Driving techniques and strategies for freight trains

P. Lukaszewicz

Railway Technology
KTH (Royal Institute of Technology), Sweden.

Abstract

Driving techniques for freight trains are affected by parameters such as terrain, available adhesion, available power, running resistance and signalling. In order to simulate running times and energy usage, these parameters must be taken into consideration. A locomotive dedicated for freight traffic has been equipped with instrumentation which monitors actions, powering and braking, taken by the driver together with the parameters mentioned. The locomotive is located by means of GPS and ATC antennas. A general model of a freight train and a driver is deduced from the full scale measurements. Energy usage and running times differ as on average by 1.3% and 0.4% respectively, from full scale tests. Implementation of the verified freight train and driver model results in significant improvement in determining train running times and energy usage in simulations.

In the paper a review of the research will be made with conclusions.

1 Introduction

For estimating energy consumption and running times of freight trains, which are in most cases driven manually, many current simulation models are not sufficient. It is often assumed that the train is driven according to what the train, track and signalling system allows and there is almost no room for driver behaviour. Since driver’s behaviour has a big impact on energy consumption [1], [2], it is desirable
to make simulations with different driving modes. To be able to do this, a train model which resembles a real train as much as possible must be used in the simulations. Even a relatively small discrepancy between a model and a real train may cause misleading results.

In cooperation with Swedish State Railways (SJ), an electric locomotive of type SJ Rc4 with DC traction motors has been equipped with instruments which monitors parameters such as speed, power intake, line voltage, engine currents, auxiliary power, signalling, driver’s actions, etc. The locomotive hauls different train configurations and operates in ordinary traffic and its geographical position is determined by means of GPS.

The aim of the full scale test is to provide necessary data for making a model of the train and the driver.

### 2 Train model

The virtual train which is used in the simulation program is a distributed mass model and consists basically of modules or functions which calculates:

- tractive forces, $F_t$
- braking forces, $F_b$
- running resistance, $F_R$
- efficiency, incl. auxiliary power, $\eta$
- running time, running distance and energy consumption.

Two data bases are used, containing:

- different freight trains, including train length, number of axles, axle loads, wagon types and destinations
- track data and fixed signalling data.

The tractive force at the wheel rims delivered by the motors, $F_{mot}$, is expressed in the model as a function of speed, slippage, wheel radius, throttle level (0-9) and line voltage. The force that can be applied at the wheel rim is also limited by adhesion, $F_\alpha$, [3]. Adhesion is an empirical expression and depends upon speed [3], [4]. The resulting tractive force, $F_t$, is obtained by taking the minimum of $F_{mot}$ and $F_\alpha$

$$F_t = \min(F_{mot}, F_\alpha)$$  \hspace{1cm} (1)

A special attention in the model is given to wheel slippage ratio. An example from full scale tests of wheel slippage ratio is shown in Figure 1. The slippage ratio in the model, $\zeta$, is empirical and expressed as a function of tractive force per axle. Slippage affects the energy utilised, tractive force and the speed, which is normally
measured from one of the locos axles. To be able to compare simulations with full scale tests it is important to include the slippage in the model. Below 15 kN, it is assumed that slippage does not occur. Above 15 kN, it is assumed that slippage increases linearly with the tractive force.

![Slippage ratio vs. tractive force](image)

**Figure 1:** Example of slippage ratio of axle No. 2 as a function of tractive force. Axle No. 1 is leading.

The braking force, $F_b$, in the model is an empirical expression deduced from the full scale tests and is expressed as a function of brake level applied by the driver, brake gain time, duration and brake release time. An example of how the brake cylinder pressure varies with time is shown in Figure 2.
Figure 2: Example of how brake cylinder pressure varies with time.

Running resistance, $F_R$, of different Swedish freight trains have been studied and reported in [5]. The resistance depends on train configuration, type of wagon and is expressed as a function of speed, axle load, train length, grade and curve radius.

