Fuel system reliability of gas tank tractors

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Abstract. The article is devoted to the analysis of works on the use of alternative fuels. Reliability indicators of the elements of the compressed natural gas and diesel fuel supply system have been studied to substantiate the maintenance system. On the basis of statistical observations, the performance indicators of intensity of the event flow $\lambda$ and probability of failure are obtained. It is shown that the elements of the gas and fuel supply system have high reliability. At the same time, the fuel supply system elements have slightly lower reliability than when a diesel engine is running on pure diesel fuel. It is recommended to maintain the dual-fuel gas-supply system of the diesel engine according to the regulations used for engines running on mineral fuel with additional control of the gas-supply system elements.

1. Introduction

In connection with depletion of stocks of mineral fuels for operation of internal combustion engines and harm caused by the use of these fuels, working in agricultural and industrial enterprises, the question of replacement of mineral fuels for alternative fuels is acute [1, 2]. The analysis of works on alternative fuels use carried out by scientists of our country and other countries shows that one of the alternative fuels is gas [2–4]. And gas is natural gas, the reserves of which significantly exceed the reserves of oil from which mineral fuels are currently produced. Besides, when natural gas is burned in the internal combustion engine, significantly less harmful to living organisms poisonous substances are emitted. Typically, natural gas is used as a fuel for internal combustion engines in the form of compressed gas.

2. Problem Statement

The main issue that arises in the development of a diesel power system due to the high temperature of gas self-ignition is the development of a power system [4, 5]. Currently, the most common is a two-phase power system where diesel fuel is used as an ignition dose at the start and during normal operation, and compressed natural gas (CNG) is used during normal operation. V.P. Goryachkin, V.V. Vasilenko, A.B. Lurieu, S.A. Iofinov, A.A. Zangiev, A.N. Karpenko, E.I. Lipkovich, E.V. Zhalnin, V.A. Markov, S.N. Devyanin, A.I. Gaivoronsky, V.N. Luknin, V.V. Volodin and other scientists deal with the issues of efficiency of natural gas use as a fuel for diesel engines and environmental safety assessment. The analysis of these works shows that the use of compressed natural gas allows reducing diesel fuel consumption by 50 % and emissions of toxic gas components into the atmosphere by 10 %. At the same time, considerably less attention is paid to the reliability of such systems. The given question becomes actual in connection with an unsteady mode of work of tractors that negatively influences on reliability of elements of tractors and a feeding system [6, 7]. In the given work the
statistical analysis of reliability of two-fuel systems of a feeding of diesel engines by the natural compressed gas has been spent.

3. Research Questions
It is shown that the elements of the gas and fuel supply system have high reliability.
At the same time, the fuel supply system elements have slightly lower reliability than when a diesel engine is running on pure diesel fuel. It is recommended to maintain the dual-fuel gas-supply system of the diesel engine according to the regulations used for engines running on mineral fuel with additional control of the gas-supply system elements.

4. Purpose of the Study
The purpose of this article is to study the reliability indicators of power system elements with compressed natural gas and diesel fuel to justify the maintenance system.

5. Research Methods
Statistical observations were made in farms of the Omsk region. 20 MTZ-80 tractors were examined. Tractors were re-equipped with compressed natural gas according to the scheme [8, 9] taking into account the recommendations for re-equipping stated in [10, 11]. Tractors worked on the same type of works (cultivation, harrowing, sowing) during 2017 - 2019. The working time of each tractor during the season was 1000-1200 moto-hours.
During the tests we used diesel fuel of L grade according to GOST 305-82 [12], engine oil M-10-G2 according to GOST 17479.1-85 [13] and compressed natural gas in cylinders according to GOST 27577-2000 [14] (Table 2).

![Figure 1. Diesel fuel supply system with compressed natural gas](image)
The MTZ-80 tractor equipped with the D-240 engine is equipped with the additional gas supply system, which includes elements (Table 1).

