The Methodology for Energy Efficiency on Electric Locomotive Traction for the Heaviest and Longest Trains in the Operation of the Kazakh Railway

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Abstract

This article includes in two parts: the first is the description of a new electric locomotive AC and the second determines the maximum traction capabilities at the train weighing 9,000 tons with a resistance movement from the slope. Summary of the research allows to determine power constraints in conditions of Kazakhstan. The results can be used in normative documents of exploitation, allow to guarantee the safe exploitation at maximum load of the locomotive.

Keywords: Freight, Electric locomotive, Power consumption, tractive effort, Tractive resistance, Tractive effort, Velocity, Energy, Power of a locomotive, Kazakhstan, VL80, KZ4A, KZ8A

1. Introduction

The statistical methods allow forecasting a power consumption by electric locomotives for hauling trains. One method of such is the method of tractive energy passport. This method takes into account influence of the slope of the railway, the speed of the train, weight of the locomotive, weight of the train and the load per axle. The uniqueness of this method consists in forecasting the power consumption by electric locomotives for hauling trains with different cargo loading without accumulation of a preliminary statistical sampling.

The theory was tested on the Northern Kazakhstan railways. That railway direction has different kinds of cargo train weights. The first kind is empty trains which weights no more by 1800 tons. The second and most popular kind is mixed trains which weight from 1800 tons to 5400 tons. The third kind is heaviest trains which weight from 5400 tons to 9000 tons. Also on this site are operate three types of electric locomotives VL80S, KZ4A, KZ8A.

The main purpose of this paper is to determine the amount of train weight for maximum effective hauling by each type of locomotive.

2. Power balance equation

Type The power balance of electric traction involves the distribution of locomotive useful work on components. The power efficiency when the locomotive is in traction mode is:

\[ P = P_M + P_a + \Delta P, \]  

where \( P \) is the power of locomotive, kW; \( P_M \) is the mechanical power of the locomotive, kW; \( P_a \) is the power consumption of auxiliary equipment’s, kW; \( \Delta P \) denotes a total loss of power within the locomotive, kW and

\[ P_M = P_R + P_K + P_P, \]  

where \( P_K \) - is the power of the kinetic energy, kW; \( P_P \) – is the power of the potential energy, kW; \( F_{TE} \) is the tractive effort of the locomotive, kN; \( v \) – is the velocity (km/h); \( P_R \) is the power of the force required to move a train, is the sum of the rolling resistance on tangent level track, grade resistance and curve resistance of the locomotives and cars.

The power balance equation for braking

\[ P = P_a + \Delta P, \]  

\[ \Delta P_B + P_R + P_K + P_P = 0, \]  

where \( \Delta P_B \) – is the braking loss, kW.
This article describes the estimation of power efficiency without power consumption by auxiliary equipment’s, $P_a$. It requires an individual study.

Electromechanical and tractive characteristics in technical literature include an internal loss of power $\Delta P$. These characteristics are presented implicitly in power efficiency by work of locomotives which described in more detail below.

A complete mechanical power $P_M$ of electric trains includes in three parts: the energy by the tractive effort, the energy consumption of auxiliary equipment’s and the energy produced by braking. Each part keeps acceleration constant $dv/dt$.

From the power balance equation follows an energy balance:

$$ E_{sum} = E_{recup} + E_r $$

where $E_{sum}$ is the energy at pantograph, kWh; $E_{recup}$ is the recuperation energy, kWh; $E_r$ is the energy of locomotive, kWh.

This useful energy is the energy of the force that required to move $E_r$:

$$ E_r = \int(R_0 + R_{curve})dv $$

where $S$ is the resistance component that is independent of speed (e.g., axle resistance); $b$ is the resistance that varies with speed; $c$ is the resistance that varies with the square of speed;

$$ r_{loc} = a + b \cdot v + c \cdot v^2, $$

where $r_{loc}$ is the resistance of locomotive, N/ton; $a$ is the resistance component that is independent of speed (e.g., axle resistance); $b$ is the resistance that varies with speed; $c$ is the resistance that varies with the square of speed;

2. Internal resistance of the cars rolling resistance with load axle equal 17 tons to axle:

$$ r_{cars} = 0.7 + a \cdot b \cdot v + c \cdot v^2, $$

where $r_{loc}$ is the resistance of cars, $w_{cars}$ is the axle load, tons/ axle; $a$, $b$ and $c$ are the resistance components which are independent of type of rolling stock and type of railway track.

The grade resistance is additional resistance $r_i$, calculated in this equation:

$$ R_i = r_i(W_{loc} + W_{cars}), $$

where $W_{loc}$ is the weight of the electric locomotive, t; $W_{cars}$ is the weight of the freight cars, t.

5. Plot a curve of the tractive effort $F_{TE}(v)$, various curves of the tractive resistance $R(v)$ depend on slope $i$;

6. Definition of the average consumption of the traction $a$, kWh/t·km·br:

$$ a = \frac{10^4 \cdot U \cdot \Sigma I}{(W_{loc} + W_{cars}) \cdot v_p}, $$

where $v_p$ is the velocity in point of intersection curves $F_{TE}(v)$ and $R(v)$, km/h; $\Sigma I$ is the active current of electric locomotive, A.

Finally, to plot according the velocity $v_p(i)$ and the average consumption of the traction $a(i)$, which are representing tractive energy properties of the selected locomotive.

