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ENERGY SAVING IN RAIL TRANSPORT

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Abstract. Aim of this article is to introduce and present advantages and possibilities of using simulation tools to calculate energy flows of tractive vehicle in all phases of its ride.

The focus is on the braking phase, especially on the braking energy recuperation that offers the highest energy saving potential.

Energetic simulation was carried out as a part of a current railway reconstruction study, which is a good example of possible energetic calculation use. Energetic calculation in the simulation are performed using so called "exact method" developed at the Faculty of Transportation. The advantage of the method is that it provides a high degree of accuracy. Due to the simulation calculation being performed in real-time, the user can enter the calculation even during the simulation. Crucial part of every simulation are quality input data, such as vehicle braking characteristic (including all working points below the envelope line together with the efficiency characteristics of the power train parts (engine, transmission, convertor and others)). Also, sufficiently precise (with a precision of 1 meter) railway track details (detailed geometrical and other information on the current and reconstructed railway track or on the railway track proposal.

To present savings during the ride, the railway track section on the track Montreál-Sherbrooke was chosen. On this track, (especially electrification and partial reconstruction of the superstructure) is planned. Reconstruction level will be dependant on the local economical and social conditions. However, in the most optimistic case, total electrification of the track will be undertaken, or lower level of the reconstruction when the vehicles that have very similar characteristics. The railway track section is located between the cities of Montreál and Sherbrooke, that are 160 km apart. To compare the current, and possible future, state, comparison of energy consumption of the vehicle was conducted on the same track with the same geometrical characteristics.

We can assume that the overall energy intensity of the ride on the newly reconstructed track (eg. with greater radius of the arches) will be lower than the overall energy intensity of the ride on the track before reconstruction. Current data on energetic consumption are not available, therefore they were obtained by simulation and verified by calculations and considered sufficiently accurate.

Presumably, the input simulation parameters required for the simulation will not always be delivered in the sufficient quality or will be partly missing completely. In these cases they will be substituted by various algorithms, that can be machine-processed and that are part of the simulation calculations. One of the crucial algorithms is so called "moment efficiency". Its machine processing is not entirely developed and therefore, this simulation will be conducted without its usage. For financial reasons, simulation calculation was verified only by the theoretical physical calculation method. Based on several partial results, emergent computing tool is functional and sufficiently accurate. The simulation program is supposed to be experimentally verified after its finishing.

The outcomes presented in this article are calculated by simulated computation and were not confronted with the real situation in any way. However, relevant calculation algorithms, processes and theoretical background of the simulation were already verified on the older software versions. Therefore, the simulated outcomes are supposed to be at least sufficiently accurate to provide preliminary study for the railway reconstruction. Presented calculations were executed by using author's simulation software. Part of the methodology was taken from the previous, already verified, versions of the software for vehicle ride simulation.

Keywords: Energetic simulation, consumption, efficiency, Montreál.

1. Introduction

There are two main ways to achieve Energy Saving in Rail Transport. We can achieve energy savings by complete change of the vehicle type (its propulsion) or the infrastructure. Moreover, we can achieve energy savings by improving either vehicle type or the infrastructure. To solve both versions successfully, energetic, computer-processed proposition of the relevant transport cases (transport energetic simulation) could help.

In this work, I am dealing with the vehicle energy. Therefore, the vehicle operation (not infrastructure) will be analysed from energetic aspect in this article. To do so, energetic simulation of the vehicle ride on the specific railway section was conducted.

Energetic simulation was carried out as a part of a current railway reconstruction study, which is a good example of possible energetic calculation use.

This energetic simulation was part of the railway track Montreál-Sherbrooke reconstruction study. In this study, energy aspect was not the main parameter. Therefore, simulation inputs are partly less quality than are required by purely energetic simulation. For given purpose, the railway track description is simplified. However, to compare the outcomes, the same input data (track parameters etc.) were so the inaccuracy is negligible. In general, the more accurate input data, the more accurate simulation outcomes. Therefore, it is crucial to ensure that the input data used for the following characteristics is as detailed and comprehensive as possible:

- ***Vehicle*** (tractive and braking capacity of the vehicle, weight, etc.),
- ***Railway track and external conditions in its surrounding*** (meteorological conditions, temperature, humidity etc.).

To demonstrate this energetic simulation, one of widespread locomotives from series 363, or more precisely its modernised successor 363.5, was chosen. This locomotive is capable of electric energy recuperation, in other words the possibility to export electric energy back to the grid or to other use. Using these two (almost the same) locomotives will be demonstrated on the example of the ride on the track between Montreál – Sherbrooke with the same encumbrance (the same number of equally loaded carriages).

The vehicle chosen for the simulation is not to be used on the track. However, it was agreed that it is more than sufficient for the demonstration of the possible energetic savings needs.

