ON THE EFFICIENCY OF USING AUTONOMOUS LOCOMOTIVES ON THE RAILWAYS OF MONGOLIA

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ABSTRACT

The requirements of speed, reliability, safety and cost-effectiveness of cargo transportation pose a number of complex logistics tasks for Ulaanbaatar Railroad (UBZhD), including the choice of optimal train mass, series and number of locomotive sections for driving a freight train of a given weight. The mass of the train selected in the course of the study was checked by the condition of starting from the place on the calculated ascent. Based on the analysis of the longitudinal track profile, a computational profile scheme was compiled. Calculation of the minimum traction force of the locomotive was given by the mass of the train, the series and the number of sections. Using the diagrams of the specific slowing and accelerating forces, the train speed curve was constructed by the method of A. I. Lipets, after which by the method of G. V. Lebedev the total train travel time and the operating time of TED in various modes was found, which allows finding the specific fuel consumption. After considering three possible variants, it is established that the combination of locomotives 2TE116UM-23AGAL allows for faster and more economical cargo transportation. Given the equipment of the UBZhD with these locomotives, the idea proposed in the article can be realized on the most heavily stressed sections.

Keywords: railway, locomotive, Mongolia, cargo transportation optimization, calculations, efficiency.

Background. *In connection with the forecasted growth of the Mongolian economy, it becomes necessary to solve complex logistics tasks on a countrywide scale. Actually, in particular, the choice of a locomotive that meets a set of requirements, including such as minimizing the time of transportation, observing traffic speeds ensuring safety in emergency situations, determining the optimal specific fuel consumption becomes a topical one. In this study, on the basis of the analysis of the longitudinal track profile, optimal parameters of the mass of the train, the series and the number of sections of the locomotive for conducting a freight train of a given weight were chosen on the most heavily stressed section Tolgoit–Choir. For each of the proposed options indicators of relative effectiveness were found and recommendations for operation were developed.*

Objective. *The objective of the authors is to consider efficiency of using autonomous locomotives on the railways of Mongolia.*

Methods. *The authors use general scientific and engineering methods, mathematical apparatus, statistical method, comparative analysis.*

Results.

1. Method of calculation

The calculation of performance indicators for the operation of different locomotives is based on the following standard procedure. At the initial stage it is necessary to study the longitudinal profile of the investigated track section (in this example, Tolgoit–Choir, data provided by the Ulaanbaatar Railroad – UBZhD). The calculated profile scheme is obtained due to the grouping of similar elements and the replacement of the curves of the track sections with fictitious ascents. Then, specifying the mass of the train, it is necessary to choose the series and number of sections of the locomotive on the basis of calculating the minimum traction force of the locomotive for conducting a freight train of the established weight according to the calculated ascent with a calculated constant speed [6]:

$$F_{K\min} = Q \cdot (\omega_0 + i_P) \cdot \left(\frac{q+1}{q}\right), \quad (1)$$

where Q is the weight of the freight train composition, kN; i_P is steepness of the calculated ascent; q is the ratio of the weight of the train to the weight of the locomotive. The main resistivity of train movement ω_0 is determined from:

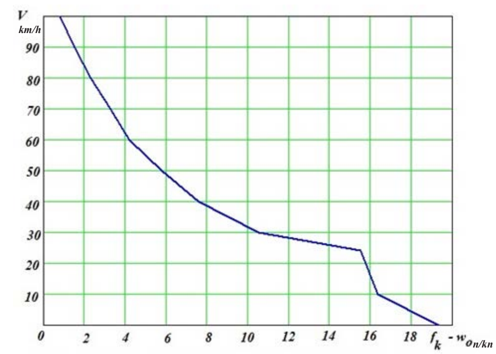
$$\omega_0 = \frac{\omega_0' + q\omega_0''}{1+q}. \quad (2)$$

The values ω_0', ω_0'', characterizing the main resistivity of movement of train and freight train are