3. A simulation model

Estimation of locomotive's energy balance could be based on the tractive energy passpport. For creating tractive energy passport needed following inputs: type of the electric locomotive, weight of the locomotive, weight of the cars, and load of axle. Estimation of locomotive energy efficiency is not requiring detail train running states outputted from train performance simulator or speed profile generator, including train velocity, distance branch line station and curve of train resistance.

It involves the following procedure:

1. Internal resistance of the locomotives:

$$ r_{loc} = a + b \cdot v + c \cdot v^2, $$

2. Internal resistance of the cars rolling resistance with load axle equal 17 tons to axle:

$$ r_{cars} = 0.7 + a + b \cdot v + c \cdot v^2, $$

where $r_{loc}$ is the resistance of cars, $w_{cars}$ is the axle load, tons/ axle; $a$, $b$ and $c$ are the resistance components which are independent of type of rolling stock and type of railway track.

An axle resistance is primarily reflected in $a$, while $b$ reflects flange friction and dynamic flange impacts, which increase with speed. Rolling resistance and track resistance are reflected in $a$ and $b$. $C$ is a streamlining coefficient that captures many aerodynamic effects such as frontal air pressure, rear drag, the swirling of air in open top cars, and turbulence between cars.

These equations are defined in Chapter 1, Section 1.2 of the Foundation of Traction Calculations for Train Operation, published by the Ministry of Railways of the Union of Soviet Socialist Republics (VNIIZHT, 1985).

3. Total tractive resistance of train $R(v)$ at the various slope from $i = 0$% to maximum $i = i_{max}$, and at the various velocity from $v = 0$ to $v = v_{max}$:

$$ R(v) = R_0 + R_{loc}, $$

$$ R_0 = (W_{loc} + W_{cars})r_{cars}, $$

The grade resistance is additional resistance $r_{i} = i$. calculated in this equation:

$$ R_i = r_{i}(W_{loc} + W_{cars}), $$

where $W_{loc}$ is the weight of the electric locomotive, t; $W_{cars}$ is the weight of the freight cars, t.

5. Plot a curve of the tractive effort $F_{TE}(v)$, various curves of the tractive resistance $R(v)$ depend on slope $i$;

6. Definition of the average consumption of the traction $a$, kWh/t·km·br:

$$ a = \frac{10^4 \cdot U \cdot \Sigma I}{(W_{loc} + W_{cars}) \cdot v_p}, $$

where $v_p$ is the velocity in point of intersection curves $F_{TE}(v)$ and $R(v)$, km/h; $\Sigma I$ is the active current of electric locomotive, A;

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4. Case study

4.1 Input Data

In this section, estimates from the analytical method and statistical model are compared to each other and, where possible, to estimate derived from other studies.

Almost 200 billion freight ton-kilometres travel around rail network of the Republic of Kazakhstan every year. 70 percent of all freight rail transportation was carried by electric traction. The electric locomotives are often used for long distance for social and economic reasons. Such a transport system is expected to be further increased in the future.
transportation the heaviest and longest freight trains, with the largest numbers of cars.

4.2 The simulation of Result
As shown in Fig. 1, freight traffic on the Astana – Karaganda have different weight of the freight trains.

The weights of the freight trains have three main group: the first group is empty trains with weights until 1800 tons, the second group is freight trains with weights from 1800 to 5400 tons and the third group is heaviest freight trains with weights from 5400 to 9000 tons, in Fig. 2.

These three groups are distributed by three type locomotive depend on their Power Output in kW and estimate of energy efficiency each one locomotives with tractive energy passport.

The traction capabilities of locomotives VL80S and KZ8A have been compared.

In this paper tractive efforts of the VL80S and KZ8A were compared from the slope with a weight of 6000 tons. This weight (6000 tons) was chosen as the maximum of train's weight in statistics in 2015. As you can see electric locomotive VL80S can not overcome some slopes. On the other hand, electrical locomotive KZ8A that easily overcomes up to 8‰ (Table 2). Therefore, the approximation of weight up to 9,000 tons.
tons was made for the purpose to know what kind of slopes can overcome KZ8A.

It indicates that the locomotive has a reserve of power for traction of freight trains weighing up to 9000 tons. The values of the resistance of the train depending on the slope, with a weight of 9 000 tons were shown in the Figs. 3, 4.

5. Conclusion and recommendations

Omitting the calculation methodology of traction and energy passport which are described in many works that devoted to the study of the theory of traction, on the results of the study can be noted that electric locomotive KZ8A can be used in traction of trains weighing up to 9 000 tons and it is capable to overcome slopes no more than 8 promile for a given weight.

In conclusion, it is worth noting, that the exploitation of electric KZ8A increases a precinct speed, weight standards and optimal implementation of traction force that aids to reduce the specific energy consumption.

In the traction of empty and mixed trains with a weight of less than 5 400 tons the electric locomotive KZ8A has lower energy efficiency. So that, it is recommended to use electric locomotives such as VL80, KZ4A with power not exceeding 6 000 kW. The electric locomotive KZ4A is energy efficient when it is pulling trains with a weight of 1,800 tons on slopes up to 9. The electric locomotive VL80 is energy efficient when it is pulling trains with a weight about 5400 tons on slopes up to 7.

The electric locomotive KZ8A is energy efficient when it is pulling trains with a weight about 9000 tons on slopes up to 7. This locomotive is energy efficient when carrying long and heavy trains. The Kazakh Railway is planned to use heavier trains in the future.

The methodology of tractive energy passport allows to determine the efficiency of the locomotive by input data: weight, slopes of the railway and power of traction. The methodology can be recommended for the various railways with different types of trains.

References