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Methodology for Assessing the Energy Efficiency of Using Locomotives under Operating Conditions

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Abstract

A methodology is given for assessing the energy efficiency of using locomotives under operating conditions based on data from decoding speed tapes and driver route sheets, taking into account additional recommendations that clarify the calculations of energy (thermal technical) indicators of the transportation work of locomotives along the route of rolling stock. Analytical expressions are proposed to substantiate the parameters of the specified recommendations by the speed measuring tape - the values of the mechanical work of the braking forces and the forces of the main resistance to the movement of the train, necessary to identify the force load of locomotives, as well as the actual coefficient efficiency of the technological process of transportation work of locomotives and an algorithm for identifying locomotives with inefficient operating power plants during the implementation of railway transportation of goods and passengers. A preliminary analysis of the research results shows that the criterion for determining the timing of maintenance and current repairs of diesel locomotives based on their linear mileage is not sufficiently justified.

Key Words: *Diesel locomotive, transportation work, efficiency, mechanical work, working stroke, idling, braking, fuel consumption, movement resistance, indicator*

1 Introduction

The complexity of the task of identifying the actual power load and the achieved efficiency of locomotives in operation is determined by the very diverse conditions for performing transportation work by locomotives and the unsteady operating modes prevailing in operation, as well as possible deviations of the traction and thermal technical characteristics of locomotives from their passport data. Accordingly, as a consequence, the above also applies to the task associated with the actual need to submit locomotives for technical diagnostics, various types of maintenance (inspection) and of current repairs.

The existing system of placing locomotives for repairs depending on the linear mileage is fully justified only if the traction shoulders on which the locomotives of a given depot are used have sufficiently similar characteristics of the driving conditions: steepness of slopes, speed limits, presence of temporary warnings, causing the need for additional braking, and so on.

On sections of many railways, including Uzbek ones, this system turns out to be insufficiently effective, as a result of which it becomes necessary to introduce a parameter characterizing the actual power load of the locomotive, more objective than the number of kilometers traveled. In addition, there also arises the problem of choosing the optimal ratio of the amount of money

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spent on repairs and maintenance of locomotives to the cost of energy consumed by them in moving trains, depending on the technical condition and the realized actual efficiency factors.

Solving these problems, as well as clarifying the planned norms of energy consumption for train traction and developing measures to reduce it require the introduction into the daily work of linear enterprises of the locomotive complex of calculations of actual loads and efficiency of locomotives operated in the depot.

The results of comparing the actual efficiency of locomotives with the calculated ones obtained on the basis of traction and energy calculations for the same operating conditions, with the average actual data for the depot, can serve as a criterion for the level of energy efficiency of using locomotives and will allow identifying locomotives with large deviations in the technical condition of energy plants from the norm and take the necessary measures in a timely manner, as well as clarify the actual load of locomotive power units and their overhaul intervals.
In this regard, at the Department of «Locomotives and Locomotive Economy» of the Tashkent State Transport University, theoretical and experimental research is being carried out to substantiate the energy efficiency of using locomotives during the organization of railway transportation of goods and passengers.

2 Objects and Methods of Research

Scientists [1-13 and others], attaching great importance to research in the field of increasing the efficiency of using locomotives on railway sections by improving the structure of the organization and the quality of repair production, do not take into account at all the influence of operational factors on the actual load of energy plants and the efficiency of locomotives through special locomotive devices that record all the actions of the locomotive crew along the route when driving trains onto a speed measuring tape.

The work [14] sets out a methodology for determining the operational coefficient efficiency of diesel locomotives for the total running time and periods of working running along the haul and the railway section as a whole, which requires special experimental trips with a dynamometer car on each shoulder of the work of locomotive crews, followed by complex calculations. Therefore, all this makes it difficult to apply this method in practice.

It should be said that all actions of the locomotive crew along the route when driving trains are recorded with a special device on a speed movement measurement tape. A paper-type speed measuring tape coated with barium sulfate is used to record various parameters during the movement of trains and automatic locomotive signaling and hitchhiking devices, which is divided into two fields - the speed field and the time field with lines marked on these fields indicating the minimum, maximum and intermediate values, recorded quantities. On the speed field, the value of speed, brake pressure and direction of movement is recorded, on the time field - half-hour and hourly time intervals, locomotive traffic lights (yellow, red-yellow, red), power supply to the driver's "vigilance" coil (EPC), the state of the automatic control system brakes (SACB).

