# ANALYSIS OF CONTROLLABILITY OF A FREIGHT CAR BRAKE SYSTEM

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## ABSTRACT

The article considers failures of a brake system of a car, leading to train delays, their causes are determined, and an analysis is made of the control- and maintainability of the elements that are subject to regular maintenance. Recommendations are formulated aimed at reducing train delays on guarantee sections caused by a failure of a freight car brake system. At the same time, the emphasis is on an integrated approach that implies a wide range of tasks, including the stages of design, construction, operation and financial and economic support of the process.

*Keywords:* *railway, freight car, brake system, maintenance, failure, controllability, maintainability.*

**Background.** *An important task in operation of freight cars remains provision of accident-free movement of trains on guarantee sections, implementation of which often causes the following problems:*

*– limited or even zero controllability of some responsible elements of the car's construction at the service station (SS);*

*– car inspectors are forced to rely in their work mainly not on technical means, but on so-called organoleptic methods of detecting damages and failures of car construction (vision, hearing);*

*– restriction of time for monitoring the technical condition of the car, set by the train traffic schedule;*

*– need to perform maintenance at night and in difficult weather conditions (rain, snow, etc.).*

*This often explains the cases of non-detection and non-elimination of faults by car inspectors at SS, each of which leads at least to train's stop on a haul. Such cases are considered to be technical equipment failures on the guarantee section of the relevant SS, and now they are registered in the integrated automated accounting system, control of elimination of equipment failures and analysis of their reliability in railway transport (CAS ANT).*

**Objective.** *The objective of the authors is to analyze controllability of a freight car brake system.*

**Methods.** *The authors use general scientific and engineering methods, comparative analysis, experiments, scientific description.*

**Results.**

***Failures and their causes***

*Depending on the consequences of failures, JSC Russian Railways introduced the following classification of them according to the categories:*

*failures of the 1st category – failures resulting in a train delay on a haul (station) for 1 hour or more, or leading to transport accidents or events related to violation of safety rules for movement and operation of the railway transport;*

*failures of the 2nd category – failures that led to a train delay on a haul (station) lasting from 6 minutes to 1 hour;*

*failures of the 3rd category – failures that do not have consequences related to the failures of the 1st and 2nd categories [1].*

*So, on the railways of the Russian Federation in the CAS ANT system, in 2015, 1766 cases of technical equipment failures were recorded, the largest number, or 61 % of which were committed due to a malfunction of the car's auto-braking equipment [2].*

*As experience in operation of freight cars shows, the main causes of brake system failures are air distributor, brake line, brake rigging, brake fittings. Failures of auto mode, brake cylinder, spare tank, parking brake are less common.*

*There are also cases of failures of the car brake system due to poor performance of the functions of servicing and repairing brake equipment by the inspector at SS. These include:*

*– discrepancy between the distance from the end of the clutch of the protective tube of brake rigging auto regulator before the beginning of the connecting thread on its screw;*

*– reverse camber of vertical levers of brake rigging of a bogie at a dead center;*

*– discrepancy between the distance between the body of the autoregulator and the thrust lever (stop);*

*– gapping of the main or principal part of the air distributor to the working chamber;*