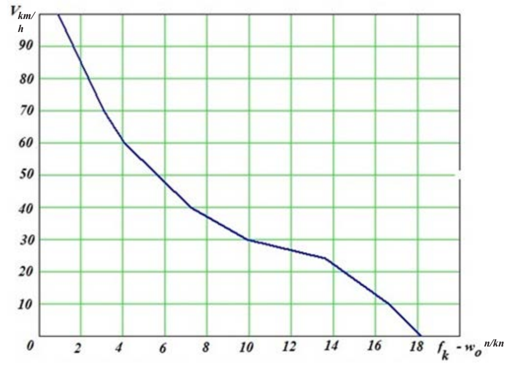
Table 1

The initial parameters of the compared series of locomotives

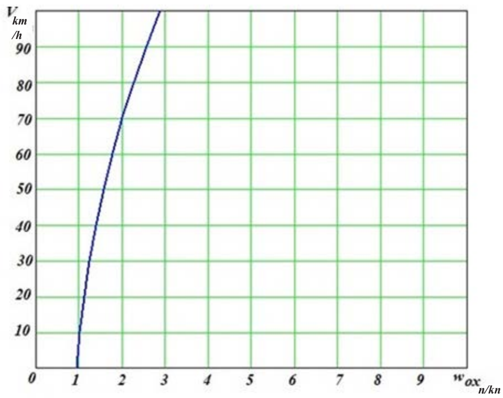
№	Basic parameters of locomotives	Series of locomotives	
		1st variant	2nd variant
		4TE116UM	2TE116UM-23AGAL
1.	Effective capacity (continuous power), kW	5300	5287
2.	Number of sections	4	4
3.	Calculated traction force, N	1460	1430
4.	Calculated speed, km / h	24,4	24,4
5.	Constructional speed, km / h	100	100
6.	Calculated weight, kN	5520	5364



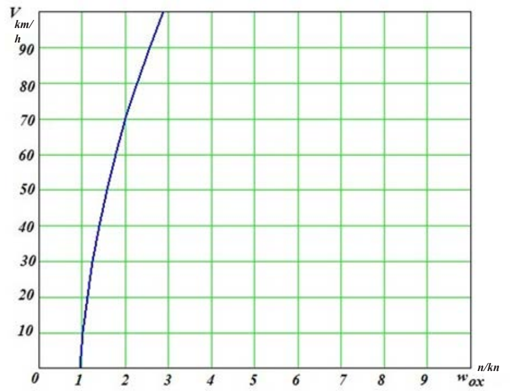
Pic. 1a. Specific accelerating force (in traction mode) 4TE116UM.



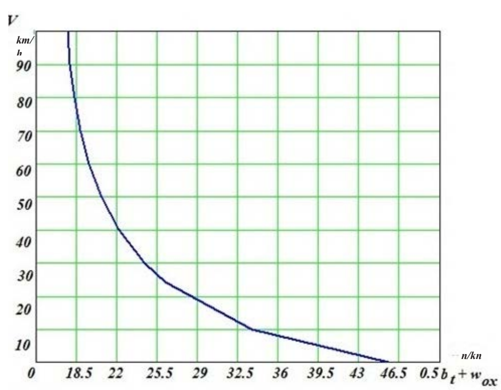
Pic. 2a. Specific accelerating force (in traction mode) 2TE116UM-23AGAL.



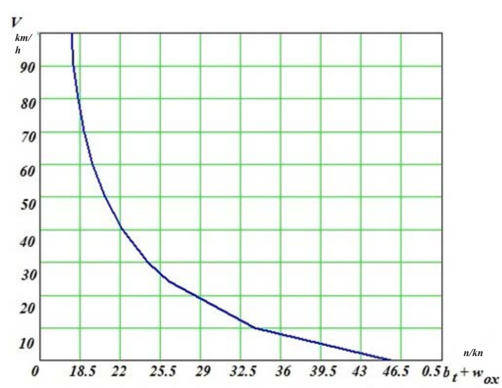
Pic. 1b. Specific deceleration force (in idling mode) 4TE116UM.



Pic. 2b. Specific deceleration force (in idling mode) 2TE116UM-23AGAL.



Pic. 1c. Specific deceleration force (braking mode) 4TE116UM.

