Alvydas PIKŪNAS
Bronislovas SPRUOGIS
J. JUREVIČIUS

INVESTIGATION OF RELIABILITY OF HIGH-PRESSURE FUEL PUMPS

This paper presents the research of faults of high-pressure fuel pumps (HPFP) as the main units of fuel equipment having influence on its reliability. Based by example of distributive-type ram HPFP-s, produced in Vilnius (Lithuania), there were examined the main indications of such failures and in accordance with the Waybull`s distribution law thwere were determined distributions of frequency of the random failures.
Histogram of distribution of the random value, differential function and diagram of failure distribution of the HPFP-s are also presented.

Keywords: *fuel pump, fault, failure, reliability*

1. Introduction

Fuel equipment is a basic component of high-speed diesel engines. Their power and economic performance as well as reliability and stable operation considerably depend on it. Therefore, the research aimed at increasing the reliability and strength of fuel pumps, their units and joints is a very important problem. The analysis of deterioration and wear of the fuel pump joint elements in operation, in qualitative and quantitative terms, is needed to assess and increase the reliability of fuel pumps.

Lately, diesel engines have been widely used in car industry due to their low fuel consumption. In fact, the dynamic characteristic of modern cars using diesel engines are comparable with those based on petrol engines.

The present investigation is focussed on fault finding in high-pressure fuel pumps (HPFP) as major units of fuel equipment. The solution of this problem may help to increase their reliability.

It is well-known that in using diesel engines some problems may arise. Specialists consider high-pressure fuel pump (HPFP) an essential and the most sophisticated unit of diesel engines. In diesel engines, the use of a faulty HPFP may lead to:

1. higher fuel consumption;
2. lower power;
3. premature wear of a kinematic couple piston-cylinder and their elements;
4. larger carbon deposit;
5. oxidation of fuel injection ports.

High-pressure fuel pumps (HPFP) may be referred to multiram pumps having a ram in each cylinder and those of a distribution type, with one or two rams servicing all the cylinders.

According to the way of supplying fuel to cylinders the pumps of a distribution type are divided into ram pumps and other kinds of pumps.

According to cyclic fuel measuring the distribution-type pumps may be divided into the following types:

- injection pumps;
- pumps with throttling in drawing in;
- pumps with an end cam;
- pumps with the internal profile cam.

Fuel pumps of the above types are manufactured at the “Fuel Equipment” plant in Vilnius (Lithuania). These are mainly ram pumps of distribution type measuring fuel by injection, while the ram drive has a cam of a corresponding external profile.

2. Major indicators of HPFP malfunction and determination of failure frequency distribution

Based on the data collected during two years of HPFP operation, a number of random values m_i and heights of histograms H_i were determined, assuming the intervals Δ_t = 100 motor hours.

The data were tabulated (Table 1) and then a histogram of random value distribution was drawn. From it we can see that the experimental distribution of the random value may be determined according to Waybull’s distribution law.

Tab. 1. Statistical representation of initial data

Category №	Interval t_i	Experimental frequences m_i^*	Statistical probabilities P_i	Height of histograms H_i
1	100	30	0,1091	0,001091
2	200	23	0,0836	0,000836
3	300	24	0,0873	0,000873
4	400	20	0,0727	0,000727
5	500	15	0,0545	0,000545
6	600	10	0,0364	0,000364
7	700	11	0,0400	0,0004
8	800	11	0,0400	0,0004
9	900	6	0,0218	0,000218
10	1000	11	0,0400	0,0004
11	1100	10	0,0364	0,000364
12	1200	12	0,0436	0,000436
13	1300	6	0,0218	0,000218
14	1400	9	0,0327	0,000327
15	1500	6	0,0218	0,000218
16	1600	7	0,0255	0,000255
17	1700	4	0,0145	0,000145
18	1800	3	0,0109	0,000109
19	1900	7	0,0255	0,000255
20	2000	8	0,0364	0,000364
21	2100	10	0,0364	0,000364
22	2200	4	0,0145	0,000145
23	2300	4	0,0145	0,000145
24	2400	5	0,0182	0,000182
25	2500	3	0,0109	0,000109
26	2600	1	0,0036	3,64E-05
27	2700	3	0,0109	0,000109
28	2800	5	0,0182	0,000182
29	2900	3	0,0109	0,000109
30	3000	2	0,0073	7,27E-05
31	3100	2	0,0073	7,27E-05

Mean life:

$$M(t) = \sum_{i=1}^{n} t_i \frac{m_i^*}{\sum_{i=1}^{n} m_i^*} = 100\frac{30}{275} + 200\frac{23}{275} + \ldots + \tag{1}$$

$$+ 310\frac{2}{275} = 1035{,}64 \text{ motorhours}$$

Mean square deviation:

$$\sigma(t) = \sqrt{\sum_{i=1}^{n} [t_i - M(t)]^2 \cdot p_i} = 824{,}7 \text{motorhours} \tag{2}$$

