Analysis of the resistance to motion in the passenger trains hauled by the locomotive LE 060 EA 5100kW

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DOI: 10.13111/2066-8201.2014.6.3.2

Abstract: *Two distinct situations were analysed in order to achieve the study: a train consisting of a locomotive LE 060 EA 5100 kW and single-deck wagons, a train that uses the same type of locomotive and double-deck wagons. The tendency to increase the running speed in electric rail vehicles leads to the question: What is the maximum speed that can be reached by a locomotive? The successive modernizations to the electric locomotive LE 060 EA 5100 kW (mainly used by railway companies in Romania), to increase traction performance requires an analysis of running resistance. This study tries to answer the question stated above, taking into account the constructive characteristics of the vehicles that form the structure of passenger trains and the existing regulations relating to the trains structuring.*

Key Words: *running resistance, maximum speed of train, passenger trains, aerodynamic drag.*

1. INTRODUCTION

The thrust developed by the power equipment and the sum of resistance forces opposing the movement in the desired direction acts on railway vehicle engines when they are moving. The values of these forces must be smaller or equal to the limit of adhesion force at the wheel/rail contact.

The mathematical relationship which expresses the connection between these forces (during displacement) can be written according to [1-14], as follows:

$$F_{t(v)} - R_{t(v)} - F_{f(v)} \leq F_{a(v)} \tag{1}$$

where: $F_{t(v)}$ – the motor vehicles tractive force of developed under acceleration;

$R_{t(v)}$ – the train total resistance to motion

$F_{f(v)}$ – vehicle braking force under deceleration;

$F_{a(v)}$ – the limit of adhesion force at the wheel-rail contact ;

In turn, the value of the limit of adhesion force is expressed, according to [1-4] and [9-14], depending on the adherent mass, the acceleration due to gravity and the wheel-rail adhesion coefficient as follows:

$$F_{a(v)} = m_a \cdot g \cdot \Psi_{(v)} \tag{2}$$

where: $m_a = n_o \cdot m_o$ – adhesion mass of the motor vehicles;

n_o – the number of powered axles;

m_o – the mass on the axle of the motor vehicles;

g – acceleration due to gravity;

$\psi_{(v)} = 0{,}161 + \dfrac{7{,}5}{44+v}$ – empirical relationship regarding the mediation of experimental values for the coefficient of adhesion determined by Curtius and Kniffler in the case of dry rails [1-4] and [9-15];

The resistance forces acting while the train is moving on the towing section profile which is in alignment and plane (straight line without ruling gradients) are determined by friction, for instance: friction on the axles bearings, rolling and/ or sliding friction, road surface friction, air friction, etc. Usually, Davis' relationship is generalized as the mathematical expression of the vehicles resistance to motion. According to this, the resistance to motion may be described as a polynomial function of the second degree dependent on the speed of the vehicle [16-32]:

$$R_{veh} = A + B \cdot v + C \cdot v^2 \tag{3}$$

where: R_{veh} –Total resistance to motion of the vehicle;

A – Mechanical rolling resistances caused by the axle loads;

$B \cdot v$ – Non-aerodynamic drag;

$C \cdot v^2$ – Aerodynamic drag;

v – Speed of the vehicle.

Davis' constants from the resistance to motion formula depend on the type and characteristics of each vehicle. In the case of the locomotive LE 060 EA by 5100 kW and towed wagons (both single-deck and double-deck), that form the majority of the Romanian passenger trains, these constants are given in the literature of the field [3], [9-11], [13] and summarized in Table 1:

Table 1 – The values of Davis's constants for vehicles which compose the train

Type of vehicle	A [N]	B [N/(km/h)]	C [N/(km/h)^2]
LE 060 EA - v.1 (120 t)	1770	5,9	0,333
LE 060 EA - v.2 (120 t)	1500	12	0,3
4-axes loaded double-deck wagon (average 50t)	86,5	0	0,0140449
4-axes loaded single-deck wagon (average 50t)	82,5	0	0,0125

