

Traction Energy Consumption of Electric Locomotives and Electric Multiple Units at Speed Restrictions

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Abstract: In this article the author reports the measurements made by traction measuring car of Railway Engineering and Metrological Service Centre (REMSC) in the research and development work “Complex investigation of reduction possibilities of additional costs due to speed restrictions on electric traction railway lines”. As results it can be stated that α correction parameters in the research and development work made between 2008 and 2010 should be changed because of specifying. These parameters can be used for calculation of additional acceleration energy after speed restriction sites.

Keywords: *railway engineering, traction energy consumption, speed restriction, locomotive, EMU*

1. Introduction

Analysing electric railway haul there is an important aspect to be considered: speed restrictions will substantially increase traction energy consumption as well as journey time [1,2]. Speed restrictions are needed because of transport safety due to railway track faults as well as cancelling of these railway track faults' elimination [3,4,5]. In case of diesel locomotives and diesel multiple units (DMUs) the additional traction energy consumption is related naturally to diesel oil.

There are some other disadvantages due to railway track faults:

- irregular vehicle movements [6,7],
- higher stresses in the elements of railway super- and substructure [3,4,8],
- much faster deterioration process of the railway track in case of cancelling of railway track faults' elimination [4,9].

The author has to mention there are a lot of technologies to avoid track faults or slow down deterioration process that can reduce traction energy consumption in the aspect of railway track, some of them:

- superstructure geometry stabilization with geogrids [10], steel sleepers [11], safety cap and ballast bonding technology [12],
- ballastless superstructure and special railway fastening system [13],
- etc.

There are special methods to decrease total traction energy consumption of the trains publicised in the international literatures. For example recuperated energy can be used and stored more efficiently [14], onboard storage batteries can be utilized for hybrid drive systems [15], onboard ultracaps are useful to energy storage [16]. Fully or partially automated Train Control Systems (TCS) and related operation mathematical algorithms are developed to optimize energy consumption of the trains [17]. Less energy consumption can be reached by target speed optimization [18], and it has to be considered that increased speed influences the wasted energy too [19]. In case of determination of train speed and timetable on the tracks, the difficult sections have to be taken into consideration [20]. These methods are suitable for reducing total traction energy of the trains, but they aren't or only partially adequate for taking into account the energy consumption of the locomotives due to acceleration process after discrete speed restriction.

The research team of Széchenyi István University firstly got research work for exact determination of additional traction energy consumption due to speed restrictions [21,22,23], after that the research and development work was related to comparison of additional traction energy consumption costs and costs of elimination of railway track faults caused by speed restrictions [24].

In the author's [25,26], his pensioner colleague's [22,23] and his research team's previous papers and research reports [21,24] there is an adequate calculation method for determining traction energy consumption of electric locomotives and electric multiple units (EMUs). The α correction parameters are formerly calculated from own energy consumption measurements on locomotives and EMUs, but the used α correction parameters are needed to be specified.

The Hungarian Railways ordered another research and development work from Széchenyi István University in 2011, the topic of this research was the complex analysis of reduction possibilities of additional costs due to speed restrictions on electric haul railway lines. In this research work there are measurements made by traction measuring car of REMSC [27] related to three types of electric locomotives and one type of EMU.

This paper reports the results of new measurements and calculations that belong to traction energy consumption of electric locomotives and EMUs.

2. Necessity and description of measurements made by traction measuring car

In the previous researches of our team calculations can be done only with own measured data on locomotives and EMUs.

These vehicles are the followings:

- Railjet trains hauled by 1116 Siemens Taurus locomotives [28],
- passenger trains hauled by 1047 and 1116 Siemens Taurus locomotives [29],
- freight trains hauled by 1047 and 1116 Siemens Taurus locomotives [29],

- 5341 Stadler Flirt EMU [30],
- 5342 Bombardier Talent EMU [31].

In case total traction energy consumption should be calculated for a determined railway line, correct data are needed for another locomotive too. To get these data additional measurements have to be done. The aim of these measurements is to state the fact that more precise α correction parameters can be used in the calculations which are controlled by traction measurement car.