Mean square deviation of the mean result:

$$\sigma_{M(t)} = \frac{\sigma(t)}{\sqrt{K}} = \frac{824{,}7}{\sqrt{31}} = 148{,}1 \text{ motorhours} \tag{3}$$

Coefficient of variation:

$$V = \frac{\sigma(t)}{M(t)} = \frac{824{,}7}{1035{,}64} = 0{,}796 \tag{4}$$

Equalization of experimental distribution is carried out according to Waybull's law

Basing ourselves on Table 2 we determine the parameters of distribution of Waybull's values:

$$n = \psi(V) = \psi(0{,}796) = 1{,}27\ ;\ K_V = 0{,}93\ ;\ C_V = 0{,}74 \tag{5}$$

The second parameter of Waybull's distribution:

$$a = \frac{\sigma}{C_V} = \frac{824{,}7}{0{,}74} = 1114 \tag{6}$$

The corrected mean life:

$$M_{pat} = a \cdot K_V = 1114 \cdot 0{,}93 = 1036{,}4 \text{ motorhours} \tag{7}$$

Finally, the density of probability for a considered flow of failures is of the form:

$$f(t) = \frac{n}{a} \cdot \left(\frac{t}{a}\right)^{n-1} \cdot e^{-\left(\frac{t}{a}\right)^n} \tag{8}$$

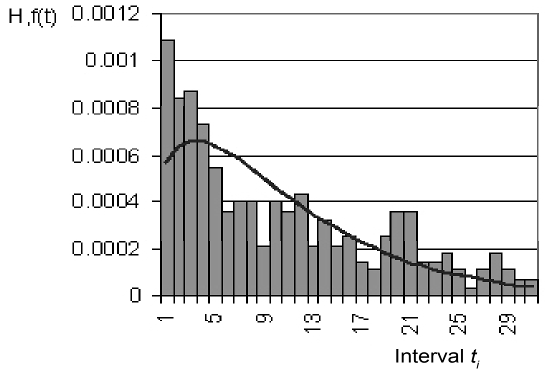

Fig.1. Histogram of random value distribution and differential function

The integral function:

$$F(t) = 1 - e^{-\left(\frac{t}{a}\right)^n} \qquad (9)$$

Then, we calculate the probability density of Waybull's law and the integral function.

The obtained data are tabulated (Table 2). The obtained values of probability densities are plotted in a graph (Fig.1), thereby equalizing the experimental distribution according to Waybull's law.

One can see that the experimental distribution is quite comparable to a particular case of Waybull's law. For this purpose, let us calculate the probabilities of occurrence of a random value in the categories from an approximate formula:

$$P(\alpha_i < t < \beta_i) \sim f(t)\Delta t \qquad (10)$$

By multiplying $P_i \cdot N$, we will get the theoretical frequencies of the occurrence in the categories. The data of calculation are given in Table 2. Now, let us determine the values of Pearson's criterion x^2:

$$\chi^2 = \sum_{i=1}^{n} \frac{(m_i^* - m_i)^2}{m_i} = \frac{(30-16,78)^2}{16,78} + \frac{(23-17,99)^2}{17,99} + \ldots + \frac{(2-1)^2}{1} = 57,9 \qquad (11)$$

Tab. 2. Calculation of values f (t) and F (t) for Waybull's distribution law

Class mark t_i	t_i /a	$a \cdot f(t)$	$f(t)$	Theoretical frequencies m_i	$F(t)$
100	0,090	0,635	0,00057	16,78	0,0457
200	0,180	0,713	0,00064	17,99	0,1067
300	0,269	0,735	0,00066	18,21	0,1721
400	0,359	0,735	0,00066	17,88	0,2383
500	0,449	0,713	0,00064	17,22	0,3033
600	0,539	0,680	0,00061	16,36	0,3659
700	0,628	0,646	0,00058	15,37	0,4254
800	0,718	0,602	0,00054	14,33	0,4813
900	0,808	0,557	0,0005	13,28	0,5334
1000	0,898	0,512	0,00046	12,18	0,5817
1100	0,987	0,468	0,00042	11,17	0,626
1200	1,077	0,434	0,00039	10,18	0,6666
1300	1,167	0,390	0,00035	9,21	0,7036
1400	1,257	0,356	0,00032	8,33	0,7371
1500	1,346	0,323	0,00029	7,48	0,7674
1600	1,436	0,290	0,00026	6,74	0,7946
1700	1,526	0,256	0,00023	5,99	0,8191
1800	1,616	0,234	0,00021	5,36	0,8409
1900	1,706	0,201	0,00018	4,76	0,8604
2000	1,795	0,178	0,00016	4,23	0,8777
2100	1,885	0,156	0,00014	3,74	0,8931
2200	1,975	0,145	0,00013	3,30	0,9067
2300	2,065	0,123	0,00011	2,92	0,9187
2400	2,154	0,111	0,0001	2,56	0,9293
2500	2,244	0,100	0,00009	2,23	0,9386
2600	2,334	0,089	0,00008	1,98	0,9467
2700	2,424	0,078	0,00007	1,71	0,9539
2800	2,513	0,067	0,00006	1,51	0,9601
2900	2,603	0,056	0,00005	1,29	0,9656
3000	2,693	0,045	0,00004	1,13	0,9703
3100	2,783	0,045	0,00004	7,04	0,9744