The study [15] proposed a methodology for determining the coefficient efficiency of the transportation work of diesel locomotives on sections, based on the use of data from speed measurement tapes and driver route sheets, as well as the results of mathematical modeling of train movement processes on railway sections.

Tables of normalized mechanical work developed on the basis of modeling [16] make it possible to quite simply and accurately determine the amount of mechanical work of the locomotive under study, and then, according to the data of the driver's route sheets, the values of the coefficient efficiency of the transportation work of locomotives on railway sections.

However, for the practical use of this methodology in real areas of train servicing by locomotives and the work of locomotive crews in operating conditions, it is necessary to develop a number of additional recommendations that simplify the decoding of the speed measurement tape and clarify the calculations of the energy indicators of the transportation work of locomotives based on the data obtained.

Therefore, the purpose of this study is to develop a methodology for identifying the actual values of the mechanical work of the braking forces and the forces of the main resistance to the movement of the train, necessary for the correct justification (determination) of the total power load of locomotives with using receptions of differentiation of the graphical dependence V(S) of speed by the track recorded on the speed measurement tape.

All the author's considerations necessary to achieve the stated goal of the research, which form the basis of the above methodology, are given below.

3 Results and their Discussion

Analytical calculation of the value of the specific resultant force of the train (N/kN, kgf/t) is carried out using this expression:

$$u_{av} = \frac{\Delta V_{mov} \cdot V_{sc}}{\Delta S_{sc} \cdot K} \tag{1}$$

where ΔV_{mov} - speed interval for a given section of the speed measurement tape, mil;

V_{sc} - average speed for the same section, mil;

ΔS_{sc} - path interval, mil;

K - forces scale (for standard speed measuring tapes the force scale is *K* = 1,705 mil:kgf/t).

Differentiation of the speed curve *V*(*S*) of train movement on railway sections of the same profile when moving with the traction machine turned off makes it possible to determine the actual values of the specific basic resistance to the movement of the train (N/kN, kgf/t), that is

$$w_0^{"} = \frac{(P+Q) \cdot w_{ox} - P \cdot w_x}{Q} \tag{2}$$

where *P* and *Q* - weight (mass) of the locomotive and of composition, t;

w_{idl} - specific main resistance to movement of the locomotive at idle, N/kN, kgf/t (determined by RTC formulas [17, 18] at the average speed of the train, in the considered speed range);

$w_{o\ idl}$ – specific main resistance to train movement at idle (N/kN, kgf/t), determined for a known value u_{av} by the formula:

$$w_{o\ idl} = u_{av} - i_{к} \tag{3}$$

where $i_{к}$ - the value of the reduced rise (slope) at which the movement of the train is being considered, ‰.

Differentiation of braking sections gives the value of the specific braking force of the train (N/kN, kgf//t) in the considered braking distance interval ΔS_{br}, that is

$$b_{к} = u_{ср} - (w_{ох} + i_{к}) \quad (4)$$

Based on the found value of b_k, it is possible to determine the actual value of the train braking coefficient ϑ, namely:

$$\vartheta = \frac{b_k}{1000 \cdot \varphi_{kcal}} \quad (5)$$

where φ_{kcal} - calculated coefficient of friction between the pads and the wheel, which is determined according to the recommendations RTC [17, 18].

In some cases, this is necessary to analyze train traffic conditions.

The actual values of b_k and w_0'' are used in further calculations to determine the mechanical work of the braking forces and of the work of the main resistance forces to trains movement.

In this case, the mechanical work of the train braking forces - $A_{br} = (P + Q) \cdot \sum b_{ki} \cdot \Delta S_{br}$ can be divided into the work of braking forces according to permanent speed limits (A_{bro}), the work of braking forces according to temporary warnings (A_{tw}) and the work of braking forces when stopping at stations (A_{brz}), as well as braking work associated with of try out brake while driving ($A_{br\ brt}$).

This distinction allows us to clarify the analysis of energy costs for all types of braking.