The simple equations are below:

$$E_{calc} = 0,5 \cdot m \cdot (v^2 - v_0^2) \cdot 3.6 \cdot 10^6, \quad (1)$$

$$E = \alpha \cdot E_{calc}, \quad (2)$$

where

m – total mass of the train (locomotive and cars) in kg unit,

v and v_0 – values of acceleration speed step in m/s unit,

E – measured electric energy at an acceleration of a locomotive or EMU in kWh unit,

α – correction parameter (factor),

E_{calc} – calculated electric energy after Eq. 1 in kWh unit.

Because of the fact that measurements were done only for Railjet, passenger and freight trains hauled by Taurus locomotives as well as Flirt and Talent EMUs (values of Table 1), α correction parameters for other vehicles are determined by our specialist mechanical engineer colleagues to be able to assume traction energy consumption, these parameters are the followings:

- | | |
|--|--------|
| - passenger train hauled by V63-1 (1163) [32]: | 1.166, |
| - freight train hauled by V63-1 (1163) [32]: | 1.280, |
| - passenger train hauled by V43 (1043, 1143, 1243, 1343) [33]: | 1.266, |
| - freight train hauled by V43 (1043, 1143, 1243, 1343) [33]: | 1.313, |
| - passenger train hauled by M41 (2241, 2341) [34]: | 1.884, |
| - freight train hauled by M41 (2241, 2341) [34]: | 2.000, |
| - passenger train hauled by M62-0 (2062) [35]: | 1.639, |
| - freight train hauled by M62-0 (2062) [35]: | 1.927, |
| - 5429 [36] and 6312 [37] EMUs: | 1.570. |

The goal of the measurement series is to determine α parameter related to several locomotives and passenger as well as freight trains more precisely.

REMSC processed the plan for measurements in October, 2011, after that the measurements were done in April, 2012. Fig. 1. shows the measure train.



Figure 1. Measure train at Öttevény railway station (Ferenc Horvát's photo)

In Fig. 2. there is the set-up of measure train. At the front there is the analysed haul locomotive, behind that there is the VMK-002 [27] traction measuring car, at the back there is a 1047 Siemens Taurus locomotive that brakes the train.

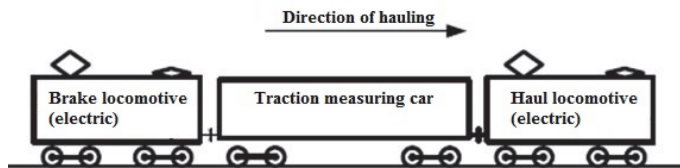


Figure 2. Set-up of measure train

The haul locomotives were the followings in the tests:

- V43 (1338) electric locomotive [33],
- 1047 Siemens Taurus electric locomotive (Taurus) [29],
- V63 (151) electric locomotive [32],
- 5341 (044) Stadler Flirt EMU (Flirt) [30].

Data of the measuring car:

- line number: 60 55 99-80 002-2,
- max. speed: 160 km/h,
- length: 24.5 m,
- weight: 41,000 kg,
- brake mass: 61,000 kg.

Braking simulation was always done with the same 1047 Taurus locomotive. Maximal brake force of this locomotive is 240 kN.

Measure tests were made between railway stations Öttevény and Hegyeshalom on the Hungarian main railway line No. 1. In this section the allowed maximal speed is 160 km/h. The horizontal geometry is quite straight and the vertical geometry does not contain high slopes only quite horizontal sections, as well as the geometrical condition of the track was good, in this way there isn't any distortional effect to energy consumption results.

The final measure program was as below:

- 16th and 17th of April in 2012: measurements with V43 (1338) locomotive, 40-60-80-100-120 km/h constant speed, as well as several speed steps between 40 and 120 km/h,
- 18th and 19th of April in 2012: measurements with Taurus (1047) locomotive, 40-60-80-100-120-140-160 km/h constant speed, as well as several speed steps between 40 and 160 km/h,
- 23rd and 24th of April in 2012: measurements with V63 (151) locomotive, 40-60-80-100-120 km/h constant speed, as well as several speed steps between 40 and 120 km/h,
- 25th and 26th of April in 2012: measurements with Stadler Flirt EMU (5341) locomotive, 40-60-80-100-120-140-160 km/h constant speed, as well as several speed steps between 40 and 160 km/h.