If the coefficient $\alpha = 0{,}0001$, then, by using the tables [1] of distribution of x^2, we will get $x^2_{0,9999,31}=61{,}1$. Therefore, it may be stated that the hypothesis was true.

The admissible intervals of Waybull's distribution law may be calculated from the following formulas:

$$M_V = M(t)\cdot\sqrt[\eta]{r_1} = 1036{,}4\cdot\sqrt[1{,}27]{1{,}38} = 1335{,}58 \text{ motoval} \quad (12)$$

$$M_A = M(t)\cdot\sqrt[\eta]{r_3} = 1036{,}4\cdot\sqrt[1{,}27]{0{,}76} = 834{,}99 \text{ motoval} \quad (13)$$

here, r_1 and r_3 – coefficients depending on the number of the observed objects N and the assumed expected probabilities [1], which are 0,95 in our case.

It may be stated with the probability of 95 % that HPFP will operate without failure not less than 834, 99 motor hours and not more than 1335, 58 motor hours.

3. Causes of HPFP failure

All causes of failure of the pumps may be classified as shown in the diagram in Fig.2. Major causes of failure are as follows:

- ram jamming – due to poor fuel filtering, tiny dirt particles get into the gap between the cylinder and the ram, making a kinematic couple. Their amount depends on the gap;
- jumping out of the lock pusher – poor machining of the crankshaft;
- jamming of meter or its drive – poor fuel filtering system;
- malfunction of automatic clutches – manufacturing defects;
- fuel penetration into the crankcase – damaged or poor quality gaskets;

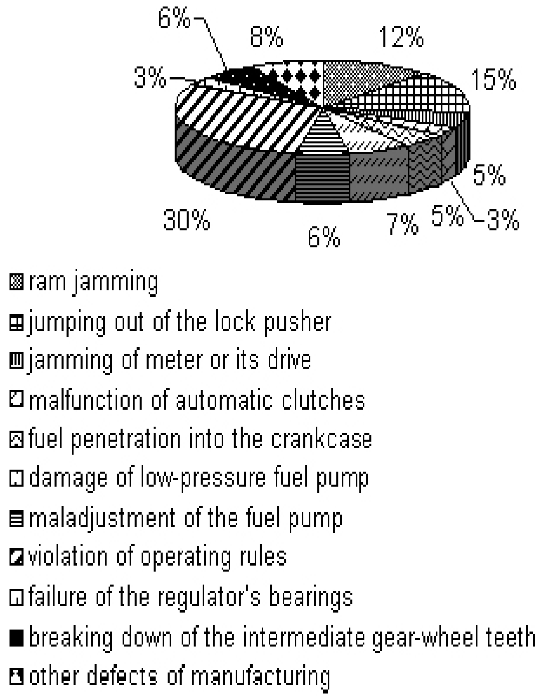

Fig. 2. HPFP failure distribution

- damage of low-pressure fuel pump – worn-out parts, poor work of coarse filter;
- violation of operating rules – irregular inspection and poor maintenance;
- breaking down of the intermediate gear-wheel teeth – defects of assembly.

4. References

[1] Ivčenko G.I., Medvedev J.J.: *Mathematical Statistics*, Moscow, Vysshaya Shkola, 1984, 248 p.
[2] Golubkov L.N., Savastenko A.A.: *High-Pressure Fuel Pumps of Distribution Type*. Moscow, Legion – Avtodata, 2000, 176 p.

Prof. dr hab. Alvydas PIKŪNAS
Automobile Transport Department, Vilnius Gediminas Technical University,
Basanaviciaus g. 28, LT-2009 Vilnius, Lithuania,
Tel.: 370-5-2744789; Fax: 370-5-2745068
E-mail: vaida@ti.vtu.lt

Prof. dr hab. Bronislovas SPRUOGIS
J. JUREVIČIUS
Department of Transport Technologic Equipment, Vilnius Gediminas Technical University,
Plytinės g. 27, LT-2040 Vilnius, Lithuania,
Tel.: 370-5-2744783; Fax: 370-5-2745060
E-mail: tti@ti.vtu.lt