*– incorrect activation of the braking / tempering mode of the air distributor.*

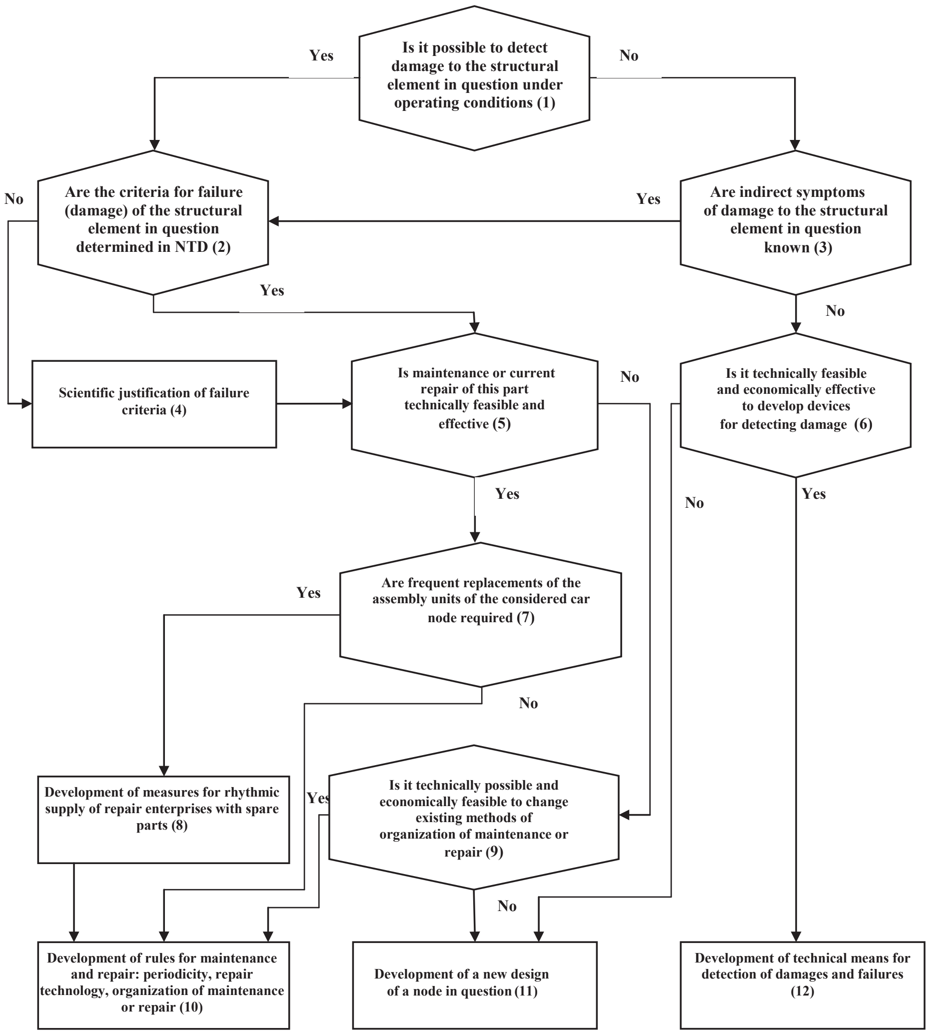
*Another reason that leads to inability of the brake system to provide necessary efficiency of train braking is interference by unauthorized persons. These include disconnection of connecting hoses, closing of end valves, tightening of a parking brake.*

***Technical means of control***

*Operated now automated means of diagnostics of rolling stock (complex of technical means multifunctional (KTSM-02), post of acoustic control, complex for measuring geometrical parameters of wheel sets, system for detecting cars with negative dynamics (ASOOD), rolling stock derailment control device (UKSPS) with which approaches to sorting stations and hauls are equipped everywhere), allow to monitor the technical parameters of individual nodes of the car, increasing the probability of identifying their fault condition. However, at the present time there are no technical means determining the approach of the brake system of the car to an inoperable type [3]. That is, the failures can be attributed to sudden failures, which are not controlled by automated diagnostic complexes, and therefore the task directly connected with determining the size of the guarantee section for maintenance and repair of freight cars, as well as frequency of control of their brake system, clearly arises.*

*To solve this problem, it is necessary to perform an analysis of the level of control- and maintainability of the elements of the brake system under operating conditions, to assess the very possibility of detecting and eliminating failures of auto-braking equipment when the car is used for the intended purpose.*

*It is known that maintainability is a property of the product, consisting in its fitness to maintain and restore the operable condition through maintenance and repair. A controllability is a property of the product, which characterizes its fitness to conduct control by specified means.*




