Artemchuk Viktor, Krasnov Roman, Karasev Oleksandr
Артемчук Віктор, Краснов Роман, Карасьов Олександр

FEASIBILITY STUDY FOR EXTENDING THE ROLLING STOCK COMPONENT LIFE

1. Problem statement

Rail transport in the world is one of the important industries that provides the movement of raw materials, individual elements and finished products, as well as renders transportation services to the population. The latter is very important for many spheres of life, for example, the movement of labour resources, the development of the tourism industry, etc. Thus, in Ukraine, railway operates 82% of freight and almost 50% of passenger traffic [1]. According to the same source [1], in terms of freight traffic, the Ukrainian railways are ranked fourth in the Eurasian continent and in 2018 transported almost 56 million people. The operational length of the tracks is more than 21,500 km, almost half of which is electrified. At the same time, the railway absorbs a fair amount of resources to support its functions. A considerable part of cost is used to replace or repair faulty or worn parts. Given a sufficiently large number of rolling stock units, that is: almost 4000 locomotives, more than 1600 units of motor-car rolling stock, more than 5000 passenger cars and almost 110 thousand freight cars and the heavy wear of fixed assets in terms of rolling stock (more than 65%), there is a need for an urgent search for opportunities to extend the life of rolling stock and its modernization. Herewith, it is necessary to ensure the level of reliability and safety of operation specified by the normative documentation and to develop a strategy for updating the locomotive and car fleet [2, 3]. Another important direction for enhancing the competitiveness of this type of transport against the background of constant increase in energy and other resources is the active development and implementation of energy and resource-saving technologies. However, investing financial resources in repair without economic justification can lead to excessive and unjustifiable costs, so the solution to such tasks is relevant.

2. Presentation of the main research material

The lifecycle of any object consists of several stages [4, 5], but when addressing the above-mentioned problem, the rolling stock can be considered at the stages of operation and repair. It is obvious that the operation of vehicles is the main function of the transport industry and, ideally, from an economic point of view, vehicles should be operated continuously throughout the product designed durability. For example, for most locomotives, this term is set as 30 years. But at this stage of development of science and technology to ensure uninterrupted reliable work of technical products is not possible, and not depending on the adopted repair system. Therefore, issues related to maintenance and repair of vehicles are and will remain in the future. On the other hand, any idle time of a transport unit (downtime, breakage, maintenance, repair, etc.) leads to the decrease in its economic efficiency. Particularly, it should be noted, unplanned repair reduces the economic performance significantly. The analysis of the technical condition of the mechanical part of locomotives over the past three years has shown that the distribution of unplanned repairs by their causes is as follows: insufficient quality of repair and maintenance at the repair shed - 43.3%, insufficient quality of maintenance - 16.2% insufficient quality of repair at locomotive repair plants - 19.8%, other causes - 20.7%. As can be seen from the above data, the largest number of locomotive events for unplanned repairs was made due to violated repair technology, as well as their performance modes. It is also evident that a significant number of unplanned electric locomotive repairs is due to the poor repair quality of electric locomotives and equipment at locomotive repair plants. The technical condition of the locomotive fleet is significantly influenced by insufficient quality of repair and maintenance in locomotive sheds and major repairs at locomotive repair plants; shortage of skilled repair personnel; lack of proper locomotive repair and maintenance base, technological equipment; absence of the required amount of technological equipment of electric locomotives and diesel locomotives, spare parts and materials; insufficient control over the quality of repairs and maintenance; tardy repair of locomotives. Thus, an attempt to increase the inter-repair mileage, and hence the durability of individual components of the rolling stock, is quite fair. However, on the other hand, unjustified increase in the durability of all components is not feasible, since the life of individual components may be greater than the life of the entire unit. As the world experience shows, it is not expedient to extend the life for all the details, but only that of the most responsible and (or) most worn out, which greatly affect the service life of the assembly or unit as a whole. That is, there is a need to match the life of the entire assembly and individual components. This assertion is related to the economic expediency of life extension, since, as a rule, highly effective restoration technologies require a considerable amount of additional financial investments. Attempts to extend the life of a particular component that exceeds the unit life, whose part it is, will in fact be meaningless. If it is possible to extend the life of the least reliable or short-life components, thus affecting the durability of the whole unit, then such an approach can be economically justified.

It should be noted that a lot of theoretical studies [6 - 10] are devoted to the issue of estimating optimum durability and reliability. Common to many works is to determine the durability of products as a function of time, which is logical. An interpretation of the use of the time index may be, for example, a durability factor or otherwise a technical use coefficient that can be represented as:

$$k_d = \frac{T_o}{T_o + t_{sr} + t_{nsr} + t_{dg} + \cdots + t_w + t_{reg}}, \tag{1}$$

where T_o – total time of product operation for the whole or the established period of operation;
t_{sr} – scheduled repair idle time;
t_{nsr} – non-scheduled repair idle time;
t_{dg} – product diagnostics idle time (if provided);
t_w - repair waiting idle time (diagnostics, etc.);
t_{reg} - product regulation idle time.

