Study of the Results of Fuel Injection Advance Angle Measurement by Probabilistic and Statistical Methods

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Abstract - This paper investigates one of the diagnostic parameters affecting quality performance of a diesel engine fuel system, the fuel injection advance angle. As a result of statistical analysis we received graphical models of the probability of false and undetected failure, which can help predict the accuracy of the diagnosis. Within the scope of the study there has been developed a laid on optical pressure sensor in the fuel injection line of a superimposed diesel engine.

Fuel system equipment maintenance for diesel engines is based on a periodic review and adjustment of the fuel injection pump assembly and injectors on special stands in workshops of a transport park [1]. Removing the fuel system and installing it on the engine after checking and adjusting is related on the one hand to the cost of labor for installation and dismantling, and on the other hand, it will inevitably lead to increased wear. Besides, check of the fuel equipment in conditions different from operating ones, does not always allow detecting all faults and adjustment disorders. [2] Based on the above we will consider the possibility of diagnostics of fuel equipment directly on the engine while it is running.

The quality of the fuel supply affects the engine power, fuel consumption and the content of harmful substances in the exhaust gases. [3] If the fuel injection starts too early, an engine works hard, with a loud noise of combustion, low fuel consumption, but with a high content of nitrogen oxides in the exhaust gas. The early fuel injection increases opacity, as the increased ignition delay results in low cycle temperature. At the late start of fuel injection an engine responds by a loss of power and increased fuel consumption. Besides, the late fuel injection increases exhaust gas temperature, which can result in damage of the exhaust valves. [4] Thus, a major role is played by the diesel engine fuel system diagnosis, which includes checking and precise setting of the beginning of the fuel injection [5]. Let us consider the process of diagnosis.

Diagnosis is made by measuring the most important parameters of the fuel supply system: the engine speed at different operational modes, the advance angle of fuel injection, the spread of the angle of advance in pump sections, fuel injection medium-pressure. [6]

In this paper we consider one of the parameters of diagnosing fuel systems – measurement and control of the fuel injection advance angle. There has been designed an optical sensor for its control and measurement. The sensor is installed onto the fuel system line without disassembling it, i.e. it is laid on.

It is known [5] that the engine feed line extends by 0,001 mm in diameter when the fuel injection pressure increases. The principle of operation of the sensor is based on the fact that the surface of the engine feed line is illuminated by a LED or laser, the reflected light falls on the detector, which detects changes in brightness caused by the expansion of the engine feed line. The infrared range is selected in order to minimize the value of external exposure.

The advantage of the optical method is in greater sensitiveness (compared to the strain sensor). [7]

The design of the sensor case allows mounting it on the surface of the engine feed line. A LED and a photodiode (photodetector) are set so that the reflection from the surface, a beam of light from the LED, got to the photodetector. A schematic cross-section of the sensor is shown in Figure 1.

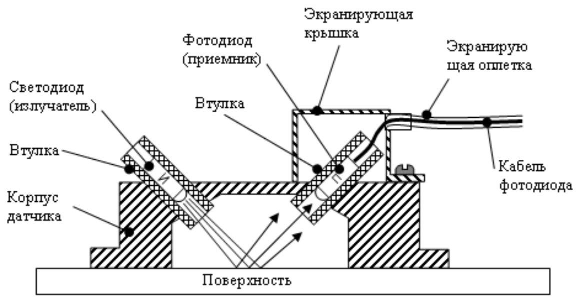

Figure 1: Schematic sensor cross section

The measurements were performed on a laboratory stand simulating a diesel engine.The signal was registered by an oscilloscope at the engine speed within 600 rpm.

The use of a microcontroller allows for statistical analysis. As a result of statistical processing it is possible to assess the control risks [8].

Accuracy is the criterion of quality control. The accuracy of diagnosis is the degree of confidence that the measured values reflect the true state of an object. [9]

The measurement results were summarized in the statistical series and after statistical analysis it was found that the values of the distribution of the statistics are subject to the normal law.

Control errors to a large extent depend on the measurement errors and the value of standards for the monitored parameter. Since the recorded parameters contain random errors, in the process occur control errors, which are called P_f - the probability of false failure and R_u - undetected failure [9]. To quantitatively measure and predict the indicated probabilities it is necessary to develop a mathematical model.