2. Simulation of energy masses on track Montreál-Sherbrooke assignment

2.1. Information on the vehicle, exact calculation method

Following values were used in the simulation:

Figure 1. Locomotive series 363, Source: Author.

- locomotive series 363 and 363.5 (weight 89 tons) see in Figure 1,
- encumbrance: 5 carriages with the total weight 270 tons,
- length of the train 157 m,
- calculated maximum change of the tensile power and braking power: **39** N/kN,
- rotating mass coefficients for the locomotive and carriages: **1,2** and **1,05**,
- constants to determine resistance to rolling of the locomotive: a = **1,05**; b = **0,0104**; c = **0,00025**,
- constants to determine resistance to rolling of the carriages: a = **0,98**; b = **0,0104**; c = **0,00021**.

Other inputs for the simulation are detailed tensile and power vehicle characteristics (vehicle series 363) and braking characteristic of the same vehicle (based on the manufacturer's data). Unfortunately, this braking characteristic includes only "envelope" (values only for 100%) of the relative ride, other lower grades of the relative ride in the simulation were obtained by calculation.

2.2. Detailed information on the railway line and external conditions

The simulation as such is ready for entering all elements that can be part of the particular railway section (arches, rail-switches, tunnels etc.). For the above mentioned reasons, the real state of the railways is simplified. In the calculations, approximately 5% error is used compared to the state with more precisely entered inputs, which is satisfactory considering task assignment with the railway track section with route length almost 160 km. This approach was taken to avoid unnecessary complexity of the task.

Given conditions:

- There are no elevation changes on the track (**ascent**, **descent**), which is in accordance with the real state as the railway track is on the level ground,

- The railway track was assigned as a straight track, with no bends. This assumption does not correspond with the real situation and this difference will cause possible 5-10% deviation from the precise calculation,
- Other parts of the track (rail-switches, tunnels,...) also were not assigned. However, there are no tunnels on the real track and the inaccuracy is therefore very small,
- Nevertheless, speed restriction on the railway track were assigned (both technical and legal) see Figure 2. The most important is the maximum speed limit. Considering that we are dealing with a side railway track, it is not supposed to be, not even after the reconstruction, grade separated with all roads. The speed limit for this type of railway track I Canada is 85 miles per hour, (roughly 137 km/h). Moreover, there are four stations along the railway line, that the train calls at. See Table 1.

Stationing [km]	**Station name**
0	MONTREAL CENT. STATION
39, 642	ST. JEAN STATION
60, 744	FARNHAM STATION
88, 900	BROMONT STATION
133, 783	MAGOG STATION
158, 753	SHERBROOKE STATION

Table 1. Station on the line Montreál-Sherbrooke, Source: Author.

Considering environmental conditions (eg. Temperature, air humidity and density, wind speed and direction) is vital part of the simulation. Within the scope of the simulation, simplified conditions were considered, such as normal temperature (20°C), dry real heads (air humidity close to zero) and weather conditions near zero.

3. Course of the simulation

One of the main criteria for this study was the shortest running time, not the energy consumption. Therefore, the type of ride set up for the simulation was the one with the shortest running time under the given circumstances. To achieve shortest running time, the train ride consist of the following stages only:

- **maximum possible acceleration** of a **train** (thus always with 100% relative thrust) to reach the maximum allowedspeed,
- riding at a constant speed (the maximum allowedspeed),
- **maximum possible deceleration** (the brake action with constant moderation with maximal value $-1m.s^{-2}$ was chosen) to the given next lower allowed speed, or to stop vehicle completely.

This type of ride does not include any coating. It is crucial to stress that this does not often occur in real life. Simulation of two train rides were conducted. Both cases have the same simulation assignment (including the same type of ride to achieve shortest running time) to enable their comparison.

The first ride was simulated with the locomotive series 363 (older type) without energy recuperation capability. The second ride simulation was conducted with the reconstructed locomotive series 363.5, that is capable of recuperating of energy. Outcomes of these two simulations can be seen on the following Figures 3, 4 and 5.

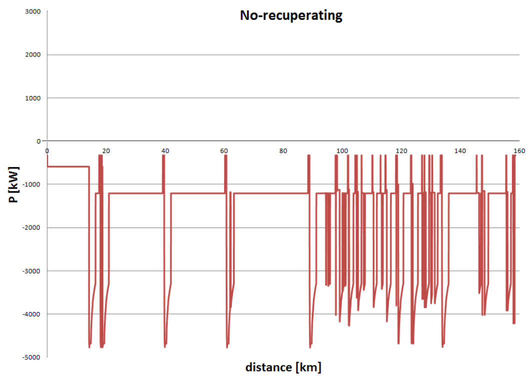

Figure 3. Wattage on the collector for the non-recuperating vehicle, Source: Author.

