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ON THE ISSUE OF ENERGY EFFICIENCY OF INDUSTRIAL LOCOMOTIVES

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Summary. The analysis of research results of fuel consumption by diesel locomotives is done. The structure and different variants of defining the rates of fuel consumption by industrial locomotives are examined.

Key words: fuel consumption, diesel locomotives, modernization, consumption rate.

INTRODUCTION

The length of industrial railway tracks in Ukraine comprises 25, 000 km, including broad gauge with 18,700 km. The industrial rail transport functions as a component part of production and transports 1 billion tons (more than 70 %) of goods of enterprises [Kategorenko 2005].

From the total volume of expenses for the operation of shunting locomotive, 80% goes onto the fuel expense ratio, 10% onto the locomotive crew salary, and another 10% goes onto the depreciation charges [Dan'ko 2005].

In the operation it is accepted to record the quantity of fuel, acquired by every diesel locomotive in the handling plant, to take into account the fuel consumption during the shift according to the running schedule, which should contain the data about the fuel consumption by diesel locomotive during the shift as the fuel level difference in the diesel locomotive tank.

The use of fuel meters is the alternative method of fuel consumption assessment. There are a lot of flow meters and different ways of fuel consumption assessment [Sirota 1973, Voskoboynik 1978, Mokridenko 1982, EI VINITY 1988].

OBJECTS AND PROBLEMS

The urgency of the topic is defined by the nagging problem of energy saving on the rail transport and in the whole country. The analysis of enterprises work of rail transport showed that the average expenses on the locomotive sector comprise 31,6%

from the total sum of expenses on the enterprises, which is the biggest part among other sectors of rail transport. In connection with the price increase on the diesel fuel, for some diesel locomotive depots the part of expenses comprises 40% and more operating costs. The decrease of these expenses is a great reserve of raising the effectiveness of locomotive traction [Bojelarskiy 2007, Orlov 2009].

The science-based rates of fuel consumption are the basis of defining the real quantity of necessary energy consumption, which answer the level of technological equipment, the organization of technological process of transportation and designated amount of transport work. These rates should represent the technical and economic parameters of diesel locomotives, the rates of using the diesel generating capacity and diesel stock, the peculiarities of the tracks, the work of energy-transducing devices and other factors, which define the efficiency of energy consumption. The saving of diesel fuel in the diesel locomotives depends on good technical condition of diesel locomotive, skillful driving of trains by crews, proper organization of train formation and many other factors. Along with this important source of fuel saving and its careful use, there is the decrease of quantitative and qualitative fuel loss during transportation, drain, storage and its delivery to the diesel locomotives.

The setting of the explained rates of fuel consumption for the shunting operation will allow to improve the accuracy of planning its needs, evaluate the efficiency of expenses, stimulate the rational and economic use of diesel fuel. In connection with this, the task of improving the methodic of diesel fuel rationing for the shunting operation is very important and urgent.

The aim of the article is to analyze the determining factors on the improvement of diesel fuel rationing during shunting operation for the increasing the efficiency of shunting locomotive.

It is necessary to *define* the main factors, which influence the fuel consumption during performing the designated amount of shunting work, to *analyze* present diesel locomotive stock, methods of rationing the diesel fuel consumption ad to suggest the cost method of diesel fuel consumption.

The continuous control of diesel locomotive parameters during operation is one of the ways of increasing their operation efficiency. It can be achieved at the expense of improving the rationing of diesel fuel consumption on the basis of objective information about the diesel locomotive operating conditions and diesel fuel consumption in the operation; the increase of reliability of power plant work as a result of timely detection and prevention of emergency operation, the improvement of technical and heat engineering condition of diesel locomotive.

The subsystem of control the diesel fuel quantity in the diesel locomotive tanks is one of the most important components of the continuous control systems of diesel locomotive parameters in the operation. The experience shows that it is the measuring of diesel fuel quantity, which allows solving the tasks of assessing the diesel fuel use for the train traction, as far as it provides the possibility of quantity control of not only consumed, but also of filled diesel fuel [Molchanov 2004].

