DESIGNING AN IMPROVED STRUCTURE OF THE TOOL FOR REPAIRING THE BRAKE PIPE CONNECTORS IN VEHICLES

This paper addresses the issue of difficulties in servicing the brake pipe connectors for passenger cars, the service life of which exceeds 8–10 years, which is associated with the deteriorated loosening of connectors. The existing ways to loosen the connectors of brake pipes have been investigated, especially those whose dismantling is complicated due to the corrosion and contamination of mated surfaces as a result of their wetting when driving a car. A conventional structure of the connector has been analyzed, which is installed in that place of the car that is the most unprotected from moisture and dirt – on the brake cylinder. The conditions that do not contribute to its failure-free loosening have been examined. The design of a specialized split clamping ring wrench has been considered, which can transmit the greatest value of the torque to the connector when loosening it; sometimes, however, its predefined value would not suffice. A computer-based finite-element simulation was employed to derive the models of the deformation state for the node «connector – wrench». Based on the analysis of the models of different deformation state of a specialized split clamping ring wrench, the required profile of the geometrically balanced locked hexagonal profile of the wrench was defined. The analysis of the efficiency of the tightening and loosening level is determined by comparing the numerical values of the torque, which is applied to the connectors of the brake pipes. The torque values are measured by a specially devised technique. The introduction of the developed measurement technique makes it possible to compare the efficiency of wrenches of different designs by analyzing the maximum values of torques, which the wrenches can transmit to the connectors. Taking into consideration the identified shortcomings in the structure of the brake pipe connectors, the shape of the connector has been designed that is free from the specified drawbacks. The new structure provides for the possibility of using a conventional carob wrench for loosening when the mated surfaces are exposed to contamination and corrosion

Keywords: connector, brake pipes, box-end wrench, spanner, split wrench, crumpling of faces

S. Gnitko
PhD, Associate Professor, Director
LLC «VESTTEPLOTECH»
Avtobazivska str., 1, Poltava, Ukraine, 36000
E-mail: novtehwest@gmail.com
Ie. Vasyliev
PhD, Associate Professor
Department of Construction Machinery and Equipment
National University
«Yuri Kondratyuk Poltava Polytechnic»
Pershotravneviy ave., 24, Poltava, Ukraine, 36011
E-mail: vas.eugene@gmail.com
S. Popov
PhD, Associate Professor
Department of Industrial Engineering
Poltava State Agrarian University
Skovorody str., 1/3, Poltava, Ukraine, 36003
E-mail: psv26@.i.ua

1. Introduction

Mostly almost all braking systems of passenger cars are built on the hydraulic drive [1–3]. The braking units of cars such as blocks, cylinders, etc. are interconnected by steel brake pipes [4] to enable the reliable braking of the car at a proper time.

Metallic brake pipes are connected to the brake units by means of brake connectors [5], which should ensure quick connection to the brake units, thereby providing for a reliable connection over time, taking into consideration the constant vibration.

In different models of cars, both pipes and connectors can differ in size. However, when designing cars, the purpose is to ensure the interchangeability of components; in most cases, the pipes have an outer diameter of 6 mm; the connectors have a thread of M10×1 and M12×1.

Car design does not fully provide for the possibility of repair operations if the cars' service life is significant and exceeds 8–10 years or more. The specified service life is typical of cars operated in this country; their share, according to [6], is up to 65 %. Even though all parts of the cars are galvanized [7], including fasteners such as bolts and nuts, the repeated loosening of threaded connections is significantly complicated as time goes by [8]. Especially so if fasteners are operated in a polluted and humid environment. The protective anticorrosive film breaks down and the corrosion process begins, which can significantly complicate the repeated loosening [9].

It is a relevant task to undertake serious scientific research aimed at improving repair properties in order to improve servicing the braking system of a passenger car. The practical result of such a study will be the proposals for introducing a new design of tools for servicing the connectors

of the brake pipes of cars as the existing tools do not meet the requirements for such operations.

