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Ensuring Safe Working Conditions under the Influence of Vibroacoustic Factors on Train Crew Workers

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Abstract
Introduction. The increased intensity of noise and vibration of railway traffic may become not only an urgent problem in the field of occupational safety, but also a serious environmental problem in the near future due to the constant need to increase the weight of freight trains, the speed of passenger trains and the capacity of railway lines. Recently, a lot has been done to minimize the negative effects of noise and vibration in railway transport. However, the problem of exceeding the indicators of vibration noise factors remains relevant. Reducing the harmful effects helps to improve the working conditions of train crew employees and improve the comfortable conditions of transport passengers. As a rule, the main focus of the analysis is on the external impact of vibroacoustic factors on residential areas and less attention is paid to the impact on rolling stock. However, these studies do not provide a complete picture of how noise and vibration actually affect the train in motion. The aim of the study was to obtain the result of an analysis of the impact of vibroacoustic factors on train crew workers and to propose a method of comprehensive protection based on the use of vibration damping materials.
Materials and Methods. In the course of the work, regulatory documents were studied, a comprehensive analysis of relevant information on this topic was carried out, and methods for calculating vibration and vibration acceleration were used. The values of the sound pressure levels were obtained using a SPM-101 sound level meter. The object of the study was a carriage of the "reserved seat" type in the process of movement. As part of the research plan, sound pressure was measured at selected sites and a class of working conditions was determined.
Results. The result of the analysis of the impact of vibroacoustic factors on train crew workers indicated the need to strengthen comprehensive measures to protect them. The obtained calculation of the vibration force became the basis of the method proposed by the authors to minimize the harmful effects of vibroacoustic factors, which was based on the use of vibration and sound insulation materials suitable for the necessary acoustic parameters in the construction of the car. In particular, it was proposed to cover the floor of the car with dense rubber and the ceiling of the car with an inorganic fiber material for sound insulation. The work also provides an economic assessment of the effectiveness of measures to minimize harmful vibration noise effects.
Discussion and Conclusion. The proposed methods for minimizing noise and vibration impacts can help reduce the level of sound pressure and vibration indicators to standard values, which will significantly reduce the negative impact of vibroacoustic factors on train crew workers and railway passengers. The considered complex for minimizing vibration and noise includes a set of methods in which affordable materials based on recycled substances have found application.

Keywords: sound pressure, vibration, noise pollution, sound insulation

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Научная статья

Обеспечение безопасных условий труда при воздействии на работников поездных бригад виброакустических факторов

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Аннотация

Введение. Повышенная интенсивность шума и вибрации на железнодорожном транспорте может стать не только актуальной проблемой в области охраны труда, но и серьезной экологической проблемой в ближайшем будущем из-за необходимости постоянного увеличения веса грузовых поездов, повышения скорости движения пассажирских поездов и возрастания пропускной способности железнодорожных линий. В последнее время немало сделано для минимизации негативного воздействия шума и вибрации на железнодорожном транспорте. Однако проблема превышения показателей виброшумовых факторов остается актуальной. Уменьшение вредного воздействия шума и вибрации способствует улучшению условий труда работников поездных бригад и повышению комфортных условий для пассажиров. Как правило, основное внимание при анализе воздействия виброакустических факторов уделяется внешнему их воздействию на селитебную территорию и меньше — воздействию на подвижной состав. К тому же такие исследования не являются комплексными, так как не дают полного представления о воздействии шума и вибрации непосредственно на состав в движении. Цель данного исследования — анализ воздействия виброакустических факторов на работников поездных бригад и пассажиров для разработки метода их комплексной защиты, основанного на применении виброгасящих материалов.

Материалы и методы. В ходе работе были изучены нормативные документы, проведен комплексный анализ актуальной информации по данной теме, использованы методики по расчету вибрации и виброускорения. Значения уровней звукового давления были получены с помощью шумомера SPM-101. Объектом исследования был выбран вагон типа «плацкарт» во время движения. В рамках исследования было измерено звуковое давление на выбранных участках дороги и определен класс условий труда.