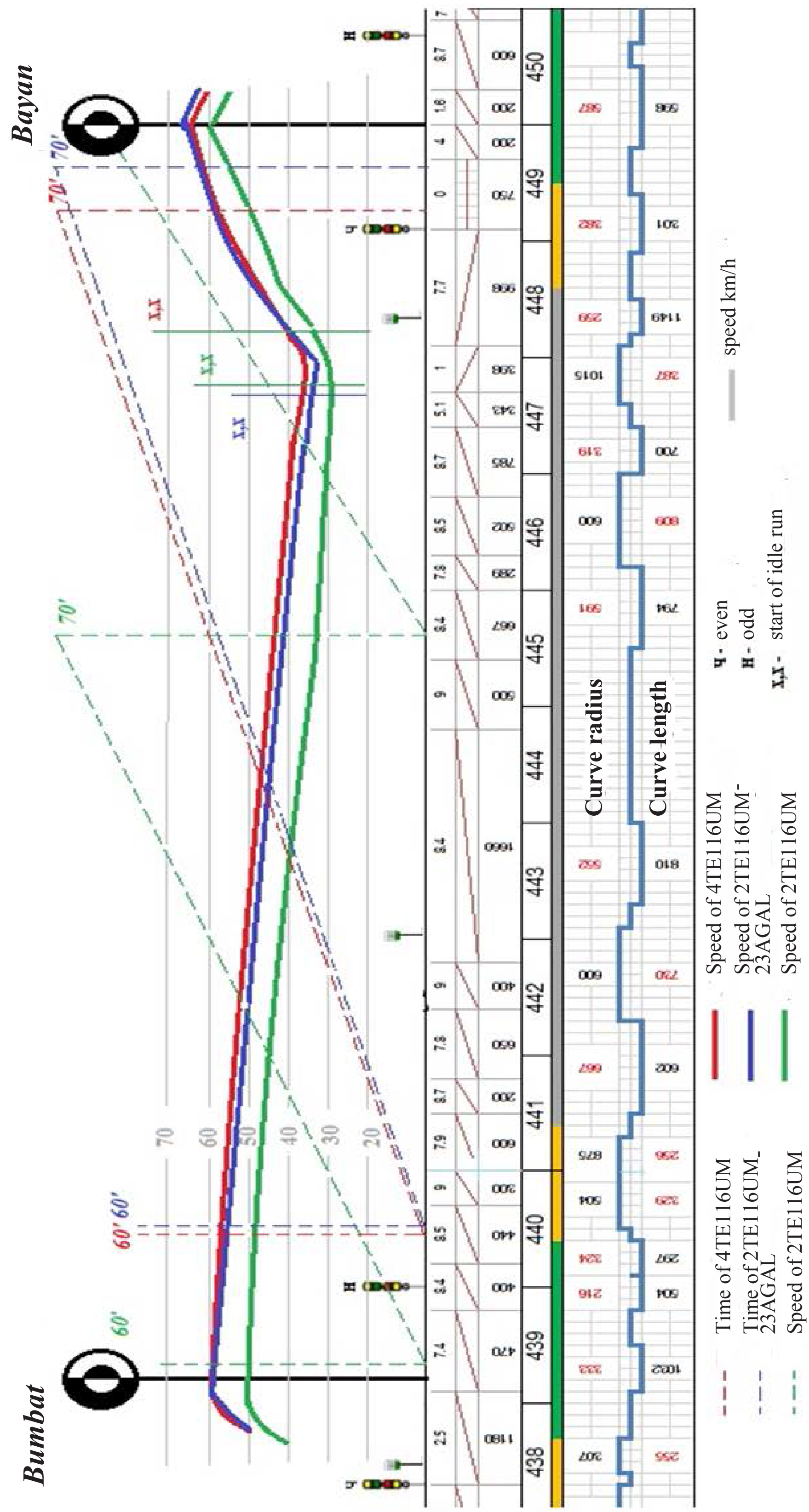


Pic. 2c. Specific deceleration force (braking mode) 2TE116UM-23AGAL.

taken from [1, 7] for the calculated speed v_p = 24 km/h. The minimum power required to drive a train is found according to the formula [6]:

$$N_{K\min} = \frac{F_{K\min} \cdot v_P}{3600}. \qquad (3)$$

By the values of F_{Kmin} or N_{Kmin}, it is possible to choose a series of locomotives with a corresponding number of sections and calculation parameters that are not lower than the minimum required. The calculated parameters of such series are shown in Table 1.



Pic. 3. Results of calculation of speed and time curve on Bumbat–Bayan section.