2. Literature review and problem statement

The issue under consideration is typical of the brake pipes of cars as they are exposed to the abrasive and wet environment [10]. Fig. 1 shows the consequences of loosening the connector, which is located on the rear axle of the Citroen Berlingo (France) car. The specified connector connects the pipe to the brake cylinder [11]. When loosening, the connector's faces were crumpled. The final loosening led to a broken brake pipe, which required that a box-end wrench should be used. This type of tool typically loosens the connectors whose faces were crumpled. Earlier, it was certainly assumed that this connector was problematic in terms of ease of loosening [12–14]. The connector was cleaned with a metal brush, filled with «WD 40», a liquid to facilitate the loosening, and hammered with a hand hammer to transmit vibration loads. However, the mated connector's surfaces in the region of threading, as a result of pollution and corrosion, did not make it possible to use conventional measures for loosening.

Fig. 1. A connector of the brake cylinder on the rear axle of a Citroen Berlingo car

The hydraulic pipe from the brake cylinder was required to be disconnected due to the need for repair, namely the replacement of the cylinder due to the leakage of brake fluid into the cuff seals [15]. To loosen the connector, in addition to the measures outlined above, the entire toolset was used, starting with the carob wrench and ending with the box-end wrench.

The connector is located in a place where atmospheric moisture, including from puddles, has access to the car during operation. The threaded connection and a cavity between the pipe and connector during operation are filled with atmospheric moisture and dirt [16]. Moisture does not dry out in a timely manner and, together with dirt, stays on these surfaces, which causes their corrosion destruction. All this causes a tight stopping of the connector in the brake cylinder housing [17].

To unscrew the brake systems connector, a specialized tool is used, which is shown in Fig. 2.

More common is the design of a box spanner for brake pipes with end heads fixed at both ends (Fig. 2, a, top). To enable installing the wrench on the hexagonal surface

of a brake pipe connector, a slot is made in the longitudinal direction of the head. The width of the slot typically exceeds the diameter of the brake pipe, which makes it possible to properly install the wrench on the connector.
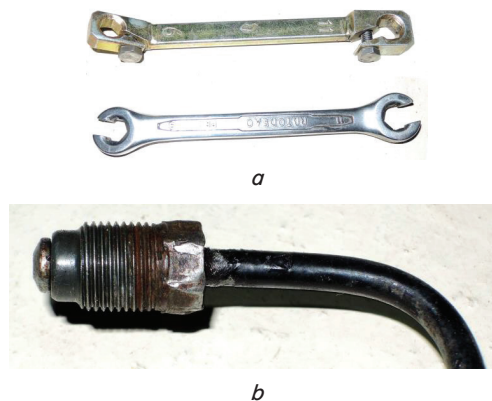

Fig. 2. Specialized tools used to loosen brake pipe connectors: a — a carob nut split wrench (top) and a split clamping wrench; b — connector with damaged clamping faces

However, the specified design of the carob wrench performs properly only within a limited range of rotating moments, which are applied to the hexagonal surface of the connector. If there is a need to apply a larger torque to loosen the connector, given the longitudinal slot in the wrench, the stiffness of the jaws becomes insufficient. The wrench jaws are deformed due to excessive torque, opening up in a radial direction away from the mounting faces of the connector. The contact between the supporting surfaces of the carob wrench and the mounting faces of the connector is lost. The connector is not loosened; a further increase in the torque leads to the destruction of the connector, whereby its faces are crumpled (Fig. 2, b). The wrench slips on the faces of the connector; no further loosening of the connector is possible.

Recently, the design of a specialized split clamping ring wrench has been used [18] for brake pipes (Fig. 2, a, bottom). Its structure represents a wrench with end heads fixed at both ends with a cut in the longitudinal direction whose width is not less than the diameter of the brake pipe. However, to increase the stiffness of jaws and prevent their opening under a load, the wrench structure includes a clamping bolt. Installing the wrench on the connector is followed by the installation of a clamping bolt that is clamped, making it impossible to open the jaws of the wrench under load. However, with the growth of the torque, which is applied by the wrench when loosening the brake pipe connector, there is also a deformation of the wrench jaws. The deformation no longer has a radial direction but is rather directed toward the distortion of the hexagonal profile. This deformation also promotes conditions for slipping the wrench over the mounting faces of the connector. Faces are then crumpled; no other options for loosening the connector exist. The following sequence of operations to loosen the connector with the crumpled mounting faces is absolutely trivial – the brake pipe is forcibly broken and a conventional box spanner is installed, which loosens the connector. However, the restoration of the braking system subsequently requires more time and material resources. It is necessary to replace both the destroyed connector and the section of the brake pipeline.

