# TECHNICAL MAINTENANCE OF VEHICLES: IMPROVEMENT OF RELIABILITY OF THE MAJOR COMPONENTS AND UNITS

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***Resume***

The purpose is to determine the impact of operating conditions on the reliability of vehicles, to identify the main causes of failure of truck units and assemblies and to find ways to improve their reliability. The main methods are a systematic approach to analysis of complex technological systems, the fault tree analysis to identify the most common causes of failure of trucks in the climatic conditions of Central Asia. It has been revealed that one of the frequent causes of failure of units and assemblies is fatigue failure, the finite element modelling of which allowed the study to obtain a diagram of limit deviations for various cycle asymmetries and as a result, the ability to predict the process of fatigue failure under the influence of external factors. The study results are aimed at the possibility of predicting the failure of components and assemblies of trucks conditioned by fatigue failure.

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## 1 Introduction

A modern vehicle is a complex system, a set of joint elements - components that ensure the performance of its functions, made of various materials, with high precision machining of the surfaces of parts and, in turn, is part of the "vehicle-driver-road-environment" system and its properties are manifested in interaction with the elements of this system. The operation of vehicles is carried out in various road and climatic conditions, which is conditioned by the influence of various mechanical, physical and chemical factors on it, causing a change in its technical condition. Therefore, the significance of the criteria for the vehicle operation depends on the conditions in which this criterion is manifested, on the operating conditions and natural and climatic environment [1-3]. The study by Mozharova [4] defines operational conditions as conditions that were formed as a result of the organisation of production with the participation of an automobile fleet and the performance of technical and technological maintenance of vehicles. The natural and climatic conditions include the terrain, the amount of precipitation per year, the average temperature and the type (connectivity) of soil. The performance of systems and assemblies, that is, the intensity of their wear is affected by the quality of the road surface, which, in turn, depends on the terrain [5-6].

In the Republic of Kazakhstan and in the Central Asian region, a sharply continental and dry climate prevails with a hydrothermal coefficient of no more than 0.8, which corresponds to an arid zone. The annual temperature difference is significant, since in winter the temperature can drop to -50 °C and in summer it can rise to + 70 °C in some areas. Daily temperature drops reach 20-30 °C. With the exception of the northern regions, soils in Kazakhstan are represented by chestnut, brown semi-desert soil, dry-type playa and desert sands. Considering the type (connectivity) of soils and low precipitation, the air dustiness reaches 0.1-0.3 g of dust per 1 $m^3$ of air [7]. The technical conditions of a vehicle are determined by the changing properties of its components, affecting serviceability and operability. The theoretical state parameter curves change smoothly over time but are influenced by external factors resulting in broken curves. The main causes of technical changes

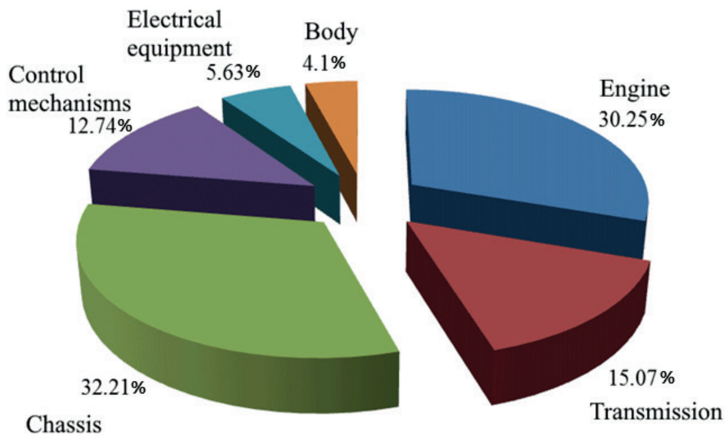


***Figure 1** Percentage of malfunctions in the major units of trucks, source: compiled by the authors*

***Table 1** Parameters of reliability indicators*

| Characterized reliability property | Indicators | Basic equation |
|---|---|---|
| Reliability | Probability of no-failure | $P(t) = \frac{N - n(t)}{N}$ |
| | Failure rate | $\lambda(t) = \frac{n(t)}{N_{cp} \cdot \Delta t}$ |
| | Failure intensity | $\mu(t) = \frac{n(t_2) - n(t_1)}{t_2 - t_1}$ |
| | Time to failure | $T = \frac{1}{\mu(t)}$ |

in vehicles, units, and mechanisms are wear, plastic deformation, fatigue damage, corrosion, and physico-chemical and temperature changes. Figure 1 shows the percentage of malfunctions for major truck units.

Analysis of research papers byTurdikulov and Kushakov [8], V. G. Kozlovet al. [9] showed that natural and climatic conditions (temperature differences, air dustiness) have a negative impact on the fatigue strength of vehicle components. Fatigue failure occurs on surfaces of the cams and gear teeth, in the rolling bearings of the transmission, in the antifriction layer of the engine crankshaft bearing shells. Fatigue failure is also observed in extreme operating conditions (prolonged overloads, low or high temperatures) in springs, semi-axles, frames. In the reference literature and technical characteristics of materials, $\sigma_{-1}$ is used as a criterion of the fatigue endurance limit. However, to investigate fatigue strength in difficult operating conditions, this criterion is low informative, therefore, in the presented studies, a more informative criterion will be used that characterizes the resistance of metal to cyclic loads - a diagram of limit deviations for various cycle asymmetries. The fault-tolerance of products is determined by their reliability, durability, maintainability and preservation. Reliability of components and assemblies of trucks is a key property for studying fault-tolerance, the calculations of which would allow predicting the operating time of a vehicle. Reliability, durability, maintainability and survivability are characterized by the quantitative single and complex indicators [10-11]. The currently available parameters of reliability indicators in accordance with the assessed properties are shown in Table 1.

