 Calculation of Locomotive Tractive Effort

The data on the previous pages enables the tractive effort required to start and haul a train to be calculated for any particular set of requirements, the example in the box below and overleaf being for a locomotive intended for service on a large garden railway requiring the full equivalent of the prototype's performance, but the method is equally applicable to less demanding duties.

The Railway:
Large outdoor system, mainly straight track or large radius curves. The maximum gradient of 1 in 70 occurs on a 2.4m (8ft) radius curve.

Locomotive Duty:
To haul passenger trains of up to 12 coaches and freight trains of up to 40 wagons and to be able to start them on the 1 in 70 grade and curve. Desired train speed on level track: Passenger, 75 mph. Freight, 45 mph.

Train Weights:
Assume an average coach weighs 500 grams and a wagon 250 grams, (50% of the wagons assumed loaded). At this stage allow 2500 grams locomotive weight (including the tender). This may require correction if it proves insufficient for the starting duty.

Passenger train weight:

Coaches 12 x 500: loco 2500 grams	total	=	8.5 kg
Freight train weight: wagons 40 x 250: loco 2500 grams	total	=	12.5 kg

Tractive Resistance:
Assume rolling stock of average construction with a frictional resistance on level straight track of 20 grams per kilogram. A 2.4m radius curve will increase this by 10%.

Note: The acceleration rates used in this example are much higher than those of prototype locomotive hauled trains.

continued …

Passenger train resistance:

Resistance on level straight track (coaches) :	20 x 6.0	=	120 grams
(loco) :		=	70 grams
Curve resistance (train + loco) :	10% of 190	=	19 grams
Grade resistance (train + loco) :	8.5 x 1000 ÷ 70	=	121 grams
Total tractive resistance on grade and curve:		=	330 grams
Tractive effort to accelerate the train at 3 mph/sec :	1.1 x 8.5 x 3	=	28 grams
Total starting tractive effort on 1 in 70 grade and 2.4m curve :		=	358 grams
Deduct locomotive frictional resistance (excluding curve resistance):		=	70 grams
Starting tractive effort required at the wheeltread:		=	288 grams

Freight train resistance:

Resistance on level straight track (wagons) :	20 x 10.0	=	200 grams
(loco) :		=	70 grams
Curve resistance (train + loco) :	10% of 270	=	27 grams
Grade resistance (total) :	12.5 x 1000 ÷ 70	=	178 grams
Total tractive resistance on grade and curve:		=	475 grams
Tractive effort to accelerate the train at 2 mph/sec :	1.1 x 12.5 x 2	=	27 grams
Total starting tractive effort on 1 in 70 grade and 2.4m curve :		=	502 grams
Deduct locomotive frictional resistance (excluding curve resistance):		=	70 grams
Starting tractive effort required at the wheeltread :		=	432 grams

Limiting tractive effort requirements derived from the calculations:

To haul the passenger train at 75 mph on the level :	190 grams
To haul the freight train at 45 mph on level straight track:	270 grams
To haul the freight train on the grade and curve :	475 grams
Total starting tractive effort :	502 grams
Maximum tractive effort required at the wheeltread :	432 grams

Using the average adhesion value of 20% the weight on the driving wheels needs to be not less than 432 x 5 ÷ 1000 = 2.16 kg. Thus the assumed weight of 2.5 kg for the locomotive and tender should be adequate to give the desired starting performance.

The selection of a motor and gear ratio to meet these requirements is described in Sections 3 and 4.

1.7 Typical Locomotive Performance Requirements

The following typical locomotive performance requirements are given as a guide to modellers who do not wish to calculate the requirements for specific applications.

Models of final generation mixed traffic steam locomotives with 1830mm (6ft) driving wheels should develop a stalled tractive effort of not less than 450 grams and a total tractive effort of 180 to 220 grams at a speed equivalent to a prototype 75 mph. Their weight should be about 2.5kg including the tender.

To be fully representative of prototype performance models of the most powerful classes of electric and diesel locomotives should develop 220 to 260 grams total tractive effort at a speed equivalent to a prototype 90 mph with a stalled tractive effort of not less than 600 grams. Very few, if any, model railways will be able to fully utilise the haulage capacity of such a locomotive and consequently many builders of these models motorise only sufficient wheels to meet their performance requirements. This being the case, it is recommended that diesel and electric locomotives should be able to develop at least 100 grams stalled tractive effort per motored axle falling to 50 to 60 grams per axle at 90 mph. The weight on each driven axle should be about 0.75kg.

The frictional resistance of the locomotive should be deducted from all the above values to obtain the tractive effort at the drawbar on level straight track.