Результаты исследований. Результат анализа воздействия виброакустических факторов на работников поездных бригад свидетельствует в необходимости усиления комплексных мер их защиты. Полученный расчет силы вибрации стал основой предложенного авторами метода минимизации вредного воздействия виброакустических факторов, в основе которого использование в конструкции вагона вибро- и звукоизолирующих материалов, подходящих по необходимым акустическим параметрам. В частности, предложено с целью шумоизоляции на пол вагона уложить плотную резину, а на потолок — материал из неорганического волокна. В работе также дана экономическая оценка эффективности мероприятий по минимизации вредного виброшумового воздействия.

Обсуждение и заключение. Предложенные методы минимизации шумового и вибрационного воздействия могут способствовать снижению уровня звукового давления и показателей вибрации до нормативных значений, что сократит негативное воздействие виброакустических факторов на работников поездной бригады и пассажиров. Рассмотренный комплекс по минимизации вибрации и шума включает в себя совокупность методов, в которых нашли применение бюджетные материалы, созданные на основе вторично переработанного сырья.

Ключевые слова: звуковое давление, вибрация, шумовое загрязнение, шумоизоляция

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Introduction. Rail transport has always created and continues to create noise and vibration, which, in most cases, cannot be fully eliminated and are likely to have a negative impact on the environment, despite the use of various mitigation measures. The problem of reducing the impact of noise and vibration of railway transport on people and the impact on engineering structures is very difficult due to the large number of parameters and factors of distribution of noise and vibration energy. The negative impact of vibroacoustic factors is growing every year due to an increase in the number and weight of freight cars, their high wear and tear, untimely maintenance of passenger cars, as well as the lack of free space in urban areas, as a result of which new business and residential facilities are located in close proximity to the railway. The problem of noise and vibration from railway transport is especially acute in large cities with large railway connections, mainly due to short distances from the railway tracks to the nearest buildings. This fact limits the possibilities for taking measures to reduce noise and vibration. To date, the primary task is to protect against excess sound pressure using the "external noise source — environment" system. The system implies the impact of noise on nearby infrastructure facilities, residential areas, and nature. Protection against such impacts is achieved by installing acoustic screens. With their help, it is possible to significantly reduce the sound pressure.

The problem of complex protection against vibroacoustic effects is still poorly studied. It is also worth noting the lack of vibration damping devices that would be able to reduce the combined effects of noise and vibration. According to the authors, the scientific novelty of this study lies precisely in the fact that an integrated approach to solving the problem of minimizing the impact of vibroacoustic factors is considered and simple noise-absorbing materials for their mass installation are proposed.

Vibration from rail transport can have negative effects directly or in combination with background noise. A significant excess of noise level standards causes discomfort not only to employees and passengers, but also to residents of areas adjacent to the railway track, and is often a significant cause of deterioration in well-being and decreased performance. The specificity of noise pollution in railway transport is such that, with long-term exposure in combination with vibration, it has a very negative effect on railway transport workers [1]. Prolonged and systematic exposure to excessive noise pressure can lead to the development of chronic diseases of the nervous system, musculoskeletal system, be the cause of loss of vigilance, deterioration of well-being, discomfort, feelings of irritation [2]. Constant exposure to noise, even at nominal values (especially at night), can cause sleep disorders and chronic neuroses [3]. The number of people with sleep disorders is very large — most are exposed to constant noise of 50-60 dB at night, which, in the absence of other daytime noise sources, is one of the main factors of insomnia [4].

Of all the harmful environmental factors, vibration is one of the most widespread ones. From 50 to 70% of the population is under its influence [5]. The analysis of vibrations resulting from the movement of rolling stock is very important, since the railway is the main transport system covering most of the territory of our country and neighboring countries. The volume and quantity of goods transported by rail are growing every year [6].

