ESP Workshop

SPE-GULF COAST

Procedure of submersible equipment reliability measurement and experience of its implementation

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A procedure of submersible equipment reliability measurement by incomplete operational data has been suggested by Novomet. Its algorithm is based on a combination of computational methods of the nonparametric statistics ensuring high accuracy of the reliability calculation and methods of the parametric statistics that allow forecasting the equipment performance. For the first time we had the opportunity to apply objective methods of mathematical statistics to measure submersible equipment reliability, to find weak components of a unit and main operational mistakes when using ESP installations. As an example of the procedure implementation we did a comparative analysis of the reliability of the equipment made by Russian and leading American companies and run in the Western Siberia.

Operational properties of submersible equipment are characterized by two groups of parameters. The first group includes discharge head, performance and power consumption. The second group defines the ability of the equipment to keep the above-mentioned values during operation, that is, reliability. Both groups are equally important in describing operational properties. Therefore, it is necessary to have valid measurement procedures for both parameters.

Today it is an accepted practice to measure the parameters of the first group on the test bench, while the parameters of the second group are evaluated in working conditions. It is possible to measure equipment reliability in bench tests, but these bench (i.e. accelerated) tests can only approximately imitate the real working conditions and, therefore, they are not attractive. In the present work we limit ourselves to considering the problem of reliability measurement in working conditions.

Failures are stochastic; therefore the characteristics of submersible equipment reliability can be obtained using the probability theory, to be more precise, its part – mathematical statistics. However, in practice of the oil production industry ubiquitous are such empirical characteristics as “overhaul period” and “mean time between failures” [1]. These characteristics have the following drawbacks:

1. They are not stochastic, which contradicts the nature of the characterized process.
2. They artificially limit the volume of data subject to analysis to one year.
3. The precision of the reliability measurement is not defined, so the proper comparison of the obtained results is not possible.

Therefore, the Novomet Company has developed a procedure based on the probability theory that allows realizing submersible equipment reliability measurement by operational data. The procedure has been implemented in a number of oil companies of the Western Siberia (Russia).

Procedure of the reliability measurement. In accordance with the accepted approach of the reliability theory [2], we will divide the operational data about the equipment operating time into two groups.

To the first group we refer the operating time that ended in failure, meaning every case of irreversible work stoppage. This operating time will be called complete.

To the second group we refer the operating time of the equipment that was interrupted or stopped, not due to failure but because of other reasons. This operating time will be called incomplete or censored.

The incomplete operating time contains less information about the equipment reliability than the complete one that ended in failure. However, the volume of the censored operating time is usually substantial. If we take it into account we will increase the precision of the reliability measurement.

The main value that exhaustively describes reliability is the probability of survival *P(t)* or a proportion of the equipment that worked during the period *t* without failure (see Supplement, and [2]). All other reliability characteristics are expressed through *P(t)* and give an additional pictorial information.

In the present work, apart from $P(t)$, we used T_γ – the guaranteed resource or time that the portion of the equipment equal to γ will work without failure. For example, $T_{0.5}$ – is the time during which 50% of the equipment will work without failure. We also used the function $P(t_0)$ or the portion of the equipment with the survival time equal to t_0, for example 1000 days. These values are easily definable from the diagrams *P(t)*.

The calculations has been carried out with the software NeoStat-Pro developed by Novomet, that applies general approaches of the mathematical reliability theory based on multiplying algorithms of reliability evaluation (Kaplan-Meyer, Herd, life time table) to the given task. The novelty of this method, described in Supplement 1, consists in the combination of methods of the nonparametric statistics (based on multiplying algorithms and ensuring high accuracy of the reliability measurement) and methods of the parametric statistics (we offered a model of failures that allows forecasting equipment performance).

The level of the confidence probability was assumed to be equal to 80%. It means that in 80% of the cases the true values of *P(t)* will be within the confidence intervals shown on the diagrams below, and in 20% out of them.

For all the diagrams, the solid line corresponds to the results of the reliability calculation, while the dotted line shows the forecast. The reliability of the forecast is based on the hypothesis that during the forecasted period the mechanism of failures will not change.

The reliability of the «well – ESP installation» system

According to the accepted practice in the industry, we will divide the failures into operational (due to exploitation mistakes) and design/constructional (equipment failure under the regular exploitation).

In accordance with this classification we should distinguish operational and constructional reliability [4]-[6]. The operational reliability of the «well – ESP installation» system is characterized by the *unfaulty operation of the exploiting equipment of the plan,* the constructional reliability of ESP installation – *the unfaulty operation of the manufacturer.*

The operational reliability of the « well – ESP installation» system can be structured or divided into reliability types by different operational factors. The constructional reliability of ESP installation includes the reliability of the individual ESP components, see fig. 1.

Besides, by the results of the pulled-out equipment inspection (if it is carried out) the portion of faultless ESP installations' components suitable for reuse can be calculated.

We should note, that to achieve the maximum reliability of the « well – ESP installation» system one should not carry out optimization separately by operational and constructional parameters. This scheme makes it improbable to find the global maximum. Optimization should be realized by all parameters at once [7].