Mechanical work (N km, kgf km) of the main resistance forces to train movement during the trip $A_0 = A'_{0\ idl} + A''_0$ with known dependences of the specific basic resistance of the locomotive movement on the speed $w' = 0{,}5 \cdot (w'_0 + w_{idl})$ and the specific main resistance to movement of the composition w''_0, which is found, as shown above, when decrypting the speed measurement tape and is determined by the following expressions:

$$A'_{0\ idl} = P\alpha' w'_{ср} L \text{ и } A''_0 = Q \sum w''_{ос} \Delta S \quad (6)$$

where α' - indicator of the perfection of the train driving mode based on the mechanical work of the main resistance to the movement of the locomotive. Since the value of α' has little effect on the change in the specified mechanical work, it is therefore taken from calculation experience within the limits α' = 1,00 -1,06;

w'_{av} - specific basic resistance of the locomotive at the average technical speed movement of the train on the section under consideration;

L - section length, km;

$w''_{ос}$ – the value of the specific basic resistance of the composition (N/kN, kgf/t) at an average speed $V_{av} = 0{,}5(V_1 + V_2)$ of the selected distance interval ΔS, while the speed interval is selected taking into account $\Delta V \leq 10$ km/h.

The total (general) mechanical work of the locomotive to move the train from the moment of starting to stopping the train ($V_{н} = V_{к} = 0$) is determined by the expression:

$$A_{mov} = A_0 + A_{sl} + A_{br} \quad (7)$$

where A_{sl} - mechanical work of forces of additional resistance to train movement from rises (slopes) and curved sections of the railway track, N km, kgf km.

In this case, the value A_{sl} is calculated by the expression:

$$A_{sl} = (P + Q) \cdot i_{kc} \cdot L \tag{8}$$

where i_{kc} - weighted average value of the slope (rise) of a section along the route $L = \sum l_{tri}$, including a sequence of elements with steepness i_{tri}, ‰ and length l_{tri}, km.

Calculated per trip, turnover, decade, month, etc. mechanical work of A_{mov} can serve as a criterion for assessing the energy efficiency of using locomotives. Calculations are carried out for each locomotive based on data from the driver's route sheets, using pre-compiled mechanical work standardization tables [15].

The thermal technical condition of the diesel generator set of a diesel locomotive is largely influenced, in addition to the work of moving the diesel locomotive, by mechanical work spent on service needs.

Based on this, to determine the between-repair mileage of a locomotive based on its service life, it is advisable to calculate the total mechanical work of the diesel engine, namely:

$$A_{gen} = A_{mov} + A_{ad\ n} + A_{st} + A_o \tag{9}$$

where $A_{ad\ n}$, A_{st}, A_o - mechanical work of a diesel engine spent on official needs during the period of movement, parking and at locomotive turnover points; which is determined (found) by separate calculations.

Calculation of the efficiency of the train movement process (average efficiency of the locomotive power circuit) for a trip is carried out according to the formula [16]:

$$\eta = \frac{K_э \cdot A_п}{E_к} \tag{10}$$

where $E_к$ - energy costs to create mechanical work of the tangential traction force of a locomotive, kg. $E_к = E - (E_{ad\ n} + E_{st} + E_0)$;

E - total energy consumption for the trip (along the route), kg;

$E_{ad\ n}, E_{st}, E_0$ - energy consumption for service needs, respectively, during the period of travel, parking at intermediate stations and at locomotive turnover points, kg;

K_e - coefficient of recount.

The value of the indicated value η does not depend on the periods of idling, braking, parking and is not directly related to the linear mileage of the locomotive. Consequently, this value of η can serve as an objective criterion for the need to submit a locomotive for maintenance, repair or technical in-place diagnostics based on its energy (thermal technical) state.

Thus, based on the above, to identify locomotives with inefficiently operating power plants, we can recommend the following sequence (algorithm) of actions:

- using the tables of standardization of mechanical work on train movement and diesel loading for each locomotive, calculate the mechanical work A_{mov} and A_{ad} performed for a given period of operation time;
- according to the driver's route sheets and speed measurement tapes, determine the amount of fuel consumed to create tangential mechanical work E_t;
- calculate the value η, which characterizes the energy efficiency of the locomotive;

- to clarify the calculation of the value of η using decoding data from a number of speed measurement tapes of locomotives that have a deteriorated thermal technical state;
- make recommendations for submitting specific locomotives for technical diagnostics and repairs.