2. THE RESISTANCE TO MOTION OF THE TRAIN

The running resistance to motion of the trains when the displacement is performed in alignment and plane can be determined according to the values of the resistance to motion of the vehicles that form the structure of train, as follows:

$$R_{t(v)} = R_{v.m(v)} + R_{v.r(v)} = R_{L(v)} + n \cdot R_{vg(v)} \tag{4}$$

where: $R_{v.m(v)}$ – the total resistance to motion of the motors vehicles;

$R_{v.r(v)}$ – the total resistance to motion of towed vehicles;

$R_{L(v)}$ – the total resistance to motion of the locomotive;

n – number of wagons in the train composition;

$R_{vg(v)}$ – the total resistance to motion of a towed wagon.

Taking into account the relation (4) and the Davis' polynomial, we can write:

$$R_{t(v)} = A_t + B_t \cdot v + C_t \cdot v^2 = A_L + B_L \cdot v + C_L \cdot v^2 + n \cdot \left(A_{vg} + B_{vg} \cdot v + C_{vg} \cdot v^2\right) \quad (5)$$

where: $\mathrm{A_t, B_t, C_t}$ – Davis' constants corresponding to the train;

$\mathrm{A_L, B_L, C_L}$ – Davis' constants corresponding to the locomotive;

$\mathrm{A_{vg}, B_{vg}, C_{vg}}$ – Davis' constants corresponding to the type of the towed wagon (double-deck or single-deck).

The values of the force limited by adhesion and the values of the resistance to motion for a locomotive having a constructive shape analogous to that of LE 060 EA 5100 kW type without a speed limit given by the power equipment and with a maximum load on the driving axle ranging between 20t and 21t are shown in Figure 1 and Figure 2, respectively.

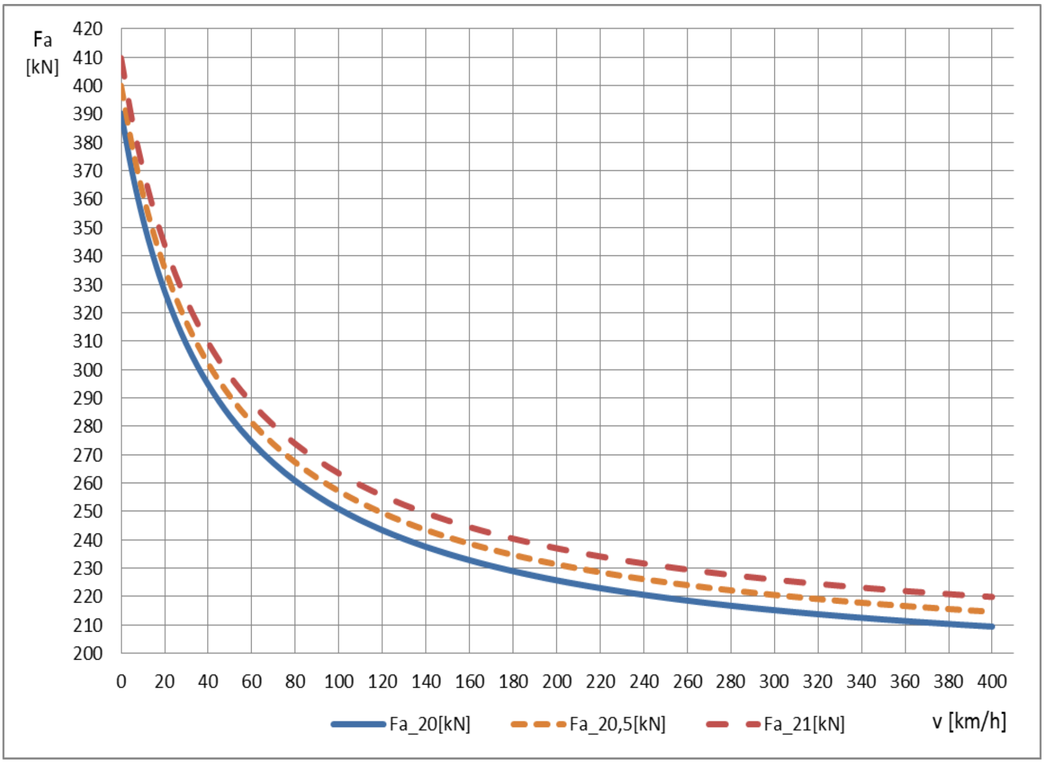


Fig. 1 – The adhesion limit of a LE 060 EA locomotive of 5100 kW without speed limit given by the power equipment

As it can be seen in Figure 2 there isn't a great difference between the two versions of the Davis' coefficients with respect to the resistance to motion for the shape of LE 060 EA locomotive of 51000kW.