Research in the field of predicting failures of complex engineering systems is conducted in various countries and in various areas: information systems, production equipment, vehicles as complex systems [12-15]. Despite a large number of research papers on the reliability of vehicles, the problem of reduced reliability in difficult climatic conditions has been rather understudied, which leads to high repair costs, downtime. This paper considers reliability in relation to engineering systems and their elements from the position of adapting them to difficult conditions, which would allow comprehensively considering the causes of vehicle failure and suggesting ways to improve reliability.

The purpose of the study is to determine the impact of operating conditions on the reliability of vehicles, to identify the main causes of failure of truck units and assemblies and to find ways to improve their reliability.

## 2 Materials and methods

The study focused on a KrAZ-65053 motor vehicle chassis from Kremenchuk Automobile Plant, equipped with PAP-60/80 lifting units for major repairs of oil and gas wells and used in heavy machinery plant production in Kazakhstan. The reliability analysis

***Table 2** Mechanical properties of 40CN2MA steel*

| Yield strength $\sigma_t$ (MPa) | Tensile strength $\sigma_V$ (MPa) | Elongation 5% | Reduction $\psi$ (%) | Impact strength (J/mm) | Brinell hardness HB |
|---|---|---|---|---|---|
| 780 | 980 | 15 | 50 | 6 | 230-285 |

showed a significant number of failures in wheels and axles during technological operation. Statistical methods identified the main causes of failures, which were analyzed and formed the basis for building a fault tree. The semi-axle of the front-drive axle was selected as the investigated part, during its operation, fatigue failures were most often observed. The half-axle of the front-drive axle is included in the assembly unit of the differential of the front axle of the KrAZ truck, designed to rotate the half-axles at different speeds when turning the vehicle and prevent twisting of the shafts and the distribution of torque between the wheels. The semi-axle, in turn, is designed to transfer torque from the differential to the wheels. The part in the assembly unit operates at high rotational speeds as well as in a reverse loading cycle. The working environment of the part is the front axle casing. The maximum dimensions of the part are Ø 66 mm and length 1.108 mm.

The part is made of 40CN2MA steel, the mechanical properties of the material are shown in Table 2 [16]. The presented mechanical properties are necessary for further finite element modelling.

Fatigue (cyclic) loading is the most common type of loading that parts and components of mechanisms experience during operation. It is accepted that the assessment of the strength of the product, from the action of cyclic loading, is reduced to comparing the values of the calculated stresses obtained and the values of the endurance limit of the material from which the product is made. $\sigma_{-1}$ is used as a criterion of the fatigue endurance limit. Its values are obtained as a result of fatigue tests. The tests are carried out on laboratory samples of small diameter (7-10 mm) made of a rod. The surface of the samples is carefully polished. Next, a series of tests of samples is carried out during bending by a symmetrical loading cycle. In the first test, a load value is applied that creates maximum cycle stresses close to the yield strength. The number of loading cycles that the sample has sustained before destruction is measured. Next, the load is reduced and the next test is carried out to measure the number of loading cycles that the sample withstands before destruction. Thus, the load is gradually reduced until the sample can withstand the base number of loading cycles (107 cycles) without destruction. According to the test results, a “Stress-cycle” graph is built.

Due to the fact that three main types of loading cycles are considered in mechanical engineering (symmetrical cycle, pulsating (zero) cycle, asymmetric cycle) and fatigue tests consider only symmetrical cycle, to obtain a more informative criterion characterizing the resistance of metal to cyclic loads, a diagram of limit deviations for various cycle asymmetries is constructed in the coordinates of the average cycle stress (X-axis) and maximum cycle stress (Y-axis) and allows evaluating the fatigue resistance of the future product at the design stage. The necessary characteristics of the cycle: the mean cycle stress $\sigma_m$ and the highest cycle stress $\sigma_{max}$ [17]. The ANSYS Workbench software suite was used to obtain the values necessary for constructing the diagram.

## 3 Results and discussion

Reliability indicators like failure-free operation, failure rate, and mean time to failure are important for assessing components and predicting system failures. A failure tree is an effective top-down method for analyzing product reliability and identifying causes of failure. It models the complex interactions of system parts and considers specific and general causes of failure, their interaction, and influence on each other [18]. The failure tree analysis uses Boolean abbreviations and clipping set analysis to assess system reliability and operability based on failure rate, fault mode probability, and recovery rate. The method has advantages and disadvantages depending on its scope. In mechanical engineering, the failure tree is useful for visually identifying potential failure points, analyzing system reliability quantitatively and qualitatively, and gaining detailed insight into system behavior. The method’s main advantage is the ability to eliminate irrelevant system elements and events and focus on the most significant causes of malfunctions leading to system failure or accidents.

Limitations of the method: allows presenting events that depend on the time or the order of their occurrence; if the operation of the system depends on its state, then the method ceases to be flexible when rebuilding the system. These shortcomings can be eliminated by using Markov models to study the main events of the fault tree. Thus, combining the principles of failure tree analysis with Markov models provides the best results in relation to engineering systems. [19]. In the studies [18-20], the method of analyzing the failure tree for various engineering systems was used; the use of this method allowed reducing the time for diagnosing the cause of failures and increasing the efficiency of the systems. The presented method is included in national standards, for example, as the standard of the United States of America MIL-HDBK-217 “Reliability prediction of electronic equipment” [21] or the Russian RD 03-418-01 “Guidelines for risk analysis of hazardous

