Designed brake system reliability assessment techniques application on the basis of the real one

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Abstract. The paper analyses and assesses the reliability of the designed brake system on the basis of the real one. Analysis of the basic diagram and the components’ eventual failures was made. Based on the built structural diagram of the brake system the reliability level was estimated. Measures to increase the system reliability were proposed.

Key words: brake system, reliability calculation, failure quota, operating time.
Research subject: GAZel NEXT hydraulic brake system reliability calculation.
Research purpose: build a structural diagram and estimate the level of reliability of the hydraulic brake system, refine to the required reliability level.

Introduction
Nowadays, the majority of people have a car at their disposal. Using any vehicle is permissible if it has a faultless brake system. The ability of a forced deceleration and a quick stop is the automobile most important characteristic which influences its performance criteria (efficiency, fuel consumption, and other factors); they are essential for traffic safety. The brake system technical state affects traffic safety sufficiently.

The car brake system means, firstly, its safety, therefore, it must be paid great attention to, it must be timely maintained and correctly used. In case the brake system fails in the vehicle operation the consequences may be grave both for the driver and the people involved.

Nowadays, new safety measures are being devised to prevent road accidents caused by the brake system, so reliability is the main quality indicator.

“GAZel NEXT” hydraulic brake system reliability calculation.

Reliability calculation plan.
1. The hydraulic brake system analysis and investigation of possible failures of the system components.
2. Building a system reliability structural diagram.
3. Mean time to failure analysis.
4. System reliability computing.
5. System updating to the required level.

Hydraulic brake system diagram analysis
To analyze the above the general view of the hydraulic brake system is shown below (fig. 1).
Figure 1. GAzel NEXT break system diagram

1 – Brake disk; 2 – Front wheel brake gear; 3 – Right front wheel brake gear brake pipe; 4 – Brake master cylinder; 5 – Hydraulic drive tank; 6 – Vacuum booster; 7 – Tappet; 8 – Brake pedal; 9 – Brake pedal sensor and stop light switch; 10 – Rear brake gear shoes; 11 – Wheel brake cylinder; 12 – Right rear wheel brake gear brake pipe; 13 – Left rear wheel brake gear brake pipe; 14 – Parking brake rear cables; 15 – Equalizer; 16 – ABS unit; 17 – Front cable of the parking brake; 18 – Parking brake signaling device switch; 19 – Brake handle; 20 – Brake fluid alert signaling device; 21 – Front left wheel brake gear break pipe.

Figure 2. GAzel NEXT brake system components’ manufacturers

Building system reliability structural diagram
The building is done including the following assumption:

1) All failures are independent;
2) In case one component fails the system remains non-serviceable.
   • Brake pedal
   • Brake pedal sensor and stop light switch
   • Tappet
Let us build a system reliability model of the obtained components (fig. 3):

**Figure 3.** Hydraulic brake system reliability diagram

**Mean time to failure analysis**

The initial data array was obtained from the of dealer stations OAO GAZ information on the mean time to failure (table. 1)

**Table 1 - Failure data**

| Components                        | Number of failures | Mean time to failure, km | Reconditioning mean time, norm/h |
|-----------------------------------|--------------------|--------------------------|----------------------------------|
| Brake pedal                       | -                  | $\rightarrow \infty$     | $\rightarrow 0$                 |
| Brake pedal sensor and stop light switch | -                  | $\rightarrow \infty$     | $\rightarrow 0$                 |
| Tappet                            | -                  | $\rightarrow \infty$     | $\rightarrow 0$                 |
| Vacuum booster                    | 1                  | 27                       | 1.4                              |
| Hydraulic drive tank              | -                  | $\rightarrow \infty$     | $\rightarrow 0$                 |
| Brake master cylinder             | -                  | $\rightarrow \infty$     | $\rightarrow 0$                 |
| ABS unit                          | -                  | $\rightarrow \infty$     | $\rightarrow 0$                 |
| Front axle brake gear             | 4                  | 60160                    | 0.78                             |
| Rear axle brake gear              | 23                 | 79360                    | 0.445                            |
| Brake fluid alert level signaling device | 1                  | 15048                    | 0.4                              |

Total number of failures : 29
System reliability calculation

The system reliability is estimated:

\[ P = P_1 \times P_2 \times P_3 \times P_4 \times P_5 \times P_6 \times P_7 \times P_8 \times P_9 \times P_{10} \] (1)

The probability of no-failure operation according to experimental data about the system failures is the following:

- Brake pedal \( P_1 \geq 0.98 \)
- Brake pedal sensor and stop light switch \( P_2 \geq 0.98 \)
- Tappet \( P_3 \geq 0.98 \)
- Vacuum booster \( P_4 \geq 0.97 \)
- Hydraulic drive tank \( P_5 \geq 0.98 \)
- Brake master cylinder \( P_6 \geq 0.98 \)
- ABS unit \( P_7 \geq 0.98 \)
- Front axle brake gear \( P_8 \geq 0.86 \)
- Rear axle brake gear \( P_9 \geq 0.21 \)
- Brake fluid alert signaling device \( P_{10} \geq 0.97 \)

\[ P = 0.98 \times 0.98 \times 0.98 \times 0.97 \times 0.98 \times 0.98 \times 0.98 \times 0.86 \times 0.21 \times 0.97 = 0.15 \]

As is obvious the component Rear axle brake gear has low probability of no-failure operation. Let us assume that we raise its reliability to 95% and do the calculation.

\[ P = 0.98 \times 0.98 \times 0.98 \times 0.97 \times 0.98 \times 0.98 \times 0.98 \times 0.86 \times 0.95 \times 0.97 = 0.68 \]

The system updating to the required reliability level

To update the system, the components’ reliability norms redistribution is required so that the whole system reliability must be \( P_{TF} = 0.71 \), as the allowable failure rate of the systems responsible for traffic safety is (2-10%).