Further, the analysis will consider the situation in which they determine the highest values of the resistance to motion.

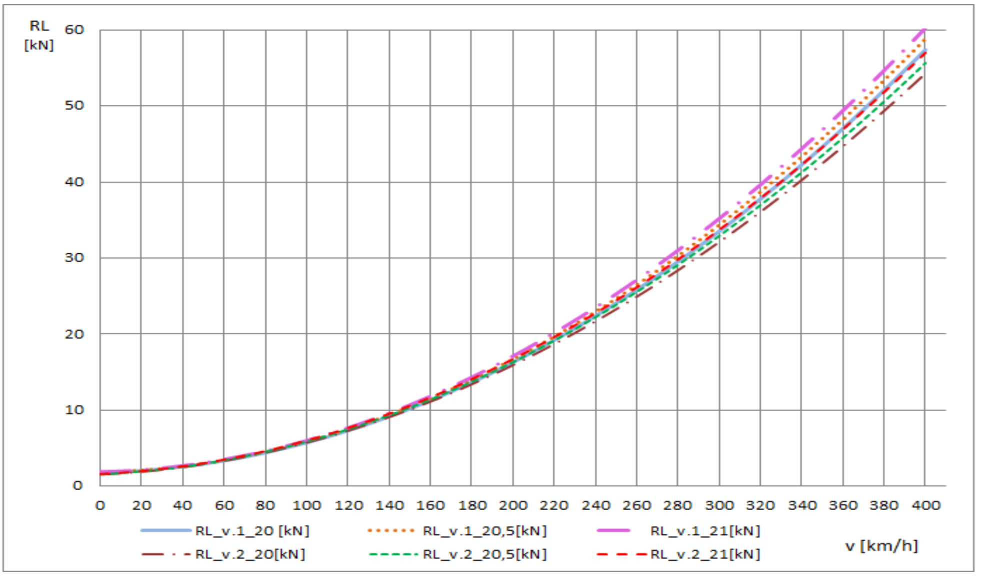


Fig. 2 – The running resistance for a locomotive by the form of locomotive LE 060 EA to 5100 kW, version 1 and 2 of the Davis coefficients

Fig. 3 shows the resistance to motion for a towed vehicle with a constructive form similar to a double-deck wagon and to a single-deck wagon, (loaded), respectively but without a speed limit.