Table 2

Locomotive (weight of the train)	t, min	v, km/h	E, kg	e, kg/10^4 t·km gr.
2TE116UM (4500 t, two trains follow each other)	265,1 + 30	58,4	3623,5	156,5
4TE116UM (8000 t)	260,2	59,5	3421,1	162,6
2TE116UM-23AGAL (8000 t)	256,5	60,3	3264,7	155,1

After the type and number of sections of the locomotive has been selected, it is necessary to draw traction calculation of the resultant forces under the main driving regimes: traction, full service braking and idling. The empirical formulas used to calculate the forces as a function of the speed of motion are taken from [2].

The specific accelerating force (in the traction mode) [1] is a function of speed and can be found according to the expression:

$$f(v) = f_K - \omega_0, \quad (4)$$

where $f_K = \dfrac{F_K}{P+Q}$ *is specific traction force (P is locomotive weight, Q is train weight). The specific decelerating force (braking mode) [1] is found as*

$$f(v) = 0{,}5b_T + \omega_{0X}. \quad (5)$$

Here $b_T = 270\dfrac{v+100}{5v+100}\cdot\upsilon_P$ *is specific braking force:*

$\omega_{0X} = \dfrac{\omega'_X \cdot P + \omega''_0 \cdot Q}{P+Q}$ *is specific decelerating force when idling.*

The main specific resistance to movement of a rolling stock in idling mode: $w'_x = 2{,}4+0{,}011\ v + 0{,}00035\ v^2$. *In the emergency braking mode the specific decelerating force [6] is calculated according to the expression*

$$f(v) = b_T + \omega_{0X}. \quad (6)$$

Calculation of the dependence of the specific accelerating and decelerating forces on the speed was carried out on an array of discrete values of the speed taken in the interval from «0» to the design speed of the locomotive v_K *with a step* $\Delta v = 10$ *km / h. In addition, calculations were made for the calculated speed and speed corresponding to the point of fracture of the locomotive tractive characteristic.*

The results of the calculations are shown in Pic. 1 (a-c) and Pic. 2 (a-c), where they are present in the form of graphs of the dependence of the resultant force (with three modes of motion) on the speed.

On the basis of the obtained data, a diagram of the specific resultant forces for different locomotives was constructed, after which a calculation of the speed of the train was carried out using the longitudinal profile graph. The method of A. I. Lipets [3] was used in the calculations, which is the most convenient for use in the conditions of railways. The essence of the method is the graphic integration of the equation of train motion. When constructing a speed curve using the Lipets method, it is necessary to resolve the contradiction: on the one hand, to strive for the development of maximum speeds in order to increase the capacity of the railway, on the other hand, energy saving should be ensured.

The task is solved due to the rational use of the accumulated kinetic and potential energy of the train. The results of calculating the speed curve are shown in Pic. 3, which shows the most difficult haul Bumbat–Bayan.

On the basis of the speed curve and using the graphical method of G. V. Lebedev [3] was obtained the total travel time and operating time of TED in various regimes in the section Tolgoit–Choir section. This method allows to get the most accurate results, is visual and does not require significant computer time. It allows a fairly simple software implementation, because it is based on the differential coupling of speed and coordinate: the tangent of the angle formed by the tangent to the graph of the dependence t = f(S) and the time axis, is proportional to the average speed of motion on a given track interval. The results of the calculation of motion are shown in Pic. 3.

Having determined the travel time t of the train by the Lebedev method, it is necessary to calculate the average technical v_T *and the sectional speed* v_{sec} *for each variant of comparison, km / h:*

$$V_T = \frac{60\cdot\sum S}{t}; \quad (7)$$

$$V_{sec} = \beta_{sec}\cdot V_T. \quad (8)$$

Here $\sum S$ *is the total length of the section of the profile (in kilometers), t is the total train travel time (in minutes),* β_{sec} *is the sector speed coefficient, which can be taken in the range* $\beta_{sec} = 0{,}8–0{,}9$.