In the measurement control by the means having a random error, there are possible 4 cases [9]:

1) The true parameter value lies within tolerance and is measured within tolerance;

2) The true parameter value lies outside the limits and is measured outside the limits;

3) The true parameter value lies within the tolerance, and the device records the value out of tolerance;

4) The true value of the parameter is out of tolerance, and the device does not record it as being out of bounds.

These four cases are a complete group of incompatible events, the total probability is of unit value. In the future, we are only interested in the latter two cases.

As a result of these calculations, we obtain an expression that determines the probability of false failure for the i-interval.

Figure 2 illustrates the process of the control error formation, where the density distribution of the diagnostic parameter $f(S)$ of a car system and the random error of measurement means $\varphi(Y)$ obey the normal law.

This paper considers the case of single-range diagnostic parameter limitation that provides car performance. Considering a single-range case, it is assumed that one of the norms is zero. Figure 2 shows the case of upper bounds by S_B norm, thus S_H=0.

We say that event A is when the current value of the diagnostic parameter is in the range of $S_i \div S_{i+1}$; and event B is when the results of measurement (reading) is greater than the limit value. Since the probability of a particular value of the parameter is zero, then we will consider the interval S_i-S_{i+1}, where randomly can be parameter S.

Then the probability of event A will be determined by the following expression:

$$P_i(A) = \int_{S_i}^{S_{i+1}} f(S)dS \qquad (1)$$

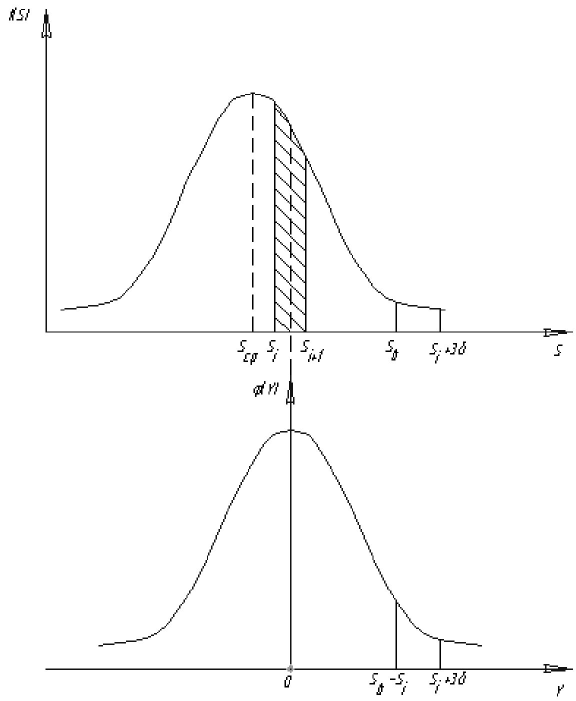

Figure 2: Scheme of formation of control error for single-range limit of the tolerance of the diagnostic parameter

where: $f(S)$ – frequency distribution function of the testing parameter;

$\varphi(Y)$ – density distribution of the random error of a measuring tool;

S_{av} – average value of the testing parameter;

S_i – actual value of the testing parameter;

$S_в$ – upper limit of the tolerance of the diagnostic parameter.

Probability of event B is given by formula 2:

$$P_i(B) = \int_{S_в - S_i}^{+\infty} \varphi(Y)dY \qquad (2)$$

Error is the probability of the simultaneous implementation of the events A and B, which is the probability of unwanted effects (probability of false failure and the probability of undetected failure).

The probability of false failure P_{lo} is determined by the formula 3:

$$P_{iло} = \int_{S_i}^{S_{i+1}} f(S)dS \cdot \int_{S_в - S_i}^{+\infty} \varphi(Y)dY \qquad (3)$$

Distribution density functions are as follows:

$$f(S)=\frac{1}{\delta_s\sqrt{2\pi}}\cdot e^{-\frac{\left(S_i-S_{cp}\right)^2}{2\delta_s^{\,2}}}$$

$$\varphi(Y)=\frac{1}{\delta_\varphi\sqrt{2\pi}}\cdot e^{-\frac{Y^2}{2\delta_\varphi^{\,2}}} \tag{4}$$

where S_{av} – the average value of the diagnostic parameter;

δ_s, δ_φ - standard deviations of the distributions of the diagnostic parameter and measuring errors, respectively.