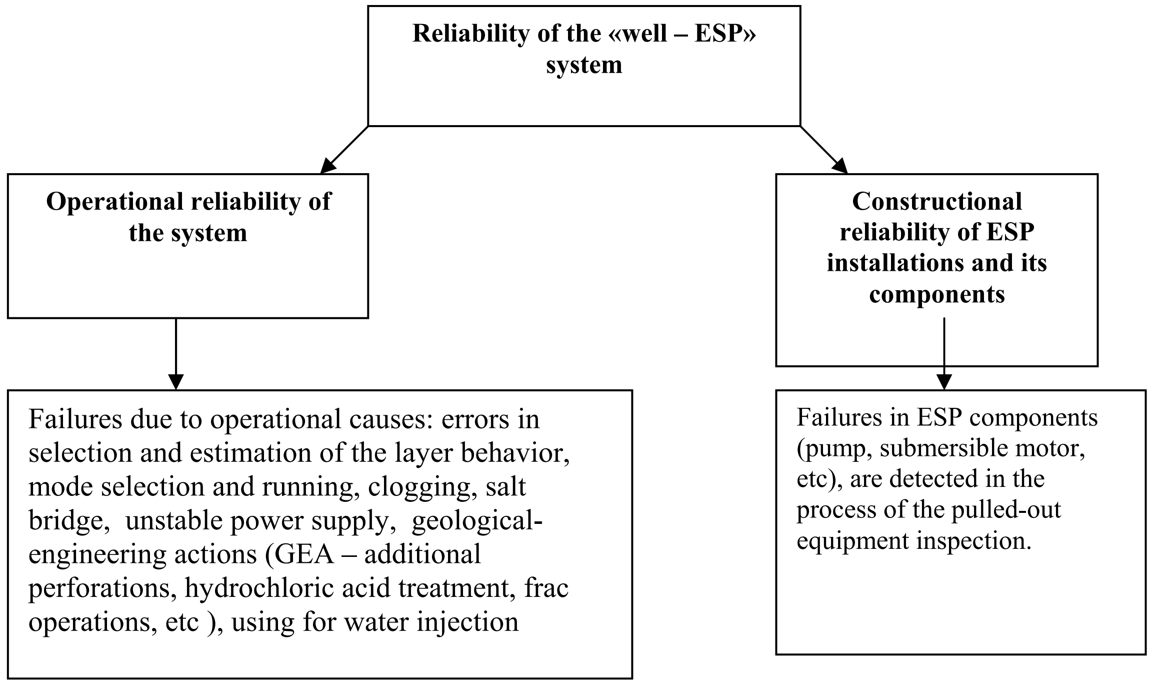

Fig. 1. Classification of the reliability types of the «well – ESP installation» system

Procedure of data preparation for the calculation. The source data are based on the operational data bases of oil companies. These data bases usually contain the following information: running time of ESP installations before pulling-out, causes of stoppage and causes of ESP installations failures, data about the defects of the ESP components detected during the equipment dismantling, and some other.

At the first stage of the sample from the data base, we should ensure the representativeness of sample. The sample must include units that work in all conditions typical for the given oilfield. It is indispensable, for example, to compare reliability of submersible equipment of different manufacturers.

The important stage of the sampling is classification of the operating data into complete operating time (that did not end in failure) and censured operating time. For example, when calculating the reliability of the «well – ESP installation» system, we should classify any case of equipment pull-out as failure. When we calculate the reliability of a pump – we consider as failure only supply stoppage due to pump breakage. In this case all other causes of ESP operation stoppage (operational factors or breakdown of ESP motor, cables, seal sections) are not considered as failures, because the pump is still operable.

The input data about operating time must include all available information about the equipment operation. It is inadmissible to take into account only information about the equipment operation during the present year, as it usually done when calculating the overhaul period or the mean time between failures. Discarding the failures that took place before, we refuse to take into consideration the less successful units and artificially overstate the reliability of the assessed equipment.

Sampling is the most responsible stage of the reliability evaluation process. Only at this stage calculation errors can occur. Calculations by the suggested method do not use presumptions about probability laws of the equipment failures and do not introduce errors.

Evaluation of the necessary amount of sampling and of the test period. The amount of sampling should be sufficient to ensure its representativeness and the required accuracy of the reliability characteristics evaluation.

The accuracy of evaluation is defined by the amount of sampling N and the test period t_0.

Our calculations showed [4], that if the test period is not limited, at the confidence probability of 0.67, the evaluation accuracy $T_{0.5}$ will be about $\pm 10\%$ at $N = 100$ and $\pm 5\%$ at $N = 500$.

If the test period is limited by the value t_0, the calculations show [4] that the accuracy of $\pm 20\%$ is attained at $N = 100,\ t_0 = 0.5T_{0.5}$ or $N = 50,\ t_0 = 0.7 \cdot T_{0.5}$, while $\pm 10\%$ at $N = 100,\ t_0 = 2.0 \cdot T_{0.5}$ or $N = 200,\ t_0 = 0.8 \cdot T_{0.5}$.

These data allow evaluating the necessary amount of equipment and time of its exploitation just at the planning stage, which is important to achieve the required accuracy of the calculations made by these data.

Insufficiency of the applied empiric reliability indexes. Until recently oil companies applied such reliability indexes as “mean time between failures” (MTBF) and “operating time between overhauls” (OTBO). Their advantage is a simple algorithm and small amount of calculations. Calculations can be done on the simplest calculators.

The drawback is the inaccuracy of these indexes not only from the point of view of the mathematical reliability theory, but also from the point of view of the common sense. This is true, that by the definition:

$$\text{OTBO} = \frac{\text{Total operating time of all installations for one year}}{\text{Number of failures}} \quad (1)$$

$$\text{MTBF} = \frac{\text{Total operating time of all failed installations for one year}}{\text{Number of failures}} \quad (2)$$

The conception «cumulative operating time» is inaccurate. For example, if 365 units of one type work without failures 24 hours each, and one unit of other type works 365 days, their MTBF and OTBO will be the same. However, in the first case the tests did not even properly start!

Besides, it is not admissible to sum up failures that occurred during a long exploitation time, because their weight it different: failures during a short operating time indicate errors, while during a long operating time – the high quality of the equipment.

The MTBF and OTBO indexes do not take into account the stage of the life span of the equipment put into operation more than a year ago. Every system goes through the “youth” stage, characterized by running-in failures, “maturity” and “old age” – when deterioration failures are most common.

Besides, OTBO ignores the operating time that did not end in failure, while these units are the best!

The disadvantages of calculation of the MTBF and OTBO indexes result in the dependence of the values from the time when the equipment was put in operation.

Let’s take an example of calculation of MTBF, OTBO and $T_{0.5}$ - guaranteed resource of MTBF of 50% units (one of the criteria accepted by the mathematical reliability theory). We used operating data of the Western Siberia oil companies. During the test period the running conditions and the applied equipment were the same. The obtained results are shown in fig. 2

As shown in the picture, the reliability calculated by the suggested method did not change.
Empirical reliability characteristics changed dramatically.