This scheme for determining the operating efficiency of locomotive power plants is quite simple and allows the use of modern computing and computer technology for basic calculations, since the summation of mechanical work and fuel consumption, preliminary calculation of the efficiency factor η of the locomotive power circuit using energy rationing tables can be conveniently carried out using computer. For large diesel locomotive depots that have the ability to quickly communicate with the Road Management Computer Center or some other computer center, the use of a computer will be beneficial in a convenient.

From the above it follows that under operating conditions it is convenient and quite simple to identify the actual coefficient efficiency of the train movement process both using speed measuring tapes and using special tables for normalizing mechanical work according to the data of the driver's route sheets of diesel locomotive.

As an example, we present the results of calculating the loading of diesel locomotives 2TE10L depot T on the basis of normalization tables for their mechanical work [16], which showed that under average conditions of transportation work in three sections in both directions, the specific mechanical tangential work of the locomotive per 1 t km on the most difficult section U - X is equal to 4.14 kgf km/t km gross, which is 39 percent more than in the U - Ch section. And the specific mechanical work of the locomotive in the section K - A in the even direction is almost 10 times greater than in the odd direction.

With the same linear mileage of diesel locomotives, the mechanical work of locomotives in three sections of the T depot when driving heavy trains will be 35 – 40 percent more than the same when driving trains whose mass (weight) is lower than their average values by the same sections.

This indicates insufficient validity of the linear mileage of locomotives for determining their overhaul mileage periods.

The results of decoding the speed measurement tape are given in table. 1.

Table 1: Decoding Data of the Speed Measurement Tape on the I-U Section of the Uzbek Railway, Section Length L = 115 Km, Diesel Locomotive 2TE10L.

Locomotive	**Conditions of transportation**			**Energy results**			**Train driving mode indicators**		
	Q	z, n	t_x	A_{mov}	E	μ	a'	A_{bro}	E_t
	m	$n_т$	t_c	A''	$\eta_э$	β''	a''	A_{br}	η
	3	4	5	6	7	8		10	11
Even direction, $i_{кс}$ = -1,39 ‰									
No. 1,	4435	3;1	138	511000	602,0	0,178	0,97	215000	402,0
	212	1	118	132000	0,198	0,258	1,04	318000	0,313
No. 2,	3410	4;1	178	457600	635,0	0,123	1,01	821000	413,0
	204	3	115	106000	0,169	0,232	1,04	300000	0,271

Source: Compiled by the Author».

From the analysis of data in table 1 shows that the average values of the efficiency coefficients of the power circuit of diesel locomotives 2TE10L, obtained on the basis of decoding the speed measurement tapes of a number of trips, showed the following. Diesel locomotive No. 1 had the actual value of the indicated efficiency. $\eta = 0.313$, while diesel locomotive No. 2 showed average values of $\eta = 0.271$, which indicates a deteriorated energy state of its power units and, apparently, the need for diagnostics, technical service (inspection) and repair.

Data on the general operational coefficient efficiency of these same diesel locomotives, the calculation of which took into account fuel consumption at stops and idling, due to different exploitation conditions on the work sections of these diesel locomotives, turned out to be, respectively, equal to $\eta_0 = 0.236$ and $\eta_0 = 0.220$, that is pretty close. According to these general efficiency η_0 it is no longer possible to judge the actual energy state of diesel locomotive power units.

4. Conclusion

Based on the analysis of the results of the research, the following general conclusions and proposals can be made.

1. The methodology for determining the magnitude of the mechanical work of the forces is substantiated acting on the train from records on the speed measurement tape, as well as the power load and the actual coefficients efficiency of the technological process transportation work of locomotives.
2. The data obtained will make it possible to improve the operational control of the thermal and energy condition of locomotives, taking into account the power load, as well as to clarify their overhaul runs associated with various types of maintenance and current repairs.
3. Taking into account the volume of mechanical work performed will make it possible to clarify the actual degree of wear of systems, components and assemblies, as well as the actual need for repair, which will eliminate unjustified costs of funds for repairs.
4. It is recommended that these studies be continued on a larger range of locomotives diesel traction, taking into account railway sections of varying degrees of difficulty, and that the assessment methodology proposed by the author be "repurposed" for mainline of locomotives electric traction.

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