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IMPROVING THE POWER CONSUMPTION OF THE 5100 kW ELECTRIC LOCOMOTIVE

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Abstract: *This paper deals with the optimization of the railway transport system from the traction point of view. Optimizing the traction segment in a railway company means especially respecting the timetable and of course, the lowest fuel / power consumption.*

Key words: *railway transport, fuel/power consumption, optimization.*

The actual requirements of the dynamic market economy are forcing the railway system to transform into a reliable alternative to the road and air traffic. From this perspective, the railways have to fulfil two key elements:

1. Economical efficiency and reliability;
2. To offer what the potential customer needs.

In particular, the railway system has to fulfil the following specific conditions:

1. Freight service must be safe, cheap, fast and accessible (taking into account the complete service pack to be offered to customers situated far from the railway line);
2. Long distance passenger service must be fast, highly comfortable (representing a true alternative to the airways) and to allow conditions for leisure, rest and entertainment;
3. Short distance passenger service (including the metropolitan railways) must ensure fast links from the centres of the cities to the suburbs at low prices, compared to the bus services.

These are the main requirements demanded by the potential customers desiring prompt, safe and affordable services. It is important to know that their perception of the quality level of the transport service changes continuously.

Railway operators have many analysis elements which might be influencing their economic efficiency.

One of the main elements is the respect of the timetables or (if possible) the decrease of the running times. The running time is the main referential, especially when it's related to the fuel or power consumption.

The optimization of the running times and the fuel / power consumption is strictly related to the safety and modern signalling systems.

This paper deals with the optimization of the railway transport system from the traction point of view. Optimizing the traction segment in a railway company means especially respecting the timetable and of course, the lowest fuel / power consumption.

Due to the fact that Romania has a large network of electrified railways, this paper will refer to this particular branch of the railway traction.

The electric traction has a series of specific particularities, such as:

- high power consumption during the starting process;

- low power consumption when running at constant speed;
- null consumption (or very low) during the braking process or inertial running;
- possible power recovering during electric braking process.

The energy supplied by the power system is transformed in mechanical energy used in the traction process. This energy is absorbed by the mechanical and aerodynamic drag and what's left is stored as kinetic or potential energy.

The motion equation for a train in each running regime is:

- traction

$$\frac{dv(t)}{dt} = \varphi \cdot \left(f(v(t)) - r(v(t)) + r_i\right) \qquad 1.$$

- no traction

$$\frac{dv(t)}{dt} = -\varphi \cdot \left(r(v(t)) + r_i\right) \qquad 2.$$

- braking

$$\frac{dv(t)}{dt} = -\varphi \cdot \left(f_f(v(t)) - r(v(t)) + r_i\right) \qquad 3.$$

where:

- φ - is the specific acceleration;
- f(v(t)) – is the specific acceleration force determined by the traction force;
- r(v(t)) – is the specific deceleration force determined by the main drag;
- v(t) – is the running speed;
- f_t(v(t)) – is the specific braking force;
- r_i – is the equivalent specific drag caused by the declivity.

The specific mechanical labour determined by the traction process may be written as:

$$l = \int_0^t f(v(t)) \cdot v(t) dt \qquad 4.$$

where

- t – stands for the time in which the motor vehicle is in traction regime.

Studies performed on different line profiles revealed that the most efficient solution (from the power consumption point of view) is the following string of operating regimes: traction (maximum acceleration) – no traction – braking (maximum deceleration) (see fig. 1 and 2) or traction (maximum acceleration) – traction at constant speed - no traction – braking (maximum deceleration) (see fig. 3 and 4).

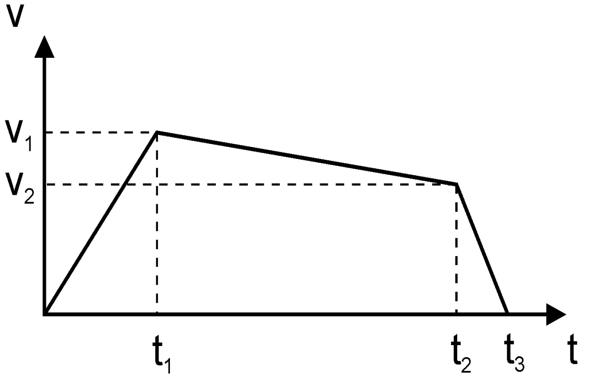

Fig. 1.