The acceleration during propulsion or coasting for each time step $\Delta t_i$ is calculated by

$$a_i = \frac{1}{M_T(1 + H)}(F_{t(i)} - F_{R(i)})$$

(2)

and during braking

$$a_i = \frac{-1}{M_T}(F_{b(i)} + F_{R(i)})$$

(3)

where $M_T$ is the train mass and $H$ is a relative factor accounting for rotational inertia. Speed is calculated by

$$v_{i+1} = v_i + a_i \Delta t_i$$

(4)

and the travelled distance for each time step is

$$\Delta x_i = \left(v_i + \frac{a_i}{2} \Delta t_i\right) \Delta t_i$$

(5)
Energy consumption, \( E \), at the locomotive’s pantograph is calculated by eqn. (6) running time, \( T \), by eqn. (7) and running distance, \( X \), by eqn. (8).

\[
E = \sum_{i=1}^{n} \frac{F_{i(i)} v_i (1 + \zeta) \Delta t_i}{\eta_i}
\]

(6)

\[
T = \sum_{i=1}^{n} \Delta t_i
\]

(7)

\[
X = \sum_{i=1}^{n} \Delta x_i
\]

(8)

3 Verification of the model

It is possible to verify the model by synchronising in a simulation the virtual train with a real train with respect to the real trains data, geographical position, throttle level, braking level and initial speed for time step number 1. After the synchronisation, only the real trains braking and powering is used as input signals into the simulation. The difference in running time and energy consumption between model and reality can then be determined. A comparison is shown in Figure 3. The simulated speed and running distance is corrected for slippage.

Figure 3: Example of comparison between model and a real freight train of 1200 tonnes.
The model has been tested for several cases and it is concluded that the average difference in energy consumption is $1.5 \pm 2.1\%$ and in running time $1.0 \pm 1.5\%$.

It is very difficult to obtain a complete agreement between simulation and reality because of ambient wind, adhesion, slippage, faulty track data etc.

4 Driver model

The level of and time for powering or braking is decided in the simulation program by a virtual driver. The decisions are mainly based upon:

- speed margin to speed restriction
- distance to next change in the speed restriction
- track inclination, grades
- instantaneous acceleration
- available adhesion, i.e. slippery to dry track

The virtual driver is driving a freight train approximately as a real average driver. An example of this is shown in Figure 4 where the real train is running on a track section containing grades up to $\pm 17\%$o. The train mass is 1200 tonnes.

Figure 4: Example of simulation (thin line) compared with measured wheel speed.
The train model together with the virtual driver has been compared with real cases and the average difference in energy consumption is $1.3 \pm 1.4\%$ and in running time $0.4 \pm 1.0\%$.

5 Influence of driving on energy and running time

Parameters, which have an influence on driving, energy usage and running times can be studied, such as:

- coasting
- speed restriction, signalling
- slippage control
- available adhesion
- running resistance including ambient wind
- driving by means of an auto pilot.

For instance, by varying the nominal speed decrease limit, $\Delta v$, below the restricted speed, where coasting is interrupted, it is possible to investigate the change in energy consumption and running time for different coasting strategies. An example of this is shown in Figure 5.

![Figure 5: Influence of speed decrease limit, where coasting is interrupted, on energy consumption and running time. The nominal speed decrease limit is in this case 2.2 m/s (100%) below the restricted speed.](image)
Decreasing the speed decrease limit where coasting is interrupted leads to increased energy consumption and decreased running times. A change in the speed decrease limit affects the energy consumption more than the running time.

Influence of adhesion, $\alpha$, on energy consumption and running time is shown in Figure 6.

Figure 6: Influence of adhesion on energy consumption and running time. The nominal adhesion (100%) is $\alpha = 0.21$.

Lowering the available adhesion in the model lowers the energy consumption and increases the running time. Below 60% of nominal adhesion, the slippage is severe and the available tractive force is not big enough for overcoming grades. The tractive force for this locomotive is not limited by adhesion above 120% of nominal.

6 Conclusions

The agreement is good between calculated and measured results, mainly due to

- the train model, which is deduced from full scale measurements
- the driver model.

The average difference in calculated energy consumption is $1.3 \pm 1.4\%$ and in running time $0.4 \pm 1.0\%$ from measurements.
The simulation program can be used to accurately determine how different driving strategies influence on energy consumption and running time of freight trains.

A small change in total running time due to driver behaviour may often result in a relatively bigger change in energy consumption.

References