Working vibration of the rails occurs at the junction of the wheel and the rail (wheel — rail system) and spreads not only through the track support system to the ground cover and surrounding buildings, but also directly to the rolling stock. In some cases, passengers can directly feel the vibration, which is usually referred to as vibration from the interaction of the rolling stock and the railroad bed. Ground vibrations caused by railway traffic mainly occur in the contact area between the wheel and the rail [7]. Therefore, it is important that the effect of this mechanism of occurrence of a negative factor is minimized. The main source of vibration on the railway is rolling vibration caused by an imperfect working surface of the wheel and defects on the working surface of the rail. These vibrations are transmitted to the wheel and track structures, which leads to the occurrence of the values exceeding the threshold for the main octave levels. As a result, vibration, transmitted through the wheelsets, the car truck, causes vibration of the car body, which is especially noticeable at high train speed. High-amplitude vibrations can lead to a critical condition of car components, damage to the structure of the rail rolling stock. In order to preserve equipment, vibrations of this kind should be reduced not only in the wheel — rail system, but also by directly taking measures to protect the main parts of the car. This, in turn, minimizes the appearance of secondary vibration from the car body. To minimize the mechanical impact of the wheel and rail, the surface of the rail should be as smooth as possible. The vibrations created by the construction of the car and car truck should also be minimized in order to reduce the amount of vibrations transmitted to people in the car [8]. In order to create a system with the desired acoustic and structural-dynamic properties, while minimizing human exposure to noise and vibration, it is necessary to take into account the design of the track, wheels, trucks, and cars. Another important aspect is to ensure that these parts are maintained appropriately (timely maintenance and scheduled repairs).

Current vibration reduction methods are generally divided into two main categories: the category of passive measures and the category of active measures. Currently, passive measures are most often used. These include the use of traditional vibration dampers, shock absorption systems of various kinds (collision of cars) and insulation of the base [5]. However, modern vibration reduction methods should be aimed at passive-active vibration control, which consists in the active application of a force equal to the opposite forces created by external vibration. Sometimes, to dampen the vibrations, it is proposed to use developed control systems and damping forces that create vibration, as well as structures created on the basis of new composite materials. In particular, piezoelectric elements can be used to dampen excessive vibration[1]. The essence of this method is that a piezoelectric element generates electrical energy under mechanical tension and reacts in the form of deformation if electric energy is applied to it. Another method of minimizing noise and vibration is the method of using disc brakes instead of cast iron pads. The replacement of cast-iron blocks with agglomeration or composite ones is an alternative to disc brakes, which are more difficult to adapt, install and are expensive. All the methods mentioned above are aimed at the main components of the car. The authors carried out a calculation of vibration insulation in the car itself in the passenger seats.

Materials and Methods. A "reserved seat" type car was considered as the research material. The measurements were carried out using a sound pressure measuring device — SPM-101 sound level meter. The areas with the most negative impact of the vibroacoustic factor were selected based on the design features of the car truck and the internal structure of the car space. Consequently, the research plan included measuring the sound pressure in the car and determining the class of working conditions.

To analyze the possibility of noise reduction in the source of a "reserved seat" type car, the scheme of the car was considered and the areas of the most negative impact of vibroacoustic factors were marked on it (Fig. 1). These sections implied the highest sound pressure levels in the car, and as a result, a critical negative impact from vibroacoustic effects under various conditions (speed, state of the railway track, etc.)

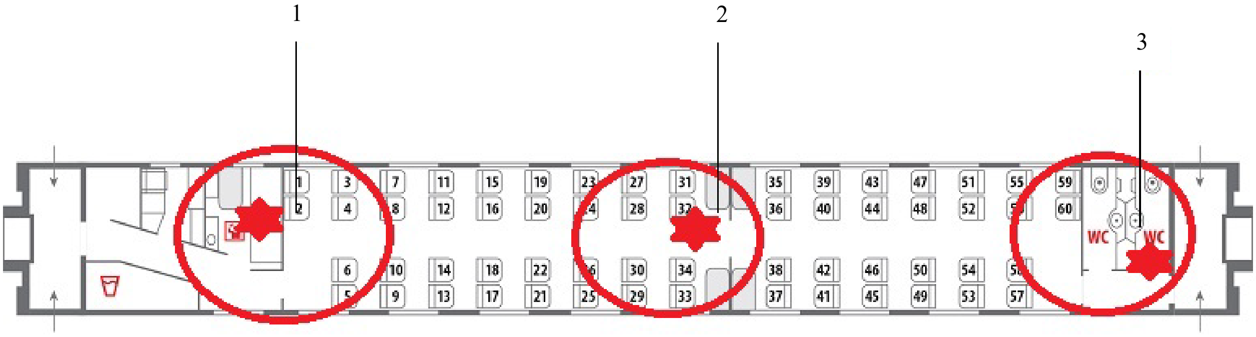

Fig. 1. Sound pressure values in the car by sections (1, 2, 3)