The main factors, which influence the diesel fuel consumption by diesel locomotive during the operation at the iron-and-steel plant, are observed in a number of works [The manual 1967]. The main amount of transport work at the industrial

enterprises is done by shunting locomotives, which so far are not equipped with the devices of automatized assessment of diesel fuel consumption.

It has been revealed that technical rates of diesel fuel rationing for the shunting operation are not set, that is why the fuel consumption rates are defined by practice. There is no data about the traction-energetic registration certificates for shunting locomotives of class TGM, TEM and others in the Manual [1967]. On the basis of analysis of given methods, the necessity of defining the initial rate of diesel fuel n0 consumption for the diesel locomotives of stated classes and average power of diesel locomotives Ncp, used on different sectors of enterprises, has been found out.

Since in the first decade of new millennium it has been predicted the end of service life of diesel locomotives, produced during the Soviet Union time, the board of Ukrzaliznitsya had to develop the strategy of proving the transport work on the rail tracks in Ukraine. The main directions of developing the diesel locomotive sector of Ukrzaliznitsya and its technical re-equipment were formulated there [The strategy 1998].

All the diesel locomotives, produced by the plant, will reach the end of its service life till the end of the Program on the reforming rail transport.

The problem of **rolling** stock replacement is being solved at the expense of increasing the efficiency and usage of today's **rolling** stock through modernization and prolonging the service life of today's rolling stock at the expense of overhaul reconditioning. The modernization also gives the possibility to improve technical and economical rates of diesel locomotive work, and also to improve its ergonomic rates, to increase power and traction parameters of diesel locomotive [Dzetsina 2010]. The example can be OAO "Teplovozoremontniy zavod" (Open JSC "The diesel locomotive repair plant") in Poltava. It carries out the complex modernization of shunting locomotives ChME3, TEM7 and others, produced by Czech republic.

The parameters of diesel locomotives before and after modernization are shown in the tables 1 and 2.

As it can be seen from the table 1 and 2, the main diesel engines under modernization are the diesel locomotives of class D49, produced by diesel locomotive plant in Kolomna (Russia).

The family of diesel engines, produced in Kolomna, has different energy forcing depending on the purpose of diesel locomotive. The main parameters of diesels are given in the table 3.

The heat engineering condition influences the diesel fuel consumption by diesel locomotive.

The diesel fuel equipment, piston-cylinder-unit, turbocompressor and discharge section of gas-air flow duct are ones of the major units and diesel devices, which influence the diesel fuel consumption. In all the cases of disturbance into the normal process of diesel fuel combustion, the efficiency of diesel engine deteriorates and the exhaust opacity increases.

During driving the train, the locomotive driver should choose the most advantageous mode of diesel operating and generator set, to use skillfully the kinetic energy of train, and also antiskid and brake means, to support constantly the optimal temperate of oil and cooling water in the diesel, as long as the decrease of oil's temperature on 4-5 ^{0}C increases the diesel fuel consumption on 1%.

Table 1. **Comparative parameters of main diesel locomotives before and after modernization**

Locomotive	Old engine / New engine	KVA (h.p.)	Crankshaft speed, revolutions per minute	Specific diesel fuel consumption on the full power, g/KVA per hour	The hourly diesel fuel consumption on the idle running, kg per hour	Specific oil consumption on the full power, g/KVA per hour	The service life before the first overhaul, number of kilometers traveled	The service life before complete overhaul, number of kilometers traveled
TE10	10D100	2206 (3000)	850	226	23	1,74	200	800
	1A-9DG	2206 (3000)	850	198	13,5	0,9	400	1600
M62	4-14DG	1470 (2000)	750	215	16	1,7	250	1200
	5-26DG	1470 (2000)	750	202,5	9	1,1	300	1500
class 232	1-9DG	2232 (3035)	1000	204	15	1,63	10000	40000
	12D49M	2206 (3000)	1000	203	10	1,1	32000	60000
TE114	3-9DG T2	2059 (2800)	1000	208	16	1,63	12000	50000
	3-26DG	2059 (2800)	1000	204	10	1,14	16000	64000