***Pic. 1. Block diagram of analysis of the structural element maintainability in relation to maintenance of the car.***

*The technique for assessing maintainability is mainly based on the use of expert judgment and analysis. In this case, this idea can be implemented using the block diagram shown in Pic. 1 [4].*

*Each element of the brake system is analyzed, in the process of which the researcher, relying not only on his knowledge, experience and intuition, but also on the help of experts in the relevant fields of science and technology, as well as on printed sources, should answer in the form of «yes – no» on a series of questions located in a certain sequence.*

*The sequence of block numbers is a code characterizing the maintainability of the considered element of the brake system of the car. In this case, failures for each element will be conveniently divided into three groups:*

*1. Having zero controllability and maintainability with the direct use of the car for the intended purpose (in the conditions of SS station).*

*2. Fully controllable and maintainable in operation.*

*3. Having limited controllability and maintainability.*

*Code of main nodes*

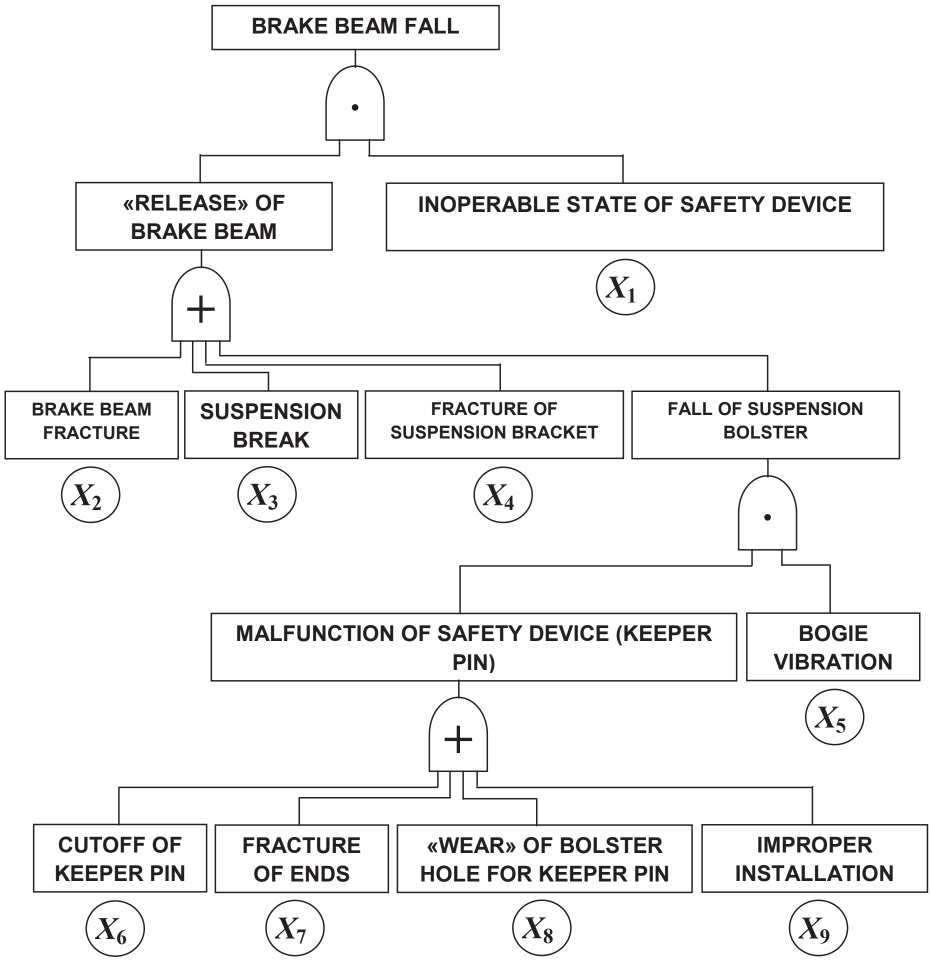
*As shown in [5], derailment of the car, which is fraught with crashes and accidents, can be caused by cases of falling parts on a track, in particular, a brake beam of bogie's brake rigging, one of the most common causes of which is fall of a bolster of the shoe suspension.*

