



Measures for Resource Saving for Diesel Locomotives

Dmytro Aulin^{1*}, Artem Zinkivskiy¹, Oleksandr Anatskiy¹, Dmytro Kovalenko¹

¹Ukrainian State University of Railway Transport

*Corresponding author E-mail: Dimmo@ex.ua

Abstract

This article discusses the measures for efficient use of fuel and energy resources in the railway industry. The calculation of the initial moment of starting the diesel engine and the necessary position of its crankshaft is made, on the basis of which it is proposed to modernize the locomotive start-up system with a decompressor. These measures are aimed at reducing the dynamic loads of engine components and reducing their wear and tear, as well as failure preventing. A method for the clean-up of fuel systems and the cylinder-piston diesel engine group of diesel locomotives was developed and tested using a special cleaning liquid that dissolves and removes solidified particles from pipelines and tanks. Measures have been proposed on the use of advanced models to test the modernized locomotives that will reduce the duration of the tests, resource and economic costs. The use of advanced testing model involves choosing the level of accuracy of the test results and, consequently, their duration and cost.

Keywords: Carbon Deposit, Clean-in-place, Diesel Engine, Resource Saving, Starting Aid, Testing Model.

1. Introduction

In research and application terms, the issue of efficient use of resources is solved by means of resource flow optimization using methods of project management, business processes, reengineering, logistics, management, marketing, implementation of specialized software, etc. provided that choosing effective management decisions is based on the comprehensive analysis of interdependent factors complex, the determination and comparative assessment of possible alternatives and feasible action plan on the basis of mathematical methods: modeling, analysis, balancing, simulation modeling, forecasting, optimization, decision support, etc. [1].

The issue of efficient use of resources particularly requires the first-priority solution in resource-intensive industries among which is the transport industry consuming 13.4 % of total primary energy resource flow.

A special attention is paid to the decrease of resource use in transport, particularly, the issue of sustainable consumption and use of material, energy, labor, information and financial resources has been solved. However, in railway transport, the issue of sustainable consumption of energy resources has been solved mainly, thus for this type of transport finding the complex solution of the issue of efficient use of resources is relevant [2].

2. Objective

The determination of resource-saving technologies efficiency and the implementation of measures and actions for locomotives.

3. Main Body

In order to more systematically consider all resource-saving measures it is reasonable to divide them into main strategic areas, namely:

- Design measures;
- Process measures;
- Operation measures;
- Managerial and engineering measures.

In turn, each of the above types of measures includes several important activities ensuring the most notable positive results [3].

Installing the decompressor during the upgrade of locomotive starting and control systems is proposed as a design measure in order to decrease pumping losses in cylinders. This measure is designed to decrease fuel consumption and increase the engine operation cost effectiveness and also increase the reliability of accumulators [4].

The starting system has disadvantages: high torque generating at the diesel engine start in order to overcome the resisting torque of crankshaft movement, resulting in the increase of starting peak current. It causes the decrease of accumulator service life and the increase of shaft line and gear friction couples' wear [5].

The critical task is to develop methods for locomotive accumulator starting current decrease on the basis of theoretical and experimental studies [6].

In order to achieve the resource saving during locomotive diesel engines start to prevent adverse effects of starting peak current and extend accumulator service life, the device for starting aid. It represents the stepping motor and reducer to be installed on cylinder test valve (Fig. 1).

The testing of this device was carried out on the test bed consisting of two-cylinder engine (piston diameter 96 mm, piston stroke 112 mm) connected with electric motor via vee-belt.

Due to the fact that we were interested only in the engine start, the torque required for overcoming of the resisting torque of crankshaft movement M_c, Nm , was calculated.

$$M_c = 390 \cdot V_h \cdot \left[\varepsilon + 6 \cdot \sqrt{\delta_H} + k_m \left(1 + \frac{\delta_H^2}{8} \right) \cdot \sqrt{\frac{\pi \cdot n_{kp}}{30}} \right] \quad (1)$$

Where V_h is the cylinder displacement, $V_h = 0.011 \text{ m}^3$, ε is the compression ratio, $\varepsilon = 13$, δ_H is the coefficient of turning variation, $\delta_H = 0.5$, k_m is the coefficient of internal combustion engine (ICE) type, $k_m = 2.8$, ν is the oil kinematic viscosity, $\nu = 14 \text{ mm}^2/\text{s}$, n_{kp} is the crankshaft speed, $n_{kp} = 180 \text{ rpm}$.

