Train Movement and Environmental Resistance

Gennady Akkerman[a] and Sergei Akkerman[b]
Ural State University of Railway Transport, Yekaterinburg, Russian Federation

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Abstract: The reason for the appearance of additional resistance to the movement of the train are weather conditions, the gravitational component of the weight, curved sections of the track, the density of train traffic, the non-normative track gauge maintenance. Some of these reasons are tied to the conditions of the railways of the Urals. The possibilities of mitigating these resistances are being considered.

1 INTRODUCTION

When a train moves along a rail track, forces appear that prevent this movement – the forces of environmental resistance. According to (JSC Russian Railways, 2016), these forces are divided into the main resistance and additional resistances.

The main resistance is the resistance to movement experienced by the rail crew when moving uniformly in a straight line on the site at a wind speed of less than 10 m/sec and an outdoor temperature of more than -25 ° C.

The term "additional resistances" combines all resistances caused by:

- weather conditions other than those of the main resistance;
- the gravitational component of the weight when the train is moving on an incline;
- curved sections of the track;
- the density of traffic flow when the speed of the train changes due to the high traffic intensity (the train cannot move "under green on green" traffic lights);
- the non-normative track maintenance (deviations in the geometry of the track).

The forces acting on 1 ton of train mass are called specific forces in all literary "transport" sources. In theoretical mechanics, there is no such concept, since the force per unit of mass, according to Newton's second law, is acceleration. Therefore, we should talk about the influence of all these factors on the acceleration (deceleration) of the train.

2 MATERIALS AND METHODS

The parameters characterizing the movement of the train can be taken as:

- travel time or average speed;
- specific consumption of energy or fuel, specific consumption is the consumption per 1 tkm;
- a criterion for the quality of movement, which characterizes the uniformity of movement or the deviation of individual acceleration values from the average on the section. It is proposed to take for this criterion the standard deviation of acceleration at each moment of time from the average. Let's call this parameter "acceleration noise" (Akkerman, 1989; Drew, 1972). The noise of acceleration during the movement of the train "on the green under the green", i.e. with the free movement of the train, we will call the natural noise peculiar to this section of the road. It can be assumed that such an acceleration noise is equal to the acceleration noise on an ideal road with a coefficient characterizing this segment of the road.

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[a] https://orcid.org/0000-0003-1330-1825
[b] https://orcid.org/0000-0001-9237-3637

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Thus, by improving the geometry of the road, we bring the conditions of movement of the train along it to the movement on the ideal road.

3 RESULTS AND DISCUSSION

Weather conditions are determined by the main meteorological indicators:

- air temperature;
- atmospheric pressure;
- air humidity;
- the strength and direction of the wind.

The influence of these indicators on the movement of the train is different, but in the end it comes down to the forceful effect of the air environment on the moving train. Taking into account this influence affects even the design of the railway, for example, the design of the longitudinal profile.

To assess the force effect of the air environment, an experimental test of the influence of these factors on the conditions of train traffic on some sections of one of the Ural railways with electric and diesel traction was carried out.

The initial data for the study were:

- longitudinal profiles of sections;
- personal accounts of locomotive crews, according to which the specific energy consumption (fuel) was determined as a quotient of the division of energy (fuel) costs per tkm of work;
- indicators of locomotive speed gauges;
- meteorological indicators at the time of departure and arrival of trains at the final points according to weather stations;
- information from weather recorders (barographs, thermographs, etc.) installed on locomotives.

The average meteorological indicators along the route coincided with the data of the recorders installed on the locomotives, with an accuracy of up to 10%, except for the readings of barographs on the transshipment sections.

The studies were conducted separately for the "even" and "odd" directions of movement. Known ratios (Turbin, 1989) $q=3.1r$, kWh/1000tkm, $q=0.85r$, kg/1000tkm,

here q is the specific consumption of electricity or fuel for the traction of trains, adjusted for the influence of the mass of the train,

r –specific mechanical work of the traction force, tkm/1000tkm

Since part of the mechanical work of the traction force went to overcome the additional resistance to movement, then:

$$w=q/3.1 \text{ or } w=q/0.85 \text{kg/t or}$$

$w=3.29q$ for electric traction and $w=11.5$ q, n/t for diesel traction.