***Table 3*** *Fault statistics - part I*

| Indicator | Number of faults | Percentage ratio | Fault tree index |
|---|---|---|---|
| Chassis | | | |
| Frame | 635 | 100 | |
| deflections, distortions of breakage | | | F.1 |
| A) overloading of the vehicle | 336 | 53 | F.1.A |
| B) strong tremors when moving | 209 | 33 | F.1.B |
| C) unfavourable climatic conditions | 89 | 14 | F.1.C |
| Axles | 4.125 | 100 | |
| Swivel axle assembly | 1.238 | 100 | A.S. |
| 1) mounting hole thread failure | 738 | 100 | A.S.1 |
| A) natural wear and tear | 502 | 68 | A.S.1.A |
| B) plastic deformation | 236 | 32 | A.S.1.B |
| 2) hub bearing wear | 271 | 100 | A.S.2 |
| A) lack of oil | 154 | 57 | A.S.2.A |
| B) natural wear and tear | 117 | 43 | A.S.2.B |
| 3) crack formation | 223 | 100 | A.S.3 |
| A) fatigue wear | 167 | 75 | A.S.3.A |
| B) natural ageing | 56 | 25 | A.S.3.B |
| Semi-axles | 2.310 | 100 | A.S-A. |
| 1) breakage (twisting) | 1.063 | 100 | A.S-A.1 |
| A) fatigue wear | 510 | 48 | A.S-A.1.A |
| B) severe operating conditions | 213 | 20 | A.S-A.1.B |
| C) unfavourable climatic conditions | 213 | 20 | A.S-A.1.C |
| D) hidden defects (shells, microcracks) | 127 | 12 | A.S-A.1.D |
| 2) wear of the half-axle splined joint | 647 | 100 | A.S-A.2 |
| A) insufficient anchoring | 453 | 70 | A.S-A.2.A |
| B) fatigue wear | 194 | 30 | A.S-A.2.B |
| 3) wear or destruction of the half-axle bearing | 600 | 100 | A.S-A.3 |
| A) deformation of the half-axle | 360 | 60 | A.S-A.3.A |
| B) natural wear and tear | 120 | 20 | A.S-A.3.B |
| C) lack of oil | 120 | 20 | A.S-A.3.C |
| U-joint | 990 | 100 | A.U. |
| 1) wear of crosspins | 526 | 100 | A.U.1 |
| A) lack of lubrication | 274 | 52 | A.U.1.A |
| B) natural wear and tear | 252 | 48 | A.U.1.B |
| 2) wear of needle bearings | 464 | 100 | A.U.2 |
| A) lack of lubrication | 316 | 68 | A.U.2.A |
| B) natural wear and tear | 148 | 32 | A.U.2.B |

production facilities" [22]. Based on the statistics of truck malfunctions in the period from 2014 to 2017, which are listed in Tables 3 and 4, 13, 380 malfunctions account for the chassis [23]. To simplify the construction of the failure tree and for the convenience of its analysis, fault indices for the failure tree have been introduced.

Based on the analysis of statistical data, a failure tree was constructed (Figure 3). The principle of causal relationships for constructing a logical-probabilistic model of the failure tree, it can also be called tree of malfunctions, undesirable events, accidents, incidents, which is described in [24] and implemented in the constructions presented in Figure 3. To find possible causes of system failures and failures of its elements, a multilevel model is constructed that has a graphological structure of the effects of violations and malfunctions on the functioning of the system under study. Various approaches can be used to model the analysis of the failure tree, but the most common methods of construction can be summarised in several steps. First, it is necessary to identify an undesirable event. An undesirable event acts as the root for building a failure tree, one event for one tree. In this case, that is a failure (breakdown) of the truck's chassis.

Secondly, all the reasons that affect an undesirable event will be highlighted and analyzed if the probability of the influence of these reasons on the event is 0 or more, it is included in the failure tree, for trucks these data are summarised in Tables 3 and 4. To identify the causes of failures, it is recommended to use a systematic approach that can help limit the study to only those malfunctions that directly affect the failure of the system in question, but at the same time would allow avoiding skipping malfunctions affecting an undesirable event. Then, for the selected event, all the causes are numbered, then in accordance with the selected system

***Table 4** Fault statistics - part II*

| Indicator | Number of faults | Percentage ratio | Fault tree index |
|---|---|---|---|
| Suspensions | 5.420 | 100 | |
| Hydraulic absorbers | 2.331 | 100 | S.H. |
| 1) break of airtightness of the rod seal | 1.119 | 100 | S.H.1 |
| A) ageing | 358 | 32 | S.H.1.A |
| B) natural wear and tear | 425 | 38 | S.H.1.B |
| C) poor build quality | 190 | 17 | S.H.1.C |
| D) severe operating conditions | 146 | 13 | S.H.1.D |
| 2) violation of the integrity of the rod coating | 723 | 100 | S.H.2 |
| A) abrasive wear | 549 | 76 | S.H.2.A |
| B) poor build quality | 174 | 24 | S.H.2.B |
| 3) damage to internal valves | 489 | 100 | S.H.3 |
| A) severe operating conditions | 298 | 61 | S.H.3.A |
| B) unfavourable climatic conditions | 191 | 39 | S.H.3.B |
| Semi-elliptical springs | 3.089 | 100 | S.S-E. |
| 1) sagging or breakage of sheets | 1.236 | 100 | S.S-E.1 |
| A) lack of lubrication | 408 | 33 | S.S-E.1.A |
| B) fatigue wear | 445 | 36 | S.S-E.1.B |
| C) violation of the correct fixing | 272 | 22 | S.S-E.1.C |
| D) severe operating conditions | 111 | 8 | S.S-E.1.D |
| 2) loss of elasticity | 1.112 | 100 | S.S-E.2 |
| severe operating conditions | | | |
| 3) wear or breakage of pins and bushings in the spring eyes | 741 | 100 | S.S-E.3 |
| A) corrosion | 482 | 65 | S.S-E.3.A |
| B) lack of lubrication | 259 | 35 | S.S-E.3.B |
| Wheels | 3.200 | 100 | |
| Disks | 1.115 | 100 | W.D. |
| bearing backlash or jamming | | | W.D.1 |
| A) lack of lubrication | 814 | 73 | W.D.1.A |
| B) natural wear and tear | 301 | 27 | W.D.1.B |
| Tires | 2.085 | 100 | W.T. |
| tire wear | | | W.T.1 |
| A) non-compliance with pressure standards | 1.001 | 48 | W.T.1.A |
| B) violation of wheel mounting angles | 542 | 26 | W.T.1.B |
| C) severe operating conditions | 438 | 21 | W.T.1.C |
| D) unfavourable climatic conditions | 104 | 5 | W.T.1.D |

and used for graphical implementation of building a failure tree (Figure 2). The main characteristics of the fault tree are determined by the symbols "AND" and "OR", which allow building a failure tree based on the previously conducted selection of an undesirable event, substantiation and analysis of the reasons causing the system failure [25]. The "AND" gate represents a combination of events that must occur simultaneously for the top event to occur and the "OR" gate represents a combination of events where only one event needs to occur for the top event to occur.