The measurements were made only on the right track in case of V43 and V63 locomotives in the right direction (from Öttevény to Hegyeshalom), but measurements related to Taurus locomotive and Stadler Flirt EMU were made on both tracks always in the right direction.

The REMSC calculated the required traction force values for all the locomotives and EMU for constant speed traction as well as the several speed steps. The required power for traction was determined from the traction force vs. speed diagrams for each measurement cases. Speed restrictions were also simulated (braking, traction with constant speed, acceleration), and electric energy consumption was measured during it. Measurements were done by three several brake forces.

From these data the additional energy consumption could be calculated.

Parameters below were recorded during measurements:

- V – speed in km/h unit,
- s – covered distance in m unit,
- U_p – primer voltage in kV unit,
- I_p – primer amperage in A unit,
- $\cos\phi$ – phase shift,
- P – electric power in kW unit,
- E – energy consumption in kWh unit as the integral of $P(t)$ function,
- F_v – traction force measured on drawbar in kN unit, as well as
- combined speed and distance signal and the section markers.

In the Fig. 3. several parameters are shown on the display of VMK-002 traction measuring car.

All the measured data can't be published because of limited space of this paper.



Figure 3. Several parameters on the display of VMK–002 traction measuring car

3. Data processing and results of measurements

Measured data from REMSC were processed by calculated specific values, after that specific traction energy data (in kWh/100 m/kN unit) were calculated for each locomotives and EMU. The set brake force values were between 10 and 150 kN (50 kN force simulates passenger train, 100 kN light freight train, and 150 kN heavy freight train). Additional braking wasn't used in case of Stadler Flirt.

During calculation it was supposed that total consumed electric energy was used for transmission of the trains. In case of traction with constant speed the energy equals to the total resistance of the train:

$$E_{used} = Q_{total} \cdot \mu_{train} \cdot s \quad (3)$$

where

E_{used} – consumed electric energy during the travel in kWh unit,

Q_{total} – total weight of the train consideration with brake force in kN unit,

μ_{train} – resistance of the train in N/kN unit,

s – distance that was taken with constant speed in m unit.

The calculation of μ_{train} is presented below in accordance with Hungarian Railways' recommendation from year 1983 [38]:

- in case of passenger train:

$$\mu_{train} = 2 + 0.047 \cdot \frac{V^2}{100} \quad (4)$$

– in case of freight train:

$$\mu_{train} = 2 + 0.057 \cdot \frac{V^2}{100} \quad (5)$$

where

V – speed of the train in km/h unit.

The calculated weight of the train from data of measurements with constant speed is below:

$$Q_{total} = 3.6 \cdot 10^5 \cdot \frac{E_{used}}{\mu_{train} \cdot s} \quad (6)$$

The consumed electric energy equals to the sum of energy against resistance of train and acceleration energy in case of assumed uniform acceleration. The calculated train weight in tons unit is as below [39]:

$$Q_{total} = 3.6 \cdot 10^5 \cdot \frac{E_{used}}{\mu_{train,av.} \cdot s} + 110 \cdot a_{av.} \quad (7)$$

where

$\mu_{train,av.}$ – average of the resistance of the train related to speed values v_1 and v_2 in N/kN unit,

$a_{av.}$ – average acceleration in m/s^2 unit.

Fig. 4. - Fig. 6. show the calculated train weights as a function of set brake forces. The R_2 values in some cases are between 0.5 and 0.75 (weak correlation), but in most cases are between 0.75 and 1.0 (strong correlation).

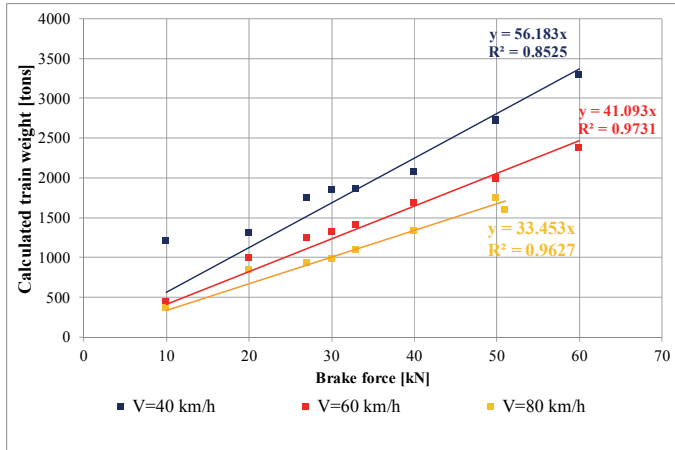


Figure 4. Calculated train weight in case of set several brake forces (V43)