*The event «Fall of a brake beam on a track» can be represented in the form of a tree-like diagram, shown in Pic. 2. Moreover, fall of the shoe suspension is a dependent failure, the occurrence of which is caused by damages or failures of other elements that are not even parts of the brake system of the car. For example, increased vibration (indivisible event $X_5$) as a consequence of a faulty wheel set (damage to tread surface of a wheel or a bearing).*

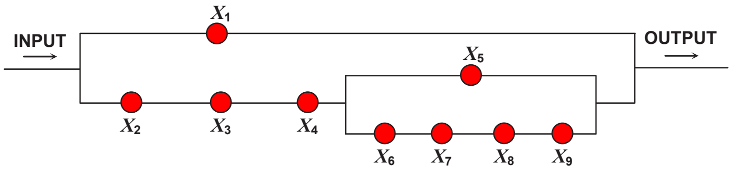
*The bipolar representation of this tree (Pic. 3) shows the causes of the event – fall of the bolster of the brake shoe suspension (brake beam) and its influence on fall of the parts of the bogie's brake gear on the track leading to car derailment.*

*For example, we consider the application of the technology of maintainability analysis of fall of the bolster of the shoe suspension of bogie's brake rigging using a tabular form of the results presentation (see Table 1).*

*Another event affecting traffic safety is considered to be absence or fracture of a brake pad, maintainability*




***Pic. 2. Tree of events regarding the fall of the brake beam on the track.***




***Pic. 3. The bipolar representation of the event tree.***

*rating of which is shown in Table 2. This fault is dangerous in that it can lead to serious damage to a wheel set: cyclic running time, slid flat and weld-on deposit on the tread surface of a wheel, and also to «weld» of a brake shoe to a wheel and blocking of a wheel set while a train is moving.*

*As can be seen from the table, such a failure, as absence or fracture of a brake pad, is completely controllable in operation and can have two codes of maintainability, depending on the prevailing consequences: 1–2–5–9–10 or 1–2–5–7–8–10.*

*We cannot ignore other failures of bogie's brake rigging: such as fall of bolsters of connecting links of rods and levers that arise due to malfunction or absence of keeper pins; breakage of the suspension of the brake shoe, which is a consequence of development of cracks due to fatigue; lowering of a clamp for uniform wear of pads, which is most often detected during movement of the train by the UKSPS device, but can also be found at SS when inspecting the car. There are also fractures (breaks) of safety devices designed to prevent the falling of brake equipment parts on a track. All of them are completely controllable.*

*According to the proven methodology, the required damage data codes:*

*– fracture(breakage) of safety devices – 1–2–5–7–8–10;*

*– fall of bolsters of connecting links of rods and levers – 1–2–5–7–8–10;*

*– breakage of the suspension of the brake shoe – 1–2–5–7–10.*

*Thus, the required code of maintainability of the main components of bogies' brake rigging is obtained: 1–2–5–7–8–10.*