The truck's chassis failure tree analysis, based on malfunctions in Kazakhstan's climate, shows severe operating conditions and unfavorable weather as the main causes of failure. Although these reasons for failure appear much more frequently in Kazakhstan, they should be considered during truck design and manufacturing and during operation and maintenance. Fatigue wear significantly impacts the chassis' trouble-free operation, especially under severe operating and adverse climatic conditions. Predicting failure due to fatigue wear is a difficult task and requires a detailed consideration of the mechanisms of fatigue failure of metals and methods of their study, since fatigue failures begin with appearance of the hard-to-detect microscopic cracks and the maximum dynamic loads that cause them are less than with static destruction [26]. Fatigue failures occur during the cyclic application of loads exceeding the endurance limit of the metal part. At a certain number of loading cycles, fatigue failure of parts occurs, associated with the gradual accumulation and growth of fatigue cracks. Improvement of calculation methods and manufacturing technology of vehicles (improvement of metal quality and manufacturing accuracy, exclusion of stress concentrators) will lead to a significant reduction in cases of fatigue failure of parts. As a rule, it is observed in extreme operating conditions (prolonged overloads, low or high temperatures) in springs, semi-axles, frames.

The analysis shows common causes of chassis failures

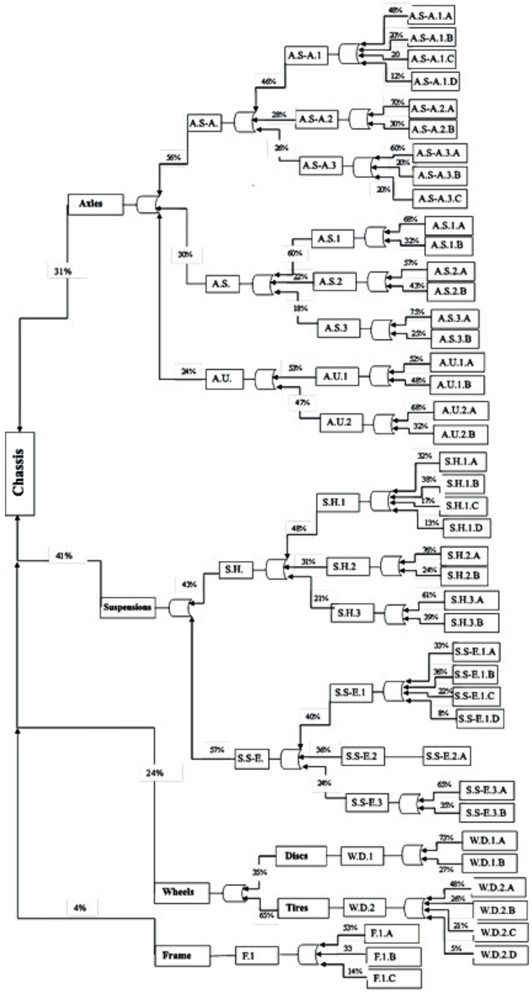


***Figure 2** Failure tree by chassis, note is presented in Table 5*

as related to suspension, axles, semi-elliptical springs, and wheels. Semi-axles and swivel axle assembly have the highest percentage of failures among axles. Wear of crosspins is the primary cause of U-joint failures. Hydraulic absorbers have the highest percentage of failures among suspensions. Sagging or breakage of sheets is the most common failure among semi-elliptical springs. Tire wear is the most common failure among wheels. Regular maintenance and inspection of all components is important to prevent system failures. The study proposes a method for constructing a diagram of limit deviations for various asymmetries of the half-axle operation cycle. Below are the steps required to obtain this diagram. At the first stage of the research, fatigue tests of a semi-axle made of 40CN2MA steel were carried out, the results of which are presented in a graph. The main criteria for failure in determining the strength limits and constructing fatigue curves are complete destruction or the appearance of macro cracks of a given size. At least 15 identical samples were tested to construct the fatigue curve and determine the endurance limits corresponding to the possibility of destruction of 50%. Three samples were tested in the stress range of 0.95-1.05 from the endurance limit corresponding to the possibility of destruction of 50%. The test base for determining the endurance limits is accepted: 10 to $10^6$ cycles. The constructed fatigue strength curve is shown in Figure 3. As can be seen from Figure 3, the curve asymptotically approaches the horizontal line. The ordinate of this asymptote is the endurance limit, the greatest stress of the cycle, at which the destruction of the material will never occur. The results correlate with the results obtained in [27].

Thus, the entry $\sigma_{-1}$ = 519 MPa for 40CN2MA steel means that this is the highest normal stress at which a small diameter rod with a polished surface will not collapse under the action of bending stress in a symmetrical cycle. Consequently, in products of a different design, size and in other cases of cyclic loading, when using the value σ-1, there is not enough information about the fatigue failure process. Based on the above, it is fair to assume that the endurance limit is not a sufficient criterion for assessing the resistance of a metal. At the second stage, a computational 3D model of the lever was created in the computer-aided design (CAD) system, which is transmitted in the ANSYS Workbench software suite via a plug-in built into the menu [28]. A material with the necessary properties was created in the ANSYS Workbench software suite. To specify the material, it is necessary to specify the