$$M_c = 390 \cdot 0.011 \cdot \left[13 + 6 \cdot \sqrt{0.5} + 2.8 \cdot \left(1 + \frac{0.5^2}{8} \right) \cdot \sqrt{14 \cdot \frac{3.14 \cdot 180}{30}} \right] = 275 \text{ Nm}$$

Crankshaft power on engine start N_n, W :

$$N_n = \frac{M_c \cdot \pi \cdot n_{kp}}{30}, \quad (2)$$

$$N_n = \frac{275 \cdot 3.14 \cdot 180}{30} = 5181 \text{ W}$$

Electric power P_e, W ,

$$P_e = \frac{N_n}{\eta_{mex} \cdot \eta_{el}}, \quad (3)$$

Where η_{mex} is the coefficient of mechanical efficiency, $\eta_{mex} = 0.97$, η_{el} is the coefficient of electric efficiency, $\eta_{el} = 0.84$.

$$P_e = \frac{5181}{0.97 \cdot 0.84} = 6359 \text{ W}$$

Further experimental starts of the test bed using decompressors were carried out; it showed the decrease of experimental unit starting current (Fig. 2).

The clean-in-place technique for fuel systems and cylinder-piston group can be referred to as process measures.

In diesel engine operation deposits on fuel supply elements, cylinder-piston group and exhaust line are formed. The main source of deposits is tar substances generated during thermal oxidation of fuel and engine oil unsaturated hydrocarbons.

The basic adverse effect of carbon deposits is delivered on fuel injection equipment (tar and coke) and cylinder-piston group elements (sludge). Carbon deposits on fuel supply system elements have various composition and generation mechanisms [7-10].

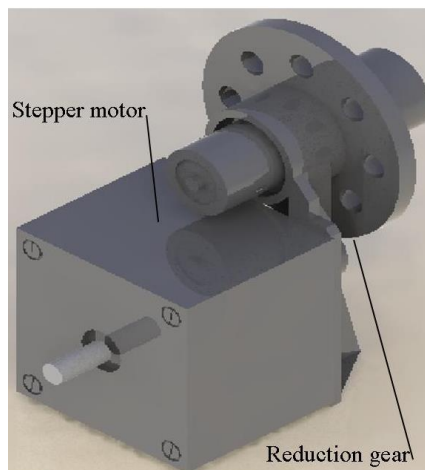


Fig. 1: The model of a device for cylinder decompression

The existing repair technique in many cases do not foresee the possibility to prevent increased contamination deposits and comes down basically to elimination of deposits related to de-installation of elements or dismantling of locomotive diesel engine mechanisms. Moreover, the mechanical carbon deposit removal results in the additional wear of cylinder-piston group and damage of piston protective coating.

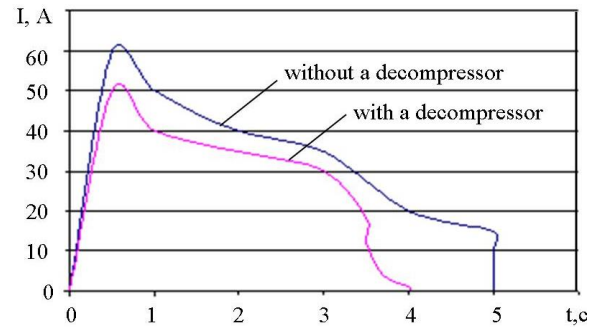


Fig. 2: Oscilloscope record of experimental unit start

Specialists of the Ukrainian State University of Railway Transport and Research and Development Enterprise "TOR" have developed and tested a clean-in-place technique for fuel systems and cylinder-piston group using special cleaning liquid [11].

Injection parameters: dispersability, uniformity and penetration depth of injected fuel flair from which depend the quality of diesel engine operation, in turn, it depends not only on dimensions injecting jets, but also on their finishing, availability of sharp edges and carbon deposits [12, 13].

In the nozzle group to be installed on the engine, values of effective opening areas of certain nozzles according to specification shall not have difference bigger than 5%.