We obtain the expression for the probability of a false failure for the i-interval S:

$$P_{iло}=\int_{S_i}^{S_{i+1}}\frac{1}{\delta_s\sqrt{2\pi}}\cdot e^{-\frac{\left(S_i-S_{cp}\right)^2}{2\delta_s^{\,2}}}dS\cdot\int_{S_в-S_i}^{+\infty}\frac{1}{\delta_\varphi\sqrt{2\pi}}\cdot e^{-\frac{Y^2}{2\delta_\varphi^{\,2}}}dY \tag{5}$$

If we proceed to a new variable (formula 6), called the normalized random variable, we get a function of Laplace (expression 7):

$$t=\frac{S-S_{cp}}{\delta_s}$$

$$z=\frac{Y}{\delta_\varphi} \tag{6}$$

$$P_{iло}=\frac{1}{\sqrt{2\pi}}\int_{S_i}^{S_{i+1}}e^{-\frac{t^2}{2}}dt\cdot\frac{1}{\sqrt{2\pi}}\int_{S_в-S_i}^{+\infty}e^{-\frac{z^2}{2}}dz \tag{7}$$

Equation (7) allows for the numerical evaluation P_{if} of a random i-interval of S parameter values in the range of Si-Si +1.

To calculate the total error P_f it is necessary to break down the interval into n sections and sum over the entire range of S values:

$$P_{ло}=\sum_{i=1}^{n}\frac{1}{\sqrt{2\pi}}\int_{S_i}^{S_{i+1}}e^{-\frac{t^2}{2}}dt\cdot\frac{1}{\sqrt{2\pi}}\int_{S_в-S_i}^{+\infty}e^{-\frac{z^2}{2}}dz \tag{8}$$

Similarly, the expression for the evaluation of undetected failure P_u will look:

$$P_{но}=\sum_{i=1}^{n}\frac{1}{\sqrt{2\pi}}\int_{S_i}^{S_{i+1}}e^{-\frac{t^2}{2}}dt\cdot\frac{1}{\sqrt{2\pi}}\int_{S_i-S_в}^{+\infty}e^{-\frac{z^2}{2}}dz \tag{9}$$

Thus, we receive an analytical model of reliability of testing process in diagnostic systems of diesel engines:

$$D=1-\left(\sum_{i=1}^{n}\frac{1}{\sqrt{2\pi}}\int_{S_i}^{S_{i+1}}e^{-\frac{t^2}{2}}dt\cdot\frac{1}{\sqrt{2\pi}}\int_{S_в-S_i}^{+\infty}e^{-\frac{z^2}{2}}dz+\sum_{i=1}^{n}\frac{1}{\sqrt{2\pi}}\int_{S_i}^{S_{i+1}}e^{-\frac{t^2}{2}}dt\cdot\frac{1}{\sqrt{2\pi}}\int_{S_i-S_в}^{+\infty}e^{-\frac{z^2}{2}}dz\right)$$

In probability theory, it is assumed that the maximum parameter deviation is ± 3δ. Figure 3 shows the arrangement of the mean square deviations. It is known [10] that each range of values corresponds to a certain amount of probability:

$$P(S_{cp}-\delta<S<S_{cp}+\delta)=68\%$$

$$P(S_{cp}-2\delta<S<S_{cp}+2\delta)=95\%$$

$$P(S_{cp}-3\delta<S<S_{cp}+3\delta)=99{,}8\%$$

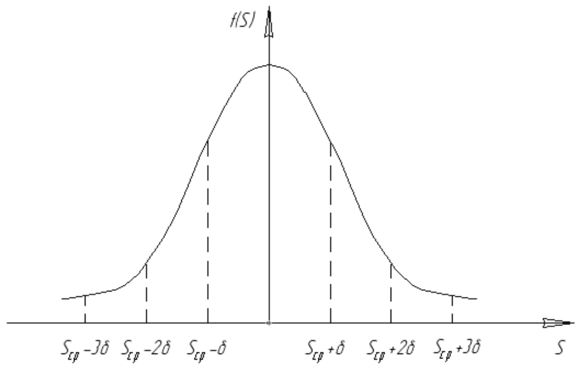

Figure 3 Arrangement of mean square deviations

We define the probability of false failure R_f and the probability of undetected failure R_u on example of one diagnostic parameter - the fuel supply advance angle.