The analysis of TED operation modes allows finding fuel consumption based on known ratios, after which it becomes possible to draw conclusions regarding the expediency of operating a locomotive. The diesel fuel consumption (in kilograms) by diesel locomotive when driving on a given section is determined by the formula:

$$E = \sum_{i=1}^{n_K} G_i\cdot t_i + g_x\cdot t_x, \quad (9)$$

where G_i *is fuel consumption for the i-th minute when the locomotive moves in the traction mode at the i-th position of the handle of the driver's controller (kg/min). These values are given in[4] in the form of flow characteristics* $G = f(v, n_K)$; n_K *is the number of the driver's handle positions used for driving the train,* g_x *is the fuel consumption for the i-th minute when the locomotive moves in idle and braking modes (kg / min). The same values are given in [5], where* t_i *is the total travel time of the locomotive in traction mode at the i-th position of the operator's controller handle (in minutes), it is determined by the curve t = f(S);* t_x *is total time of locomotive motion in idle and deceleration modes (in minutes), is determined by t = f (S).*

A more convenient value is the specific consumption of natural diesel fuel per unit of transportation work of 10^4 *t / km gross, measured in units of kg /* 10^4 *t / km gross:*

$$e = \frac{Eg}{Q\sum S}\cdot 10^4. \quad (10)$$

2. Results and analysis

The selected train mass of 8,000 tons was checked based on the maximum possible weight of the train, which was calculated according to formula (11) [6]:

$$Q_m = \frac{F_{kp} - (\omega'_0 + i_p)\cdot P}{(\omega''_0 + i_p)}. \quad (11)$$

Taking into account F_{kp} is design traction force of locomotive and calculated speed v_p. For the locomotive 4TE116UM the value Q_m = 9675 tons was obtained, for the combination of locomotives 2TE116UM-23AGAL – Q_m = 10245 tons. As can be seen, the train mass of 8000 tons was chosen with a large margin. It is also necessary because it is necessary to ensure reliable operation of the compressor, designed to maintain the calculated value of acceleration during braking, and also to prevent overheating of TED of the locomotive. Reliability calculation was carried out according to known formulas [6].

The selected mass of the train was also checked by the condition of starting from the place on the calculated ascent:

$$Q_{kmp} = \frac{F_{kmp}}{(\omega_{mp} + i_{max}) \cdot g} - P \cdot g \ . \qquad (12)$$

Here F_{kmp} is traction force of the locomotive when starting motion, measured in N; w_{mp} is specific resistance of the train when starting motion, in kgf/t. The calculation showed that for both variants the calculated mass exceeds the selected mass: for the locomotive 4TE116UM Q_{kmp} = 10015 tons, for the combination of locomotives 2TE116UM-23AGAL Q_{kmp} = 10132 tons.

One of the main criteria for the correctness of the choice of the mass of the train is also the condition for reliable braking. The calculated reliability factor should be in the range [0,28–0,33]:

$$\vartheta = \frac{\sum_{1}^{n} K \cdot \phi_{sh}}{(P+Q) \cdot g} \ . \qquad (13)$$

Here K is the force of the normal pressure of the brake pads, and ϕ is the empirical coefficient depending on the type of car and the number of axles. The calculated values turned out to be ϑ = 0.321 (for the locomotive 4TE116UM) and ϑ = 0.320 (for the combination of locomotives 2TE116UM-23AGAL).

The efficiency parameters found for the two proposed variants of locomotives were compared with the data obtained for the locomotive, which is operated on the UBZHD (on Tolgoit–Choir section): 2TE116UM-4500 tons (two trains follow each other at an interval of 30 minutes).

The calculated values of the time of motion (obtained graphically from the analysis of the speed curve, in min.), technical speed (formulas (7, 8), in km / h), the specific fuel consumption (formulas (9, 10), kg) are presented in Table 2.

As can be seen from the presented results, the combination of 2TE116UM-23AGAL locomotives allows for faster and more economical cargo transportation. At the same time, the variant proves to be the most advantageous in all parameters: specific fuel consumption, average speed of movement, time of movement and saves labor costs of personnel. Once again, we emphasize that in order to compare the variants of operation proposed in the work with the traditional variant, it is necessary to perform calculations for two trains 2TE116UM with a cargo of 4500 tons, following one another at intervals of 20–30 minutes. This interval is due to the fact that a semi-automatic blocking is used on the UBZ, which implies the presence of one train on the haul, while automatic blocking is used in the conditions of Russian Railways [8].

Conclusion. *The main priorities of the UBZHD are speed, reliability, safety and cost-effectiveness of cargo transportation. Currently used locomotive 2TE116UM fully meets all the requirements. Nevertheless, with a more detailed consideration of the possibilities of the railway, there are variants with trains of larger mass, which allow achieving better performance indicators than previously.*

The use of the proposed combination of locomotives 2TE116UM-23AGAL is more effective primarily from the point of view of three factors: driving time, design speed and fuel consumption.

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