Of all the considered weather and climatic indicators, according to our research, low outdoor temperatures have the greatest impact on the conditions of train movement in the Urals region, see Table 1.

Table 1: Increased resistance to train movement by the influence of meteorological factors.

Meteorological factors	Increasing resistance, %
Atmospheric	0.7
precipitation	15
Icy phenomena	Up to 30
Cold temperatures	Up to 39
Wind	

Precipitation "directly" does not affect the resistance to the movement of the train. However, in the form of rime or frost on the surface of the rail, i.e..as ice formations can be associated with a decrease in the coefficient of adhesion of locomotive wheels with rails, which for locomotives with limited traction force on coupling, can lead to a decrease in traction force and speed on descents due to its limitation on brakes. A decrease in the coupling coefficient to 15% (Railway transport: Ref. journal, 1971; Akkerman, 2021) under unsatisfactory weather conditions can lead to a decrease in the mass of the train to 15% or its speed on the rise at the same mass to 30%, which is equivalent to an increase in resistance by 15% with constant traction. There are cases when the formation of ice on the rails and the contact wire generally disrupted the movement of trains (Railway transport: Ref. journal, 1971; Akkerman, 2021). The presence of an electric current contributes to icy formations.

The contact fatigue strength of rails depends on the coefficient of sliding friction (Skvortsov, 1970), therefore, a change in this coefficient may affect the service life of the rail. Icy phenomena are not such a rare phenomenon: on the territory of Russia: in some areas up to 200 times a year, between San Petersburg and Novokuznetsk, ice and frost were observed for about 40 days per year (Buchinsky, 1960).

With an increase in the specific humidity of the air, the specific air resistance to the movement of the train, according to our research, decreases approximately 1.004-1.012 times compared to dry air. But we should not forget that the humidity of the air is associated with icy phenomena.

The air resistance is directly proportional to the atmospheric pressure (Akkerman, 1992), which depends on the absolute terrain marks of the region and on the meteorological conditions at a given time. An increase in the marks by 500 m. leads to a change in pressure by approximately 45 mmHg (Baranov, 1981), which reduces air resistance by 6%. In the middle Urals, the amplitude of atmospheric pressure fluctuations can exceed 11 mm Hg, which is equivalent to a change in air resistance by 1-2%

At low atmospheric pressure, the traction force of the locomotive decreases: in case of non-standard conditions (air temperature is more than 20 °C and a pressure less than 760 mmHg) the traction force (F) will be determined:

$$F = F_k(1 - k_1 - k_2) \qquad (1)$$

Where Fk is the traction force under standard meteorological conditions,

k1, k2 are coefficients that take into account the decrease in diesel power at an air temperature of more than 20 °C and atmospheric pressure less than 760mm Hg.

With an increase in the absolute relief marks, atmospheric pressure decreases, the traction force decreases, the consequence of this may be a decrease in weight norms (Astakhov, 1966) or the speed of the train (Kantor, 1984).

The totality of weather factors can be considered as a microclimate, i.e. the climate of the local section of the highway (embankments, recesses, etc.) or a macroclimate, i.e. the climate of the region. Even at the neighboring points of the route, the weather conditions may be different: the wind speed on the embankment is 15% higher than the wind speed in the field.

3.1 The Gravitational Component and the Conditions of Movement of the Train

It is known that the acceleration from the gravitational component during the movement of the train or the specific force from the slope is proportional to the slope of the longitudinal profile itself –i

$$W_i = 9{,}81i \qquad (2)$$

The force effect of the longitudinal profile in the balance of forces acting on the train can be very significant. By combining the slopes and lengths of the profile elements, it is possible to obtain such a ratio of forces acting on the train, at which the energy consumption will be minimal. We will call such a profile energy-optimal (Akkerman, 2006; Akkerman, 2018). Energy savings when moving a train along an energy-optimal profile is equal to 15% or more. The movement of the train along such a profile is more uniform, the acceleration noise is close to a minimum.