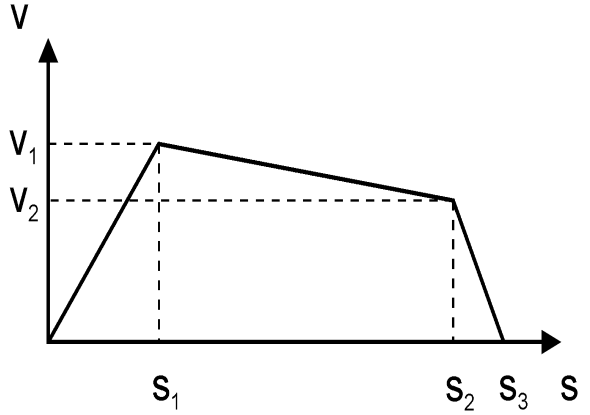

Fig. 2.

The first diagrams (see fig. 1 and 2) might be used in metropolitan railways (subways) for a distance of max. 5 km between two consecutive stops, and the last ones (see fig. 3 and 4) might be used in short or long passenger service and freight service as well.

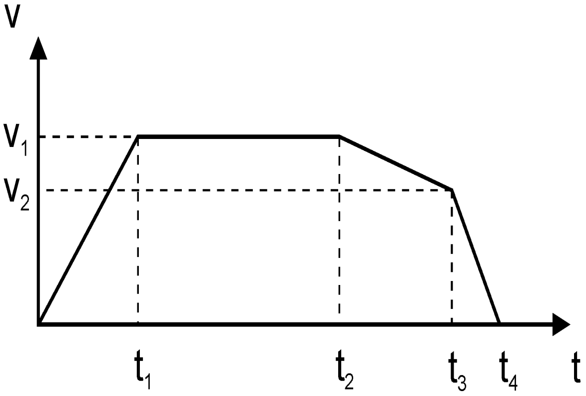

Fig. 3.

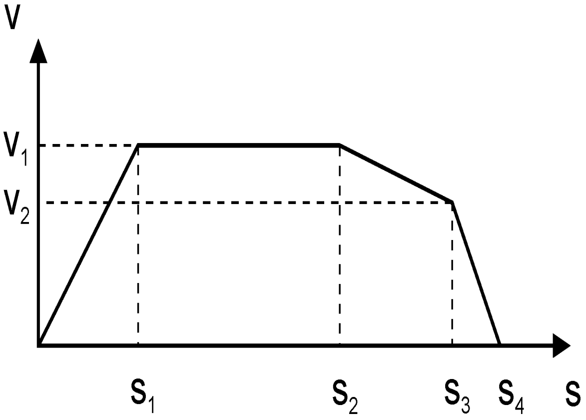

Fig. 4.

Taking into account the previous considerations, an automated system to assist the driver might be developed. This system will be designed to indicate the right operating regime or if the chosen regime is the correct one. Thus, an optimal driving diagram will result.

The strategy assumes a smooth train running, without any accidental stops or speed restrictions. This is unfortunately an ideal situation which considers correctly that the traction is the most power consuming regime.

In order to get closer to this ideal, modern traffic organization and proper infrastructure is needed as well.

The constant speed levels are limited by the maximum operating speed and the transport volume. This approach determined the rolling stock manufacturers to increase the installed power on the motor vehicles (e.g. electric locos and trains designed by Siemens AG).

When designing the control strategy, the main issues appearing are linked to the speed limits known as V_1 and V_2 corresponding to the end of the traction regime and the beginning of the 'no traction' regime and the end of the 'no traction' regime and the beginning of the braking regime, respectively. It is to mention that both values of the V_1 and V_2 may suffer slight modification according to train mass or load and total drag for each specific vehicle (motor or truck / coach).

For this reason, the following values must be followed and determined:

- the remaining time until the next stop;
- determination of the space coordinate of the train (its permanent position) and the remaining distance until the next stop;
- train speed.

The train driver needs a series of information like:

- the precise moment for cancelling the 'no traction' regime and to start braking in order for the train to reach the next stop on schedule;
- any corrections to the operating regime for keeping an accurate schedule and/or to fit in the limited space required for stopping in the next station.

The decision of switching from traction to 'no traction' regime depends on the exact position of the train, its speed, the drag, the line profile and the remaining time until the next stop. The space to be consumed during this regime is:

$$\Delta s_2 = s_2 - s_1 = \frac{(v_1)^2 - (v_2)^2}{2\left(a_{2ft} + a_{i2}\right)} \qquad 5.$$

where:

- $a_{2ft} = \varphi \cdot r_t$ – stands for the deceleration in the 'no traction' regime;
- $a_{i2} = \varphi \cdot r_{i2}$ – is the acceleration component determined by the line profile in the 'no traction' regime.

Depending on the train type and the load, Δs_2 might increase, decrease or to cancel itself.