The definition of the Operating Time Between Overhauls (1) can be formulated as follows:

$$\text{OTBO} = \frac{\text{Average installation's operating time for one year}}{\text{Failure probability}}$$

With increase of the observation time the average operating time is almost constant, while the failure probability increases, and the overhaul period decreases, as it is shown on fig.2.

The definition of MTBF (2) can be formulated as follows:

$$MTBF = \frac{\text{Average operating time of the failed ESP installation for one year}}{\text{Failure probability}}$$

The average operating time of faulty units increases with the observation time, because at the initial stage fail the less reliable units. Therefore, MTBF increased, see fig. 2b – fig. 2d.

From definitions (1) and (2) we can conclude that OTBO will be equal to MTBF when all the equipment ends in failure.

And, finally: by changing the schedule of putting the equipment into operation, you can make the dependences OTBO and MTBF non-monotone, see fig. 2b.

Further we will give examples of implementation of the developed procedure in different oil companies. We will also show a reliability comparison of the Novomet equipment and the equipment of the leading American manufacturers.

The results of the method implementation in JSC Surgutneftegas: In the middle of 2002 Novomet started to supply JSC Surgutneftegas with complete installations equipped with wear-resistant pumps. The principles of the wear-resistant pumps construction are described in [8]. The general data about the results of the equipment exploitation by 01.01.05 are shown in tables 1 and 2.

Table 1. General information about the operational data of JSC Surgutneftegas used in the study

Type	Put into operation	Total sum of mountings	In operation	Pulling-out
Novomet units with flowrates of 25 m^3/a day	July 2002	136	18	108
Novomet units with flowrates of 79 m^3/a day	December 2002	71	44	27
Imported units with flowrates of 65 m^3/a day	July 2002	473	355	118

From table 2 we see, that the gas separator and pump failures were caused by the “degradation” of the walls of the stage guide vanes and the gas separator body, i.e. were not connected with abrasive damage of the bearings. This type of deterioration was detected during an operational test. We managed to reproduce it and find out its nature on the Novomet stands. It allowed us to find a way to neutralize this type of deterioration and design pumps with a longer operating time in these conditions. Today we supply these advanced pumps and gas separators to Surgutneftegas.

Table 2 does not contain complete data about the failures structure, because every failure carries different weight regardless of operating time before failure. However, at the first stage of the equipment reliability analysis the failures structuring shown in table 2 can be useful. Later we will make the information about failures more precise using methods of the reliability theory.

Table 2. Causes of failures of the Novomet equipment in JSC Surgutneftegas

Causes	УВННПИ5-25	УВННПИ5-79
Equipment failures		
Extension stem fault	6%	14%
Gas separator degradation	1%	
Pump stage degradation		9%
Operational failures		
Paraffin plugs in tubing	2%	
Tubing leakage	8%	27%
Incorrect installation selection	12%	
GEA (geological-engineering actions)	25%	27%
Scale in the pump	15%	
Pump clogging by mechanical admixtures	7%	
Burnout of the cable line splicing	4%	
Mechanical damage of the cable line	1%	5%
Not defined	11%	9%
Other		
Waiting for commission	5%	9%
Mounted again	2%	

Fig 3 shows the results of the reliability measurement of the “well - ESP installation” system, of the operational and structural reliability. We see that the time of no-failure operation of ESP installations is determined mainly by operational factors, where, the less is the discharge – the more operational problems occur. Structural reliability is significantly higher than the operational one. Besides, we see that the reliability of the Novomet installations is no lower than that of the imported installations.

Fig 4 shows an example of operational reliability structuring. We see that for low-yield systems the main factors that lead to the reliability reduction are GEA, scale in the pump and tubing leakage. Measure of risk connected with every factor is determined quantitatively.

By the results of the dismantling of the pulled-out equipment we can determine its fitness for reuse after the standard maintenance, further referred to as “maintainability”. The obtained results are shown in fig.5. The highest maintainability, as one would expect, had submersible motors and seal sections.

The results of the method implementation in JSC Sibneft-Noyabrskneftegas. This company also purchases full-functional installations, but unlike Surgutneftegas, it exploits a considerable part of its wells by the production stimulation technology. The general data about the operational results of the Novomet installations and similar imported equipment by 01.01.05 are shown in Table 3.

Fig 6 shows the results of the reliability measurement of the “well - ESP installation” system, of the operational and structural reliability. We see that, here again, the time of no-failure operation of ESP installations is determined mainly by operational factors. The reliability of the Novomet installations is about the same as the reliability of the imported installations.

Fig 7 shows the operational reliability structuring of the “well - ESP installation” system by both manufacturers. We see that the influence of the operational factors on the reliability of ESP installations made by different manufacturers is almost the same. Most common causes are GEA, clogging and scale.

Table 3. General information about the operational data of JSC Sibneft-Noyabrskneftegas

Type	Put into operation	Total sum of mountings	In operation	Pulling-out
Novomet installations with flowrates of 124 - 280 m^3/a day	August 2003	103	31	72
Imported installations with flowrates of 125 - 300 m^3/a day	August 2003	96	30	66

Fig 8 shows structural reliability of pumps and submersible motors made by Novomet and by foreign manufacturers. Within the range of the definition error the obtained dependences closely agree.

The results of the method implementation in JSC Yuganskneftegas. From the point of view of the present analysis, the company has the following peculiarities. Firstly, the company does not purchase complete ESP installations, but only its separate parts: pumps, submersible motors,etc, out of which ESP installations are mounted. Secondly, it practices on a large scale hydraulic bed separations accompanied by proppant pumping into the created creases and lowering of ESP installations on a considerable depth (in the area of higher temperatures). That’s why its submersible equipment works in substantially more complicated conditions (the average level of $T_{0.5}$ on fig. 2a and fig. 2c). General data about the results of the exploitation by 01.02.05 are shown in Table 4.