3. The aim and objectives of the study

The aim of this study is to design a specialized clamping wrench for the brake pipes of cars that have difficulties in loosening, which could improve service conditions.

To accomplish the aim, the following tasks have been set:

– to investigate the interaction between a specialized split clamping wrench and the brake pipe connector to establish the causes that limit the transfer of torque from the wrench to the connector;

– to apply the finite-element simulation of the deformation of the wrench faces in order to establish the reasons that limit the possibility of the non-destructive loosening of the brake pipes' connectors;

– to propose a modified structure of the brake pipe connector whose operation is possible when using a conventional carob wrench, even if the connector is operated under adverse corrosion conditions that destroy the mated surfaces.

4. The study materials and methods to determine the nature of wrench face deformation

To elucidate the process of transferring the torque, we fabricated a wrench enabling the measurement of the torque applied when loosening and twisting the brake pipe connector (Fig. 3). The torque is applied through a wrench dynamometer on the wrench, which does not allow its uniaxial connection, based on the existing technique. This technique of applying torque is executed, for example, by the wrench for the oxygen sensor of a car. We employed this technique to apply torque by fixing, on a specialized wrench (Fig. 3, *b*), an additional shell with an inner quadrangle. The shell with the inner quadrangle, through which the dynamometric wrench is attached, is welded to the specialized wrench.
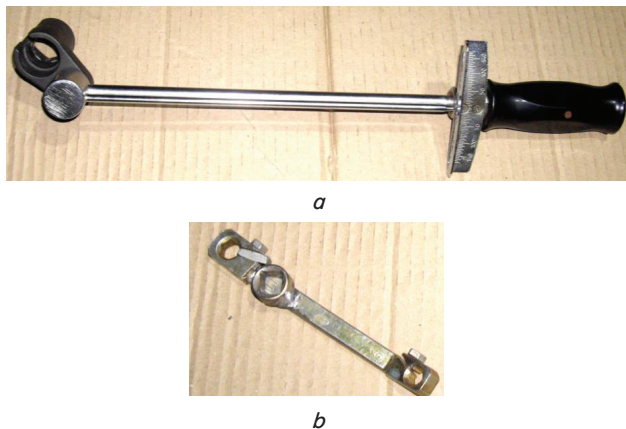

a

b

Fig. 3. The technique to apply torque via a wrench dynamometer when loosening and tightening: *a* — existing technique using a wrench for a car's oxygen sensor as an example; *b* — a similar technique, through the shell with the inner quadrangle, which is welded to the specialized wrench

The ability to control the numerical values of the torque, which is transmitted from the grip of the dynamometric wrench to the brake pipe connector, is illustrated in Fig. 4.

The numerical values of the torque are read from the scale of the dynamometric wrench. The resulting values are automatically increased by the coefficient of increasing the length of the torque lever to the connector axis compared to the length of the dynamometric wrench grip. In this case, the increase factor is 1.18. The available repair manuals [6] do not provide recommendations on the rated values of tightening the brake pipe connector, which is due to the lack of common ways to attach a dynamometric wrench. Our selected value is 18 N·m, recommended for tightening the regular bolts with a thread of M10×1.

Comparative tests of the proposed design of the specialized wrench were carried out by applying the maximum torque to the brake pipe connector (Fig. 5). To create the conditions under which a brake pipe connector is in a car, we used new connectors 1, which were screwed into nut 2 until stop. To prevent the nut from turning, it was fixed in a vise. The torque was applied to the brake pipe connector in three stages – by a box-end head of wrench 4; by specialized wrench 5 with a distance bar, and by specialized wrench 5, but without a distance bar. In each subsequent stage, a new connector was used. The torque was applied until the destruction of the connector. The shape of the connector after destruction is indicated by position 3. The torque of destruction was measured by dynamometric wrench 6.

