The use of methods for assessing reliability of the designed brake system on the basis of the existing one

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Abstract. Currently, the unmanned vehicles that require a high level of reliability of components and assemblies are being developed in the world. The subject of our research is calculation of reliability of pneumatic brake system "Gazon Vector". The research is aimed at calculating the reliability of the designed brake system, on the basis of the existing one and modify to the required level of reliability.

1. Introduction

Reliability is the object properties to keep for some time the values of all parameters characterizing the ability to perform the required functions in the specified modes and operating conditions.

Reliability depends on the following factors:

- Road operating conditions;
- Transport operating conditions;
- Geographic and Seasonal conditions of operation.

Road conditions determine the modes of operation of the car units. They are characterized by the technical category of the road, type and quality of the road surface and the terrain (the location of the road above sea level).

Transport operating conditions of the road transport are characterized by the rout conditions, the good characteristic features, degree of the actual loading. The above-mentioned is determined by several key factors and characteristics of the car transport conditions.

Geographic and Seasonal conditions of vehicles operation are characterized by the ambient temperature (AT), air humidity, dusty air, the intensity of precipitation, wind load, solar radiation, seasonal fluctuations in operating conditions, aggressiveness of the environment and the height above the sea level.

Vehicle’s operation in urban and suburban areas leads to non-stationary modes of operation of the internal combustion engine, as well as intensive wear of suspension elements under friction, brakes and transmission subjected to high loads. [1]

Currently, the unmanned vehicles that require a high level of reliability of components and assemblies are actively developed. This requires the calculation and analysis of the reliability level of the vehicle units and on the basis of the results obtained, it becomes possible to improve reliability to the required level and design new units of the vehicle.
"Gazon Vector" pneumatic brake system was chosen as the object of research. The "reliability calculation" and "completion to the required level" were made on the basis of the data obtained. Calculation of reliability of "Gazon Vector" pneumatic brake system.

Steps of reliability calculation:
1. Analysis of the pneumatic brake system
2. Building a block diagram of the system reliability
3. Analysis of mean time between failures
4. Calculation of system reliability
5. Updating of the system to the required level of reliability

2. Analysis of pneumatic brake system circuit.
A general view of the pneumatic brake system is given for the analysis in figure 1.

![Pneumatic brake system diagram](image)

**Figure 1.** Pneumatic brake system

1 – compressor; 2 – module for air preparation; 3 – receiver; 4 – pressure gauge sensor; 5 – parking brake valve; 6 – back valve; 7 - emergency air pressure drop gauge; 8 – rear receiver circuit; 9 – valve control output valve; 10 – brake chamber; 11 – accelerator valve; 12 – the brake chamber with the accumulator; 13 – modulator of ABS; 14 – solenoid of PBS; 15 – a brake valve; 16 – two-way valve; 17 – the accelerator valve; 18 – the ABS sensor; 19 – rotor-ABS-front; 20 – electronic ABS unit; 21 – rotor ABS rear; condensate drain cock; 22-EBD sensor

Figure 1 shows f pneumatic brake system consisting of subsystems which can result in failure of the whole system.
- Air preparation unit (BPV)
- Receiver
- Two-section brake valve
3. Building a block diagram of the system reliability.

It is carried out taking into account the following assumptions:
- All failures are independent;
- If one element fails, the system will remain operational.

To build a reliability scheme, we combine the elements into subsystems, based on the functional purpose (Figure 2).

![Figure 2. Scheme of reliability of pneumatic brake system](image)

Since the reliability of some elements in the scheme is multiplied, the reliability model is enlarged for convenience of calculations (Figure 3).

![Figure 3. The integrated circuit reliability](image)
4. Analysis of mean time between failures

The input data are received according to the GAS stations dealer on the average time of failure. They are shown in table. 1

**Table 1.** The input data.

| Elements                | Number of failures | Mean time between failures / km. | Average recovery time / h. |
|-------------------------|-------------------|---------------------------------|--------------------------|
| APU                     | 7                 | 46541                           | 0.45                     |
| The ABS modulator       | 1                 | 56000                           | -                        |
| Brake chamber           | 2                 | 29474                           | 0.5                      |
| Rear brake chamber      | 1                 | 60000                           | -                        |

The air brake system elements failure is shown in Figure 4.

**Figure 4 Failure rate**

As far as not all elements of the braking system are presented according to the statistics of failures, the value of failure-free operation of other systems responsible for road safety is adopted at the level of 90-98%.

5. System reliability Calculation

The algorithm of reliability calculation is presented in [2].

Reliability of such a system is determined by:

\[
P = P_1 \cdot (1 - (1 - P_2) \cdot (1 - P_3) \cdot (1 - P_4) \cdot (1 - P_5)) \cdot P_6
\]  

(1)

where:

- \(P_1\) – Air preparation unit
- \(P_2\) – Front left wheel contour
- \(P_3\) – Rear left wheel contour
- \(P_4\) – Rear right wheel contour
- \(P_5\) – Front right wheel contour
- \(P_6\) – ABS unit

The probability of failure-free operation according to the experimental data of the system is the following:

\[
P = 0.36 \cdot (1 - (1 - 0.53) \cdot (1 - 0.57) \cdot (1 - 0.89) \cdot (1 - 0.58)) \cdot 0.98 = 0.35
\]
As can be seen from the calculations of the lowest failure-free operation is observed in the air preparation unit.