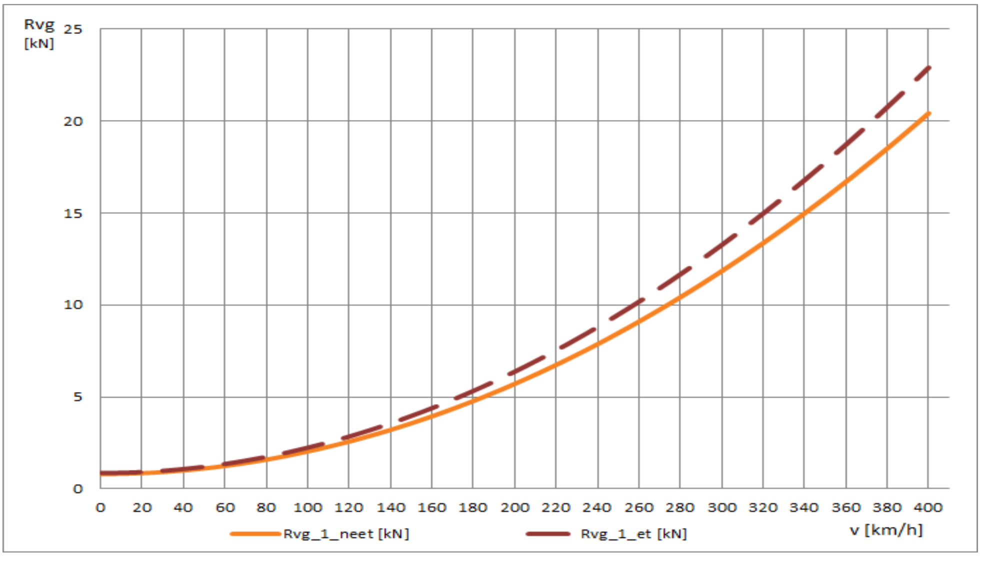


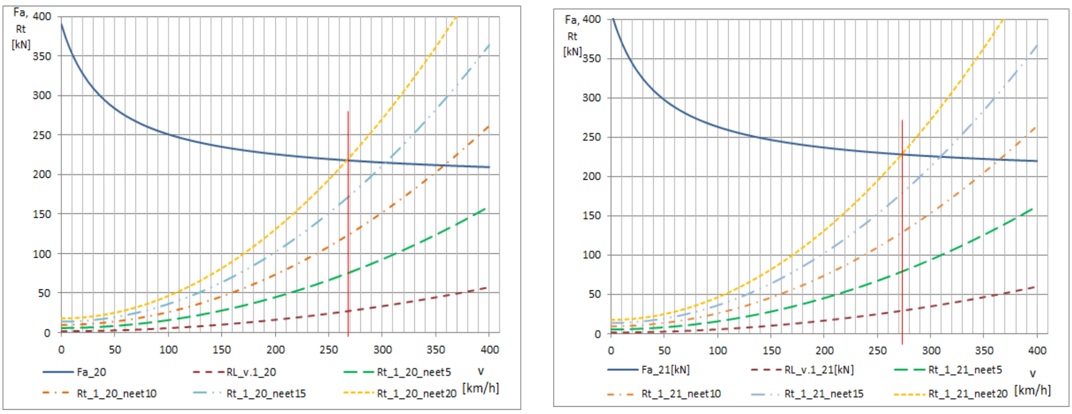
Fig. 3 – The resistance to motion in the case of the constructive form for a wagon

The structure of the passenger trains shall be in accordance with the regulations developed by the International Union of Railways by the UIC 540 sheet - Air brakes for freight trains and passenger trains [33], implemented in the internal regulations of the Romanian railway companies. Within this sheet it is stipulated that: in case of the rapid brake in the passengers regime the maximum number of the train axles is of 80. This corresponds to a maximum of 20 wagons towed on 4 axles.

Based on these regulations stipulated by the UIC 540, we considered the situations where the train is composed only of single-deck or double-deck wagons. We considered successively a number of wagons starting from 1 to a maximum of 20. So, for each type of train, consisting of a motor vehicle and a number of wagons ranging between 1 and 20 inclusive it has resulted one distinct characteristic of the resistance to motion.

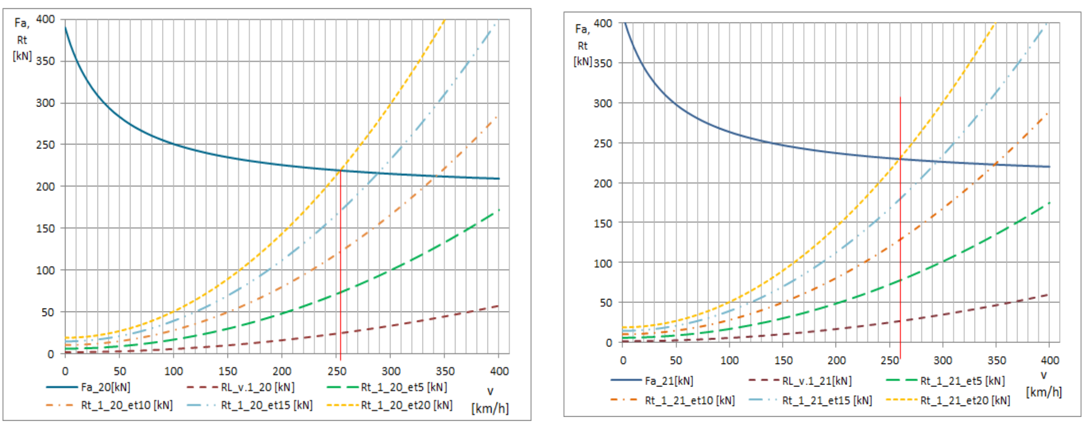
To exemplify the variation of the resistance to motion Fig. 4 and Fig. 5 present successively different cases, namely: a train composed of a locomotive travelling alone, then a train with 5, 10, 15 or 20 towered wagons. Two sets of extreme values corresponding to the limit of adhesion determined by the mass on the axle (i.e. 20t and 21t) of the motor vehicle were also taken into account.