The use of the durability factor is convenient because of its zero dimension, as well as the obviousness, that is, with its approximation to one, it is clear that the durability of the product increases.

In our opinion, another important indicator for estimation is the aggregate cost index (to be disclosed later) and the labour intensity. The aggregate cost index means the costs associated with repair operations and the lost profit due to the product idle time:

$$C = \frac{C_{sr} t_{sr} + C_{nsr} t_{nsr} + C_{dg} t_{dg} + \cdots + C_{reg} t_{reg}}{t_{sr} + t_{nsr} + t_{dg} + \cdots + t_{reg}} + C_{lp} \tag{2}$$

where C_{sr}, C_{nsr}, $C_{dg}, \ldots$, C_{reg} – costs connected with certain operations, whose indices correspond to time indices;
C_{lp} – lost profit due to the product idle time.

It can be noted that formula (2) is not absolute, but it takes into account the necessary basic costs and is sufficient for further analysis.

Also, for some tasks of determining the rational life one can take into account the labour intensity, which is related to the cost index and time spent on the product repair.

As we see, the problem arises when the manufacturing process can be measured by several indicators, and the repair cost and time minimized (simplified optimization procedure), and if necessary labour intensity index added, which is also directed to a minimum (extended procedure). To solve optimization problems we will use tools, well-developed by Professor A.A. Bosov [11]. It should be noted that the method developed by us allows to artificially impose limits on the life of individual components so that their life would not exceed the life of the product (assemblies, units, etc.). But this statement has an exception, provided that these components can be used on other products and have no other restrictions, such as, for example, obsolescence. In this case, other well-known approaches, such as in [12], need to be applied. Also, the method proposed by us allows to introduce filters that take into account the technological capabilities of repair facilities, regulatory restrictions (prohibition of use of certain technologies), the possibility of restorative technologies.

That is, the method works as follows. All components, such as the mechanical part of locomotives, are divided into groups. These groups can be composed by different principles depending on the task (types of wear, working conditions, functional purpose, etc.). In a composite database, each component is "tied" to its assembly and either the normative (if any) or the empirical life of that assembly is indicated. Next, the expediency and the ability to increase the site's resource is determined. Then the components being repaired are passed through the filters, which, as already mentioned, respond to the technological capabilities of enterprises, the possibility of using renewable technologies and their input and output parameters. So at the output of the calculation we receive a set of rational parameters of the technological process, among which the engineer-technologist can choose one or another process in the conditions of his enterprise.

The above material will be illustrated by the example. Let the locomotive shed have sufficiently developed repair facilities, which allow to repair the worn components by surfacing, gas-thermal spraying and electrolytic methods. Let it be cylindrical components that are quite common in the mechanical part of the rolling stock. As already noted, the nomenclature of components is divided into groups and the technologist begins the filtration procedure. For example, we can use all of the aforementioned restorative technologies according to the normative documentation, namely, the enterprise has these technologies, that is, we have shown the most complicated variant. The most difficult stage is the choice among different technologies, especially in the conditions of nonlinearity of functions. However, the advantage of the presented methodology is its dynamic nature, which can be adjusted to the needs of facilities. So, with the introduction of the corresponding coefficients, on the output we automatically receive a new set of rational parameters. In turn, these coefficients depend on the parameters of technological processes and vary in their weight. For example, we can take into account the material applied to the component, the presence and nature of the finishing and heat treatment of the component through the appropriate coefficients. Finally, we determine the rational restoration modes, by which we mean the modes when the costs C for component restoration are as low as possible, and service life is as long as possible. Herewith, we mean that the time repair and the labour intensity are the constituent parts of expenses.

So let $C(r, u)$ be the cost of restoring a cylindrical part of a unit length from the size of the radius r to the size of the radius $r + dr$, then the cylinder restoration from the size r_0 to $r_0 + \Delta$ will be

$$F_1(u) = \int_{r_0}^{r_0+\Delta} C(r,u)2\pi r dr \quad (3)$$

where u is the vector characterizing the restoration mode.

If $v(r)$ is the wear rate of thickness dr, then $\frac{dr}{v(r)}$ will characterize the wear life of this thickness.

Since $v(r)$ is a random variable with probability distribution density $f(\delta, r)$, then the average wear life will be

$$M\left(\frac{1}{v(r)}\right) dr = \int_a^b \frac{f(\delta,r)}{\delta} d\delta dr, \quad (4)$$

and the average wear life for thickness Δ will be equal

$$F_2(u) = \int_{r_0}^{r_0+\Delta} \left(\int_a^b \frac{f(\delta,r)}{\delta} d\delta\right) dr \quad (5)$$

In this case, the average wear life of the values *a* and *b* depends on the radius and modes of restoration, that is

$$a = a(r,u);$$
$$b = b(r,u).$$

So we arrive at the vector optimization problem

$$\begin{pmatrix} F_1(u) \\ -F_2(u) \end{pmatrix} \to min \quad (6)$$

provided that the restoration mode $u(r)$ belongs to the domain of technology permissible modes *U*.