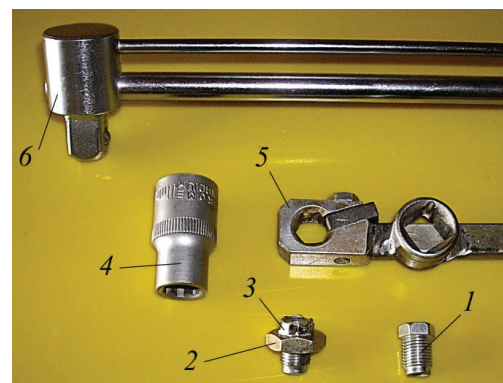Fig. 4. Measuring the torque applied to the brake pipe connector when loosening-tightening it

Fig. 5. Tools involved in the comparative tests of the proposed design of a specialized wrench: 1 — brake pipe connector; 2 — nut; 3 — brake pipe connector after tests; 4 — box-end head; 5 — modernized wrench; 6 — dynamometric wrench

5. Results of designing the structure of the clamping specialized wrench for the brake pipes of cars that have difficulties in loosening

5. 1. Studying the possibility of transferring the torque from the wrench to the brake pipe connector

We have considered a scheme to install the clamping specialized wrench for brake pipes on the connector (Fig. 6),

as well as the nature of the transfer of torque from the wrench grip to the mounting faces of the connector. However, the design of the brake pipe connector after fixing on the brake cylinder has a slight height, which is insufficient for full contact with the mounting faces of the wrench itself.
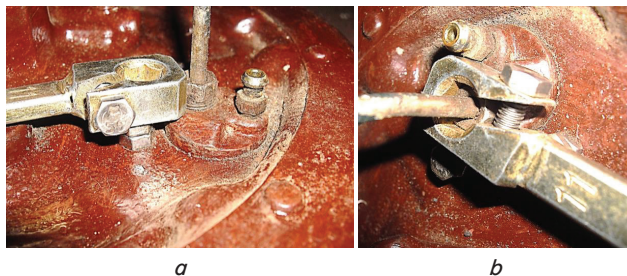

Fig. 6. The use of a box-end split clamping wrench to loosen the brake pipe connectors, which is installed: *a* — for comparison, next to the connector, which is attached to the brake cylinder and is subject to loosening; *b* — directly on the connector

Such a structure of the wrench makes it possible to increase the torque of tightening, which is applied to the brake pipe connector, compared to a conventional split wrench.

In Fig. 7, the connector is marked 1, the specialized wrench – 2. Applying the force F_1 determines the effort of the clamping bolt that closes the hexagonal profile after installing wrench 2 to connector 1. The force F_2 determines the effort applied by a locksmith's hand to the wrench grip when loosening the connector.

The split structure of the wrench determines how the wrench is mounted on the connector when tightening – loosening it. It seems rational to mount the wrench on the connector when it is loosened in the fashion shown in Fig. 6. The effort applied by the locksmith on the wrench grip in the direction of force F_2 when loosening the connector facilitates the clamping of the slot (rotation of the wrench counterclockwise). The load from the wrench to the connector is transmitted evenly to all the mounting faces of the connector. The specific contact stresses do not grow avalanche-like, which contributes to the transfer of greater value of the torque from the wrench to the connector. In the case when the wrench is not mounted rationally (for example, the rotation of the wrench clockwise at the stage of tightening the connector), the slot is opened. Accordingly, the mated area between the wrench and the connector decreases; the specific contact stresses increase, which provokes the crumpling of the mounting faces of the connector.

To find out the cause of the crumpling of faces in the process of loosening a connector, we used computer simulation. The finite-element modeling of the specified process employed the CAD SolidWorks software, the Simulation module. A technique to apply an FE-grid is «Grid on the solid body»; the number of elements was selected automatically by the system; the material is steel 40X.
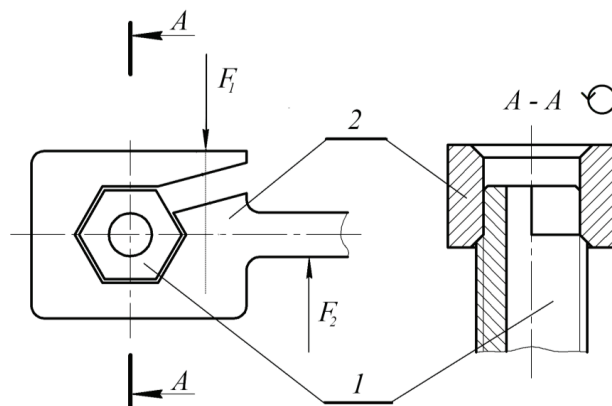

