DEVELOPMENT OF RECOMMENDATIONS FOR EXTENDING THE USEFUL LIFE OF PASSENGER CARS

Purpose. The vast majority of passenger car fleet of «Ukrzaliznytsia» have cars with outlasted service life. In this regard there is a need to find methods to justify the extending useful life of passenger cars and to assess the car body frame residual life conformity to the operating load for the next life time.

Methodology. The selection of cars enforced technical diagnostics of cars to detect the level of corrosion and mechanical damage. The following steps provided the car body frame strength analysis on the basis of experimental static and impact strength tests, the longitudinal force effect endurance tests as well as assessment and forecasting of conformity of car body operating life for the next period.

Findings. The car survey before testing showed that the technical condition of sleeper cars (SSC) is better than that of open-type cars (SOC). So, in SSC cars the thinning of the main load-bearing elements due to corrosion does not exceed 10%, there are no cracks, deformations, rack breakages, etc. At the same time in SOC cars the thinning due to local corrosion reached 35%. There are deformations and corrosion damage of side sill Z-shape of both cars, single corner post breakages, damage to the joints of longitudinal tie rod and span bolsters. The conducted static and impact strength tests with following strength assessment of the car structural members showed that the strength of the latter is provided according to the normative documents, and these cars pose no threat to traffic safety. The impact endurance tests showed that all the cars passed the endurance tests without damage, which would prevent from testing and could not be removed during the next depot repair or overhaul, and had life length that allows them to extend the useful life for the next period.

Originality. The results of experimental studies show that passenger cars after 28 … 30 and 33… 35 years of operation meet the requirements of strength and safety in accordance with regulatory documents and allow, provided the impact endurance, reasonable extending of the car service life.

Practical value. The part of the car fleet, which was to be written off based on the service life, may extend lifespan without additional measures.

Keywords: passenger car; service life; structural strength; conformity; static test; impact test; life length.

Introduction

Total passenger car fleet of «Ukrzaliznytsia» consists mainly of cars built in the eighties with the designed: normative service life – 28 years and maximum service life – 41 years. The research of passenger car fleet is considered in [1], [5].

The car fleet has about 86% of passenger cars with outlasted service life (over 28 years), about 500 cars with normative service life of 20 years, only 343 of which have the service life of 10 years. During the period 1991 – end 2013 3 298 passenger cars were scraped (written off at the end of service life), 421 cars were to be written off in 2014. Thus, the intensity of passenger car fleet aging is increasing every year.

While the new cars are purchased in small amounts – «Ukrzaliznytsia» in the period 1991 – end 2013 at their own expense purchased 561 passenger cars, as well as 10 nine-car trains and 2 double-decker six-car trains. So every year the deficit of passenger cars is becoming tangible and may reach 2,364 cars in 2017, which is detrimental to the industry.
Because of the above objective reasons it became necessary to extend the service life of cars that have exhausted their primary resource. This makes it possible to slow down the growing deficit of passenger cars due to reasonable extension of their service life. The prerequisites of the above said extension are as follows:
- Designed service life was set at substantially excessive strength coefficients;
- Detailed analysis of technical condition of the cars to be written off shows that some cars are scrapped because of the malfunction incompatible with their further safe operation, but many of cars are written off from the inventory park when they reach the normative service life. However, a certain number of the latter still remain in good condition.

The possibility of extending the life of car supporting structures should be grounded by experimental and calculation-theoretical methods that include: inspection of their technical condition; experimental determination of load level and stress state of structural members; numerical calculations based on modern software systems to determine the stress-strain state by simulating the most adverse operating modes; residual life assessment (determination of the extended service life) with the numerical calculations of fatigue damage or by experimental life length testing. In addition, it should be noted that cars require an individual approach to the definition of the next service life (life length). This range of activities must be supported by repair technologies, which go beyond the scope of this study.

Problems of need statement for adjustment of cars useful service life extension in a particular way was considered both in Ukraine [3, 7, 8, 9, 12], and in near [17] and far abroad [18, 19]. The works [7, 9, 12] studied the problems and peculiarities of passenger car technical diagnosis. And the works [3, 8, 17, 18, 19] performed numerical calculations based on the finite-element model with strength assessment by I and III design modes. Further, considering the preliminary results, the calculations of structural members fatigue damage were performed to assess the remaining service life. In addition, the work [3] provides calculations for new cars and cars with minimum thickness of members (due to corrosion), as well as calculated significant impact of mechanical or welded damage (undercuts), depending on the size of the latter, on the car service life.

