TRACTIVE EFFORT

Large Scale Model Railway Engineering

Introduction

Designing a good performing model locomotive is a relatively simple job. During the next several months I will describe the procedure that I use when I build a diesel or steam locomotive. This month we will begin by calculating the train weight and from this determine the weight and horsepower required. In future months design parameters for a diesel and steam locomotive along with construction suggestions will be covered.

So lets get started.

Section 1 The load

The first thing one needs to know is the load that one wants to pull. We will use 1 1/2 scale as an example, but this procedure also applies to the small and larger scales. One may wish to pull 6 cars with 2 people in each car. A 1 1/2 scale car weighs about 100 lbs and we will use a average weight of 125 lbs. for each person. We can then calculate the total train weight as follows:

	1 car 100 lbs.
	2 people 250 lbs.
(1)	total for each car = 350 lbs.
	350 lbs / car X 6 cars = 2100 lbs.

We must also add the weight of the locomotive which we will say is 400 lbs. The total train weight is therefore:

	locomotive 400 lbs.
	train 2100 lbs.
(2)	total train weight = 2500 lbs.

The rolling resistance of a train on straight level track is approximately 10 lbs. per ton of train weight. Using our results from equation 2 above we can calculate the rolling resistance as follows:

(3)	2500 lbs / 2000 = 1.25 tons
(4)	1.25 tons x 10 = 12.5 lbs rolling resistance

To the rolling resistance we must add the resistance due to grade and curvature. At high speed (over 30 mph) we must also add air resistance, but since our speed are much slower than this we can ignore this factor. The grade resistance is approximately 20 lbs. per ton for each 1% of grade (1 ft in 100 ft.). In our example we will assume a 2% grade.

(5) 20 lbs per ton X 2% grade = 40 lbs. per ton

Since our train weighs 1.25 tons (equation 3).

(6) 1.25 tons x 40 lbs. per ton = 50 lbs. grade resistance

The curve resistance has been found to be the following:

(7)

35 ft. radius	=	16 lbs. per ton
45 ft. radius	=	12 lbs. per ton
60 ft. radius	=	10 lbs. per ton

We will use a 45 ft radius in our example. To find the total train resistance we will add the values for the rolling resistance (equation 4), the grade resistance (equation 6) and the curve resistance (equation 7).

	rolling resistance	=	12.5 lbs.
	grade resistance	=	50 lbs.
	curve resistance	=	12 lbs.
(8)	total train resistance	=	74.5 lbs.

This means that the locomotive must have at least 74.5 lbs. of tractive effort to pull our train. In order to generate this tractive effort we need two things. First we need enough power on the wheels and second enough weight to prevent the wheels from spinning. This last factor is a function of the friction between the wheel and the rail. This is known as the coefficient of adhesion, which for steel or cast iron is approximately 0.25 under ideal conditions. This value drops off rapidly under wet conditions. The maximum tractive effort that can be generated is equal to the weight on the driving wheels times the coefficient of adhesion. In this discussion we will assume that all the weight are on the drivers.

(9) 400 lbs x .25 = 100 lbs. tractive effort

In equation 8 we calculated that we need 74.5 lbs of tractive effort to pull our train and equation 9 tells us that we can generate 100 lbs.

The next thing we must consider is the speed that the train is to run. This is typically 4 - 6 miles per hour with a maximum speed of 8 mph when dealing with 1 1/2 scale. The speed is a function of the wheel diameter and revolutions per minutes(rpm). In this example we will use a 40 inch diameter wheel which is 5" in diameter in 1 1/2 scale. To calculate the rpm required for a top speed of 8 miles per hour we proceed as follows:

(10) 1 mile per hour = 88 ft per minute

(11) 88 ft per minute = 1056 inches per minute

The circumference of a wheel is found by multiplying the diameter by the value of "pi" (3.1416).

(12) 5 in diameter x 3.1416 = 15.70 inches

(13) 8 miles per hour = 8,448 inches per minute

To find our rpm divide 8448 inches per minute by the circumference of the wheel (equation 12).

(14) 8,448 / 15.70 = 538 rpm

We now have the speed (rpm) and the required tractive effort. The last step is to calculate the axle torque required to generate this tractive effort. To do this we will use the maximum tractive effort calculated in equation 9 which was 100 lbs., and the radius of the wheel (1/2 the diameter). The total axle torque is tractive effort times the wheel radius.

(15) 100 lbs x 2.5 inches = 250 in lbs of torque

Our last step is to calculate the approximate horsepower required to generate this torque at this speed. This will be a rough approximation which we will refine latter. The horsepower is found by multiplying the torque (in in-lbs) by the speed (rpm) and dividing the result by 63025.

(16) hp = 250 in-lbs x 538 rpm / 63025 = 2.13 hp.

To sum up we have determine that we will need 250 in lbs of torque at 538 rpm to meet our performance expectations.

That's it for this month. Next month we will examine the power train for a miniature diesel locomotive.