Energy saving driving methods for freight trains

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Abstract

The power consumption of trains is a growing concern. Not only because of cost, but also because of pollution. It is possible to reduce train energy usage significantly, by driving the trains in an optimized way.

In order to study optimized train driving, with respect to energy usage and running time, a computer program is developed by KTH from full-scale tests. By means of full-scale testing and computer simulations, a parametric study is done showing which parameters are significant and their quantitative impact on energy usage. This is the aim of this study.

The study shows that energy usage is sensitive to the driver's look forward distance, the braking ratio, and the degree of coasting. By planning the driving and making use of coasting it is possible to save 10-15% in energy. If only unnecessary braking can be avoided, an energy saving of 5-7% can be achieved. Combining the studied parameters results in an even greater save in energy. The running time is only slightly affected.

The results show that in Sweden, and many other countries, there is an unused potential for saving energy. This possibility should be of interest to the train operators. In this paper a review of the study is made, with conclusions.

Keywords: freight train, power consumption, energy usage, optimized driving, driver describing parameters, running time, simulations, ERTS, SimERT.

1 Introduction

It is a well-known fact [1], [2], that power utilized by trains depends strongly on the drivers’ driving-strategy and skill. Different drivers drive their trains more or
less energy efficiently. It is therefore of interest to investigate which parameters have an effect on the energy usage of trains and by how much.

In order to investigate this matter, a project called SimERT [3], (Simulation of Energy and Running Time), is run by the division of Railway Technology at KTH.

A computer simulation program, ERTS, (Energy and Running Time Simulator) which is making use of detailed computer models of trains, drivers and track data is developed. The models of train and drivers, and the input data in ERTS are based on full-scale tests [4], thus making ERTS accurate. The difference between measured and simulated energy usage of freight trains is within the measurement error of approx. ±2%.

From observations made on how drivers are driving their trains, five driving describing parameters [5] have been suggested:

1. Look forward distance.
2. Powering ratio during acceleration: $\sigma_{pwr} = \frac{\text{power utilised}}{\text{max. available tractive power}}$
3. Braking ratio: $\sigma_{brk} = \frac{\text{brake utilised}}{\text{maximal}}$
4. Upper speed action limit: $v^+(t) = \nu(t) - \nu_{ATC}(t); \quad v \geq \nu_{ATC}$
5. Lower speed action limit: $v^-(t) = \nu(t) - \nu_{ATC}(t); \quad v < \nu_{ATC}$

$v(t)$ is the train speed and $\nu_{ATC}(t)$ is the speed restriction according to the signalling system at time $t$.

This paper summarises an analysis [5] performed by means of simulations with ERTS, on how the energy usage is affected by the driver describing parameters.

2 Description of simulations and conditions

The simulations are performed by means of ERTS. In ERTS, the level and duration of powering and braking is used as input data. This data is generated by a virtual driver which can drive the train in any desired way, thus making it possible to study driver behaviour on energy usage and running time. The relative change, variation, is studied for the 5 driver describing parameters, which are described in the introduction. Also, for each test some of the parameters are set at certain values and not varied. The constant values of the parameters chosen are making the virtual driver to drive the train as an average driver would do (as close as possible), thus making the analysis more relevant when comparing the influence of the parameters on energy usage and running.
time. The data for the computer model of the freight train used in the simulations is originating from full-scale measurements. The real train is shown in Fig. 1 and briefly described in Table 1.

Table 1: Description of freight train used.

<table>
<thead>
<tr>
<th>Type</th>
<th>Config</th>
<th>Length</th>
<th>Mass</th>
<th>No. of axles</th>
<th>Loco</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight</td>
<td>Mixed Oms/Hbis</td>
<td>413 m</td>
<td>1197 t</td>
<td>52 trailing</td>
<td>1SJ Rc4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mass = 79 t</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Power = 3.6 MW</td>
</tr>
</tbody>
</table>

Figure 1: Freight train of mixed consist, modelled and used for simulations.

Figure 2: Test track used for simulations.
The track data for the simulations is provided by the Swedish National Rail Administration (Banverket). The grades of the real track, together with signalled nominal speed restrictions $V_{ATC}$, are shown in Fig. 2. It is a “typical” hilly track of 40 km, having grades of $\pm 18\, \%$.

### 3 Results from simulations

The results for the energy usage, power consumption, are calculated at the pantograph level and do not include losses in the catenary system.

#### 3.1 Look forward

Frequently, coasting is part of the retardation mode before a speed restriction or stop. Coasting starts at a certain look forward distance $S_{frw}$ before the driver applies the brakes. In Fig. 3, the effect of the look forward distance on energy usage and running time is shown.