***Table 5** Note for Figure 2*

| Fault tree index | Possible Issues |
|---|---|
| A.S-A. | Semi-axles |
| A.S-A.1 | breakage |
| A.S-A.1.A | fatigue wear |
| A.S-A.1.B | severe operating conditions |
| A.S-A.1.C | unfavourable climatic conditions |
| A.S-A.1.D | hidden defects (shells, microcracks) |
| A.S-A.2 | wear of the half-axle splined joint |
| A.S-A.2.A | insufficient anchoring |
| A.S-A.2.B | fatigue wear |
| A.S-A.3 | wear or destruction of the half-axle bearing |
| A.S-A.3.A | deformation of the half-axle |
| A.S-A.3.B | natural wear and tear |
| A.S-A.3.C | lack of oil |
| A.S. Swivel axle assembly | mounting hole thread failure |
| A.S.1 | natural wear and tear |
| A.S.1.A | plastic deformation |
| A.S.2 | hub bearing wear |
| A.S.2.A | lack of oil |
| A.S.2.B | natural wear and tear |
| A.S.3 | crack formation |
| A.S.3.A | fatigue wear |
| A.S.3.B | natural ageing |
| A.U. U-joint | wear of crosspins |
| A.U.1.A | lack of lubrication |
| A.U.1.B | natural wear and tear |
| A.U.2 | wear of needle bearings |
| A.U.2.A | lack of lubrication |
| A.U.2.B | natural wear and tear |
| S.H. Hydraulic absorbers | break of airtightness of the rod seal |
| S.H.1 | ageing |
| S.H.1.A | natural wear and tear |
| S.H.1.B | poor build quality |
| S.H.1.C | severe operating conditions |
| S.H.1.D | severe operating conditions |
| S.H.2 | violation of the integrity of the rod coating |
| S.H.2.A | abrasive wear |
| S.H.2.B | poor build quality |
| S.H.3 | damage to internal valves |
| S.H.3.A | severe operating conditions |
| S.H.3.B | unfavourable climatic conditions |
| S.S-E. Semi-elliptical springs | sagging or breakage of sheets |
| S.S-E.1 | lack of lubrication |
| S.S-E.1.A | fatigue wear |
| S.S-E.1.B | violation of the correct fixing |
| S.S-E.1.C | severe operating conditions |
| S.S-E.1.D | severe operating conditions |
| S.S-E.2 | loss of elasticity |
| S.S-E.3 | wear or breakage of pins and bushings in the spring eyes |
| S.S-E.3.A | corrosion |
| S.S-E.3.B | lack of lubrication |
| W.D.1 | bearing backlash or jamming |
| W.D.1.A | lack of lubrication |
| W.D.1.B | natural wear and tear |
| W.D.2 | tire wear |
| W.D.2.A | non-compliance with pressure standards |
| W.D.2.B | violation of wheel mounting angles |
| W.D.2.C | severe operating conditions |
| W.D.2.D | unfavourable climatic conditions |
| F.1 | deflections, distortions of breakage |
| F.1.A | overloading of the vehicle |
| F.1.B | strong tremors when moving |
| F.1.C | unfavourable climatic conditions |