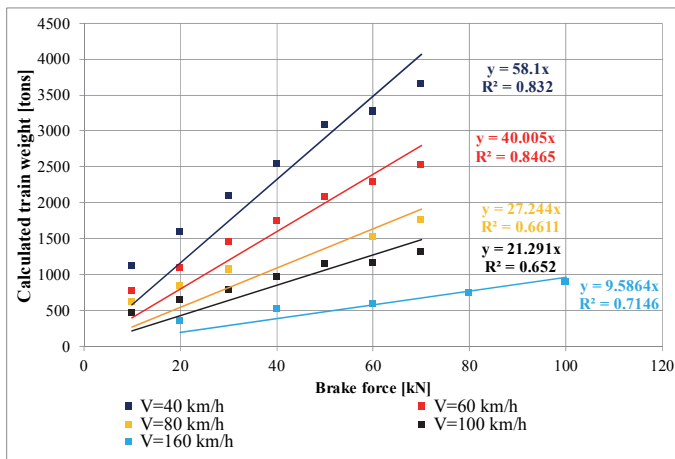


Figure 5. Calculated train weight in case of set several brake forces (Taurus)

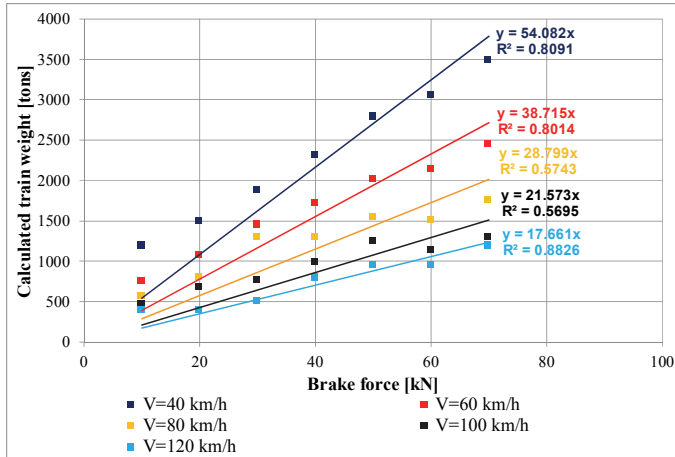


Figure 6. Calculated train weight in case of set several brake forces (V63)

Specific traction energies as a function of train speed are presented in Fig. 7 – Fig. 10. In case of measurements with V43 locomotives the maximum brake force values were 60 kN, in this way freight train diagrams couldn't be made.

Relationship was searched between used and calculated energies (Eq. 1 and Eq. 2).