The train maximum running speeds that can be reached are determined by the intersection of the resistances to motion and the adhesion limit of the train. In the case of passenger train formed by a maximal number of wagons these speed values depend on the constructive type of towed vehicles. For a train formed by single-deck wagons (Fig. 4) the value of this speed is about 270km/h while for the train consisting of double-deck wagons the speed is about 255 km/h (Fig. 5).



a) the locomotive with axle load of 20 t b) – the locomotive with axle load of 21 t

Fig. 4 – The limit of adhesion and resistance to motion of the train in the case of single -deck wagons



a) the locomotive with axle load of 20 t b) the locomotive with axle load of 21 t

Fig. 5 –The limit of adhesion and resistance to motion of the train in the case of double-deck wagons

The percentage analysis of the components of the resistance to motion and the required power used in train traction, in accordance with the components of the Davis' polynomial, is the method also used in[3], [11], [34-36]. The specifics of this type of analysis is that it depends on the type of each vehicle forming the train.

By applying this method in the case of the two types of trains composed of the maximum number of wagons that can be hauled by a locomotive of LE 060EA 5100kW shape with an axle load of 20t, without exceeding the adhesion limit, we obtained in the first instance the decomposition of the train resistance to motion components (see fig. 6) and of the required power that should be installed on vehicle engine to overcome these resistances (see fig. 7).

Increasing the speed of movement over the value of 200 km/h up to the maximum value of circulation that can be reached by the train practically requires doubling the installed power (see Fig. 7).

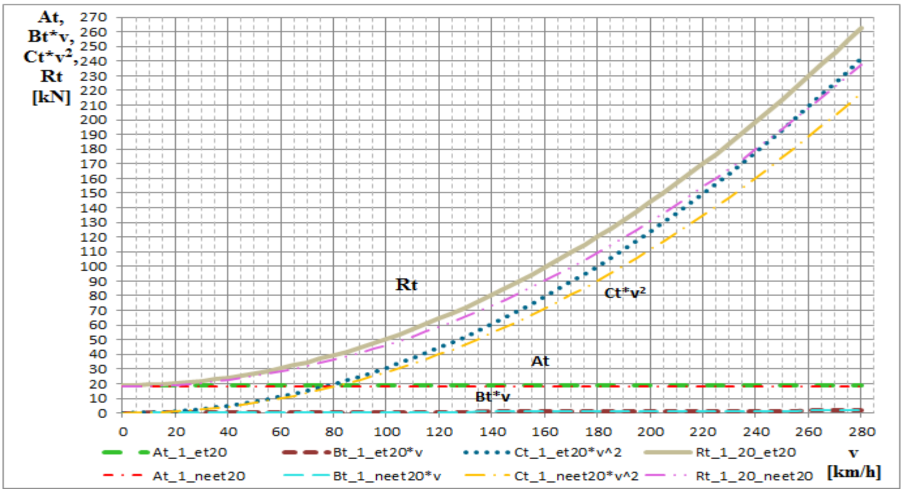


Fig. 6 – The resistances to motion components for trains towed in accordance with Davis polynomial