**Table 1. Engine gas supply system elements**

| Name                                              | Amount |
|---------------------------------------------------|--------|
| 1. Gas cylinders for compressed natural gas storage | 4      |
| 2. Valves for gas equipment maintenance with filled cylinders and in case of emergency | 5      |
| 3. Pressure gauge to estimate gas quantity in cylinders | 1      |
| 4. Filling device for gas filling of cylinders     | 1      |
| 5. Electromagnetic valve                          | 3      |
| 6. High pressure reducer to reduce gas pressure in the first control stage | 1      |
| 7. Low pressure reducer to reduce gas pressure in the second control stage | 1      |
| 8. Engine inlet manifolds                        | 1      |
| 9. Gas pressure sensor                            | 1      |
| 10. Coolant temperature sensor                    | 1      |
| 11. High pressure fuel pump                       | 4      |
| 12. Nozzle                                        | 16     |

**Table 2. Composition of natural gas used in bench tests**

| Name                | Contents, % |
|---------------------|-------------|
| Methane             | 99.25       |
| Ethan               | 0.20        |
| Propane             | 0.09        |
| Isobutane           | 0.03        |
| Nitrogen            | 0.39        |
| Carbon oxide        | 0.01        |
| Others              | 0.03        |
| Hydrogen sulfide    | The lack of |

To assess reliability, the main indicators were used: the intensity of the event flow \( \lambda \) and the probability of failure-free operation of the system as a whole for the time \( t' \). The intensity of the event flow \( \lambda \) was determined by a known formula:

\[
C = \frac{1}{t},
\]

where \( t \) - average return on failure, \( P_i(t_0) \) – probability of trouble-free operation of the \( i \)-th element of the system for the time \( t \); \( m \) - number of elements in the system:

\[
p_i(t_0) = e^{-\lambda_i t'_0},
\]

\( t'_0 \) - tractor runtime during the day. Calculations were made for \( t'_0 = 7 \).  

**6. Results**

During the whole operation of tractors there were no failures of gas cylinders for storage of compressed natural gas, manometer for evaluation of gas quantity in cylinders, engine inlet manifolds and coolant temperature sensor. Therefore, the event flow intensity \( \lambda \) of these elements was taken equal to 0, and the probability of failure-free operation during the shift \( t'0 = 7 \) motor-hours was taken equal to 1.

Figure 2 shows a histogram of operating time distribution before the first valve failure to ensure the possibility of gas equipment maintenance with filled cylinders and in case of emergency. As a result of
processing the valve failure monitoring results, the following reliability parameters were obtained: average operating time per failure was 2619.85 moto-hours, intensity of failure flow was $\lambda=0.000382$ moto-hours$^{-1}$ and probability of failure-free operation was 0.997332. Average quadratic failure time deviation was $\sigma=49.356$ motor-hours. The coefficient of variation was $K_v=1.88\%$. Figure 3 shows a histogram describing the operating time distribution of the device for gas-filling of cylinders before the first failure. As a result of processing the results of valve failure monitoring, the following parameters characterizing reliability were obtained: average operating time per failure was 3314.45 moto-hours, intensity of failure flow was $\lambda=0.000302$ moto-hours$^{-1}$ and probability of failure-free operation was 0.99789. An average square value $\sigma=213.9945$ moto-hours and the variation coefficient $K_v=6.45\%$.

![Figure 2. Bar diagram of the valve failure distribution](image1)
![Figure 3. Fault distribution histogram of the tank filling device](image2)

Figure 4 shows a histogram of the high pressure gearbox failure distribution for reducing gas pressure in the first control stage.

![Figure 4. Gearbox fault distribution histogram (first control stage)](image3)

The following parameters characterizing the reliability of the high pressure reducer were obtained: average operating time to failure - 730.6 motor-hours, intensity of the failure flow - $\lambda=0.001369$ motor-hour$^{-1}$, probability of no-failure operation - $p(t)=0.990466$, average square deviation $\sigma=185.92$ motor-hour, variation coefficient $K_v=25.61\%$.