However, only theoretical studies cannot fully take into account all the factors affecting the car during operation and possible deficiencies incorporated in the construction at the stages of design and production. It implies permissible size tolerances, replacement of materials during the manufacture, specific possible mechanical damage during repairs and corrosive damage in operation. Thus, the car physical condition for each batch of individual manufacturer will differ.

Therefore there is a need for implementing relevant tests conducted once every five years according to TSL-0070 [6]. Effectiveness of field tests and their impact on rolling stock traffic safety is proved in [10].

### Purpose

In order to determine the feasibility of extending the useful life of passenger cars the car testing laboratory of Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan by order of «Ukrzaliznytsia» conducted a set of field tests in 2013. The tests included static strength, impact strength (determining) and impact life length testing of cars.

### Methodology

The cars for testing were randomly selected from the operating park, which exhausted the set service life or underwent the required scheduled types of repair. Some cars had damages allowed under [6]. As the sample cars there were selected two SOC cars (steel open-type sleeping cars) after 29 and 33 years of service, and two SSC cars (steel close-type sleeping cars) after 30 and 33 years of service.

Before testing the condition of cars underwent technical diagnosis to detect the level of corrosion and mechanical damage while metering the member thickness. All tests were performed according to the «Standards…» [11] and «Programme and methods …» [15].

Static strength tests were performed to determine the stresses in car parts caused by structure and passenger weight. Vertical static load on the car body members caused by passenger weight was carried out by the car shed employees,
who were evenly distributed along the train, and that caused by own structure weight was determined as the total stress with the help of the factor that takes into account body weight, water and coal weight, etc. While carrying out the static tests the equipment readings were registered and the loading-unloading cycle repeated provided the sensor indication stability.

The impact strength tests were carried out to assess the stress state of the car structural members affected by the determined longitudinal forces in the range of 0.5 MN...2.5 MN [11,15]. Herewith the car structural member stress values and impact force values were recorded.

The impact life length tests were performed to calculate the life length of bearing members of car body for impact endurance affected by longitudinal force. Car impact was performed by run-up of a hammer car with the help of locomotive onto a test car, which was located in the head of a retaining wall. The tests were carried out at speeds of 3 km/h to 13 km/h [11,15] with a gradual impact velocity increase by 1...2 km/h. The impacts were carried out by series, corresponding to one year of operation. The condition for the test completion was to obtain the full amount of experimental data or the car bearing structure integrity damage, which would threaten the safety of further testing. The tests determined the impact force and selectively tensions in some structural members (at impact force over 2 MN).

All kinds of tests were carried out on the territory of a car shed. To do this, after the removal of technically diagnosed car body damages, the strain-gage sensors were attached to the cars to determine the stresses, and the serial couplers were replaced with the strain-gage ones to determine the impact force.

According to obtained results of mathematical processing of the recorded processes (structural members tension and impact force) each type of the test determined the following:

- The results of static tests defined the tension in the structural members caused by passenger weight and own body weight;
- The impact strength tests allowed to build the dependency diagrams of impact force – speed (Fig. 1), of car part stresses – impact force (Fig. 2), to define tensions in some body members and to assess the structure stress state by design mode I [11].

Findings

State of SSC car bodywork after 30 and 33 years of service differed little and is typical for vehicles operating for 30 ... 33 years. Local thinning of main bearing members (span bolster, cross-bearer and underframe end, except diagonals) due to corrosion did not exceed 10%, there were no cracks, deformations, post breakages and other damages. The largest local corrosion damages were recorded in underframe sill diagonals (about 20%).

State of SOC car bodywork after 29 and 33 years of service is even worse in general, but is typical for this class of vehicles operating for 29...33 years. The span bolster thinning due to local corrosion reached 30% for 29-year service car and 35% for 33-year service car. The largest local corrosion damages in the side sill are recorded in the car after 29 years of service – 33%, the longitudinal tie rod thinning is about the same for both cars – up to 24%. There are deformations and corrosion damage of side sill Z-shape of both cars, single corner post breakages, damage to the joints of longitudinal tie rod and span bolsters.