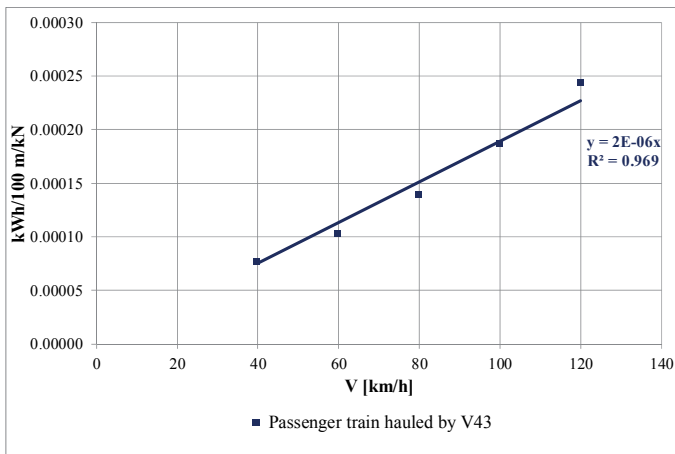


Figure 7. Specified energy consumption of V43 locomotive

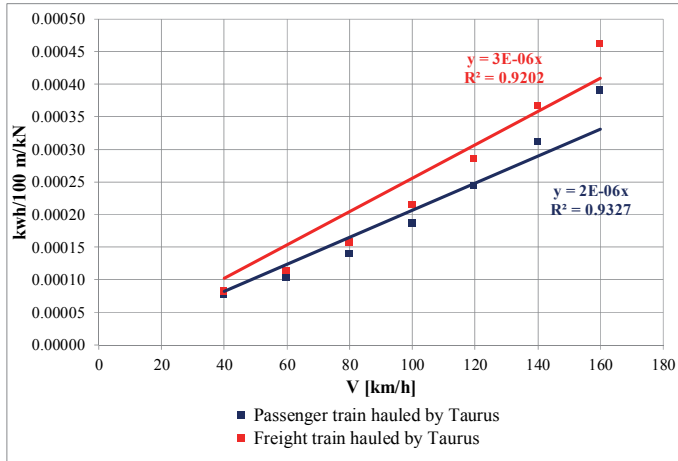


Figure 8. Specified energy consumption of Taurus locomotive

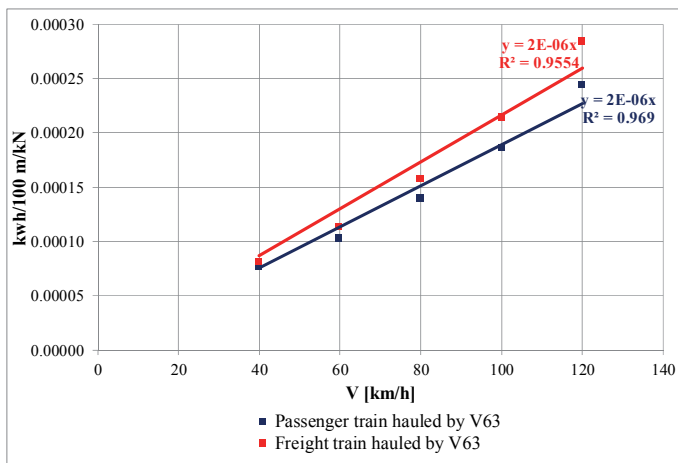


Figure 9. Specified energy consumption of V63 locomotive

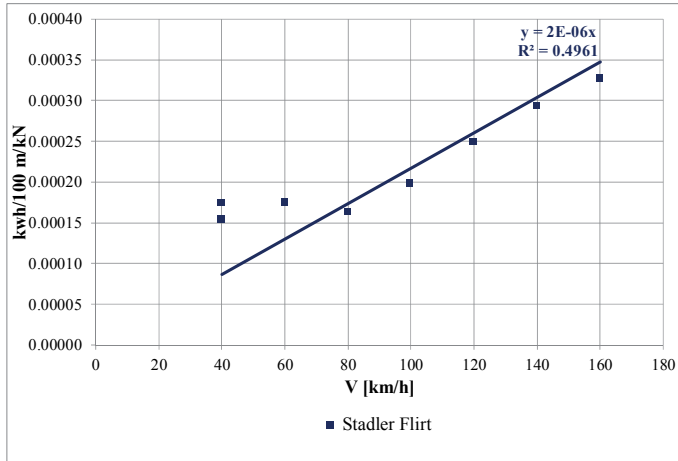


Figure 10. Specified energy consumption of Stadler Flirt EMU

Fig. 11. - Fig. 14. show the electric energy measured by REMSC as a function of calculated energy.

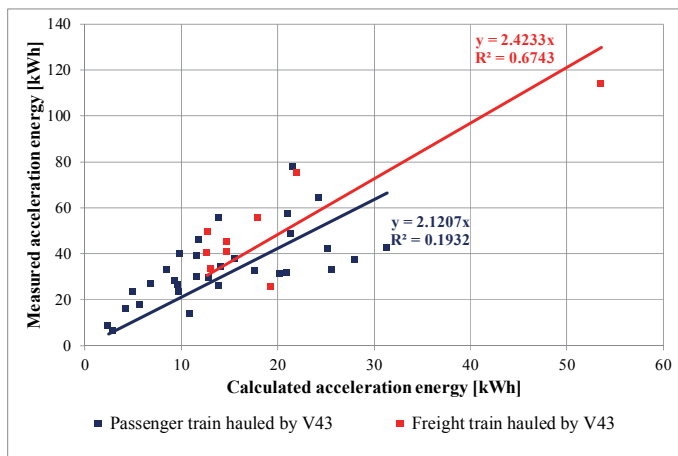


Figure 11. Electric energy measured by REMSC as a function of calculated energy (passenger and freight trains hauled by V43 locomotives)