After calculations we use the data available to construct the graphical model of the probability of a false failure R_f (Figure 4) and the graphical model of the probability of an undetected failure R_u (Figure 5).

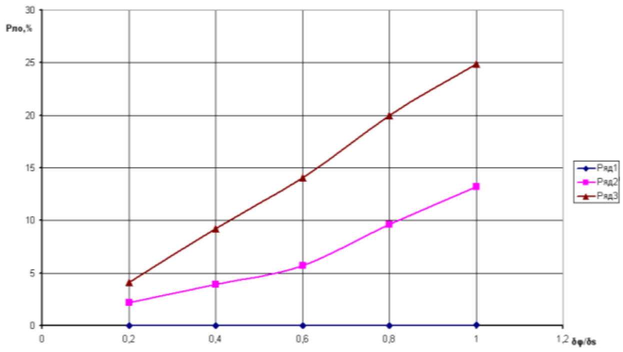

Figure 4 The graphical model of the probability of a false failure R_f

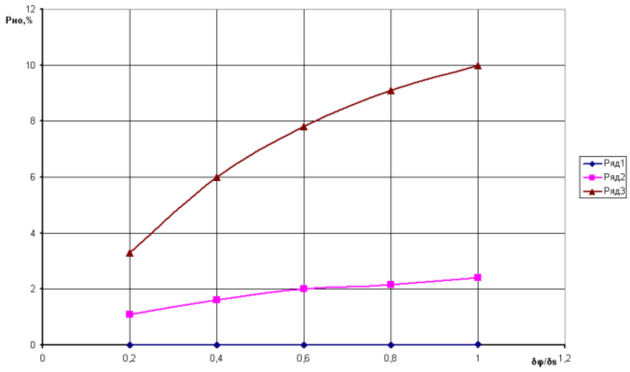

Figure 5 The graphical model of the probability of an undetected failure R_u

Thus, having received graphical models of the probability of occurrence of false and undetected failure, we can predict the accuracy of the diagnosis by the formula 10:

$$D = 1 - (P_f + P_u) \tag{10}$$

Studying Figures 4 and 5 we can conclude that the probability of false failure R_f is subject to a greater impact. If the value of the measurement error δ_φ is commensurable with the value of δ_s, the risk can be up to 25%. With an increase in the standard mean square deviation of measurement instrument errors δ_φ the error rate increases.

REFERENCES

[1] Miroshnikov L., Boldin A. Pal V. Diagnosing the technical condition of vehicles in transport companies. Moscow “Transport”, 1977 - 263 pp.

[2] Borts A., Zakin Ya., Ivanov U. Diagnostics of technical vehicle conditions. - Moscow “Transport”, 1979 - 158 pp.

[3] Kulchitsky A.R. Toxicity of automobile and tractor engines. M.: "Aademichesky Project" 2004 - 400 pp.

[4] Grekhov L.V., Ivaschenko N.A., Markov V.A. Fuel injection equipment and control systems of diesel engines: Textbook for universities. M. Legion-Avtodata, 2004. - 344 pp.

[5] Günther H. Diagnosis of diesel engines. Translated from German by Yu.G. Grudskii - Moscow LLC "Book Publishers “Za Rulyom”, 2007. – 176 pp.

[6] Kornev V.A., D.A. Porubov, B.A. Suleimenov, W. Wójcik. Diagnosing fuel system of diesel engines with the use of information and communication principles. № 1 (35), / / Engineering and technical journal "Bulletin of automation," March, 2012 p.2-3

[7] Friden J.. Modern sensors. Handbook. Translation from English by Zabolotnaya J.A., edited by Svintsov E.L. M. Technosphere., 2005 - 592 pp.

[8] Scheinin A.M., J.O. Kulseitov, Kornev V.A. Establishment of the applicability of statistical forecasting of tool reliability of diagnosis for the control tools error / / Proceedings of the MADI Issue 79 - Moscow, 1974

[9] Kuleshov V.K. Kornev V.A. Modeling of the processes of control and decision-making: monograph. - Tomsk: Tomsk Polytechnic University, 2011. - 295 pp.

[10] Sachs L. Statistical estimation. Translated from German by V.N. Varygina. Ed. P. Adler, V.G. Gorsky. M., "Statistics", 1976 - 598 p. (Foreign studies in statistics).