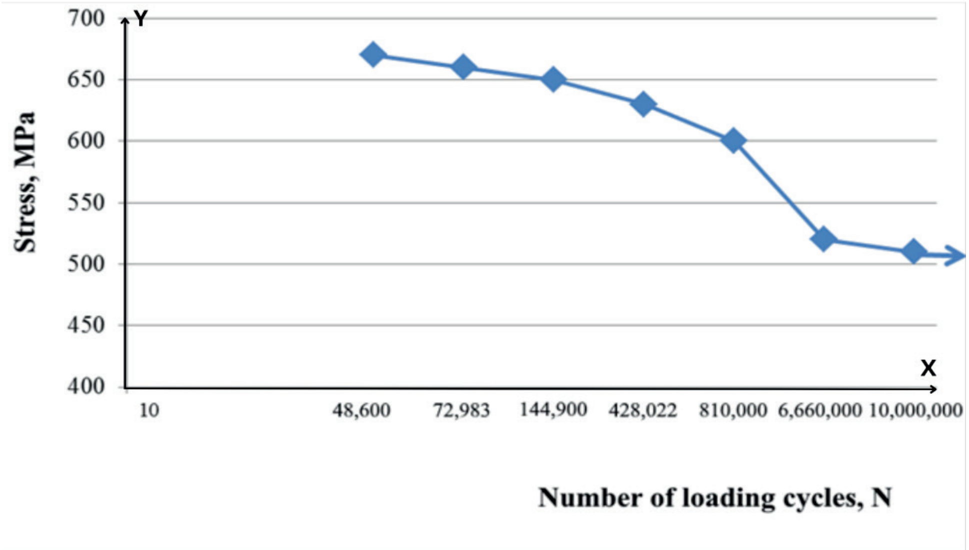


***Figure 3*** *The resulting fatigue curve in coordinates σ-N*

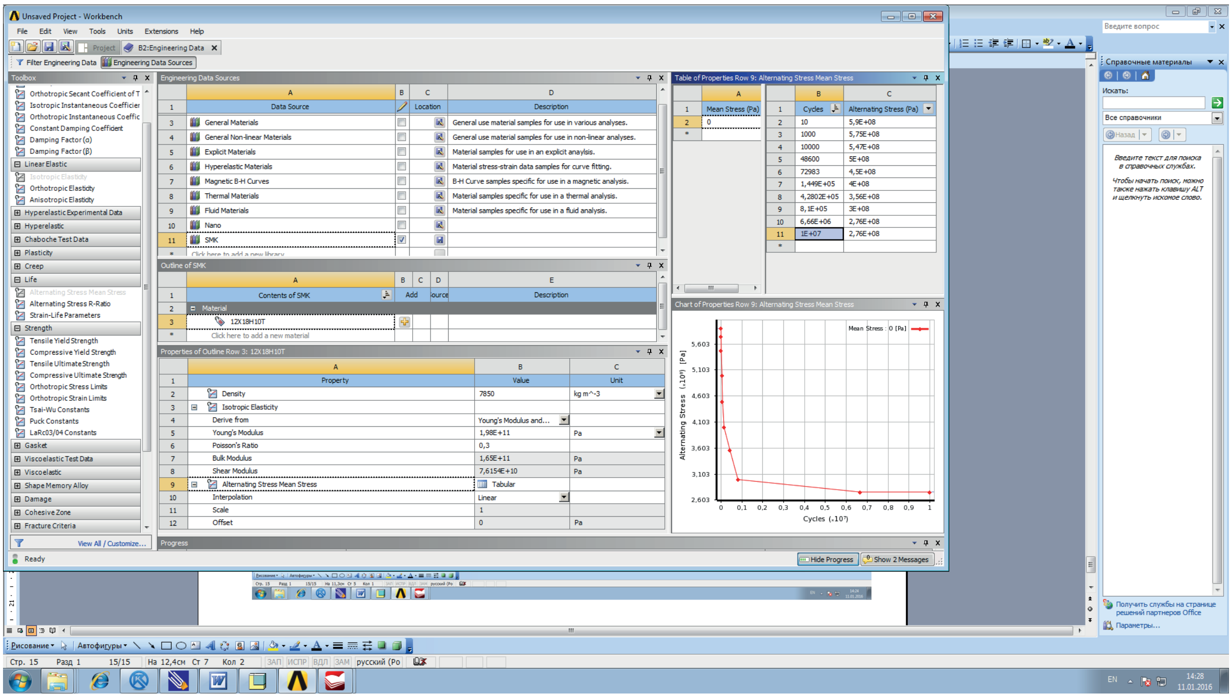

***Figure 4*** *Setting the fatigue curve*

density, modulus of elasticity and Poisson's ratio. The value of density and other parameters is taken from the reference literature [29], the temperature to which this density corresponds is optional.

For fatigue calculations, the Alternating Stress Mean Stress option from the Life option set is required. At this stage, the fatigue curve is set. The values shown in Figure 4 are entered in the Table of Properties Row 9: Alternating Stress Mean Stress window. In column B - cycles, in column C - stresses corresponding to them. Column A indicates the average cycle stress for the experimentally obtained fatigue curve (Figure 4). As already indicated earlier, the fatigue curve was obtained for a symmetric loading cycle, $\sigma_m = 0$. Calculations in the ANSYS Workbench software suite are carried out by the finite element method. Next, it is necessary to generate a grid of finite elements on the model and apply anchors and loads. The vertical load is set as - 8900 N along the Z axis. It should provide a stress level close to the endurance limit. After the calculation is completed, the type of result should be selected. The general stresses that arise in the structure are of interest. The resulting stresses are close to the endurance limit of this steel (515 MPa).

The stress limit diagram will be constructed from a series of points. The first point is the limit of endurance of steel with a symmetrical loading cycle, therefore, it will have coordinates (0; $\sigma_{-1}$) on the graph. The last point of the diagram is the tensile strength, it will have coordinates ($\sigma_B$; $\sigma_B$). It is necessary to get the points

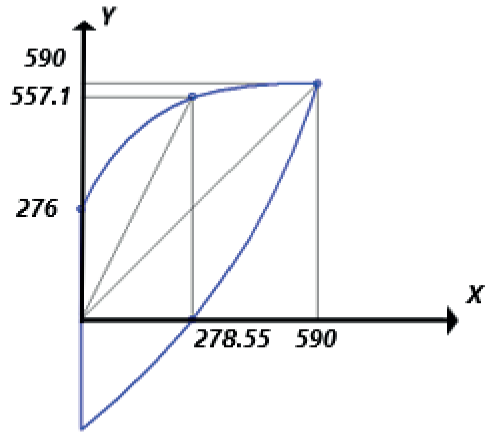


***Figure 5*** *Boundary stress diagram*

between coordinates. These will be endurance limits for the load cycles with asymmetry coefficients from -1 to 1. It is necessary to repeat the calculation with different load values to obtain endurance limits. As a result of the calculations, a number of points are obtained on which the boundary stress diagram is constructed (Figure 5). The result is the following. The endurance limit was 557.1 MPa. The average cycle stress was 278.55 MPa. The point has coordinates (278.55; 557.1). The boundary stress diagram is constructed in the coordinates of the average cycle stress (X-axis) and the maximum cycle stress (Y-axis).

This diagram allows evaluating the fatigue resistance of a future product at the design stage. It is enough to know the following cycle characteristics: the average cycle stress $\sigma_m$ and the highest cycle stress $\sigma_{max}$. Fatigue resistance is estimated as follows: a point is plotted on the diagram, the coordinates of which are the average and maximum cycle stress; if the point is in the area that is bounded by the curves $\sigma_{max}$ and $\sigma_{min}$, then the fatigue failure of the future product will not happen during the established service term. The experimental results obtained and the simulation data will serve as the basis for calculating the reliability of the front drive axle. The operability of parts can be determined by various criteria. The main criteria used in mechanical engineering are the criteria of strength, rigidity, wear resistance, heat resistance and vibration resistance.

When calculating reliability, the values obtained as a result of calculations are used and compared to the boundary values characterising strength (endurance limit, strength and fluidity), maximum load, resource, maximum displacement, heat resistance of oil and materials, dynamic stability and, according to data obtained empirically, as a result of experiments or observations during operation [30-31]. The study by Ostrejkovskii [32] presents a calculation of performance according to the strength criterion, where the limit of endurance acts as the boundary value characterizing strength. For calculations, the equivalence coefficient of the regime is used, the main criterion of which is the coefficient $k$, depending on the exponent of the degree m of the fatigue curve. The coefficient $k$ is selected depending on the stresses and the number of cycles for different samples and materials, but the proposed coefficient does not consider the asymmetry of the cycle. To expand the possibility of calculation equations for predicting trouble-free operation in various operating conditions and to improve the accuracy of the results obtained, it is proposed to use the values obtained for the boundary stress diagram instead of the values from the fatigue curve.

## 4 Conclusions

A review of methods for analyzing the reliability of engineering systems is carried out, while the truck is considered as a complex system. The calculation of statistical data to identify the most frequent failures showed that for trucks operating under constant load conditions, 32% of breakdowns occur on the chassis. The paper discusses the existing methods of predicting failures. The process of compiling a failure tree has been investigated and based on those data, the failure trees for the chassis of a truck have been developed. A scheme for constructing a failure tree is proposed, which allows analyzing the nature, causes and consequences of failures of the chassis elements, which allows solving complex issues to improve the reliability of the system.