**Table 1**

**Analysis of maintainability of bogie's brake rigging relative to fall of the bolster of the shoe suspension**

| Initial position | Decision made | Desired position | Rationale for the decision made |
|---|---|---|---|
| 1 | Yes | 2 | As a result of a survey of specialists in brake equipment of the car economy services of infrastructure directorates, it was clarified that this malfunction is revealed by visual inspection at SS. |
| 1–2 | Yes | 1–2–5 | According to the technical documentation, the absence of the bolster of the brake shoe suspension is not allowed. |
| 1–2–5 | Yes | 1–2–5–7 | At SS it is possible to install a bolster of the shoe suspension. |
| 1–2–5–7 | Yes | 1–2–5–7–8 | In order to improve maintainability, it is advisable to develop measures for rhythmic supply of SS with spare parts, namely bolsters of the shoe suspension, safety clamps (to exclude loss of a bolster), and fixing devices – keeper pins and washer plates.<br><br>Based on the norms for the use of materials and spare parts for maintenance of freight cars on the tracks of the station № PKTB TsUNR/TsUNR-13.5.0192–15, compiled on the basis of statistical data and approved by the order of Russian Railways of November 3, 2015 No. 2622r, at service stations 0,28 bolsters of the shoe suspension, 0,124 keeper pins, 30 safety clamps are replaced per each 1000 cars. |
| 1–2–5–7–8 | | 1–2–5–7–8–10 | To increase maintainability, it is necessary to develop maintenance rules, justify the frequency of its implementation, technology and organization of the works envisaged. |

***Other elements of the system***

*Using the above technology, it is possible to obtain indicators of maintainability and other elements of the brake system of the car.*

*Let's highlight separately a pneumatic part of a brake system, the feature of which is presence of such highly complex devices as an air distributor and auto mode.*

*First of all, we consider the failure due to a malfunction of an air distributor. Train delay on the guarantee section can be caused by: clogged holes of a plunger or an internal cavity; air leakage in a large diaphragm; large holes of a plunger and a pusher, which is due to poor-quality manufacturing or repair; contamination of a filter in the working chamber; a 1,3 mm diameter hole in the seat of the check valve is less than normal or clogged; a 1,3 mm diameter hole in the seat of the check valve is more than normal. External signs of these faults are failure to brake or delayed tempering.*

*Note that such malfunctions at SS have limited controllability and are detected only when testing the train auto-brakes. The probability of finding the defects of the air distributor increases when testing auto-brakes from stationary installations (UZOT, UZOT-RM, ASDT). Therefore there will be two required codes of maintainability of the air distributor:*

- *when testing autobrakes from the locomotive: 1–3–6–12;*
- *when testing from the stationary installation: 1–3–5–7–10.*

*In the auto mode in operation, there may be a malfunction of its internal components, a break of the bar of the automatic mode. Often, they are associated with improper assembly and installation during manufacturing or routine maintenance. External signs of an inoperative state of auto mode, according to the current regulatory and technical documentation, are: for an empty car – a gap of more than 3 mm, a ring groove is not visible; for a laden car – a gap between a stop nut and a pressure plate; the car's brake is not released at the opening of an exhaust valve.*

*This node of the car is considered to be controllable in operation. The desired code of maintainability for auto mode will be: 1–2–5–9–11.*

*The following faults are the causes of the failure of brake cylinders:*

*– rupture of rubber cuffs on the piston – in this case, when the brake cylinder is activated for braking, there will be an «air blast» through an atmospheric window;*

*– breakage of a return spring of a piston, which leads to a slow movement of a piston with a rod to the initial position when the brake is released;*

*– clogging of an air filter of an atmospheric window – operation of a brake cylinder becomes ineffective, air cannot circulate through the atmospheric window, which in turn, with creation of a large air pressure in the cylinder at maximum loads of the car, can lead to extrusion of the filter itself (or a gland in the front parts of a cover), dirt on a cylinder mirror (or a pipe) and, as a consequence, jamming the piston in extreme or intermediate positions.*

*The code of maintainability for the brake cylinder will be: 1–2–5–9–11.*

*Next, consider the lever transmission of the car, the damages of which, according to the analysis, are: a malfunction of the auto regulator, the indirect feature of which is the clearance of the shoe-wheel above the established rate; break of the brake rod.*

*The brake rigging is completely controllable in operation. All failures arise because of poor-quality manufacturing or repair. The desired code of maintainability for the lever transmission will be: 1–2–5–7–10.*

*It should be noted faults of such nodes, leading to the failure of the brake system of the car, as a parking brake and a spare tank.*