The above damages can be removed during the scheduled repair in accordance with the instructions of TSL-0026 [4], TSL-0036 [14], TSL-0041 [2] – so all the cars listed above have been taken for testing.

Static and impact strength tests showed:

- Total static stress caused by passenger weight with luggage is insignificant. Herewith the stress in the sleeping car body members did not exceed 10.4 MPa. In the open-type cars the maximum stress was recorded in span bolster (20 MPa), cross-bearer (23.8 MPa) and side sill (30.3 MPa);
- The obtained mathematically processed results of car impact strength tests provided the stress value and dependence in the structural members and the hammer car run-up velocity caused by impact force (Fig. 2).

The diagrams show the strict linear relationship of parameters. This dependency of stress on impact force is peculiar for the structural members of all tested cars:

- The sleeping cars constructed in 1980 and 1983 take the impact load with the draft sill (105 MPa) and the span bolster (118 MPa), as well as the side wall panel bottom (230 MPa). Other
members of the body have much lower impact stress. The largest total stress in the structural members is marked in the draft sill (130 MPa), span bolster (152 MPa), side sill (208 MPa) and cross-bearer (158 MPa). In general, the total stress does not exceed the allowable value that for 09G2-grade steel of 295 strength class is 305 MPa. The stressed state of the sleeping car bodies after 30 and 33 years of service has no significant differences;

![Fig. 1. Dependency diagram of impact force (vertical, in MPa) on hammer car run-up velocity (horizontal, in km/h).](image)

![Fig. 2. Dependency of span bolster stress (MPa) on impact force (MN) - The open-type cars constructed in 1980 and 1984 take the impact load with longitudinal tie rod (187 MPa), span bolster (164 MPa) and side wall sill (228 MPa). Other structural members have much lower impact stress. The largest total stress in the structural members is marked in the longitudinal tie rod (127 MPa), span bolster (164 MPa), cross-bearer (214 MPa) and side sill (156 MPa). It should be noted that the stress level in some parts of the car built in 1984 is by 20% lower than that of the car built in 1980. In general, total stress of both cars does not exceed the allowable values.

As a result of impact endurance tests the entire range of longitudinal forces was distributed at intervals followed by calculation of impact endurance intervals, and then by total life length for each car. Fig. 3 shows an example of impact distribution in each force range (MN) for sleeping cars.

The figure shows the lighter tone for the number of efforts received by the car in the wall, the dark one – as a hammer. The largest impact number, 202, is recorded in the operating load range (0.5 … 1.5 MN). In total each car received 257 impacts from 0.5 to 2.94 MN.

![Fig. 3. Number of impacts (vertical) in the force range (horizontal, MN)](image)

The impact endurance tests showed:
- Sleeping cars were not damaged during the test
- Open-type cars constructed in 1980 and 1984 after the tests had damages common to both cars: deformation of side sill Z-shape (Fig. 4), cracks and breakages of the corner posts from side sill, cracks in span bolster bottom sheet welds. Besides the car built in 1980 got a crack in the joint of longitudinal tie rod and span bolster (Fig. 5);
- All cars passed the endurance tests without damage which would prevent from testing and could not be removed during the next depot repair or overhaul;
- All cars have life length that allows them to extend the useful life for the next 5 years.

The conducted studies determined that the passenger sleeping cars and open-type cars constructed before the year 1989 with specific corrosion damage level have the life length sufficient for their subsequent operation over the next 5 years. After the term exhaustion it is recommended to carry out the life length tests for assessment of the remaining life, which will depend on general and operation conditions of the cars.

In relation to open-type cars after 28 years of operation, when conducting the scheduled repairs, special attention should be paid to the state of side sill and corner posts. In case of suspected breakage in corner posts and side sill (visual subsidence of side wall) it is necessary to conduct a survey with removed outer skin and appropriate repairs. And in case of OR-1 these measures are mandatory.