Effective opening areas shall be determined on the test bed for static spilling of fuel injection elements.

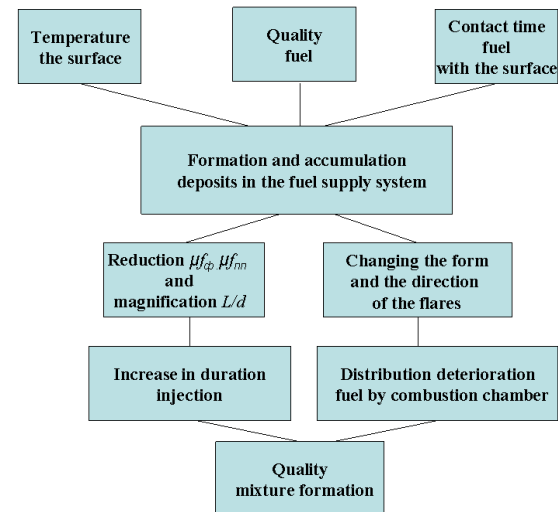


Fig. 3: Factors affecting formation and impact of carbon deposits on fuel supply system elements on fuel mixing quality

The fuel consumption through fuel injection element ΔV in m^3 per hour Δt is defined by the following formula:

$$\Delta V = 10^3 \mu f \sqrt{\frac{2P_f}{\rho F}} \Delta t \quad (4)$$

Where μ is the coefficient of bleeding, f is the area of jets, m^2 , P_f is the fuel pressure, mN/m^2 , ρF is the fuel viscosity, kg/m^3 , $\rho F = 840 \text{ kg}/\text{m}^3$, Δt is the fuel bleeding time, sec.

The effective opening area of fuel injection element is defined by the following formula:

$$\mu f = \frac{\Delta V}{10^3 \Delta t \sqrt{2 \frac{P_F}{\rho F}}} \quad (5)$$

Therefore, carbon deposit impact factors on fuel supply systems are changes of high pressure tubing and hydraulic resistance of nozzles. Levels of factors are limit and mean values of effective opening area change of fuel injection element due to carbon deposits. The combination of levels by all factors creates a condition for one experience for the object model.

In order consider changes of high pressure tubing and hydraulic resistance of nozzles, the following coefficients are introduced:

$$\Delta_{FL} = \frac{\mu f_{FL} - \mu f'_{FL}}{\mu f_{FL}} \quad (6)$$

Where μf_{FL} is the effective opening area of fuel supply line without carbon deposits, m^2 , $\mu f'_{FL}$ is the effective opening area of fuel supply line after operation, m^2 .

$$\Delta_{\dot{O}} = \frac{\mu f_N - \mu f'_N}{\mu f_N} \quad (7)$$

where: μf_N is the effective opening area of injection nozzle without carbon deposits, m^2 , $\mu f'_N$ is the effective opening area of injection nozzle after operation, m^2 .

In order to develop a mathematical model of relationship between measured value of response y and controlled variable factors $f = (x_1, \dots, x_i)$ regression analysis methods can be used, as measurement results y_u $u = 1, \dots, N$ are independent, normally distributed values, dispersion of response in different points and factor space is equal and independent from absolute values y_u ; factors x_1, \dots, x_i measured with negligibly small error in comparison with the error in definition of y .

Table 1: Levels of factors and their codes

Levels of factors	Level code	Factors		
		Coefficient of effective opening area of high pressure fuel supply line change, Δ_{FL}	Coefficient of effective opening area of nozzle change Δ_N	Locomotive mileage T , days
Main \bar{X}	0	0.985	0.833	225
Upper X^B	+1	0.977	0.666	450
Lower X^H	-1	1	1	0

The analysis of hydraulic resistance impact on response function Q shows that a linear approximation is insufficient, thus as the approximation function is assumed the second order polynomial.

$$y = b_0 + \sum_{i=1}^k b_i x_i + \sum_{\substack{i,j=1 \\ i < j}}^k b_{ij} x_i x_j + \sum_{i=1}^k b_{ii} x_i^2 \quad (8)$$

Where k is the number of factors.