Table 2. **Comparative parameters of shunting locomotives before and after modernization**

Locomotive	Old engine / New engine	KVA (h.p.)	Crankshaft speed, revolutions per minute	Specific diesel fuel consumption on the full power, g/KVA per hour	The hourly diesel fuel consumption on the idle running, kg per hour	Specific oil consumption on the full power, g/KVA per hour	The service life before the first overhaul, months or hours	The service life before complete overhaul, years or hours
TEM2	PD1M	882 (1200)	750	210,8	5,2	1,1	36	9
	3-36DG	882 (1200)	750	200	5,2	1,1	36	9
ChME3	K6S310DR	993 (1350)	750	220,3	9	2,7	18	7,5
	4-36DG	993 (1350)	750	200	5,2	1,1	36	9
TGM8, TGM6	3AE-6D49	588 (800)	860	218,9	8,5	1,2	16000	60000
	7-6D49	588 (800)	860	215	5,7	1,1	20000	80000
TEM 7	2-26DG	1470 (2000)	1000	208	9	1,9	8000	40000
	12-26DG	1470 (2000)	1000	191,5	8	1,14	12000	60000

For the purpose of economic diesel fuel use, the operation manuals should be created in every locomotive depot on the basis of generalization best practices of driving trains in the diesel locomotive sector. These manuals should contain the most rational positions of controller, the speed on the track, the place of applying the brake and other recommendations. It should be also noted that the disfunction of fine and primary purification filters of diesel furl and oil, and also air filters leads to the overuse of diesel fuel.

There is great loss during drain, storage and filling of the diesel fuel to the tanks of diesel locomotives.

One of the elements of saving is the establishment of technically-based rates of diesel fuel consumption and their systematic decrease at the expense of better use of diesel locomotive's energy, skillful driving, the increase of technical level of technical equipment repair, diesel-generator set and maintaining the diesel locomotive in the good work order during operation.

Table 3. **The basic parameters of working processes of main modifications of four-cycle diesel engines D49**

Parameters	D49			
Efficient cylinder capacity Ne_c, $h.p.$	125	150	187	250
Number of revolutions n per minute	1000	1000	1000	1000
Mean effective pressure p_e in kg/cm^2	8,16	7,79	12,23	16,3
Boost pressure $p_к$ in kg/cm^2	1,92	2,28	2,16	2,75
The air temperature after compressor t_K in $°C$.	98	122	117	150
The air temperature after air-cooler t_s in $°C$	98	122	63	70
Indicated efficiency η_i	0,475	0,465	0,46	0,455
Mechanical efficiency η_m	0,811	0,848	0,873	0,905
Effective efficiency η_e	0,385	0,394	0,402	0,412
Specific diesel fuel consumption in g (h.p. per hour)				
Indicated g_i	128,1	134	135.3	135,75
Effective g_e	158	158	155	150
Excess air factor α_c	2,3	2,2	2,0	2,0
The temperature of exhaust fumes before the turbine t_T, ^0C	520	570	610	650

The rate of diesel fuel consumption for diesel locomotives is set on 10,000 t-kms gross in the trains with single and double-header during operation; on 100 locomotive-km during single movement (reserve, pushing); on one hour of shunting operation and one hour of staying idle in the working condition. These rates are created on the basis of service, types of traffic and classes of locomotives.

Locomotive's crews should always know and control the diesel fuel consumption in every trip.

Nowadays the assessment and analysis of diesel fuel consumption in the locomotive depots is being carried out on the basis of data, put by the drivers into the running schedule. At the beginning and at the end of shift, the drivers visually estimate the amount of diesel fuel in the tank according to the fuel rack or gage glass. The diesel fuel volume flow is estimated by the difference in measurements. The diesel fuel consumption by mass is estimated on the basis of volume flow and designated diesel fuel density, which is stated in the locomotive servicing.