The next method of studying the minimization of vibration effects was the calculation of vibration insulation of passenger seats in the car based on methodology[2]. Vibration-proof inserts made of rubber material were used. The floor of the car at the base of the seat vibrated with frequency $f = 50$ Hz, with vibration velocity $v = 0.4$ m/s and a seat weight of 22 kg. Let us assume a passenger weighs 70 kg. Modulus of elasticity: $\sigma_{доп} = 0.04$ MPa, $E = 2.5$ MPa, $h = 0.1$ m, coefficient of resistance $\xi = 600$ H·s/m.

Let us determine the mass of inserts when the passenger is sitting. The passenger's weight per seat is 70%, which means:

$$m_{ч} = 70 \cdot 0.7 = 49 \text{ kg}, \tag{1}$$

$$m_{об} = 49 + 22 = 71 \text{ kg}. \tag{2}$$

Let us determine the maximum static deflection of the inserts:

$$Z = h\frac{\sigma_{доп}}{E_{д}} = 0.1 \cdot \frac{4}{250} = 16 \cdot 10^{-4}. \tag{3}$$

Frequency response of natural vibrations of an amortized passenger seat will be:

$$\omega = 2\pi\frac{0,5}{\sqrt{Z}} = 2 \cdot 3.14 \cdot \frac{0.5}{16 \cdot 10^{-4}} = 79 \text{ s}^{-1}. \tag{4}$$

Vibration transmission coefficient is determined by formula:

[1] Snizhenie urovnya shuma v krivykh. *Zheleznye dorogi mira.* 2009;6:70–76. URL: https://zdmira.com/images/pdf/dm2009-06_70-76.pdf (accessed: 14.11.2023). (In Russ.).

[2] *Posobie po akusticheskoi vibroizolyatsii tsentrobezhnykh mashin.* Moscow: Izdatel'stvo literatury po stroitel'stvu; 1973. 35 p. URL: https://meganorm.ru/Data2/1/4293801/4293801338.pdf (accessed: 14.11.2023). (In Russ.).

$$T_z = \frac{1+\left(2D\frac{\omega}{\omega_0}\right)^2}{\left[1-\left(\frac{\omega}{\omega_0}\right)^2\right]^2+\left(2D\frac{\omega}{\omega_0}\right)^2}. \quad (5)$$

Let us find relative damping D and circular frequency ω:

$$D = \frac{\xi}{2\omega_0 \cdot m_{об}} = \frac{600}{2\cdot 79\cdot 71} = 0.05. \quad (6)$$

$$\omega = 2\pi f = 2\cdot 3.14\cdot 50 = 314\ \text{s}^{-1};\ \frac{\omega}{\omega_0} = \frac{314}{79} = 4. \quad (7)$$

We get:

$$T_Z = \sqrt{\frac{1+(2\cdot 0.05\cdot 4)^2}{\left[1-(4)^2\right]^2+(2\cdot 0.05\cdot 4)^2}} = 0.071. \quad (8)$$

Then we determine the vibration velocity on the seat:

$$v = 0.4\cdot 0.071 = 0.028\ \text{m/s}. \quad (9)$$

Frequency of oscillation of the seat will be:

$$f_0 = \frac{\omega_0}{2\pi} = \frac{79}{2\cdot 3.14} = 12.57\ \text{Hz}. \quad (10)$$

Results. According to GOST 33787-2019, for a frequency of 12.57 Hz, vibration velocity should not exceed 0.0056 m/s[3]. The indicator obtained as a result of the calculation did not meet this requirement. To improve it, a vibration-proof material with other characteristics could be used — this could be a composite sheet made of tough rubbers (Fig. 2). Due to a higher coefficient of resistance, vibration exposure could be minimized.