The implementation of testing matrix allows to develop the model that includes accordingly transformed quadratic terms:

$$\hat{y} = b_0 + \sum_{i=1}^k b_i x_i + \sum_{\substack{i,j=1 \\ i < j}}^k b_{ij} x_i x_j + \sum_{i=1}^k b_{ii} (x_i^2 - \bar{x}_i^2) \quad (9)$$

The finished form of defined equation takes the following form:

$$y = 585.309 + 8.55x_1 + 49.840x_2 + 22.236x_3 + 1.25x_1x_2 - 1.5x_1x_3 - 19.5x_2x_3 - 4.88x_1^2 - 2.005x_2^2 + 0.025x_3^2 \quad (10)$$

Where x_1, x_2, x_3 are coded values of factors.

In order to use this equation it is required to turn to actual variables according to formula.

Using the Table 1 data we get:

$$\begin{cases} x_1 = \frac{\Delta_{FL} - 0,977}{0,033}; \\ x_2 = \frac{\Delta_N - 0,666}{0,334}; \\ x_3 = \frac{\dot{O} - 225}{450}. \end{cases} \quad (11)$$

All factors are significant. Dispersions S_{ad}^2 and $S_{\text{вoсnp}}^2$ are uniform and with 95% probability and their relationship meets the following requirement:

$$\frac{S_{\text{adequacy}}^2}{S_{\text{repeatability}}^2} < F \quad (12)$$

Where F is the table value of Fisher test.

The obtained dependences are reasonable to use for taking optimal decisions on the frequency and type of preventive cleaning of fuel system, fuel injection equipment and cylinder-piston group of locomotive diesel engines from carbon deposits considering operating conditions and operating modes.

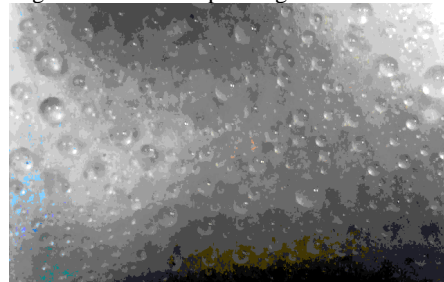


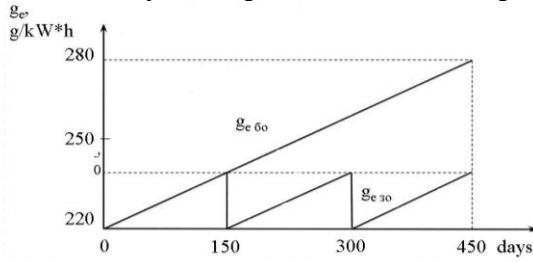
Fig. 4: Picture of fuel drops injected by nozzle $T = 300$ days, $\Delta_{FL} = 0.986$, $\Delta_N = 0.885$ (Scale 1:150).



Fig. 5: Picture of fuel drops injected by nozzle $T = 300$ days after using the fuel supply system clean-in-place technique $\Delta_{FL} = 0.998$, $\Delta_N = 0.995$ (Scale 1:150).

On the basis of mentioned experimental and theoretical studies the following conclusions about reasonability of changes to locomotive maintenance and current repair systems in order to include the clean-in-place technique. Works on continuous cleaning are proposed to perform approximately 2 times per year for locomotives in constant operation along with routine types of maintenance. It is also possible to use this technique in locomotive fuel efficiency decrease, in such case the use of clean-in-place techniques is proposed in the MNT-3.

If we proceed from the performance to effective fuel consumption, we obtain the dependence g_e from locomotive running time:



$g_e 60$ – without cleaning, $g_e 30$ – with cleaning.

Fig. 6: Dependence of effective fuel consumption g_e from locomotive running time.

Accordingly, in order to improve the locomotive repair technique it is proposed to adjust the existing regulations on locomotive run between repairs.

Measures on resource-saving as managerial and engineering foresee use of improved models of operation testing in different types of rolling stock upgrade. The implementation of improved models is directed to the definition of testing results according to set tasks and considering the current experience of locomotive standard equipment operation and use of new units or materials in other conditions.

Thus, the fuel resource saving becomes feasible, their value amounts to the significant part in the upgrade and railway transport operation value.