Fig. 7. Scheme for installing a clamping specialized wrench for brake pipes on the connector

5. 2. Results of studying the process of transferring the torque from the wrench to a brake pipe connector

The computer-based finite-element simulation was carried out for the pair «Connector-box-end clamping wrench», shown in Fig. 8. For better visualization, the connector was fabricated in the form of a bolt head and fixed motionless. The load is applied (Fig. 7) to the wrench grip in the direction of the force $F2$. The clamp bolt is conventionally non-specified; it generates a clamping force towards the force F_1. The uniformity of the load application from the wrench to the connector is controlled through the presence of a conditional light gap between the connector and the wrench (Fig. 8, *a*, view from above).

Our analysis of the stages of the deformation state of the model «Connector– box-end clamping wrench» reveals the following (Fig. 8).
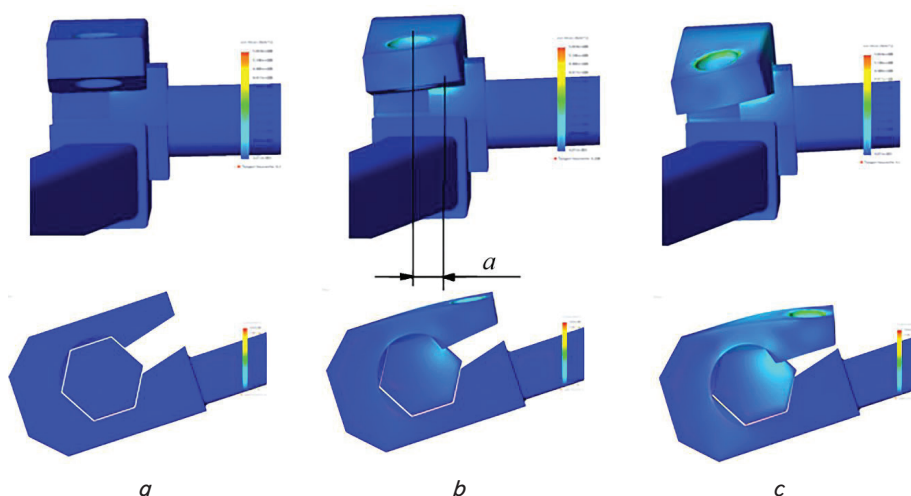

Fig. 8. Stages in the deformation state of the model «Connector-box-end clamping wrench» (views on the side and top) when applying the load to the wrench grip: *a* — the wrench is mounted onto the connector, the clamp bolt is tightened (the clamp bolt is not specified conditionally); *b* — the torque from the wrench grip is transferred to the connector; *c* — the connector is not able to perceive the torque due to the significant deformation of the wrench

Stage «a» – the wrench is mounted onto the connector; the clamp bolt is tightened (the clamp bolt is not specified conditionally). Tightening the clamp bolt is normal as the facets of the wrench are evenly mated with the mounting faces of the connector. This is evidenced by the presence of a conditional light gap between the connector and wrench. In the case of over-tightening the clamp bolt, the presence of a cut-out gap in the head of the wrench causes the uneven redistribution of specific loads in the conjugation.

Stage «b» – the torque from the wrench grip is transferred to the connector. The transverse plane of the wrench, which hosts the axis of the clamp bolt, does not coincide with the transverse plane of the middle of the connector conjugation area with the wrench (size «a» in Fig. 8, b, view on the side). This would distort the faces of the wrench and reduce the area of the mated surface of the wrench with the surface of the mounting faces of the connector.

Stage «c» – the connector cannot perceive the torque due to significant deformation of the wrench. With an insufficient torque value, which is transferred from the wrench to the connector, to loosen the connector, the connector remains stationary. A further increase in the torque on the wrench leads to an even greater distortion of the wrench faces. The area of the mated surface is decreasing while the contact stresses are increasing. The increased contact stresses cause the crumpling of the connector's mounting faces. The wrench revolves around the connector. The connector is not loosened, the mounting faces of the connector are destroyed, then re-attempt to loosen the connector is impossible.