For the simulations, the following parameters are set at:

- Upper and lower speed action limits are 1.4 m/s and 3.0 m/s, respectively.
- Powering ratio is 0.85 throughout the simulations.
- Braking ratio is 0.35.

A look forward distance of 0, means that the driver is driving the train strictly at the permitted nominal speed according to the signalling system and no room is normally given for coasting. This is also called shortest time driving. A shortest time driving strategy means normally full acceleration up to the nominal speed restricted by the ATC/ATP followed by strict speed holding, at the nominal speed, until the train must start braking, by means of full operational braking, before arriving at a station.

![Figure 3: Effect of the look forward distance on running time and energy consumption.](image)
When constructing time-tables, recovery time is often added to the shortest time driving to allow for short delays. However, if the punctuality can be improved, the recovery time can be reduced.

When the look forward distance is increased, it is possible for the driver to plan the driving strategy with respect to grades and signalling, by making use of coasting. The result show that the save in energy is 15% while the running time is slightly increased, by 4%, compared with shortest time driving.

### 3.2 Powering ratio

The powering ratio is a measure of how much power is utilised by the driver compared to the maximal available tractive power, which depends on the track conditions, adhesion, and the catenary voltage. The powering ratio of 1.0 means that the driver is using maximal available power for acceleration. This parameter has about the same effect on the running time as on the energy usage, which is shown in Fig. 4.

![Figure 4: Relative change of running time and energy usage due to change in powering ratio.](image)

For the simulations, the following parameters are set at:
- Lower and upper speed action limits are 3.0 m/s and 1.4 m/s, respectively.
- Look forward distance is 800 m.
- Braking ratio is 0.35.
- Normal manual driving.

The influence of adhesion on energy consumption and running time is basically the same as the influence of the powering ratio, as shown in Fig. 5. Lowering the available adhesion in the model reduces 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 [5].

![Graph showing the influence of adhesion on energy consumption and running time.](image)

Figure 5: Influence of adhesion on energy consumption and running time.

The increase in running time and the reduced energy usage is originating mainly from the decreased average speed of the train.

### 3.3 Braking ratio

The freight train drivers, on average, apply an average braking ratio of approximately 0.35, i.e. some 65% less than the maximum braking effort of the train [5]. For this test, the following parameters are set in ERTS, at:

- Lower and upper speed action limits are 3.0 and 1.4 m/s.
- Look forward distance is 1000 m.
- Normal manual driving.

The result from the computed influence of the braking ratio on running time and energy usage is shown in Fig. 6. The impact of the braking ratio on the energy usage is big. By reducing the braking ratio to a minimum a big save in energy can be made. A low braking ratio means a short brake recovering time for a freight train, thus making it possible for the driver to drive more efficiently [6], [7], [8].

In many cases, simulations are performed with braking ratios having values close to 1.0. For long freight trains, this often leads to overestimated and misleading results for the energy usage.
Figure 6: Influence of braking ratio on energy consumption and running time.

3.4 Lower and upper speed action limit

The two parameters upper- and lower speed action limits are telling the virtual driver how much the speed is allowed to exceed or drop below the nominal speed restriction, respectively, before an action (braking or powering) must be carried out by the virtual driver.

Figure 7: Comparison of energy consumption and running time for different upper and lower speed action limits.
For the simulations, the following parameters are set at:

- Upper speed action limit is 1.4 m/s.
- Powering ratio has a mean value of 0.85.
- Braking ratio is 0.35.
- Look forward distance is 1000 m.

The results are presented compared to normal manual driving and $v_a^- = 0$ m/s.

The computed effect of lower speed action limit, $v_a^-$, combined with a positive upper speed action limit $v_a^+$ is shown in Fig. 7.

A train running at low values of $v_a^-$ has about the same energy consumption as a train running at higher values of $v_a^-$, provided the mean speed is the same for the two trains. The mean speed can be increased for the train having higher values of $v_a^-$ by increasing the upper speed action limit $v_a^+$.

4 Conclusions

Coasting and low braking ratio is favourable to reduce energy consumption. The impact of these parameters is dependent on the look forward distance.

By making an appropriate choice, it is possible to reduce the energy consumption by 10-15% while the running time increase is relatively small, 1-5%, compared with a reference case having a look forward distance of 0 m.

If “unnecessary” braking can be avoided an energy saving of 5-7% can be achieved, without increasing the running time. To gain time, the upper speed action limit should be quite high.

By combining the driver describing parameters, it is possible to reduce the energy usage significantly, while the running time is only slightly affected.

Optimized train handling can be studied and tested. Tests show that it is possible to reduce energy usage by 10 - 25% while the running time is only slightly affected.

The results also show that it is important to take driver behaviour into account when computing energy usage of freight trains.

References