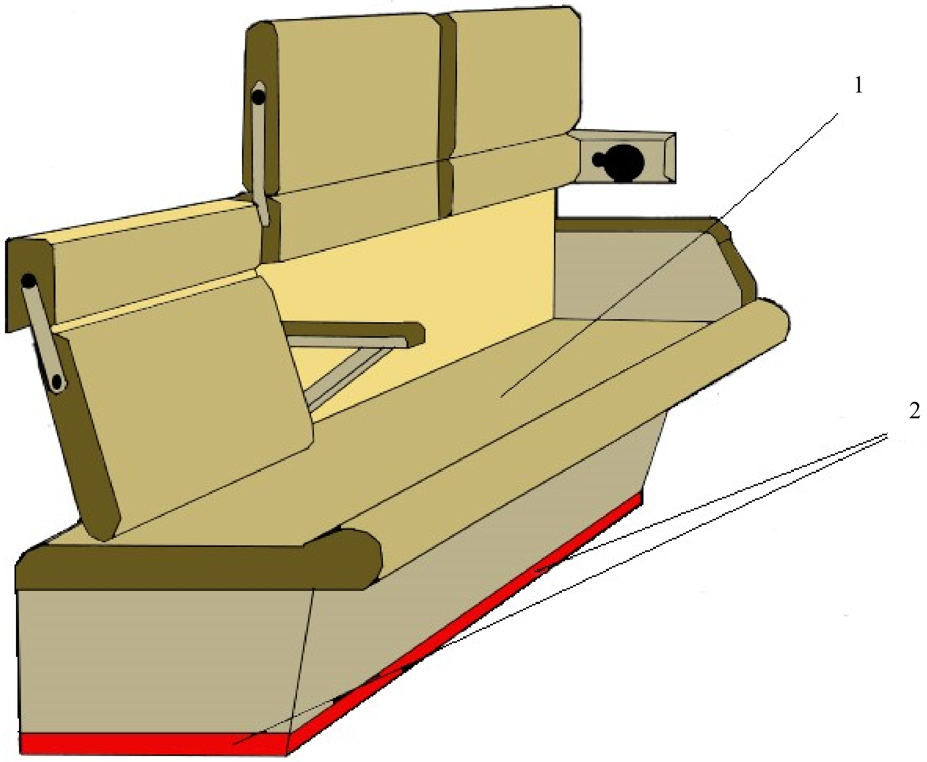

Fig. 2. Location of the vibration-proof material:
1 — passenger seat; 2 — vibration-proof insert

[3] GOST 33787-2019. *Rolling stock equipment. Shock and vibration tests*. URL: https://docs.cntd.ru/document/1200170805 (accessed: 14.12.2023). (In Russ.).

Table 1 shows the results of measuring sound pressure levels in the areas shown in Figure 1. Comparing them with the norms of the sound level in the car according to SP 2.5.3650-20, we could conclude that there was an excess of indicators[4].

Table 1

Noise pressure indicators in the car by zones

Section, no.	Sound level, dB
1	77.5
2	74.1
3	78.5

The calculations carried out in this work allowed the authors to conclude that it was necessary to use a method for minimizing vibroacoustic factors based on the use of vibration-damping materials. Its effectiveness was confirmed by the presented study. The authors have proposed a set of measures, including the installation of noise-absorbing material in the lining of the ceiling of the car in the most noise-prone areas to minimize noise pollution. The material was a composite of inorganic fibers with a sheet thickness of 2 to 4 cm. Additionally, to reduce noise and vibration, it was suggested to install inserts in the car's floor, similar to the creation of a shock-absorbing system. To calculate the effectiveness of the method, the vibration effect on the passenger seat was calculated taking into account the vibration of the floor of the car. The material was safe in operation for humans and the environment, met the fire safety criteria that were established for a passenger car in accordance with order of JSC "Russian Railways" dated November 5, 2009 No. 2255p[5].

Discussion and Conclusion. The assessment of the effects of vibration and noise obtained in this study shows that it significantly affects the working conditions of train crew workers and passengers. Workers who spend a lot of time on the road, workers who repair tracks in the immediate vicinity of the railway track, and train passengers are exposed to extremely harmful noise and vibration effects, which have a devastating effect on their health. Therefore, it is so important to minimize this harmful effect at the source of its occurrence. Undoubtedly, the improvement of the existing and the introduction of new methods to minimize the effects of noise and vibration factors on the railway will positively affect the health of employees and will contribute to the creation of a favorable social environment. It is worth emphasizing that measures to minimize the negative effects of noise and vibration from railway trains give a relatively small economic effect, but at the same time, they are of great value for ensuring the protection of the health of both employees and passengers, creating conditions that are more comfortable for them.