Table 4. General information about the operational data of JSC Yuganskneftegas

Type	Put into operation	Total sum of mountings	In operation	Pulling-out
Novomet pumps with flowrates of 124 - 280 m^3/a day	January 2003.	187	37	150
Imported pumps with flowrates of 160 - 560 m^3/a day	January 2003	76	22	54

Fig 9 shows the results of the reliability measurement of the “well – ESP installation” system, operational reliability of the ESP installation and structural reliability of the Novomet pumps. We see that, here again, the dependability of the “well – ESP installation” system with the Novomet pumps and with imported pumps is the same. And, as before, the structural reliability is substantially higher than the operational reliability. It’s interesting to note that even in such complicated operational conditions, as it is shown on fig.9, more than 60% of the Novomet pumps can operate without failure more than 1000 days.

The results of the method implementation in Lukoil-Western Sieberia LLC. This company also does not purchase complete ESP installations. They purchase separate units: pumps, submersible motors, etc, out of which ESP installations are mounted. Unlike Nefteyugansk, this company does not implement large-scale oil production intensification. General data about the results of the exploitation by 01.01.05 are shown in Table 5

Fig 10 shows the results of the reliability measurement of the “well – ESP installation” system, operational reliability of the ESP installation and structural reliability of the Novomet pumps. We see that the dependability of the “well – ESP installation” system with the Novomet pumps and with imported pumps is almost the same; while the structural reliability of the pumps is substantially higher, to be more precise - no incidence of the pump failure was registered during the guaranteed operation life, equal to one year. According to the existing regulations of the company, the equipment that worked longer than its guaranteed operation period is not subject to the commission analysis.

Maintainability of the ESP units is shown on fig. 11. We see that the Novomet pumps and submersible motors showed a higher reliability than the corresponding imported equipment.

Таблица 5. General information about the operational data of Lukoil-Western Sieberia LLC

Type	Put into operation	Total sum of mountings	In operation	Pulling-out
Novomet pumps with flowrates of 25 m^3/a day	April 2002	924	424	500
Imported pumps with flowrates of 50 m^3/a day	April 2001	1224	458	766

Conclusion

A procedure of submersible equipment reliability measurement by incomplete operational data has been suggested by Novomet. Every stage of the procedure – from the initial sampling to the final result – is strictly formalized by methods of the mathematical reliability theory. The human factor is totally excluded. We calculate characteristics that give a comprehensive description of reliability. The calculations are made by the specially designed software - NeoStat-Pro.

We did an analysis of the submersible equipment working in the Western Siberia. It showed that today it is the operational factors that cause most of failures. The structural reliability of ESP installations is substantially higher than the operational reliability of the “well – ESP installation” systems.

The analysis of the extensive statistical data showed that the structural reliability of the Novomet equipment is not lower that that of the imported equipment run in the Western Siberia.

Besides, the method allows detecting the weak units of the equipment basing on the operational data, and therefore – knowingly improving their quality. In the process of cooperation with the oil companies of the Western Siberia we created equipment with the first-rate operational reliability and structural reliability of more than 1000 days.

Supplement. Description of the method of the operational data processing.

The main value that gives comprehensive description of reliability is the probability of no-failure work $P(t)$ or the part of installations that worked time t without failures. It can be explained as follows: $P(t)$ is also the distribution function of the random value t – time of no-failure work of the installation, and, in terms of the reliability theory [4], gives a comprehensive description of reliability.

In the oil production industry they started to apply the probability approach apparently in the 60s of the last century [9], [10]. However, due to the fact that it required considerable calculations and the computer techniques were not easily accessible, it did not have the wide distribution it deserved.

To calculate $P(t)$ in the reliability theory we use the algorithms based on the hypothesis about independence of the failures that occurred in the adjacent moments. Calculations by this algorithm reduce to the multiplication of probabilities of no-failure work at these moments, that's why these algorithms are called multiplying [11]:

$$\hat{P}_k = \left(1-\frac{r_1}{s_1}\right)\left(1-\frac{r_2}{s_2}\right)\cdots\left(1-\frac{r_k}{s_k}\right), \qquad (\Pi 1)$$

Here $\hat{P}_k$ – estimation of $P(t)$ at the moment t_k, r_i – number of failures, while s_i – number of objects under investigation in the interval from t_{i-1} to t_i.

Our calculations showed that the classical multiplying algorithms of the reliability calculation (foe example, those of Kaplan-Meyer and Gerd), as well as a comparatively new one – life tables, when processing the data about ESP installations give almost the same results.

It was found out that the time dependence of the probability of no-failure work $P(t)$ in all cases can be approximated by the function:

$$P(t) = \exp(-a_n t^n - a_{n-1} t^{n-1} - \ldots - a_1 t) \qquad (\Pi 2)$$

Coefficients a_n were calculated by the orthogonal method of least-squares [10]. Their significance was evaluated by F – Fisher criterion, which allowed calculating the power of the polynomial n, and thus totally exclude the human factor when selecting the approximating function.

Then, by the residual sum of the squared approximation errors, using the methods of the mathematical statistics we calculated the dispersion of the probability of no-failure work $D(P)$. It allowed calculating the calculation error $P(t)$, i.e. the confidence interval $P \pm \kappa\sqrt{D(P)}$. The corresponding confidence probability β in the general case can be calculated by the criterion of Chebyshev [12]. Thus, at $\kappa = 2$ we have $\beta \geq 0.75$. If the calculation error is not big (the standard deviation does not exceed 20–30% from the calculated value), according to the experience [13], β can be approximately estimated by the normal distribution.

The approximating function (П2) allows forecasting the dependence of the probability of no-failure work from the time outside the time period under investigation.