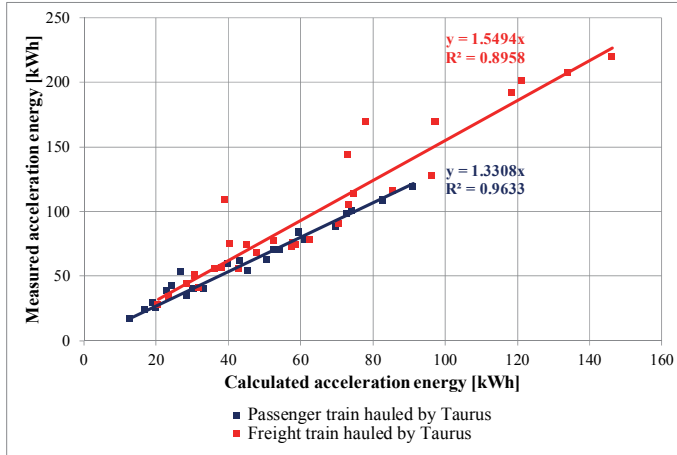


Figure 12. Electric energy measured by REMSC as a function of calculated energy (passenger and freight trains hauled by Taurus locomotives)

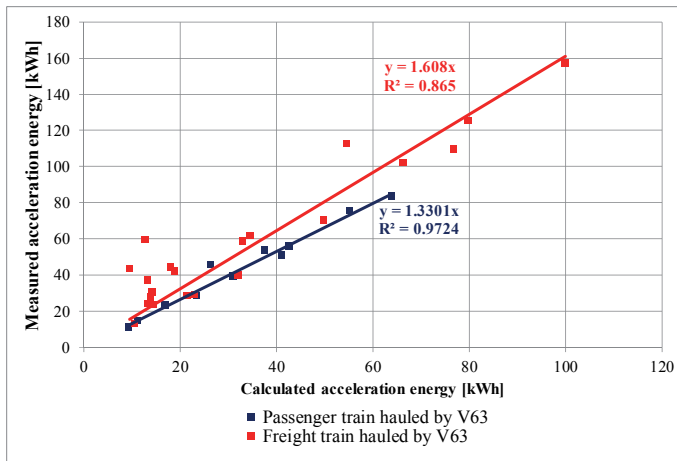


Figure 13. Electric energy measured by REMSC as a function of calculated energy (passenger and freight trains hauled by V63 locomotives)

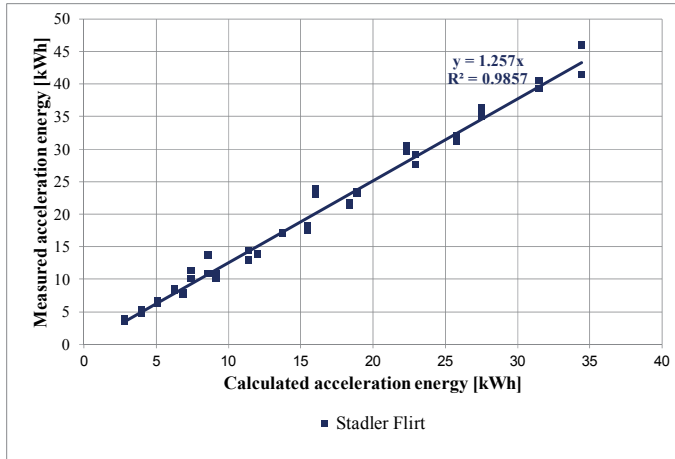


Figure 14. Electric energy measured by REMSC as a function of calculated energy (Stadler Flirt EMU)

Fig. 15. presents the relationship between measured and calculated recuperated energy.