Figure 5 shows a histogram of the low pressure gearbox failure distribution for reducing gas pressure in the second stage of regulation.
The following parameters characterizing the reliability of the low pressure reducer were obtained: average operating time to failure - 797.15 motor-hours, intensity of the failure flow - \( \lambda = 0.001254 \) motor-hour - 1, probability of no-failure operation - \( p(t) = 0.991257 \), average square deviation - \( \sigma = 162.47162 \) motor-hour, variation coefficient - \( K_v = 20.38\% \).

Figure 6 shows a histogram of operating time distribution before the first failure of the gas pressure sensor.

As a result of processing the results of failure monitoring of the gas pressure sensor, the following reliability parameters were obtained: average operating time per failure was 2901 motor-hours, intensity of failure flow was \( \lambda = 0.000345 \) motor-hours - 1 and probability of failure-free operation was 0.99759. An average quadratic error - \( \sigma = 201,123 \) moto-hours. The coefficient of variation - \( K_v = 6.93\% \).

Figure 7 shows a histogram of the operating time distribution before the first high pressure fuel pump failure.

As a result of processing the results of the high-pressure fuel pump failure monitoring the following parameters characterizing reliability were obtained: the average operating time per failure was 2751.8 motor-hours, the intensity of the failure flow was \( \lambda = 0.000363 \) motor-hours - 1 and the probability of no-failure operation was 0.997459. An average high-pressure fuel pump - \( \sigma = 156.12386 \) moto-hours. The coefficient of variation - \( K_v = 5.67\% \).
As a result of processing the results of the nozzle failure monitoring, the following parameters characterizing reliability were obtained: average operating time per failure was 1.064 moto-hours, intensity of the failure flow was $\lambda=0.00094$ moto-hours$^{-1}$ and probability of the failure-free operation was 0.993443. An average high pressure fuel pump $\sigma=171,900,12$ moto-hours. The coefficient of variation - $K_v=16.16\%$.

Calculated by formulas (1) and (2), characterizing reliability of CNG power supply system, data are given in Table 3.

**Table 3.** Summary table of parameters characterizing the reliability of the D-240 diesel engine compressed gas supply system elements

| Name | $\lambda$ | $p(t)$ |
|------|-----------|--------|
| 1. Gas cylinders for compressed natural gas storage | 0 | 1 |
| 2. Valves for gas equipment maintenance with filled cylinders and in case of emergency | 0.000382 | 0.997332 |
| 3. Pressure gauge to estimate gas quantity in cylinders | 0 | 1 |
| 4. Cylinder gas filling device | 0.000302 | 0.99789 |
| 5. Electromagnetic valve | 0 | 1 |
| 6. High pressure reducer to reduce gas pressure in the first control stage | 0.001369 | 0.990466 |
| 7. Low pressure reducer to reduce gas pressure in the second control stage | 0.001254 | 0.991257 |
| 8. Engine inlet manifolds | 0 | 1 |
| 9. Gas pressure sensor | 0.000345 | 0.99759 |
| 10. Coolant temperature sensor | 0 | 1 |
| 11. High pressure fuel pump | 0.000363 | 0.997459 |
| 12. FD-22 nozzles | 0.00094 | 0.993443 |

The analysis of the diagrams presented in Figures 2-8 shows that the parameters characterizing the reliability of the CNG diesel engine power system elements change in a wide range of random ways and do not obey a certain distribution law. According to Table 3, the CNG diesel power system elements have high reliability. The average failure probability varies from 0.990466 to 1. Therefore, when improving the maintenance system of tractors converted to CNG power, the frequency of
maintenance of gas equipment is taken similar to the frequency of standard tractor, but it is necessary to take into account the fire safety properties.

7. Conclusion

The analysis of literary sources has shown that at present there are practically no scientific works considering the reliability of fuel systems of tractors converted to CNG power. Reliability indicators of CNG and diesel fuel supply system have high reliability, so the frequency of maintenance of converted tractors is the same as that of serial tractors.

The indices characterizing the reliability of CNG diesel power supply system elements change randomly in a wide range and do not follow some regularities. Taking into account the fire hazard of CNG it is necessary to pay more attention to the maintenance of the CNG supply system elements, the operation of which is associated with a possible gas leak.

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