Assuming $f_1 = C(r,u)2\pi r$;
and

$$f_2 = -\int_{a(r,u)}^{b(r,u)} \frac{f(\delta,r)}{\delta} d\delta,$$

and entering $f = f_1 + t \cdot f_2$,
we are able to apply the necessary condition:

$$\left(\frac{\partial}{\partial u} - \frac{d}{dx}\frac{\partial f}{\partial u'}\right) = 0. \quad (7)$$

With a certain degree of accuracy, we take $C(r,u) = p \cdot u^2$, and we calculate the wear rate by a random variable whose limits of change are

$$a = \frac{a_0 r}{u};\ b = \frac{b_0 r}{u};\ 0 < a_0 < b_0.$$

In this case f_2 will be equal to

$$f_2 = \frac{u \cdot ln\frac{b_0}{a_0}}{(b_0 - a_0) \cdot r}. \quad (8)$$

Condition (7) in this case will be the following

$$4\pi p \cdot r \cdot u - t = \frac{u \cdot ln\frac{b_0}{a_0}}{(b_0 - a_0) \cdot r} = 0, \quad (9)$$

where we obtain

$$u = t\frac{ln\frac{b_0}{a_0}}{4\pi p (b_0 - a_0) \cdot r^2} = 0. \quad (10)$$

By substituting this u in the formulas (3) and (5) we obtain

$$F_1(t) = \frac{1}{8\pi p} \cdot \left(\frac{ln\frac{b_0}{a_0}}{b_0 - a_0}\right)^2 \cdot \left(\frac{1}{r_0^2} - \frac{1}{(r_0+\Delta)^2}\right) \cdot t^2; \quad (11)$$

$$F_2(t) = \frac{1}{8\pi p} \cdot \left(\frac{ln\frac{b_0}{a_0}}{b_0 - a_0}\right)^2 \cdot \left(\frac{1}{r_0^2} - \frac{1}{(r_0+\Delta)^2}\right) \cdot t. \quad (12)$$

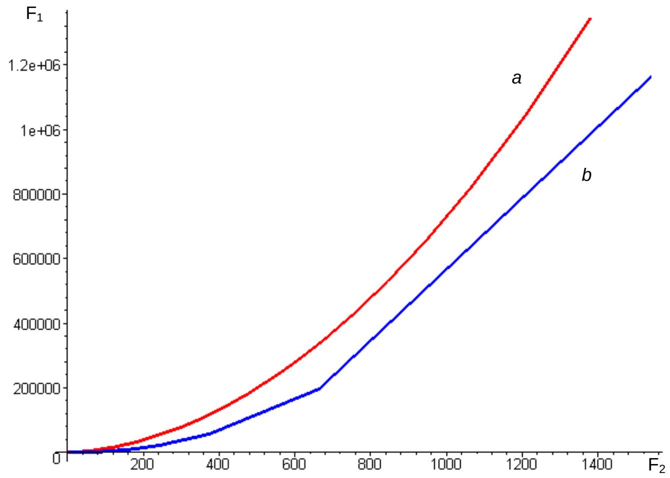
Setting

$$S = \frac{1}{8\pi p} \cdot \left(\frac{ln\frac{b_0}{a_0}}{b_0 - a_0}\right)^2 \cdot \left(\frac{1}{r_0^2} - \frac{1}{(r_0+\Delta)^2}\right),$$

we will find the connection between F_1 and F_2:

$$F_1 = \frac{{F_2}^2}{S}. \quad (13)$$

We will show the results of calculating an arbitrary example for two component restoration technologies (Fig.).



Interconnection between functionals F_1 and F_2 for two restoration technologies

Since the cylindrical components of the locomotive mechanical part can be used on other locomotives of the same series or similar design, we did not introduce the life limits. If it is necessary to introduce such limits, then on the life functional axis (in this case,F_2) we plot the corresponding projection to the points of intersection with the received functions.

3. Conclusions

We conducted the study to solve the complex task of extending the rolling stock component life taking into account the life of the assemblies and the unit as a whole. When searching for rational parameters, we investigated the component durability, the life affecting factors and took into account the possibilities of various restorative and strengthening technologies. The developed approach allows for consideration of technological limitations of production, financial constraints and the introduction of life limits for a specific component. The complexity and disadvantage of this method is the need to collect, accumulate and process a large amount of statistical data of worn components, as well as possible errors in predicting the life of the components after their restoration. However, previous calculations have shown that this approach allows for more attractive use of restoration technologies, saves significant resources and makes it possible to find the required restorative or strengthening technology that will bring the life of different components closer to the life of the assembly or mechanism as a whole. In addition, with the development of the diagnostic system, obtaining the necessary data will be less labour intensive and will require less time, and with the development of the necessary software, the accumulation and processing of statistics can be fully automated.

It also follows from the obtained results that the extension of the average wear life of the restored component requires a quadratic restoration costs, which confirms the assumption of the need to determine the estimated rational life (mileage) of the components and to choose and adjust the parameters of the technological process for the set period (mileage). This approach allows receiving a certain (determined) life of the restored components without unnecessary expenses for repair and restoration work.

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