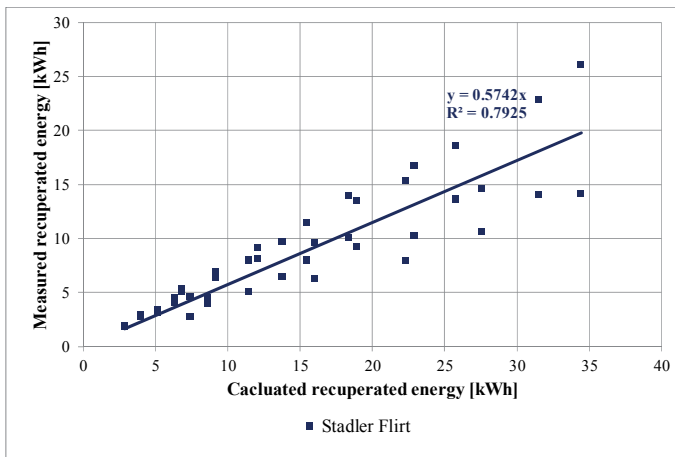


Figure 15. Relationship between measured and calculated recuperated energy (Stadler Flirt EMU)

Comparison of the values measured by REMSC and earlier by our research team is presented in Table 1.

Table 1. Variance of α correction parameters

Type of train	α		$\Delta\alpha$	Deviation from the values from REMSC measurements (%)
	From measurements by REMSC	From earlier studies and papers [24,25,26]		
<i>P. train – Taurus locomotive</i>	1.331	1.415	0.084	6.3
<i>F. train – Taurus locomotive</i>	1.549	1.495	0.054	-3.5
<i>RJ train – Taurus locomotive</i>	–	1.316	–	–
<i>Stadler Flirt EMU</i>	1.257	1.128	0.129	-10.3
<i>Bombardier Talent EMU</i>	–	1.095	–	–
<i>P. train – V43 locomotive</i>	2.121	1.266	0.855	-40.3
<i>F. train – V43 locomotive</i>	2.423	1.313	1.110	-45.8
<i>P. train – V63 locomotive</i>	1.330	1.166	0.164	12.3
<i>F. train – V63 locomotive</i>	1.608	1.280	0.328	20.4

Note: P. train means passenger train, F. train means freight train, RJ means Railjet

4. Evaluation of the data measured by traction measuring car

There isn't significant difference between the theoretical calculated and measured (by REMSC) value of α parameter in case of Taurus locomotive and Stadler Flirt EMU, but there is significant deviation in case of V43 and V63 locomotives. This fact should be answered. The theoretical values were determined in the years 2008 and 2009. That time measurements couldn't be done by these locomotives, correction parameters were calculated assuming new locomotives use special data and diagrams. REMSC made measurements by the V0431 338 locomotive in 2012 which vehicle is older than 30 years. Because of this fact a lot of influencing parameters should be considered:

- the efficiency of traction of V43 locomotive is not the best due to the out of date silicon rectifier,
- the main parts and other accessories aren't the original ones in the locomotives.

Main parts and accessories of V0431 338 locomotive used during the measurements have different lifetime and efficiency, they are in different condition too. 1 % decrease of efficiency of main parts with causes about 3...5 % decrease of whole efficiency of the vehicle.

The first V63 locomotives are ca. 18...20 years younger than V43s. Maintenance strategy is similar to V43's. Because of this fact significant decrease of efficiency can be assumed. This can explain the experienced difference between theoretical and practical values.

Determined correction parameters derived from measurements of REMSC should be used in the future. Parameters from earlier studies are needed to use only in case of Railjet trains and Bombardier Talent EMUs. Because of the fact that there isn't significant difference between correction parameters in Table 1 related to Taurus locomotive, it can be assumed that correction parameter related to Railjet hauled by Taurus is approximately equals to 1.316. This statement may be true in case of Bombardier Talent EMUs.

5. Summary

This paper summarizes the results and evaluation of measurements done by REMSC's traction measuring car related to R&D work financed by Hungarian Railways [40]. Publicised α correction parameters determined in earlier studies could be refined. These more accurate values should be used in case of calculation of additional traction energy consumption due to speed restriction [41].

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