*According to the operating experience, there are cases of falling parts of the parking brake on a track. This is due to a fracture of details of the fastening mechanism (keeper pin, finger, etc.) or support clamp, which is a consequence of development of cracks or excessive wear.*

**Table 2**

**Analysis of maintainability of bogie's brake rigging with respect to absence or facture of a brake pad**

| Absence or fracture of a brake pad | | | |
|---|---|---|---|
| Initial position | Decision made | Desired position | Rationale for the decision made |
| 1 | Yes | 2 | The fault is detected when visual inspection of the brake linkage of the bogie by the car inspector at SS, but it can be detected when inspecting the train «on the move», i.e. during movement of the train arriving at the station. |
| 1–2 | Yes | 1–2–5 | In the instruction to the car inspector it is specified, that absence or fracture of a brake pad is not allowed. |
| 1–2–5 | Yes<br>No | 1–2–5–7<br>1–2–5–9 | At SS it is possible to install or replace a brake pad. But if this failure led to a «weld» of a brake shoe to a wheel, presence of defects on tread surface of a wheel of faulty dimensions, then it is necessary to uncouple a car for routine repairs. |
| 1–2–5–7 | Yes | 1–2–5–7–8 | To improve maintainability, it is advisable to develop measures for rhythmic supply of SS with spare parts, namely brake pads and coupler keys of brake pads. Based on the norms for the use of materials and spare parts for maintenance of freight cars on the tracks of the station № PKTB TsUNR/TsUNR-13.5.0192–15, compiled on the basis of statistical data and approved by the order of Russian Railways of November 3, 2015 No. 2622r, 15,2 brake pads, two coupler keys of brake pads are replaced per each 1000 cars. |
| 1–2–5–9 | Yes | 1–2–5–9–10 | To increase maintainability, it is necessary to develop a technology for changing a wheel set at a SS for a limited time of stay of the train under maintenance. |
| 1–2–5–7–8 | | 1–2–5–7–8–10 | To increase maintainability, the periodicity of maintenance operations should be justified. |

*As it is known, cracks often occur in a zone invisible for inspection. But with their development they can and go into the visible zone. Therefore, it is customary to assume that the cracks in the parking brake parts cannot always be detected during inspection at SS and this defect is attributed to partially controllable in operation.*

*The desired code of maintainability of the parking brake: 1–3–2–5–7–10.*

*The failure of the reserve tank is mainly due to failure of the drain valve due to leaks, non-opening, mechanical damage, and leakage in the connections. To a certain extent, it can be attributed to fully controllable. Desired code of maintainability for the reserve tank: 1–2–5–7–10.*

*In conclusion, consider air and power parts of the brake system of the car, which are characterized by weakening of an air pipe, cracks, breaks, broken pipes, broken pipe connections, freezing of moisture in the pipes and their clogging, and blow in the cranes.*

*The air line and brake fittings have malfunctions that cause air leakage or obstruct its movement. In the brake hoses, a stratification of the rubber occurs, which prevents passage of air, there is a flow of air in the connection of the heads in the event of a failure of the sealing ring, in the joints of the rubber tube with the head or the tip, as well as through cracks, breaks and fraying in the tube itself.*

*Air leakage or weakening of the fastening occur also in the working chambers, disconnection and end cranes.*

*The density of the brake network is checked when testing the brakes. Leaks are detected by the noise of air that emerges through leaks, through dark spots on pipes, accumulation of dust and dirt with a characteristic rough surface, during winter, a bolster in the form of frost is observed in the places of leakage.*

*In relation to the damages considered, the brake line and the fittings of the brake equipment of the car can be attributed to partially controllable in operation. The existing level of fitness for the current technical content is estimated by the code: 1–2–4–5–7–10.*

***Causal relationships***

*The analysis showed that the reasons for the failure of the brake system of the car when the train moves on the guarantee section can be divided into the following groups:*