We will increase the reliability of the above elements to 95% and carry out the calculation:

\[ P = 0.95 \cdot (1 - (1 - 0.53) \cdot (1 - 0.57) \cdot (1 - 0.89) \cdot (1 - 0.58)) \cdot 0.98 = 0.94 \]

6. Upgrading of the system to the required level of reliability

It is required to redistribute the reliability standards of the elements so as the reliability of the entire system \( P_{TP} = 0.96 \). Since the permissible value of failures for systems responsible for the BDD is 2-10 % the decision could be the following:

**Decision:**
1. Reliability of the whole system
2. Air preparation unit
3. Brake system contour
4. ABS unit

\[ P = P_1 \cdot P_2 \cdot P_3 = 0.35 \]  \hspace{1cm} (2)

To improve the system, the elements in the increasing sequence of reliability are considered

\[ P_1 \quad P_3 \quad P_2 \]

\[ i_1 < i_2 < i_3 \]

where \( i \) – serial number

Appropriate numbers are assigned.

Introduces \( P_4 = 1 \) is introduced as an imaginary element of the system

The values of the rank are:

\[ r_1 = \left( \frac{P_{TP}}{P_2 P_3 P_4} \right)^{\frac{1}{3}} = \left( \frac{0.96}{0.98 \cdot 0.99} \right)^{\frac{1}{3}} = 0.99 \]  \hspace{1cm} (3)

Where \( P_{TP} \) – the required reliability of the system

\[ r_2 = \left( \frac{P_{TP}}{P_3 P_4} \right)^{\frac{1}{2}} = \left( \frac{0.96}{0.99} \right)^{\frac{1}{2}} = 0.984 \]  \hspace{1cm} (4)

\[ r_3 = \left( \frac{P_{TP}}{P_4} \right)^{\frac{1}{1}} = \left( \frac{0.96}{1} \right)^{\frac{1}{1}} = 0.986 \]  \hspace{1cm} (5)

The number of "K" – item reliability" is determined in table 2.

**Table 2** The number of "K"

| №  | \( P_i \) | \( r_i \) | Sign |
|----|-----------|-----------|------|
| 1  | 0.36      | 0.99      | <    |
| 2  | **0.98**  | **0.984** | <    |
| 3  | 0.99      | 0.986     | >    |

To improve the system to the required level, it is necessary to increase the reliability of "K=2" elements. Their reliability increases to the level of:

\[ P_{TP} = r_k = r_2 = 0.984 \].

System reliability is determined by:

\[ P = \left( P_0^{TP} \right)^{K} \cdot \prod_{i=k+1}^{n+1} P_i = \left( P_0^{TP} \right)^{2} \cdot P_3 \cdot P_4 = (0.984)^{2} \cdot 0.99 \cdot 1 = 0.96 \]

To improve the system, the reliability of the first element should be increased from 0.36 to 0.984; the reliability of the second element should be increased from 0.98 to 0.984; the reliability of the third element is 0.99.

7. Discussion
The probability of failure-free operation according to the experimental data of the pneumatic brake system was \( P = 0.35 < P_{\text{req}} \). Since the reliability of the air preparation unit is below the permissible reliability it is necessary to increase the level of reliability of the air preparation unit to 0.95.

To modify the system to the required level of reliability, it is necessary to increase the level of reliability with \( P_1 = 0.35 \) to \( P_1 = 0.984 \).

8. Summary

The analysis of pneumatic brake system of the scheme is carried out.

The block diagram of reliability is built.

The histogram of mean time between failures is constructed.

The reliability of the pneumatic brake system is calculated.

The system was improved to the required level of reliability.

References

[1] Kuzmin N A and Borisov G V 2014 Regularities of change of working capacity of cars Nizhny Novgorod NSTU
[2] Berdnikov L A, Suvorov I A and Vilkov N A 2013 An integrated approach to examine factors determining the reliability of the automotive internal combustion engine turbochargers Collection of materials 12 International youth scientific and technical conference "The future of technical science", Nizhny Novgorod NSTU 195-196
[3] Korchazhkin M G, Khoryaev E A 2016 The study of reliability of fuel systems of automobile diesel engines Collection of materials 94 international scientific and technical conference of the Association of automotive engineers "Unmanned vehicles: problems and prospects", Nizhny Novgorod NSTU 240-245
[4] Korchazhkin M G, Soloviev S S 2013 Features of operational reliability of automatic transmissions of cars Works of NSTU 4 (101) 66-71
[5] Tokarev A V and Berdnikov L A 2017 Features of diagnostics of technical brake systems at technical inspection Transport system 3 21-26