3.2 Resistance to Train Movement on Curved Sections of Track

Curved sections of the railway, as a rule, are represented by a circular curve, mated at the ends with straight transition curves. In this case, the length of such a section is equal to the sum of the lengths of the circular lk, and the transition lp, curves. The resistance from the curve according to (Akkerman, 2008) is inversely proportional to the radius of the curve, Rcr. For example: wr=6870/Rcr.

Our department proposed to design curved sections with two transition curves without a circular curve, the so-called biclottoid projecting. With such projecting, the average additional resistivity is two times less.

3.3 The Density of the Traffic Flow and the Resistance to the Movement of the Train

The intensity (throughput) of the traffic flow N is determined by:

$$N = KV \qquad (4)$$

Here: -K is flow density,

V is the speed of the traffic flow.

Applying the hydrodynamic analogy for the traffic flow, we obtain the optimal Kopt density, where

Kj is the maximum density of the traffic flow.

$$К_{opt} = \frac{4К_i}{9}, \qquad (5)$$

the optimal speed, -Vopt, i.e. the speed at which the throughput is maximum (km/h):

$$V_{opt} = 0{,}33V_f \qquad (6)$$

and throughput:

$$N = V_f + K_f \qquad (7)$$

Here V_f is the speed in free movement, i.e. "on the green under the green" without speed limits.

Additional exposure to the environment leads to a decrease in speed V_f.

According to our data, an increase in resistivity by 9.81 n/t leads to a drop in the speed of free movement by an average of 7.7%, and hence the throughput by the same proportion. You can increase the speed V_f by appropriate profile design, 9.81 $^{\text{H}}/_{\text{T}}$is the resistivity at $\iota = 1\,{}^{0}/_{00} \cdot \vartheta$

3.4 The Non-normative Track Maintenance

When trains move, deformations accumulate in the railway track, which is expressed in the appearance of deviations in the geometry of the track gauge - irregularities occur. The irregularities vary: by location, length, amplitude, area and intensity (quantity per 1 km). Deviations differ in degrees: the first degree is not taken into account, the second degree of deviation does not require a reduction in speed and immediate straightening of the path, the third requires immediate correction and speed reduction, at the fourth degree the running line is closed. Therefore, the deviation of the second degree was taken into account. According to our data, if the deviation is within the curve, then the transverse forces of the wheel-rail increase to 20%, and an increase in additional resistance in the curve should be expected by the same amount. In (Shapetko, 2020), it is concluded that irregularities in the longitudinal profile can lead to excessive electricity consumption on each km of track per 1000 tons of train of 0.82 kWh, which is equivalent to 2.64kN per km of mechanical work of the locomotive traction force or 2.64 n/t of resistivity - this is approximately 0.18 wo. An example is also given here that on the Trans-Baikal Railway, additional resistance from irregularities reached (0.3-0.4) wo. Therefore, it can be assumed that irregularities lead to an increase in additional resistance to the movement of the train within (0.18-0.4) of the main resistance.

4 CONCLUSIONS

1. Adverse weather conditions can increase the resistance to train movement by up to 39%.
2. The design of an energy-optimal profile allows you to reduce energy costs on the rise by up to 15% or more. Moreover, the movement of the train on such a rise is more uniform.
3. The resistance to the movement of the train on curved sections of the track is reduced by half when using biclottoid projecting of such sections.
4. The additional environmental resistance by 9.81 n/t leads to a drop in the speed of free movement by 7.7%, and hence the throughput by the same proportion.
5. Unevenness of the track leads to an increase in additional resistance to the movement of the train to 0.4 of the main resistance.

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