The works on introduction of fuel measuring systems are being carried out in some depots and sections of the tracks [Molchanov 2004]. They register the temporary characteristics of diesel locomotive work with stating the idle and traffic condition, the work of diesel on the idle running, under the load and stopped diesel, the temporary

characteristics of diesel locomotive's running under the traction and running-out, average road speed and average fuel consumption rate. The expenses during diesel locomotive's running under the traction (with load) and on the idle running with the stating out the diesel fuel amount, given during servicing, are being separated from the total amount of diesel fuel consumption. The assessment of diesel fuel consumption by diesel locomotive during the shift is being carried out with taking into account the operation of diesel during idle running and under the load. The determining of diesel fuel saving or excessive consumption during the shift is being done by comparing the actual expenses with calculated value.

There are many methods of obtaining the calculated value of diesel fuel consumption. The big amount of works is dedicated to the designing the efficient methods of rationing and analyzing the diesel fuel consumption. The most famous works belong to the following authors: A.A. Baklanov, A.I. Volodin, A.I. Dolinzhev, G.A. Ilyin, N.N. Kornev, P.L. Korkhovoy, E.E. Kosov, A.M. Kostromin, A.P. Novikov, S.S. Petrakovkiy, B.G. Postol, Yu.E. Prosvirov, D.K. Sivaev, E.D. Tartakovskiy, V.N. Tveritin, A.V. Tolkachev, N.M. Khutoryanskiy, N.A. Fufrynskiy and others.

The methods of rationing the diesel fuel consumption are given in the fig. 1.

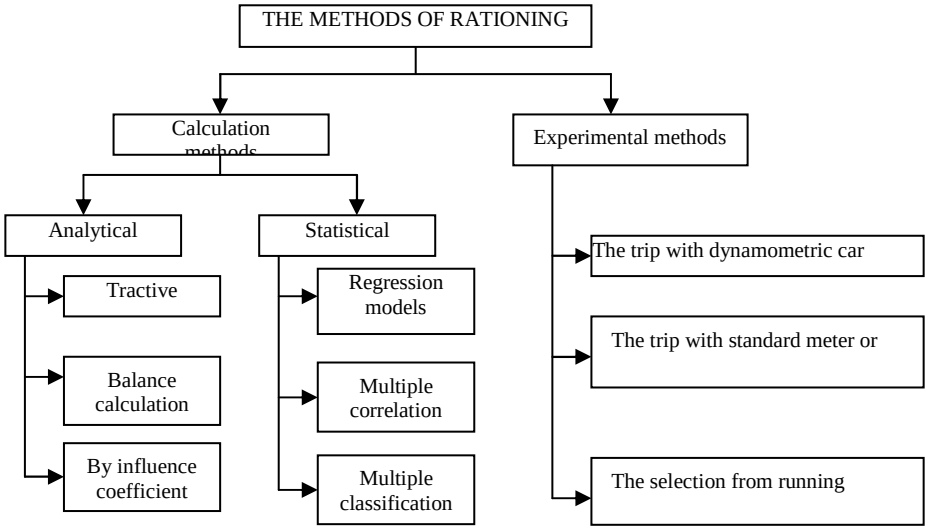

Fig. 1. The methods of rationing energy consumption

The calculation-analytical methods are based on the laws of saving and transforming energy under the following assumptions: the idealization of movement process during the shunting operations and gravity shunting, the constancy of Tractive-energetic characteristics of shunting locomotives during the operation, the input of influence coefficient of operation factors.

Calculation-statistical methods are based on the mathematical treatment of Tractive-energetic tests, initial and periodical reporting.

Operational methods use the results of long-term experience of heat engineering groups of locomotive's depots on the rationing diesel fuel consumption.

In different times, different authors suggested the methods of rationing the diesel fuel consumption in the operating conditions. The following formulas by different authors can serve as the examples.