**LIST OF REFERENCE LINKS**


С. В. МЯМЛИН1, А. Г. РЕЙДЕМЕЙСТЕР2, А. Л. ПУЛАРИЯ3, В. А. КАЛАШНИК4

1 Каф. «Вагони и вагонное хозяйство», Днепропетровский национальный университет железнодорожного транспорта имени академика В. Лазаряна, ул. Лазаряна, 2, Днепропетровск, Украина, 49010, тел. +38 (056) 776 84 98, эл. почта sergeymyamlin@gmail.com, ORCID 0000-0002-7383-9304

2 Каф. «Вагоны и вагонное хозяйство», Днепропетровский национальный университет железнодорожного транспорта имени академика В. Лазаряна, ул. Лазаряна, 2, Днепропетровск, Украина, 49010, тел./факс +38 (056) 793 19 16, эл. почта reideemeister@mail.ru, ORCID 0000-0001-7490-7180

3 Каф. «Вагоны и вагонное хозяйство», Днепропетровский национальный университет железнодорожного транспорта имени академика В. Лазаряна, ул. Лазаряна, 2, Днепропетровск, Украина, 49010, тел./факс +38 (056) 793 19 16, эл. почта pularia@mail.ru, ORCID 0000-0003-1144-4179

4 Каф. «Вагоны и вагонное хозяйство», Днепропетровский национальный университет железнодорожного транспорта имени академика В. Лазаряна, ул. Лазаряна, 2, Днепропетровск, Украина, 49010, тел./факс +38 (056) 793 19 16, эл. почта kv47@i.ua, ORCID 0000-0002-8073-4631
РАЗРАБОТКА РЕКОМЕНДАЦИЙ ПО ПРОДЛЕНИЮ СРОКА ПОЛЕЗНОЙ ЭКСПЛУАТАЦИИ ПАССАЖИРСКИХ ВАГОНОВ

Цель. Пассажирский вагонный парк Укрзализныци в подавляющем большинстве имеет вагоны со сверхнормированным сроком службы. В связи с этим возникает необходимость поиска методов обоснования продления полезной эксплуатации пассажирских вагонов и оценки соответствия остаточного ресурса конструкции кузовов вагонов эксплуатационным нагрузкам в течение следующего срока использования.

Методика. При отборе вагонов выполнялось техническое диагностирование их состояния с целью выявления уровня коррозионных и механических повреждений. На следующих этапах выполнялось исследование прочности несущих конструкций кузовов вагонов на основе экспериментальных статических и ударных испытаний на прочность, ресурсных испытаний на действие продолжительных сил. Выполнялась оценка и прогнозирование соответствия ресурса кузовов вагонов на следующий период.

Результаты. Обследования вагонов до испытаний показали, что техническое состояние кузовов вагонов ЦМК лучше, чем вагонов открытого типа ЦМО. Так, в вагонах ЦМК уменьшение толщины основных несущих элементов вследствие коррозии не превышало 10 %, отсутствовали трещины, деформация, обрывы стоеч и прочее. В то же время в вагонах ЦМО уменьшение толщины вследствие коррозии составляло 35 %. Имеются деформации и коррозионные повреждения в нижней обшивке кузова. Экспериментальные исследования показали, что прочность последних обеспечивается согласно нормативным документам и такие вагоны несут угрозы безопасности движения. Ударные ресурсные испытания показали, что все вагоны прошли их без повреждений. Данные испытания могли бы препятствовать проведению испытаний и не могли быть устранены при проведении очередного деповского или капитального ремонта и имели наработку на ресурс, которые позволяют продлить срок их полезной эксплуатации на следующий период.

Ключевые слова: пассажирский вагон; срок эксплуатации; прочность конструкции; соответствие; статические испытания; ударные испытания; наработка на ресурс