It is revealed that the main causes of failure are natural wear, fatigue failure, severe operating conditions. Unfavourable conditions are the complex causes of malfunctions of the chassis of trucks operating in the Republic of Kazakhstan. The data obtained would allow reducing the time for troubleshooting vehicles during the technical operation and maintenance. It is determined that when the vehicle components work at different loading cycles, the value of the endurance limit used is not always sufficiently informative. Thus, the study proposes a method for constructing a boundary stress diagram using the example of the front axle half-axle, which allows evaluating and predicting the behaviour of the part material depending on its design and with different cycle asymmetries. The values of the cycle stresses, obtained as a result of modelling, can be used to calculate the reliability of the semi-axle according to the criterion of endurance chapel, which would improve the accuracy of calculations.

In terms of future research, it may be useful to expand the study to include other types of vehicles or machinery and to consider additional factors that may contribute to failures. It may also be beneficial to conduct more detailed analyses of specific components or subsystems within the vehicle to gain a better understanding of the root causes of failures. Additionally, the study highlights the importance of considering the effects of severe operating conditions and unfavorable climate on reliability of the chassis. Therefore, it may be worthwhile to conduct further research on the effects of these factors on other vehicle components and systems.

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**Conflicts of interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**References**

[1] THULE, C., LAUSDAHL, K., GOMES, C., MEISL G., LARSEN, P. G. Maestro: the INTO-CPS co-simulation framework. *Simulation Modelling Practice and Theory* [online]. 2019, **92**, p. 45-61. ISSN 1569-190X. Available from: https://doi.org/10.1016/j.jmsy.2019.04.008
[2] DOLZHENKO, N., MAILYANOVA, E., ASSILBEKOVA, I., KONAKBAY, Z. Analysis of meteorological conditions significant for small aviation and training flights at the airfield "balkhash" for planning and flight safety purposes. *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences* [online]. 2021, **2**(446), p. 62-67. ISSN 2224-5278. Available from: https://doi.org/10.32014/2021.2518-170X.35
[3] IMASHEVA, G. M., DOLZHENKO, N. A., ANAYATOVA, R. K., DORONINA, Y. V. Commercial use of aircraft based on safety risk. *Journal of Advanced Research in Law and Economics* [online]. 2018, **9**(8), p. 2615-2621. ISSN 2068-696X. Available from: https://doi.org/10.14505/jarle.v9.8(38).10
[4] MOZHAROVA, V. Transport in Kazakhstan: modern situation, problems and development prospects. Almaty: Kazakhstan Institute for Strategic Studies under the President of the Republic of Kazakhstan, 2011.
[5] PRENTKOVSKIS, O., TRETJAKOVAS, J., SVEDAS, A., BIELIATYNSKYI, A., DANIŪNAS, A., KRAYUSHKINA, K. The analysis of the deformation state of the double-wave guardrail mounted on bridges and viaducts of the motor roads in Lithuania and Ukraine. *Journal of Civil Engineering and Management* [online]. 2012, **18**(5), p. 761-771. ISSN 1392-3730. Available from: https://doi.org/10.3846/13923730.2012.731252
[6] OLEKSANDRA, S., KRAYUSHKINA, K., KHYMERIK, T., ANDRII, B. Method of increasing the roughness of the existing road. *Procedia Engineering* [online]. 2016, **165**, p. 1766-1770. ISSN 1877-7058. Available from: https://doi.org/10.1016/j.proeng.2016.11.920
[7] Competitiveness of logistics and transport in the Republic of Kazakhstan [online]. 2019. Available from: https://www.un-ilibrary.org/content/books/9789210042208/read
[8] TURDIKULOV, M., KUSHAKOV, S. Testing vehicles in mountainous conditions and dry and hot climate. In: *Wheeled vehicle safety in operating conditions*. FEDOTOV, A. I. (ed.). Irkutsk: National Research Irkutsk State Technical University, 2017. p. 169-173.
[9] KOZLOV, V. G., SKRYPNIKOV, A. V., SAMTSOV, V. V., NIKITIN, V. V., BOLTNEV, D. E., BOROVLEV, A. O. Influence of natural and technogenic factors on the complexity of construction of timber highways [online]. 2021. Available from: https://iopscience.iop.org/article/10.1088/1755-1315/659/1/012137/pdf
[10] GOST 27.002-2015 "Dependability in technics. Terms and definitions" [online]. 2017. Available from: https://docs.cntd.ru/document/1200136419.
[11] KURMANOV, A. K., ERMAGANBET, A. C., AHANOV, S. M., RAHATOV, S. Z., RYSPAYEV, K. S. Improvement of rotary disperser efficiency. *Life Science Journal*. 2014, **11**(10 spec. issue), p. 407-411. ISSN 1097-8135.
[12] KAUR, K., KAUR, K. Failure prediction and health status assessment of storage systems with decision trees. In: *Advanced informatics for computing research* [online]. LUHACH, A., SINGH, D., HSIUNG, P. A., HAWARI, K., LINGRAS, P., SINGH, P. (eds.). Cham: Springer, 2019, ISBN 978-981-15-0110-4, eISBN 978-981-15-0111-1, p. 366-376. Available from: https://doi.org/10.1007/978-981-15-0111-1
[13] MARTINEZ-LUCAS, G., PEREZ-DIAZ, J. I., CHAZARRA, M., SARASUA, J. I., CAVAZZINI, G., PAVESI, G., ARDIZZON, G. Risk of penstock fatigue in pumped-storage power plants operating with variable speed