Solution:
- Whole system reliability
- Brake pedal \( P_1 \)
- Brake pedal sensor and stop-light switch \( P_2 \)
- Tappet \( P_3 \)
- Vacuum booster \( P_4 \)
- Hydraulic drive tank \( P_5 \)
- Brake master cylinder \( P_6 \)
ABS unit $P_1$
- Front axle brakes gear $P_8$
- Rear axle brakes gear $P_9$
- Brake fluid alert level signaling device $P_{10}$
- To update the system let us consider the components in reliability ascending sequence

$P_9$ $P_8$ $P_4$ $P_{10}$ $P_2$ $P_3$ $P_5$ $P_6$ $P_7$ $P_1$

$0.21 < 0.86 < 0.97 < 0.97 < 0.98 < 0.98 < 0.98 < 0.98 < 0.98 < 0.98$

$i_1$ $i_2$ $i_3$ $i_4$ $i_5$ $i_6$ $i_7$ $i_8$ $i_9$ $i_{10}$

where $i$ is the order number

Let us assign respective numbers.

Introduce $P_{11} = 1$ which is an imaginary element of the system

- Let us value ranks:

\[ r_1 = \left( \frac{P_T}{P_9} \right)^{\frac{1}{3}} = \frac{0.71}{(0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+1)^3} = 0.99 \] (2)
\[ r_2 = \left( \frac{P_T}{P_9} \right)^{\frac{1}{3}} = \frac{0.71}{(0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+1)^3} = 0.92 \] (3)
\[ r_3 = \left( \frac{P_T}{P_9} \right)^{\frac{1}{3}} = \frac{0.71}{(0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+1)^3} = 0.94 \] (4)
\[ r_4 = \left( \frac{P_T}{P_9} \right)^{\frac{1}{3}} = \frac{0.71}{(0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+1)^3} = 0.95 \] (5)
\[ r_5 = \left( \frac{P_T}{P_9} \right)^{\frac{1}{3}} = \frac{0.71}{(0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+1)^3} = 0.95 \] (6)
\[ r_6 = \left( \frac{P_T}{P_9} \right)^{\frac{1}{3}} = \frac{0.71}{(0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+1)^3} = 0.96 \] (7)
\[ r_7 = \left( \frac{P_T}{P_9} \right)^{\frac{1}{3}} = \frac{0.71}{(0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+1)^3} = 0.96 \] (8)
\[ r_8 = \left( \frac{P_T}{P_9} \right)^{\frac{1}{3}} = \frac{0.71}{(0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+1)^3} = 0.96 \] (9)
\[ r_9 = \left( \frac{P_T}{P_9} \right)^{\frac{1}{3}} = \frac{0.71}{(0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+1)^3} = 0.96 \] (10)
\[ r_{10} = \left( \frac{P_T}{P_9} \right)^{\frac{1}{3}} = \frac{0.71}{(0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+0.98+1)^3} = 0.97 \] (11)

Let us estimate the «K» number which is a reliability element (table 2)

**Table 2 - Number of updated components calculation**

| №  | $P_i$  | $r_i$  | Symbol |
|----|--------|--------|--------|
| 1  | 0.21   | 0.99   | <      |
| 2  | 0.86   | 0.92   | <      |
| 3  | 0.97   | 0.94   | >      |
| 4  | 0.97   | 0.95   | >      |
| 5  | 0.98   | 0.95   | >      |
| 6  | 0.98   | 0.96   | >      |
| 7  | 0.98   | 0.96   | >      |
| 8  | 0.98   | 0.96   | >      |
| 9  | 0.98   | 0.96   | >      |
| 10 | 0.98   | 0.97   | >      |
To update the system to the required level the reliability of \( K=2 \) components must be increased. Their reliability is raised to the level: \( P_{n}^{TP} = r_k = r_2 = 0.92 \).

The system reliability is calculated as follows:

\[
P = (P_{0}^{TP})^K \times \prod_{i=k+1}^{n+1} P_i = (P_{0}^{TP})^2 \times P_3 \times P_4 = (0.92)^2 \times 0.97 \times 0.97 \times 0.98 \times 0.98 \times 0.98 \times 0.98 \times 0.98 \times 1 = 0.71
\]

To update the system the following must be done: the reliability of the first component is 0.98; the reliability of the second component is 0.98; the reliability of the third component is 0.98; the reliability of the fourth component is 0.97; the reliability of the fifth component is 0.98; the reliability of the sixth component is 0.98; the reliability of the seventh component is 0.98; the reliability of the eighth component must be raised from 0.86 to 0.92; the reliability of the ninth component must be raised from 0.21 to 0.92; the reliability of the tenth component is 0.97.

Reliability probability according to the observed data of the hydraulic brake system is \( P = 0.15 < P_{add} \). As the reliability of the rear axle brake gear is lower than the allowable one. Reliability level of the rear axle brake gear must be raised to 0.92.

The system updating to goal was done, reliability level must be raised from \( P = 0.15 \) to \( P = 0.71 \).

**Conclusion**

In the course of investigation, the hydraulic brake system was analyzed, based on it a reliability structural diagram was built. Proceeding from the obtained data a mean time to failure histogram was built; it shows the main components subject to risk. In calculating the system reliability it was found that to raise the whole system reliability to the required level the brake gear reliability of front and rear axles must be increased to 0.92.

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