Considering the implementation objective and use of all above-mentioned resource-saving measures, the comparison criterion - the specific consumption of fuel and energy resources' impact on the locomotive operation was selected considering expert methods:

$$K_{p.b.} = f(M_{por}^{opt}, G_{fuel}) = \frac{\sum E^{ex}}{\sum Q_{br}} \quad (13)$$

Where $K_{p.b.}$ is the comparison criterion of specific consumption of fuel and energy resources by locomotive under normal conditions and upon implementation of resource-saving measures, M_{por}^{opt} is the nomenclature massive of resource-saving measures, $\sum E^{ex}$ is the locomotive operation expenses, UAH, $\sum Q_{br}$ is the total work performed by locomotive, gross ton-kilometer.

Conversely the locomotive operation expenses consist of:

- Expenses on diesel fuel and oil during testing;
- Value of 1 ton of diesel fuel and oil, UAH;
- Number of completed maintenance (MNT) and emergency repairs (ER);
- Expenses on MNT and ER, UAH.

This criterion forms the resource-saving index function and depends on the locomotive fuel and oil consumption.

In accordance with the resource-saving purpose the objective function representing the dependence of operation expenses and index massive describing resource-saving measures and economy resulted from their implementation is formed and tends to minimum:

$$E_{por}^{extest} = f(M_{por}^{opt} \in \Pi_{por}^{now}, E_{por}^{test}) \Rightarrow \min, \quad (14)$$

Where E_{por}^{extest} are expenses on uneconomic locomotive operation, thousand UAH, $M_{por}^{opt}, \Pi_{por}^{now}$ are indexes that are controlled and changed upon introducing new measures, E_{por}^{test} are expenses on resource-saving measures' implementation.

In accordance with the determined objective, the objective function and comparison criterion, the process of resource-saving

measures use is limited by requirements, considering the index massive:

$$\lim_{por} = \begin{cases} T \geq 0; P(t) \geq 0,85; K_r \geq 0,9; \\ g_f \leq g_e^{max}; g_{oil} \leq g_{oil}^{max}. \end{cases} \quad (15)$$

Where \lim_{por} is the system of resource-saving measures' implementation mathematic model limits, T is the duration of locomotive operation with implemented measures, $P(t)$ is the probability of fail-safe operation, the value established in accordance with requirements for railway transport, K_r is the availability factor, the value established in accordance with requirements for railway transport, $g_f \leq g_e^{max}; g_{oil} \leq g_{oil}^{max}$ are the fuel and oil specific consumption that accordingly shall not exceed the maximum value of effective indexes.

The mathematic model for locomotive resource-saving measures' implementation adequacy was verified by the cost relationship before their implementation and shows the magnitude of error according to formula (16) and shall not exceed 0,08.

$$\beta = \frac{1}{N} \cdot \sum_{M_{por}^{opt}, \lim} \left| \frac{E_{porM_{por}^{opt}}^{extest} - E_{porM_{por}^{ex}}^{extest}}{E_{por\Pi_{por}^{ex}}^{extest}} \right|, \quad (16)$$

Where β is the mathematic model adequacy index, N is the number of locomotives with implemented resource-saving measures, $E_{porM_{por}^{opt}}^{extest}$ are expenses on locomotive operation with implemented resource-saving measures, $E_{por\Pi_{por}^{ex}}^{extest}$ are expenses on locomotive operation without implemented resource-saving measures.

The catholicity of this mathematic model is confirmed by the possibility of its use for evaluation of resource-saving measures' implementation on different locomotive types and series, when the implemented measures conditions, purpose and limits coincide with the mentioned measures.

5. Conclusion

The articles examined resource-saving measures and methods for locomotives which are among major strategic concerns of implementation of resource-saving measures on locomotive facilities of Ukrainian railways.

It is proposed:

- to install the decompressor during the upgrade of locomotive starting and control systems in order to decrease pumping losses in cylinders. Using the mathematical apparatus the torque required for overcoming the resisting torque of crankshaft movement was calculated in order to select the required engine;
- the clean-in-place technique for fuel systems and cylinder-piston group using special cleaning liquid. Using the mathematical modeling were obtained dependences that are reasonable to use for taking optimal decisions on the frequency and type of preventive cleaning of fuel system;
- Measures on use of advanced model for testing of upgraded locomotives allowing to decrease resource consumption during testing, and determine with required accuracy the list of indexes that will form the value of rolling stock service life.

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