in pumping mode, *Renewable Energy* [online]. 2019, **133**, p. 636-646. ISSN 0960-1481. Available from: https://doi.org/10.1016/j.renene.2018.10.060
[14] HELMER, T., KUHBECK, T., GRUBER, CH., KATES, R. Development of an integrated test bed and virtual laboratory for safety performance prediction in active safety systems. In: FISITA 2012 World Automotive Congress: proceedings [online]. Lecture Notes in Electrical Engineering, vol 197. Springer, Berlin, Heidelberg, 2013. ISBN 978-3-642-33804-5, eISBN 978-3-642-33805-2, p. 417-431. Available from: https://doi.org/10.1007/978-3-642-33805-2_34
[15] TULTAYEV, B., BALBAYEV, G., ZHAUYT, A. A Kinematic analysis of flat leverage mechanism of the fourth class for manipulators. *IOP Conference Series: Materials Science and Engineering* [online]. 2017, **230**(1), 012047. ISSN 1757-8981 Available from: https://doi.org/10.1088/1757-899X/230/1/012047
[16] GOST 4543-71 "Structural alloy steel bars. Specifications" [online]. 1973. Available from: https://docs.cntd.ru/document/1200005485
[17] SERENSEN, S. V., KOGAEV, V. P., SHNEIDEROVICH, R. M. *Bearing capacity and strength calculation of machine parts*. Moscow, Mashinostroyeniye, 1985.
[18] WANG, F., ZHENG, P., DAI, J., WANG, H., WANG, R. Fault tree analysis of the causes of urban smog events associated with vehicle exhaust emissions: a case study in Jinan, China, *Science of the Total Environment* [online] 2019, **668**, p. 245-253. ISNN 1569-1705 Available from: http://dx.doi.org/10.1016/j.scitotenv.2019.02.348
[19] MA, D., ZHOU, ZH., JIANG, Y., DING, W. Constructing bayesian network by integrating FMEA with FTA. In: International Conference on Instrumentation, Measurement, Computer, Communication and Control: proceedings [online]. IEEE. 2014, ISBN 978-1-4799-6575-5, p. 696-700. Available from: https://doi.org/10.1109/IMCCC.2014.148
[20] TANG, T., LU, Y., ZHOU, T., JING, H., SUN, H. FTA and FMEA of braking system based on relex 2009. In: International Conference on Information Systems for Crisis Response and Management: proceedings [online]. IEEE. 2012. ISBN 978-1-4577-0369-0, eISBN 978-1-4577-0368-3, p. 106-112. Available from: https://doi.org/10.1109/ISCRAM.2011.6184087
[21] MIL-HDBK-217 "Reliability prediction of electronic equipment" [online]. 1991. Available from: https://www.quanterion.com/wp-content/uploads/2014/09/MIL-HDBK-217F.pdf
[22] RD 03-418-01 "Guidelines for risk analysis of hazardous production facilities" [online]. 2001. Available from: https://docs.cntd.ru/document/1200012878
[23] Agency for strategic planning and reforms of the Republic of Kazakhstan Bureau of National statistics [online]. 2021. Available from: https://stat.gov.kz/
[24] MAKAROVA, I., SHUBENKOVA, K., MUKHAMETDINOV, E., MAVRIN, V., ANTOV, D., PASHKEVICH, A. ITS safety ensuring through situational management methods. In: *Intelligent transport systems - from research and development to the market uptake* [online]. T. KOVACIKOVA, L. BUZNA, G. POURHASHEM, G. LUGANO, Y. CORNET, N. LUGANO (eds.). Cham, Springer, 2018. ISBN 978-3-319-93709-0, eISBN 978-3-319-93710-6, p. 133-143. Available from: https://doi.org/10.1007/978-3-319-93710-6
[25] XIN, S., ZHANG, L., JIN, X., ZHANG, Q. Reconstruction of the fault tree based on accident evolution. *Process Safety and Environmental Protection* [online]. 2019, **121**, p. 307-311. ISSN 0957-5820. Available from: http://dx.doi.org/10.1016/j.psep.2018.11.003
[26] WANG, Z., WEI, S., BAO, K., LIU, Y., PENG, S., ZHANG, Q. Analysis of multiple failure behaviors of steering knuckle ball hinge of multi-axle heavy vehicle. 2021, **13**(10), p. 1-8. ISSN 1687-8132. Available from: https://doi.org/10.1177/16878140211052287
[27] TORYIAMA, T., MURAKAMI, Y. The √area parameter model for evaluation of effects of various artificial defects and mutual interaction of small defects at the fatigue limit. *Journal of the Society of Materials Science* [online]. 1993, **42**, p. 1160-1166. ISSN 1880-7488. Available from: https://doi.org/10.2472/jsms.42.1160
[28] BASOV, K. A., KRASKOVSKIJ, D. G. *ANSYS in examples and tasks*. Moscow, KompyuterPress, 2002. ISBN 5-89959-092-0.
[29] SURJADI, J. U., GAO, L., DU, H., LI, X., XIONG, X., FANG, N.X., LU, Y. Mechanical metamaterials and their engineering applications. *Advanced Engineering Materials* [online]. 2019, **21**(3), 1800864. ISSN 1438-1656. Available from: https://doi.org/10.1002/adem.201800864
[30] WU, P., MENG, X., SONG, L., ZUO, W. Crash risk evaluation and crash severity pattern analysis for different types of urban junctions: fault tree analysis and association rules approaches. *Transportation Research Record: Journal of the Transportation Research Board* [online]. 2019, **2673**(1), p. 403-416. ISSN 0361-1981, eISSN 2169-4052. Available from: https://doi.org/10.1177/0361198118822
[31] PERNEBEKOV, S. S., USSIPBAYEV, U., SADYKOV, Z., AZHIBEKOV, K., URALOV, B. Selection of methods of optimization of indicators of reliability of cars. *PONTE Journal* [online]. 2018, **74**(10), p. 32-36. ISSN 2694-4839. Available from: http://dx.doi.org/10.21506/j.ponte.2018.10.3
[32] OSTREJKOVSKIJ, V.A. *Reliability theory*. Moscow, Vysshaya shkola, 2003. ISBN 5-06-004053-4