The complex of measures proposed by the authors to minimize vibration and noise uses materials created from recycled raw materials. Tough rubber is used for the floor of the car, and an inorganic fiber composite with a thickness of 2–4 cm is used for the ceiling. By equipping wagons with these materials, it is possible to achieve:

– minimization of noise pressure in the car by 7–12 Db;

– reduction of the vibration effect.

References

1. Sokolov DA. Kharakteristika shumovogo zagryazneniya i vibratsii zheleznodorozhnogo transporta. Minimizatsiya vozdeistviya shuma i vibratsii na rabotnikov zheleznodorozhnogo transporta. *Student i nauka.* 2022;1(20):65–67. (In Russ.).

2. Kaptsov VA, Leksin AG. Physical factors of the industrial environment and traffic safety. *Hygiene and Sanitation*. 2009;5:87–93. URL: https://cyberleninka.ru/article/n/fizicheskie-faktory-proizvodstvennoy-sredy-i-bezopasnost-dvizheniya/viewer (accessed: 14.12.2023). (In Russ.).

3. Epanchintseva EA. Environmental problems on the railway. In: *Materialy XI Mezhdunarodnoi studencheskoi nauchnoi konferentsii "Studencheskii nauchnyi forum-2019"*. Moscow; 2019. URL: https://scienceforum.ru/2019/article/2018010394 (accessed: 10.10.2023). (In Russ.).

[4] *Sanitarno-epidemiologicheskie trebovaniya k otdel'nym vidam transporta i ob"ektam transportnoi infrastruktury.* Sanitary-Epidemiological Requirements SP 2.5.3650-20. URL: https://docs.cntd.ru/document/566406892?marker=6560IO (accessed: 14.11.2023). (In Russ.).

[5] *O vvedenii Instruktsii po obespecheniyu pozharnoi bezopasnosti v vagonakh passazhirskikh poezdov.* Order of JSC "Russian Railways" No. 2255r dated 05.11.2009URL: https://legalacts.ru/doc/rasporjazhenie-oao-rzhd-ot-05112009-n-2255r/?ysclid=lpav14zomo74285296 (accessed: 14.11.2023). (In Russ.).

4. Golovina EI, Sokolov DA. Ensuring occupational safety at railway transport operation by upgrading the systems of vibration damping plates and rail plates. *Safety of Technogenic and Natural Systems.* 2023;(1):39–46. https://doi.org/10.23947/2541-9129-2023-1-39-46 (In Russ.).

5. Karabaeva MU, Saidov SM, Yusufkhanov ZYu. Rasprostraneniya vibratsii pri prokhozhdenii poezdov v zavisimosti ot raspolozheniya zheleznodorozhnogo polotna. *Symbol of science*. 2017;(5):25–27. URL: https://os-russia.com/SBORNIKI/SN-2017-05.pdf?ysclid=lpgkp9yw9r840350762 (accessed: 10.10.2023). (In Russ.).

6. Kharlamov AA, Komogortsev MG. Metod vizualizatsii i otsenki vibratsionnykh vozdeistvii na verkhnie stroeniya zheleznodorozhnogo puti. *Molodoi uchenyi.* 2011;3(26):88–91. URL: https://moluch.ru/archive/26/2816/?ysclid=lpgkuevag721587460 (accessed: 10.10.2023). (In Russ.).

7. Borisov EK, Alimov SG, Nazarov AYu. Vibratsiya grunta ot zheleznodorozhnogo trafika. *Vologdinskie chteniya.* 2005;48:87–92. (In Russ.).

8. Romanov SN. *Biologicheskoe deistvie vibratsii i zvuka: Paradoksy i problemy XX veka.* Vartanyan IA (ed.). Saint-Petersburg: Nauka; 1991. 158 p. URL: https://studizba.com/files/show/djvu/165-1-romanov--biologicheskoe-deystvie.html (accessed: 14.12.2023). (In Russ.).

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EI Golovina: academic advising, formulation of the basic concept, goals and objectives of the study.

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