Other reliability characteristics are expressed through $P(t)$ and give additional visual information. Generally, we have the following characteristics: the function of the probability density:

$$f(t) = -dP/dt \qquad (\Pi 3)$$

The intensity of failures $\lambda(t)$ (a ratio of the number of installations that had a failure per time unit to the number of fault-free installations):

$$\lambda(t) = \frac{f(t)}{P(t)} = \frac{a_n t^n - a_{n-1} t^{n-1} - \ldots - a_1 t}{\exp\left(-a_n t^n + a_{n-1} t^{n-1} + \ldots + a_1 t\right)}, \qquad (\Pi 4)$$

The average no-failure work T_m:

$$T_m = \int_0^\infty t f(t)\, dt = \int_0^\infty P(t)\, dt = \int_0^\infty \exp(-a_n t^n + a_{n-1} t^{n-1} + \ldots + a_1 t)\, dt, \qquad (\Pi 5)$$

The guaranteed resource T_γ (the time period during which the given part of installations will work without failure, usually $\gamma = 0.5$):

$$\exp\left(-a_n T_\gamma^n + a_{n-1} T_\gamma^{n-1} + \ldots + a_1 T_\gamma\right) = \gamma \,. \qquad (\Pi6)$$

The methods of the mathematical statistics [7] allow calculating the dispersions for the coefficients a_j in (3)–(6), i.e. $D(a_j)$. The values of $D(a_j)$ were used to find the calculation errors of $f(t)$, $\lambda(t)$, T_m и $T_{0.5}$.

The method does not use any assumptions about the probable model of failures. Therefore, the calculated characteristics can be considered as the generalization of the empirical information about the operational reliability.

Function of failures distribution of the submersible equipment. In general, failures can have different nature. There are sudden and gradual failures. The sudden failures are caused by chance factors, which can appear at any moment. They have the intensity of failures $\lambda_1 = const$ that does not depend on time, see [2]. These are defects that appeared during the construction, errors at the stage of the well preparation, equipment selection, its operation. Gradual failures occur due to the accumulation of damages during the exploitation: deterioration, corrosion, scale in the flowing channel and in the bearing, ageing of the electric cable, etc. Their intensity of failures $\lambda_2(t)$ depends on time. As these mechanisms of failures are independent, then

$$\lambda(t) = \lambda_1 + \lambda_2(t) \,. \qquad (\Pi7)$$

The time dependence of the probability of no-failure work $P(t)$ of the submersible equipment in all cases considered above is approximated by the function:

$$P(t) = \exp\left\{-a_1 t - a_2 t^2\right\} \qquad (\Pi8)$$

The corresponding (8) probability of failure per time unit, i.e. the function of the intensity of failures (4), is equal to:

$$\lambda(t) = a_1 + 2a_2 t \,. \qquad (\Pi9)$$

If $a_2 = 0$, then the function of the intensity of failures is constant and $P(t)$ has an exponential distribution [2]. If $a_2 \neq 0$, then the Waybull distribution, for which in the general case $P(t) = \exp\left\{-\lambda t^\alpha\right\}$. In our case, see (П4), (П9), $\alpha = 2$.

Therefore, the sudden failures of the submersible equipment are described by the exponential law, while the gradual failures are described by the Waybull distribution.

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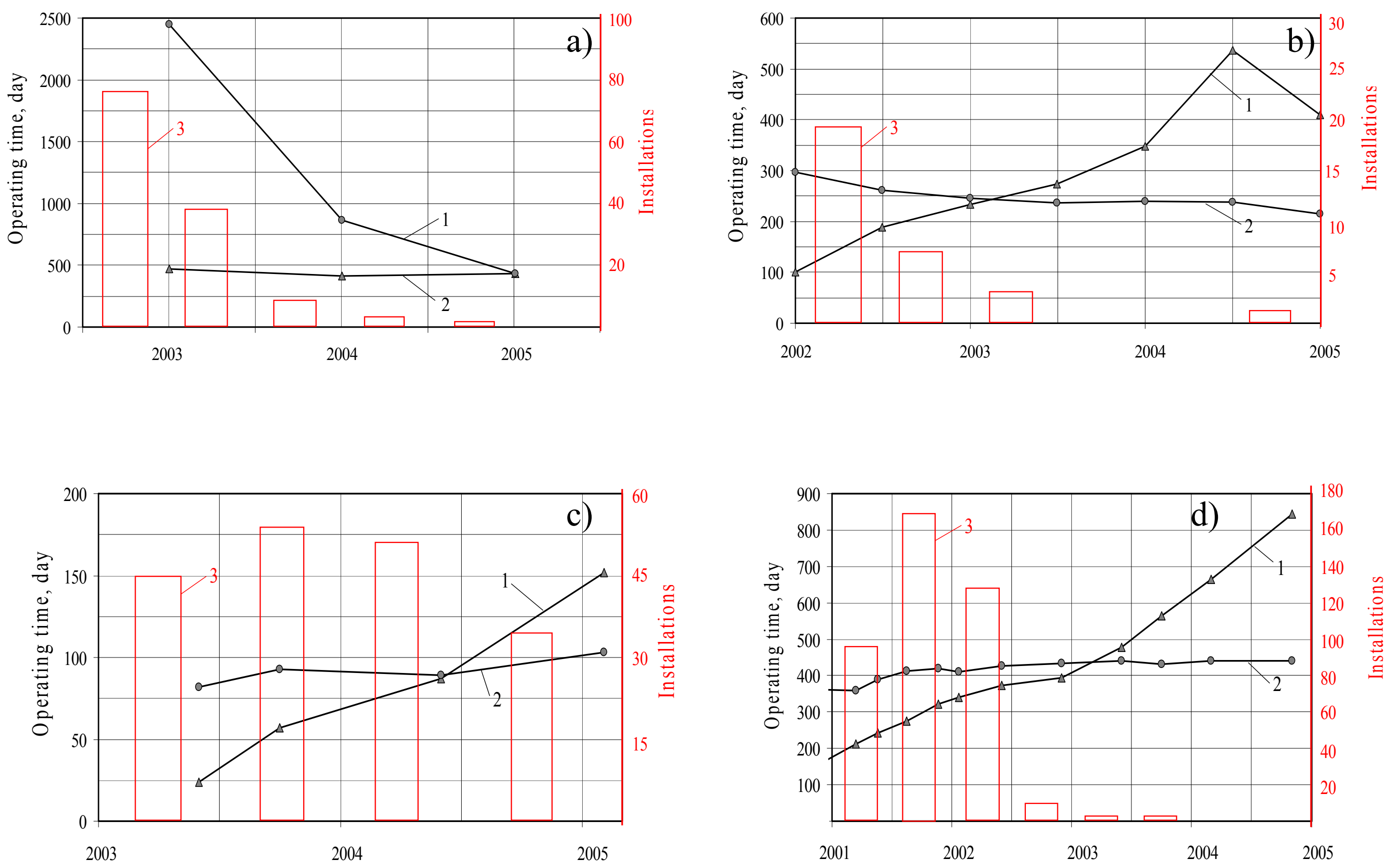

Fig. 2. The dynamics of the reliability changes of the “well – ESP installation” system made by Novomet and operated in the oil companies: a) Surgutneftegas, b) Sibneft-Noyabrskneftegas, c) Yuganskneftegas, d) Lukoil – Western Siberia.