*1) constructive (associated with imperfect design or poor-quality manufacturing);*

*2) production (associated with poor-quality repairs);*

*3) operational (associated with violation of the rules of operation);*

*4) degradation (associated with natural processes of destruction, aging, deterioration, etc.).*

*It should be noted that the failures of the first three groups are not relevant to reliability of the brake system, but they affect train delays and can lead to traffic safety violations [6].*

*In general, failures, not detected in the process of technical maintenance at SS, are related to metal fatigue, as well as wear of friction units. To justify regularity of maintenance of cars, the period from failure to destruction of the part is of particular interest. This kind of condition is called survivability, i.e. ability to perform the required functions, being in an inoperative state. To reduce the terms of this period, technical diagnostic tools are used, which could replace some of the functions of car inspectors for technical control of brake equipment, in particular to identify cracks. However, they are still far from the required level. Reliable methods of detecting defects by indirect and direct signs are clearly not enough.*

*It is necessary to pay attention, of course, to the failures associated with imperfection of the design* *of the brake system of the car. As it is known, it is the most relevant to solve this issue at the design stage. Improving the quality of projects relies on methods of complex analysis and evaluation of performance indicators of the design in a wide range of existing and future operating conditions. The creation of new generation cars necessitates development of higher technical requirements for brake systems, including taking into account the peculiarities of foreign experience and advanced technologies, justifying the most advanced output characteristics and standards. For the time being, the methods used at the design stage do not allow, for example, to assess the effect of operating conditions on the performance indicators of autobrakes [7] or to provide safety guarantees for certain nodes for a relatively long period.*

*The established codes of maintainability of the brake system of the car should be used both at the stage of designing the nodes, justifying the parameters of their maintenance and repair system. In practice, the results obtained can be used to split the responsibility for the failure of the brake system between the car inspector who did not detect the existing dangerous damage at SS, and the employees of car repair depots, manufacturers [8].*

*Another important solution should be modernization of the brake systems of the already operated freight cars, their equipping with special marks or indicators of control of deviations from the normal state. The introduction of modern systems of visual inspection of parts and components by tags and indicators will significantly reduce the unproductive losses that arise during maintenance of cars in the train. To ensure these capabilities, nodes and parts in their manufacture should be marked with indicators or matchmarks that allow minimizing the scope of work of the car inspector, eliminating the use of special templates. In particular:*

*– the brake shoe must have an indicator or a matchmark to determine the minimum permissible thickness at which the shoe is to be replaced;*

*– the brake cylinder on its rod should be an indicator or a matchmark indicating the maximum allowable size of the rod exit from the cylinder;*

*– the regulator of brake rigging must have:*

*a) depending on the type of the regulator, an indicator or a matchmark determining the size of «a» – the distance from the end of the clutch of the protective tube of the regulator to the connecting thread on its screw;*

*b) depending on the type of the car, brake pads and drive of the regulator, an indicator or a matchmark that determines the size of «A» is the adjusting size of the regulator drive (clearance between the regulator body and the thrust lever (the regulator's lever)).*

*Conclusion. Analysis of the brake system of the freight car as a repair and maintenance object has shown that failures and faults that occur are responsible for relevance of the integrated approach in solving problems covering design, construction, repair and operation. The implementation of the approach requires certain studies and analysis of cause-effect relationships that help to identify the unfavorable factors that worsen the technical condition of the structure. At the same time, the code of maintainability of parts and components of the brake equipment plays its role.*

*In the future, it is necessary to increase reliability of the elements of the brake system of cars, including improvement of control- and maintainability. Additional costs for changing the design of auto-brake equipment and improving its repair system should be compensated for by reducing maintenance costs and paying fines for delaying trains on the hauls. At the same time, investments in the introduction of modern means of technical diagnostics of cars in the context of SS, will pay for the consequences of even one crash or accident of a medium-sized train.*

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