The formula by Dolinzhev A. [1960]: $b = \left[\frac{3,35 \cdot (\omega_0 + i_k)}{\eta} + g_x \right] \cdot \frac{P+Q}{Q}$,

where: b- is cost per unit of standard fuel, kg/10^4 t-kms gross; ω_0 - is main specific resistance to train movement, N/kN; i_k - is additional resistance to train movement, N/kN; η - is the coefficient of efficiency of diesel locomotive; g_x - is the diesel fuel consumption during idle running, kg per hour; P, Q – the weight of train and locomotive respectively, t;

The formula by Tveritin V. and Korkhovoy P. [1961]: $b = \frac{B_h \cdot 60}{Q \cdot V_{av.t} \cdot 10^{-4}}$,

where: B_h - is the diesel fuel consumption by diesel locomotive in the traction condition per hour, kg per hour; $V_{av.t.}$ - is the average technical speed of train, km per hour.

The formula by Molyarchuk V. [1966]: $e = e_0 \cdot k_\mu \cdot k_\omega \cdot k_t \cdot k_i + Z' \cdot \Delta e_0 + k_x \cdot e_x + Q_c \cdot k'_x \cdot e_x$, where: e_0 - is the initial rate, kg/10^4t.km.gross; $k_\mu, k_\omega, k_t, k_i$ – the influence coefficient of rate stating factors; Z' - is a number of stops, set by train running schedule on 100 train-km; Δe_0 - is the diesel fuel consumption on one stop, referred to 100 train-km, kg/100 t.km; k_x - is the coefficient of train idle running, calculated by working time ratio of diesel locomotive in the idle running to the total amount of time of train running; e_x - is the specific diesel fuel consumption per one hour of idle running; Q_c - is the ratio of time of stops to the total amount of time of train running; k'_x - is the coefficient of diesel locomotive idle running, which is defined as a ratio of diesel locomotive working time during stops to total duration of stops.

The formula by Novikov A. and Sivaev D. [1971]: $e = e_o + \Delta e_k + \Delta e_{ew} + \Sigma \Delta e_{st}$, where: e_0 - is the main component of specific diesel fuel consumption, kg/10^4 t.km.gross; $\Delta e_k, \Delta e_{ew}, \Delta e_{st}$ - are the additional components of diesel fuel consumption, caused by corresponding change of loading the wagon axes, number of empty wagons and train stops.

It is necessary to note that the majority of works on rationing the diesel fuel consumption in the operation is based on statistical information and refers to main diesel locomotives. A number of works on rationing the diesel fuel consumption by shunting locomotives have been done during the last years.

Many others state the fact the heat engineering condition of diesel locomotive influence greatly the diesel fuel consumption. Taking into account the fact of mass modernization of diesel locomotives, in which the replacement of power units in diesel locomotives takes place, which served its life on the diesels of Д49 class, the

prospective can be the creating of method of rationing the diesel fuel consumption in the operation on the basis of parameters, characterized by heat engineering condition of diesel locomotive.

CONCLUSIONS

1. The operation efficiency is achieved on the basis of objective information about modes of diesel locomotive operation and diesel fuel consumption in the operation.
2. There are different ways of obtaining this information and they are defined by designated task and financial possibilities.
3. The majority of enterprises carry out the modernization at the expense of diesel locomotives of diesel locomotive plant in Kolomna.
4. Having the data on the results on heat engineering experiments of diesel locomotives of D49 class, it is possible to specify the calculation method of rationing the diesel fuel consumption by diesel locomotives in the operation.

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К ВОПРОСУ ЭНЕРГЕТИЧЕСКОЙ ЭФФЕКТИВНОСТИ ПРОМЫШЛЕННЫХ ЛОКОМОТИВОВ

Олег Дзецина, Виктор Федорченко

Аннотация. Выполнен анализ результатов исследования расхода топлива тепловозов. Рассмотрены структура и различные варианты определения нормы расхода топлива промышленными локомотивами.

Ключевые слова. Расход топлива, тепловозы модернизация, норма расхода.