С. В. МЯМЛИН1, О. Г. РЕЙДЕМЕЙСТЕР2, А. Л. ПУЛАРИЯ3, В. О. КАЛАШНИК4

1 Каф. «Вагони і вагонне господарство», Дніпродзержинський національний університет залізничного транспорту імені академіка В. Лазарина, вул. Лазарина, 2, Дніпродзержинськ, Україна, 49010, тел. +38 (056) 776 84 98, ел. пошта sergy myamlin@gmail.com, ORCID 0000-0002-7383-9304
2 Каф. «Вагони і вагонне господарство», Дніпродзержинський національний університет залізничного транспорту імені академіка В. Лазарина, вул. Лазарина, 2, Дніпродзержинськ, Україна, 49010, тел./факс +38 (056) 793 19 16, ел. пошта reidemeister@mail.ru, ORCID 0000-0001-7490-7180
3 Каф. «Вагони і вагонне господарство», Дніпродзержинський національний університет залізничного транспорту імені академіка В. Лазарина, вул. Лазарина, 2, Дніпродзержинськ, Україна, 49010, тел./факс +38 (056) 793 19 16, ел. пошта pularia@mail.ru, ORCID 0000-0003-1144-4179
4 Каф. «Вагони і вагонне господарство», Дніпродзержинський національний університет залізничного транспорту імені академіка В. Лазарина, вул. Лазарина, 2, Дніпродзержинськ, Україна, 49010, тел./факс +38 (056) 793 19 16, ел. пошта kv47@i.ua, ORCID 0000-0002-8073-4631

РОЗРОБКА РЕКОМЕНДАЦІЙ ІЗ ПРОДОВЖЕННЯ ТЕРМІНУ КОРИСНОЇ ЕКСПЛУАТАЦІЇ ПАСАЖИРСЬКИХ ВАГОНІВ

Мета. Пасажирский вагонный парк Укрзализныци в переважній більшості має вагони з понаднормованим терміном служби. У зв’язку з цим виникає необхідність пошуку методів обґрунтування продовження корисної експлуатації пасажирських вагонів та оцінки відповідності залишкового ресурсу конструкції кузовів вагонів експлуатаційним навантаженням протягом наступного терміну використання. Методика.

РУХОМІЙ СКЛАД і ТЯГА ПОЇЗДІВ

При відборі вагонів виконувалось технічне діагностування їх стану з метою виявлення рівня корозійних та механічних пошкоджень. На наступних етапах виконувалось дослідження міцності несучих конструкцій кузовів вагонів на підставі експериментальних статичних та ударних на міцність випробувань, ресурсних випробувань на дію поздовжніх сил. Виконувалась оцінка та прогнозування відповідності ресурсу кузовів вагонів на наступний період. Результати. Обстеження вагонів до випробувань показало, що технічний стан кузовних вагонів ЦМК кращий, ніж вагонів відкритого типу ЦМО. Так, у вагонах ЦМК зменшення товщин основних несучих елементів внаслідок корозії не перевищувало 10 %, були відсутні тріщини, деформації, обриби стінок та інше. В той же час у вагонах ЦМО зменшення товщин випадок локальної корозії досягало 35 %. Наявні деформації та корозійні пошкодження З нижньої об’ємної обшивки вагонів, поодинокі обриби стінок, пошкодження місць з’єднання хребтової і цьорвенної балок. Проведені статичні та ударні на міцність випробування із подальшою оцінкою міцності елементів конструкції вагонів показали, що міцність останніх забезпечується згідно нормативних документів та такі вагони не несуть загрози безпеці руху. Ударні ресурсні випробування показали, що всі вагони пройшли їх без ушкоджень. Ці ушкодження могли б перешкоджати проведенню випробувань і не могли бути усунені при проведені його ремонтного або капітального ремонту та мали напрацювання на ресурс, яке дозволяє продовжити термін їх корисної експлуатації на наступний період.

Наукова новизна. Результати проведених експериментальних досліджень доводять, що пасажирські вагони після 28...30 та 33...35 років експлуатації відповідають безпекі руху. Ударні ресурсні випробування показали, що всі вагони пройшли їх без ушкоджень. Ці ушкодження могли б перешкоджати проведенню випробувань і не могли бути усунені при проведенні його ремонтного або капітального ремонту та мали напрацювання на ресурс, яке дозволяє продовжити термін їх корисної експлуатації на наступний період.

Ключові слова: пасажирський вагон; термін експлуатації; міцність конструкції; відповідність; статичні випробування; ударні випробування; напрацювання на ресурс.

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Prof. V. L. Horobets, Senior Scientific Researcher (Ukraine); F. V. Mamedov, Deputy Director of Passenger Transportations (Ukraine) recommended this article to be published

Received: Nov. 13, 2015


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