Based on the analysis of the stages of the deformation state of the model (Fig. 8) when transferring the maximum possible torque from the wrench to the connector, the following options can be proposed:

– to increase the height of the mounting faces of the connector for the possibility of increasing the area of the mated surface;

– to improve the mechanical property of the connector to increase the contact strength of the surface of the mounting faces of the connector;

– to create conditions under which applying a load to the wrench does not cause any curvature of its faces.

The first two options can be implemented only during car manufacturing; alas, we are unable to alter them. The third option remains achievable. The main reason for the curvature of the wrench faces is the presence of a longitudinal cut-out gap in the wrench's box-end head. It is proposed to install an additional distance bar in the existing wrench gap (Fig. 9, a) after mounting it onto the connector.

The thickness of distance bar 1 is determined by the width of the longitudinal slot on the wrench. The slot, in turn, exceeds the diameter of the brake pipe for easy installation of the clamping wrench on the brake pipe connector. The thickness of distance bar 1 after installing it in the wrench and tightening the clamping bolt fully should not distort the hexagonal profile of the clamping wrench.

The loosening process is carried out as follows (Fig. 10). Wrench 1 is mounted on the brake pipe through the longitudinal slot in the absence of clamp bolt 3 and distance bar 4. Before one starts loosening connector 2, distance bar 4 is installed in the wrench's longitudinal slot. The clamp bolt is tightened. Tightening the bolt creates a geometrically balanced locked hexagonal wrench profile that accurately reflects the hexagonal profile of the brake pipe connector. A full-fledged solid box-end wrench is born [11].
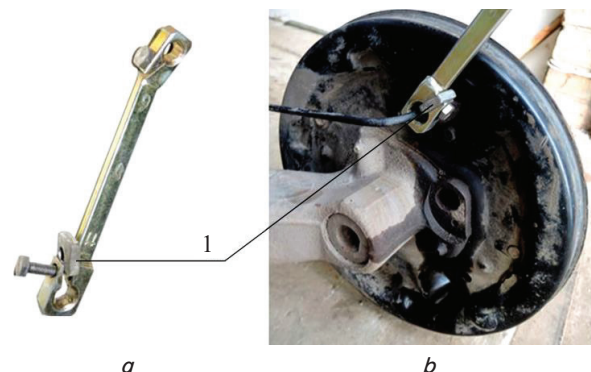

Fig. 9. Specialized box-end split clamping wrench with additional distance bar 1: a — the place of installation of the distance bar on the wrench; b — the use of the wrench with a distance bar when loosening the brake connector
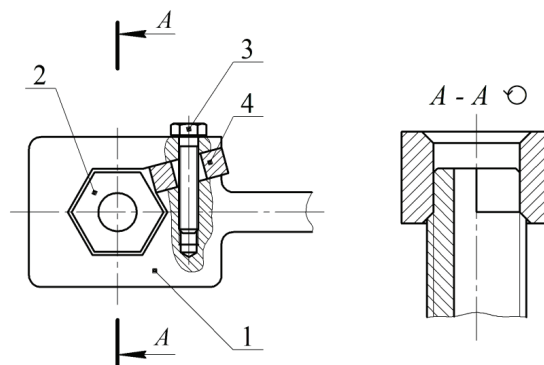

Fig. 10. A wrench structure with an additional distance bar

When the loosening torque is applied to the brake pipe connector, full tight contact between the wrench and the connector is made. Moreover, when the loosening torque is increased, the contact area between the wrench and connector does not change or decrease. Possible deformation of the wrench faces is prevented by the preliminary tightening of the bolt of the clamping wrench.

The limited height of the hexagonal profile of the connector requires a constant axial pressing of the wrench to the connector. The test results are shown in the chart (Fig. 11) of changes in the conditional mated area S, %; between the wrench jaws and the mounting faces of the connector depending on the torque, T, N·m, for various tools.
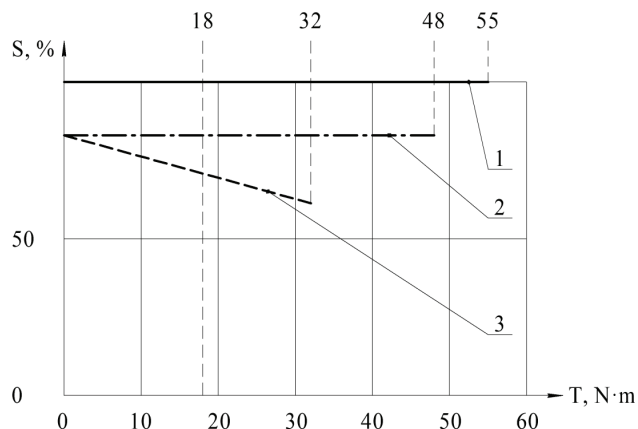