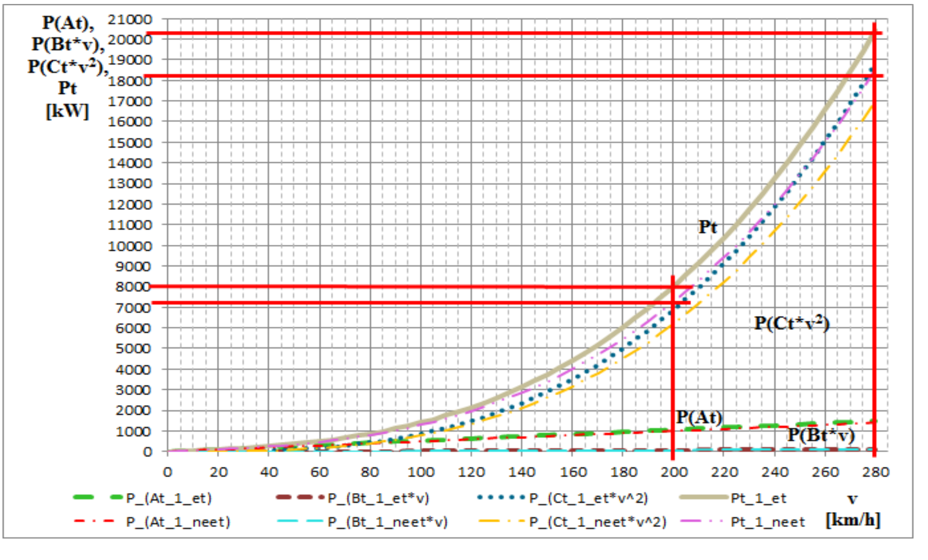


Fig. 7 – The arrangement of necessary power for hauled trains in accordance with Davis polynomial

Subsequent reporting between the components of running resistance, and this, shows that in the range of low and medium speeds (up to about 80 km/h), the largest share is occupied by mechanical rolling resistances depending on axle loads, as can be seen in Fig. 8. Above 80 km/h the largest share is occupied by the aerodynamic resistance, reaching values of 90% for the maximum speed that can be reached by the two trains.

In a similar manner, for the power required by the motor vehicles there is an increase of about 7% of the ratio rate used for overcoming the aerodynamic resistance when the speed increases from 200 km/h to the maximum that can be reached by the train (see Figure 9).

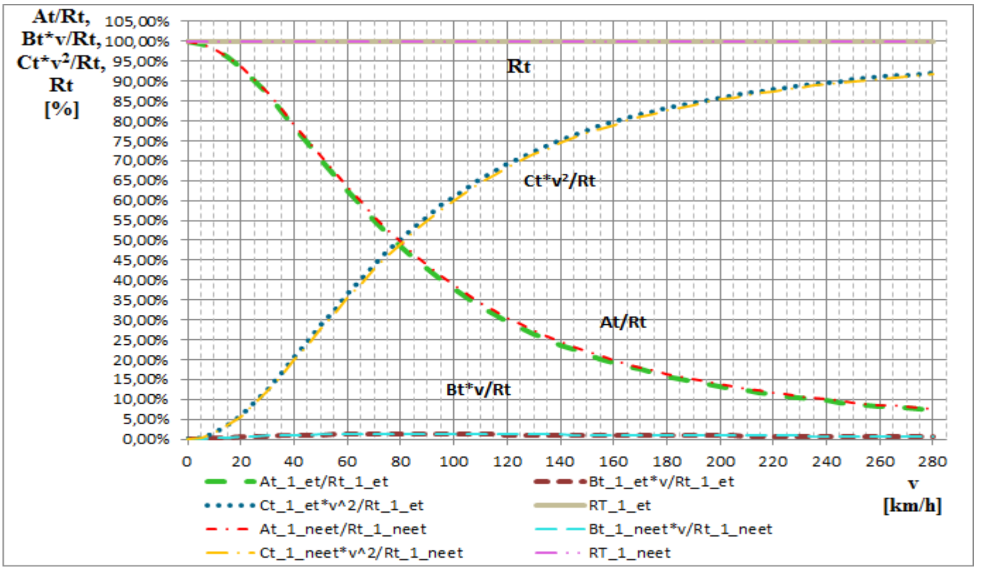


Fig. 8 – The percentage analysis of the resistance to motion components for hauled trains