If at the point where braking starts the train has the (v_2, t_2, s_2) coordinates, the space to be consumed until the next stop is:

$$\Delta s_3 = s_3 - s_2 = \frac{(v_2)^2}{2\left(a_{3f} + a_{i3}\right)} \qquad 6.$$

where:

- $a_{3f} = \varphi \cdot f_f$ – is the deceleration in the braking process corresponding the specific braking force f_f.;
- $a_{i3} = \varphi \cdot r_{i3}$ – is the acceleration component determined by the line profile in the braking regime.

The space required for braking may be determined compared to the total space:

$$\Delta s_3 = s - \Delta s_1 - \Delta s_2 \tag{7.}$$

where:

$$\Delta s_1 = s_1 - s_0 = \frac{(v_1)^2}{2 \cdot (a_{1t} + a_{i1})} \tag{8.}$$

In order to simplify the equations, the following notes were used:

$$\begin{aligned} a_1 &= a_{1t} + a_{i1} \\ a_2 &= a_{1ft} + a_{i2} \\ a_3 &= a_{3f} + a_{i3} \end{aligned} \tag{9.}$$

The result of the calculus is:

$$\Delta s_3 = \frac{2 \cdot s \cdot a_2}{a_2 - a_3} - \frac{(v_1)^2 \cdot (a_1 + a_2)}{a_1 \cdot (a_2 + a_3)} \tag{10.}$$

If □s□ < 0, the train may run in the ‘no traction’ regime and if □s□ > 0 the braking is necessary. The speed at which the braking starts is:

$$V_2 = \sqrt{2 \cdot \Delta s_3 \cdot a_3} \tag{11.}$$

The total time elapsed until stop is:

$$t = \frac{V_1}{a_1} + \frac{V_1 - V_2}{a_2} + \frac{V_2}{a_3} \tag{12.}$$

If considering the reference time t_{rs} and if $t_{rs} < t$, the train cannot use the ‘no traction’ regime for reaching the next station in time; if $t_{rs} \geq t$ the train may reach the station earlier, thus in this particular situation, the ‘no traction’ regime may be used.

If □s□ < s - □s$_1$ - □s□ the braking is not necessary and if □s□ < s - □s$_1$ -□s□ the brakes must be applied.

Switching to the braking regime depends on the train location, the line profile, the current running speed, the braking system’s performance and it’s a decision the driver has to make without being forced to make any additional regime changes until stopping.

The constant speed level (fig 3 and 4) is analyzed in the same way.

The optimization level of the running diagram depends on the maximum running speed and the running times, as the efficiency of the power consumption may be considered only compared to those criteria.

Choosing the right operating regime is crucial in order to follow the timetable (for passenger trains). As for the freight service, a total delay of 1 – 2 minutes per 100 km is acceptable if the power consumption is minimal.

Canadian and Australian studies on diesel locos revealed that an automated analyzing system reduces the fuel consumption up to 20%.

In theory, the calculus reveals that combining the advantages of the electric traction with an efficient driving manner leads to power efficiency up to 30%.

In order to illustrate the facts presented above, the power consumption of a 5100 kW electric loco is analyzed. The section Bucuresti Nord – Galati was chosen for the experiment. The line is 259 km long and is divided in 512 different profile elements. The declivities are 11.565 mm/m for a slope and 9.33 mm/m for the steepest gradient (considering the direction mentioned above).

In order to calculate the power consumption, the number of individual profile elements must be reduced to equivalent profile elements, thus simplifying the calculus. The equation for reducing a number of elements to an equivalent element is:

$$\mathrm{i_e} = \frac{\sum_{k=1}^{k=n} \mathrm{s_k} \cdot \mathrm{i_{rk}}}{\sum_{k=1}^{k=n} \mathrm{s_k}} \tag{13.}$$

where:

- i_e – the equivalent declivity;
- i_{rk} – the declivity of the element to be reduced;
- s_k – the length of the element to be reduced;

- n – the number of simplified profile elements.

The checking of the value for the equivalent declivity is:

$$s_k \le \frac{4000}{|i_e - i_{rk}|} \qquad 14.$$

The checking is necessary for determining the total number of elements that may be reduced to one single simplified element.

Besides the drag given by the line profile, the curves are also generating additional drag. The drag generated by curves may be considered as a fictional gradient, using the following equation:

$$i_c = \frac{\sum_{t=1}^{t=m} r_{ct} \cdot s_{ct}}{s} \qquad 15.$$

where:

- i_c – the declivity resulted from the straightening of the curves;
- r_{ct} – the specific curve drag, depending on the curve radius;
- s_{ct} – the curve length;
- s – the length of the profile element in which the curve is located;
- m – the number of curves in a string of curves on the same element.