Lines: 1 – a) overhaul period, b)-d) mean time between failures, 2 – $T_{0.5}$, calculated by the suggested method, 3 – number of installations put into operation during the period

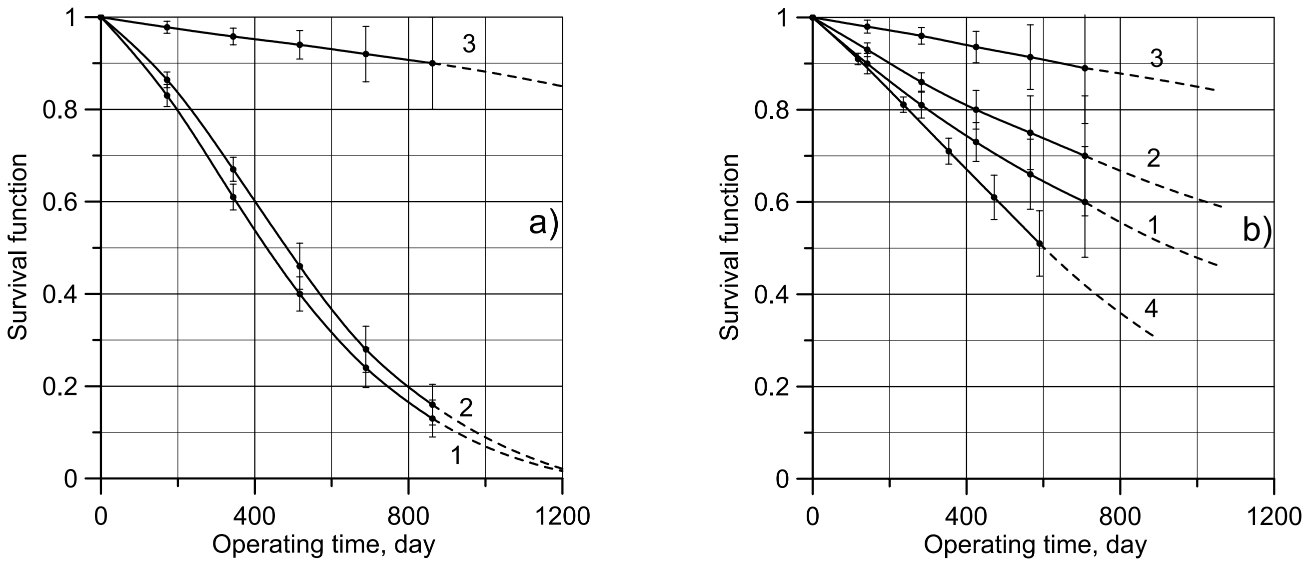

Fig. 3. By the operational data of JSC Surgutneftegas: ; 1 – reliability of the system “well – ESP installation”, 2 – operational reliability, 3 – structural reliability, 4 – reliability of imported installations.
a) UVNNPI5-25 (Novomet), b) UVNNPI5-79 (Novomet) and imported installations.

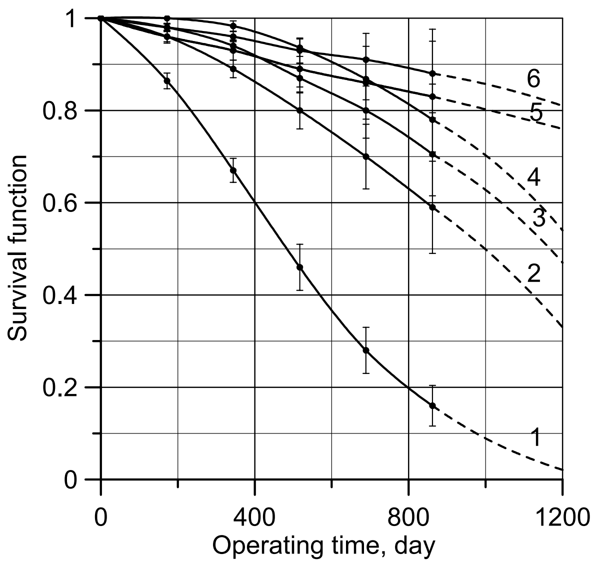

Fig. 4. Operational reliability of UVNNPI5-25 at JSC Surgutneftegas: 1 – operational reliability, 2 – GEA, 3 – scale, 4 – tubing leakage, 5 – wrong selection, 6 – clogging.

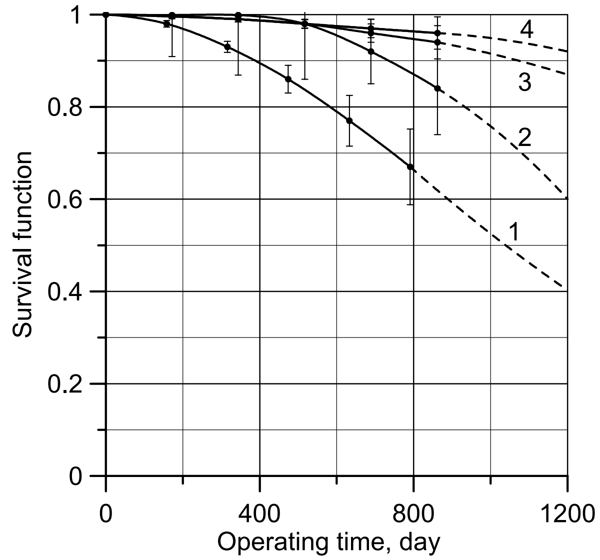

Fig. 5. Maintainability of ESP units in JSC Surgutneftegas: 1 – wear proof pumps, 2 – wear proof and corrosion-resistant pumps, 3 – seal sections, 4 – submersible motors.