Fig. 11. Chart of change in the conditional mated area S, %; between the wrench jaws and the mounting faces of the connector depending on the torque, T, N·m, for various tools

5. 3. Modernizing the design of a brake pipe connector

In case of repair work of the brake system of a car, which is accompanied by the replacement of the brake pipe connectors, it is advisable to install connectors of the modernized design. The modernized structure of the brake pipe connector should correspond to the first of the proposed options for analyzing the stages of the deformation state of the model (Fig. 12). It is necessary to propose the structure of the connector with an increased height of the mounting faces of the connector to increase the area of the mated surface, which is in contact with the wrench. Meeting the requirement to improve the mechanical properties of the connector for increasing the contact strength of the surface of the mounting faces of the connector is not necessary as the area of the mated surfaces would increase.

Simultaneously with the increase in the height of the mounting faces of the connector, it is advisable to protect the cavity between the pipe and connector, which is filled with dirt during operation. The polluted cavity may not make it possible that the brake pipe remains stationary when the connector is rotating. The pipe rotates along with the connector, causing it to break down.

To protect the specified cavity, Fig. 12 shows the modernized structure of the connector.
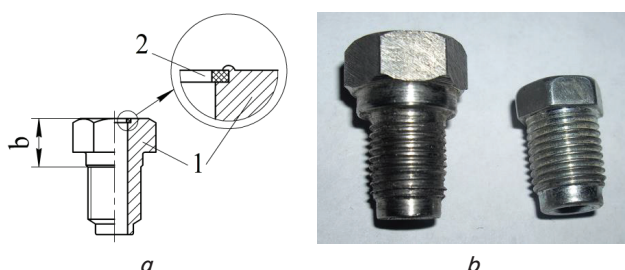

Fig. 12. Modernized connector for attaching the brake pipe: *a* — the structure of the connector; *b* — the physical appearance of the modernized and regular connectors

Teflon washer 2 is fitted into connector 1 of the brake pipe. The presence of a Teflon washer in the connector hole provides its air-tight sealing with a brake pipe, which prevents the penetration of dirt and prevents the oxidizing phenomena at the place where the connector joins the pipe. At the same time, conjugating the Teflon washer with the pipe provides for their free mutual rotation.

6. Discussion of results of experimental tests of the proposed wrench structure to loosen the brake pipe connectors

It is of course obvious from the analysis of the installation scheme (Fig. 7) that due to the reduction of metal consumption by connector structure 1 a manufacturer fabricates the mounting faces of the connector at the minimum permissible height, just to install a conventional carob wrench. And this is justified since the assembly and operation were designed for a new car or a car with short service life. In addition, the diameter of the threaded part of connector 1 (Fig. 7) exceeds the size between the diametrically opposite mounting faces of the connector, which does not make it possible to install the box-end wrench below the connector. Therefore, when installing a box-end split wrench, only a fraction of the area of the wrench faces are mated with the mounting faces of the connector.

This does not contribute to uniform contact load when transferring the torque from the wrench grip to the connector.

Before starting the loosening of the connector, a complete procedure of measures is definitely performed, which facilitates the easier loosening, such as lubrication with the WD 40 liquid, connector hammering, if possible, heating, etc. However, with the unsuccessful loosening of the connector, our experience of practical use indicates that, as a rule, the faces of the connector are crumpled. If the connector was not loosened, the torque required to loosen the connector was not transferred from the wrench to the connector. The unevenly distributed contact stresses that arose in the conjugation caused the faces to crumple.