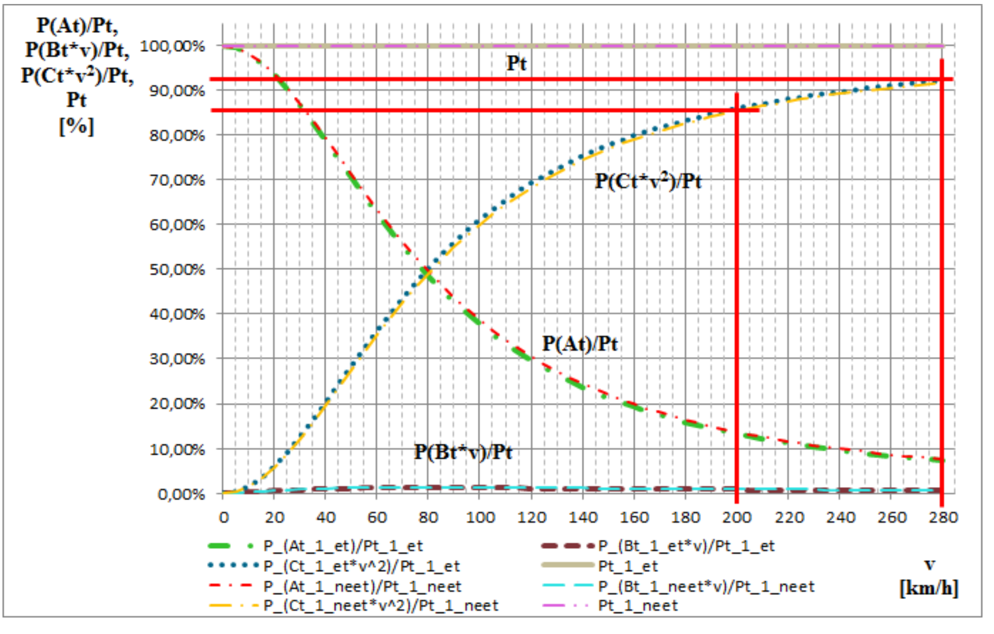


Fig. 9 – The percentage analysis of the required power components for hauled trains

3. CONCLUSION

In the case of the locomotives with total adhesion (such as LE 060 EA 5100 kW) the mass of the motor vehicle affects both the adhesion limit and the resistances to motion.

The resistance to motion of towing vehicles (wagons) depends on their constructive form. The resistance to motion of the wagons increases depending on the number of wagons and the higher the wagons number the lower the speed reached by the train.

In the case of a train consisting in a locomotive of LE 060 EA 5100 kW and a maximum of 20 double-deck or single-deck wagons, the maximum speed that could be reached does not exceed 260km/h and 275 km/h, respectively. This can be explained by the fact that the limit of adhesion depends on the number of motor axles of (in this case only 6) and the adherent mass of the motor vehicle.

A higher number of motor axles results in increasing of the adhesion mass and therefore the adhesion limit characteristic will allow higher travelling speeds. This is exemplified by the self-propelled electric trains of EMU (Electric Multiple Unit) type, where the motor axles are displayed along the train thus enabling the increase of the adhesion limit.

For running speed values higher than 80 km/h the percentage of the train aerodynamic resistance is significant ranging from 50% to more than 90% for the maximum speed that can be reached by the train.

The speed increase from200km/h up to the maximum that can be reached by the train (about 280km/h) is possible only by doubling the installed capacity of the motor vehicle, namely of the locomotive.

It can be said that for conventional passenger trains where travel speeds are greater than 200 km/h the classical train structure of locomotives and wagons is no longer justified but must be replaced by propelled electric trains of EMU type.

ACKNOWLEDGEMENT

This work is supported by the Sectorial Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and the Romanian Government under the contract number POSDRU/159/1.5/S/137390.

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