The total declivity on the entire line profile is:

$$i_t = i_c \pm i_e \qquad 16.$$

The positive/negative values for the drag are depending on the type of the declivity. Usually, the gradients and the curves are marked as positive and the slopes as negative.

A train mass of 640 tonnes was considered for a passenger train running on this line. This is the limit load that the 5100 kW electric locomotive could haul on this particular line section. The value results from the following:

$$m_{v.c} = \min\begin{pmatrix} m_{v.cl}, m_{v.cl.d}, m_{v.cl.f}, \\ m_{v.cl.cr}, m_{v.cl.s} \end{pmatrix} \qquad 17.$$

where

- $m_{v.cl}$ – the maximum mass of the coaches to be hauled on the steepest gradient;
- $m_{v.cl.d}$ – the maximum mass of the coaches admitted when starting;
- $m_{v.cl.f}$ – the maximum mass of the coaches allowed by the braking system;
- $m_{v.cl.cr}$ – the maximum mass of the coaches allowed by the coupling system;
- $m_{v.cl.s}$ – the maximum mass of the coaches allowed by the length of the stations.’

For this kind of train, the power consumption on this line is 10900 kWh in limit conditions, using maximum traction force and braking force as well.

The total running time is 2 hrs and 45 min.

As a result of the optimization process and keeping tight the timetable, the power consumption was 8980 kWh, thus resulting a 17.5 % less than the original consumption.

On a 15 km sector of the line (between km 26 and 41), the limit characteristics for the running speeds and the optimized speed diagram is presented in figure 5, in which:

- $v_{1.tr.}$, $v_{2.tr.}$, $v_{3.tr.}$, - represent the variation of the running speeds on three different simplified line profiles when using the traction regime;
- $v_{1.fr.}$, $v_{2.fr.}$, $v_{3.fr.}$ - represent the variation of the running speeds on three different simplified line profiles when using the braking regime;
- $v_{1.ct.}$, $v_{2.ct.}$, $v_{3.ct.}$ - represent the constant running speeds on three different simplified line profiles when speed restrictions occur;
- $v_{1.op.}$, $v_{2.op.}$, $v_{3.op.}$ - represent the constant optimized running speeds on three different simplified line profiles.

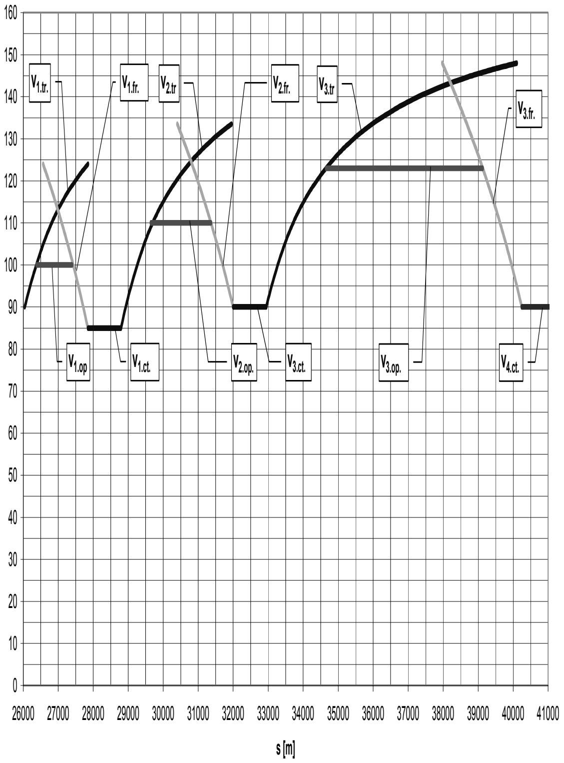

Fig. 5

By designing and manufacturing adequate automated systems to assist the train drivers, the issue of optimal power fuel consumption might be solved in the future.

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ПОДОБРЯВАНЕ НА ПОТРЕБЛЕНИЕТО НА ЕНЕРГИЯ ОТ 5100 KW ЕЛЕКТРИЧЕСКИ ЛОКОМОТИВ

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РУМЪНИЯ

Резюме: *Докладът разглежда оптимизирането на железопътната система от гледна точка на тракцията. Оптимизирането на сегмент от тракцията в една железопътна компания означава спазване на разписанието и разбира се, най-малко потребление на гориво/енергия.*

Ключови думи: *железопътен транспорт, потребление на гориво/енергия, оптимизация.*