Analyzing the chart shown in Fig. 11, one can see three lines that are marked 1, 2, and 3. Line 1 reflects the dependence of the conditional mated area on the torque for the wrench box end. This tool ensures the maximum fit between the wrench jaws and the mounting faces of the connector, so the mated area is accepted conventionally to equal 100 % and which, when applying a torque, does not significantly decrease, so it is conventionally depicted as a horizontal straight line. However, the horizontal straight breaks when the torque value is 55 N·m. At the specified value, there was a complete crimpling of the mounting faces of the connector when it was screwed into the nut. Instead of the expected tightening of the connector's core, its faces crimpled. Obviously, this is due to the insufficient area of the mounting faces of the connector, which are mated with the faces of the wrench.

Line 2 characterizes a change in the mated area for the specialized wrench with a distance bar. A decrease in the mated area to 80 % compared to the box-end wrench is due to the fact that the fit is executed only on five faces. The place of the sixth face coincides with the installation of a distance bar. With a growth of the torque, the mated area does not decrease. The faces crumple at the value of torque of 48 N·m. In terms of load capacity, the proposed wrench is completely close to a standard box-end wrench. If the distance bar in the shape of the mated surface is made in the form of a face of the wrench, the load capacity would, respectively, also increase.

Line 3 characterizes a change in the mated area for the specialized wrench without a distance bar. The mated area decreases with an increase in the torque, and the crumpling of faces occurs at the value of the torque of 32 N·m.

The chart indicates the mark of pre-tightening the connector with a torque of 18 N·m.

At the same time, we increased the wrench capture from 11 to 14 mm, and increased the height of mounting faces – size «b», from 4 to 6 mm, to ensure the crumpling strength and to facilitate unscrewing. The increased size of the hexagonal capture for the wrench on a connector provides for proper wrench access and increased torque when loosening, which eliminates the likelihood of the hexagonal connector's profile crumpling when loosening. It would suffice to use a conventional carob wrench. This, in turn, increases the reliability of operation and prolongs the service life of the car's overall braking system.

We have analyzed the compatible interaction between the wrench and the brake pipe connector when transmitting a torque during tightening and loosening. Our finite-element simulation of the deformation of the wrench faces has made it possible to establish the reasons for limiting the transfer of the torque.

Using the finite-element modeling of the wrench faces' deformation has made it possible to significantly reduce the time to establish the causes of the destruction of the wrench faces. Usually, as a possible option to analyze the nature of defor-

mations, a method of strain gauge of surfaces of deformation is employed, which is quite time-consuming.

The proposed practical solution is to install an additional distance bar in the existing gap of a box-end split wrench, which makes it possible to increase the torque that can be transferred to the brake pipe connector. The box-end wrench works as a single whole multifaceted surface. The specific loads accept uniformly-identical stresses, which does not cause the destruction of the mounting faces of the brake pipe connector.

Theoretically, there are no restrictions on the use of the technique of finite-element simulation of the deformation of wrench faces. However, one of the arguments for this modeling is the mechanical properties of the wrench material, which must be predicted. The disadvantage of this study is that the specific structure of the box-end wrench with the size of the width of the faces of 11 mm was considered.

The proposed technique of finite-element simulation of the deformation of wrench faces could be, by analogy, used for wrenches of a different design. In particular, both for the box-end split wrenches and for the carob ones. Theoretical modeling and forecasting would eliminate errors when designing both geometric dimensions and selected mechanical properties of the material for the manufacture of the wrench.

7. Conclusions

1. When mutually analyzing the conjugation between a specialized box-end split clamping wrench and a brake pipe connector, it was established that the limited height of the connector, which is laid down by the manufacturer, does not make it possible to transmit the necessary torque for its loosening due to that the connector is exposed to an aggressive environment, as its geometric dimensions change.

2. The finite-element simulation was used to establish the nature of the deformation of the wrench faces. This leads to a decrease in the mated area between the facets of the wrench and the connector, and, due to increasing pressure, crumpling the faces of the connector when it is loosened.

3. We have proposed a structure of the brake pipe connector whose operation is possible when using a conventional carob wrench under the conditions of an aggressive environment. This is possible by adding a Teflon washer to the structure, which air-tightens the seal and makes it impossible for the moisture to penetrate the node.

Applying our results during the maintenance of a car improves the repairability of the braking mechanism of the car, which helps reduce the labor intensity and cost of repair operations.

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