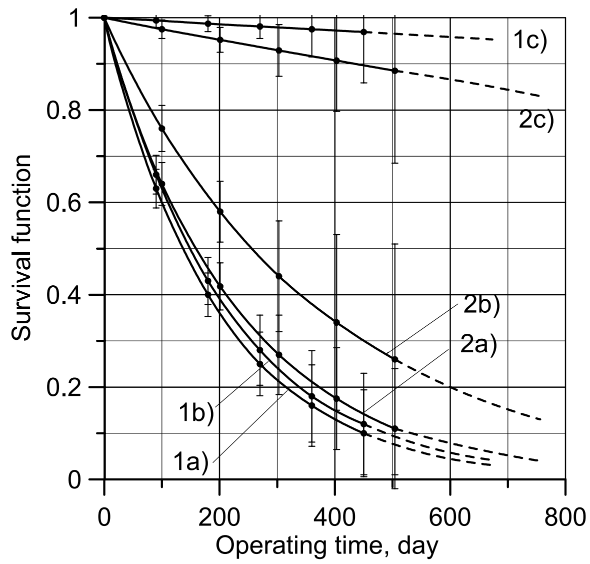

Fig. 6. By the data of JSC Sibneft-Noyabrskneftegas: a) reliability of the “well – ESP installation” system, b) operational reliability, c) structural reliability.
1 – Novomet installations, 2 – imported installations.

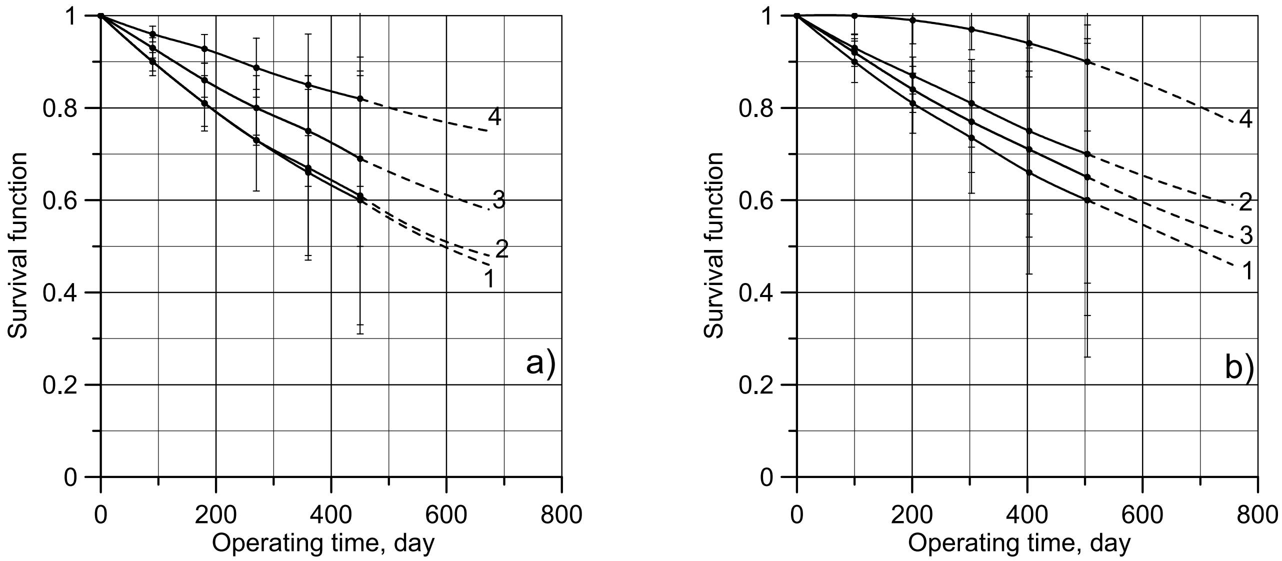

Fig. 7. Operational reliability in JSC Sibneft-Noyabrskneftegas
a) Novomet installations, b) imported installations
1 – GEA, 2 – clogging, 3 - scale, 4 – insufficient inflow