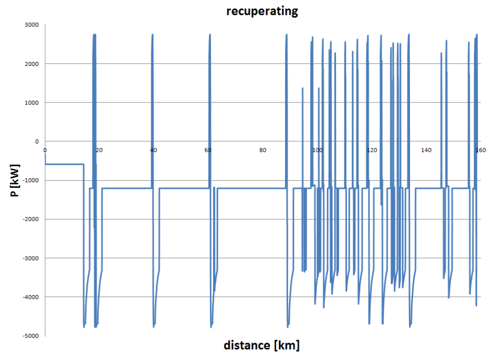

Figure 4. Wattage on the collector for the recuperating vehicle, Source: Author.

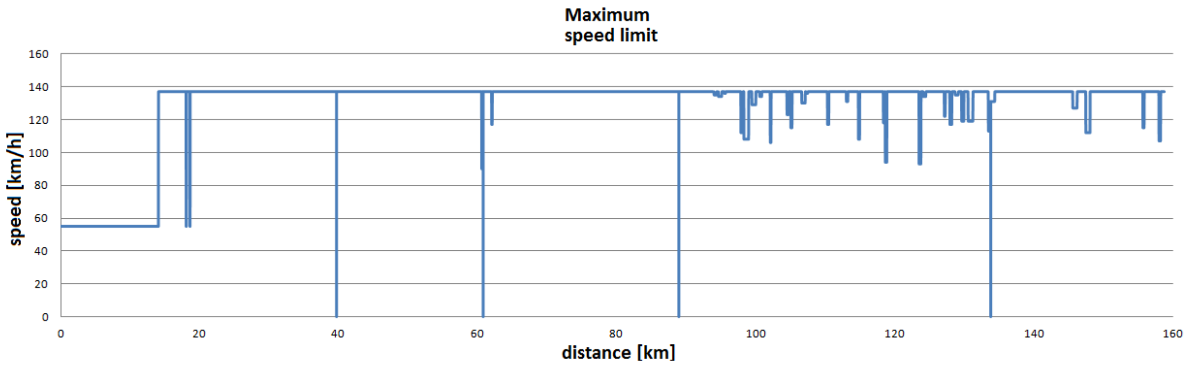

Figure 2. Speed profile of the line Montreál-Sherbrooke, Source: Author.

	Vehicle without recuperation [kWh]	Vehicle with recuperation [kWh]
Total energy consumption	2254	2034

Table 2. Simulated energy consumption on the railway track Montreál-Sherbrooke, Source: Author.

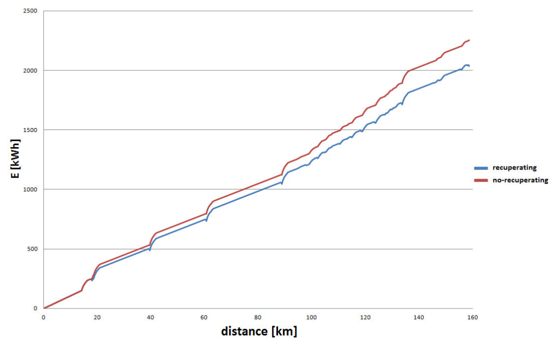

Figure 5. Cumulative energy consumption for recuperated and no-recuperated, Source: Author.

Total energy consumption of the single train ride in the same direction Montreál-Sherbrooke (see Figure 5), once with the locomotive 363 and the other time with the locomotion 363.5, can be found in the Table 2.

Total electric energy savings of the train with recuperation in comparison with the same train without recuperation on this track is **2254 kWh - 2034 kWh = 220 kWh**.

Running time, the shortest one under these conditions, was 5275 seconds, considering no staying at the stops.

4. Final energy savings within one day operation on the railway track Montreál-Sherbrooke

Presumed interval on this single-track railway is 2 hours (assuming it will not be converted into double-track railway during the reconstruction). It makes roughly 10 trains a day in each direction, therefore 20 trains a day altogether. Naturally, it is just an estimated average value, results accuracy will therefore be only ordinal. The situation is intentionally simplified, therefore it would not make sense to simulate all 20 rides under different conditions (various train, various external conditions etc.). Total energy savings within one day was obtained by simple multiplication energetic savings from one ride by expected number of rides per day.

With the savings of 220 kWh from one ride, the total saving from 20 rides a day will be **4400 kWh**.

5. Conclusion

Overall daily energy savings are roughly 4400 kWh. With the energy prices 3 CZK/kWh, the savings are roughly 13200 CZK/day. However this number may seem rather high, it is important to stress that railways operators (especially in the Czech Republic) cannot work with the gained surplus energy. As a result, majority of the excess energy is wasted in train braking resistors and the only use therefore is reduced wear on parts of brakes otherwise subjected to physical stress.

It is necessary to emphasise that these savings could be made only if the gained energy (or at least its major part) was used efficiently.

References

[1] OPAVA, J.: *Exact calculations of Traction Energy Quantities: Conference 20 years of Faculty of Transportation Sciences.* ČVUT, Fakulta dopravní, Praha, 2013.