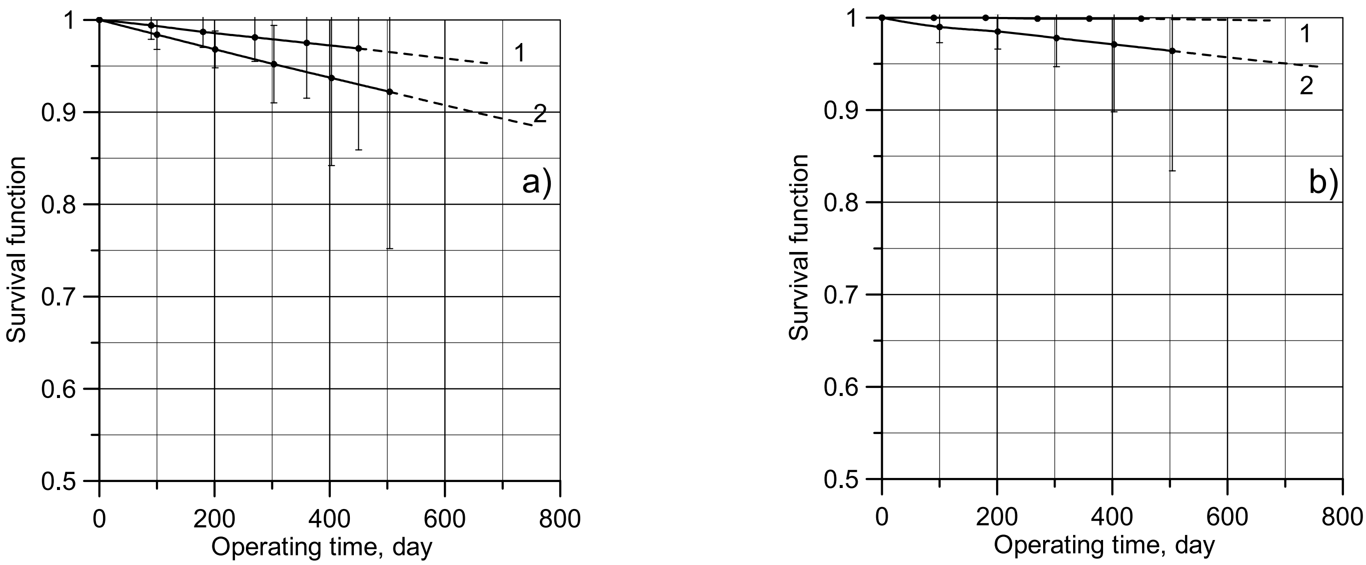

Fig. 8. Structural reliability of ESP installation units in JSC Sibneft-Noyabrskneftegas: a) pumps, b) submersible motors.
1 – Novomet equipment, 2 – imported equipment.

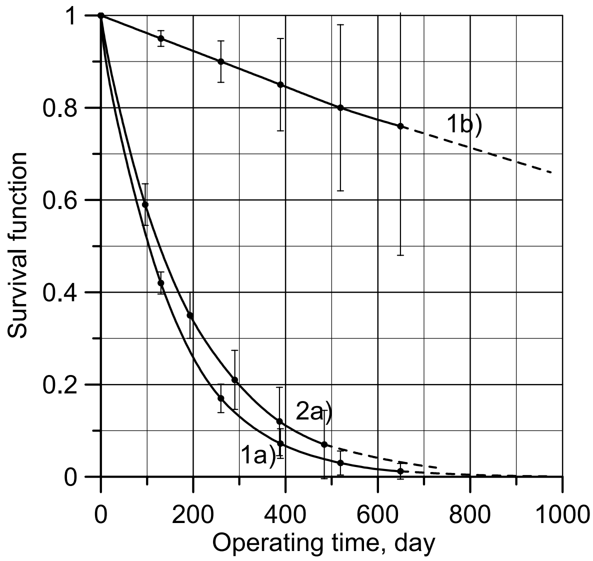

Fig. 9. By the data of JSC Yuganskneftegas: a) reliability of the “well – ESP installation” system, b) structural reliability of pumps.
1 – installations with Novomet pumps, 2 – installations with imported pumps.

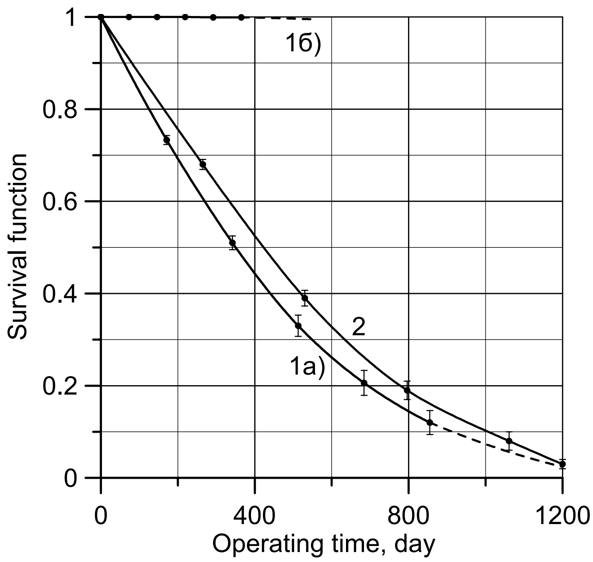

Fig. 10. By the data of Lukoil-Western Siberia LLC: a) reliability of the “well – ESP installation” system, b) structural reliability of pumps
1 – installations with Novomet pumps, 2 – installations with imported pumps.

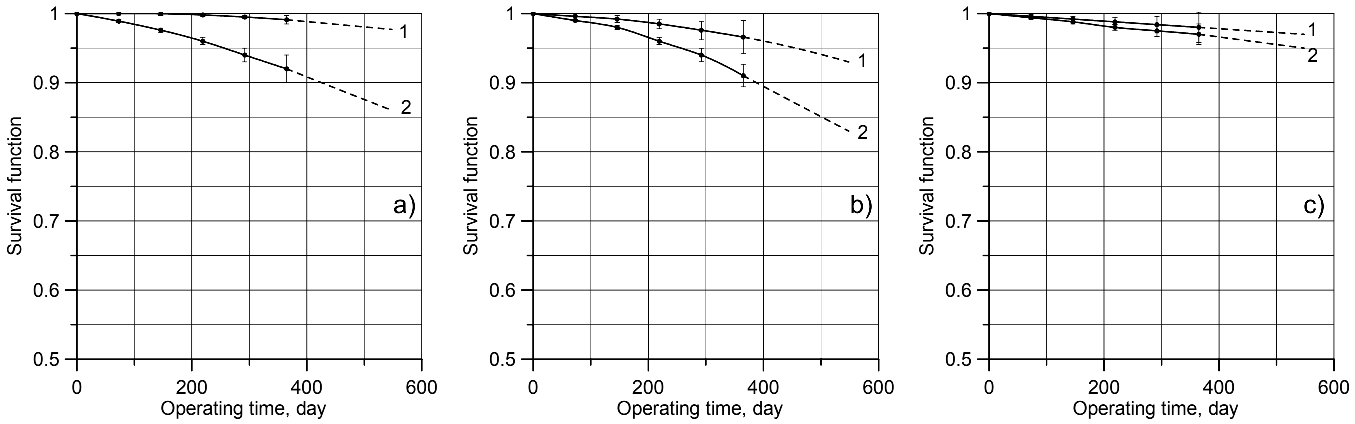

Fig. 11. Maintainability of installation units in “Lukoil-Western Siberia” LLC: a) pumps, b) submersible motors, c) seal sections.
1 – Novomet equipment, 2 – imported equipment.