DOI: 10.5604/01.3001.0013.5118

Journal of Achievements in Materials and Manufacturing Engineering

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Estimation of temporary decommissioning impact on reliability and durability of oil pipelines

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ABSTRACT

Purpose: Due to changes in the volume of oil transportation, part of the pipelines must be temporarily decommissioned. The purpose of the work is theoretical and experimental study of pressure fluctuations during operation of oil pipelines and their impact on the durability of the pipeline material in work state and after temporary decommissioning (conservation).

Design/methodology/approach: The results of oil pressure fluctuation research have given a chance to choose the terms of experimental research providing of the pipe metal mechanical features changes research during oil pipeline exploitation.

Findings: Fatigue test modes are selected based on the calculations of the mathematical model developed. Experimental studies of the dependence of the fatigue strength of the pipe material on the conditions of operation have been carried out, which made it possible to determine the parameters of the fatigue curve of the samples. Has been defined that fatigue strength for the new metal pipe samples is more for 20-25% than for the metal samples which had the contacts with lime milk and for 30-40% more than for metal samples which were under exploitation.

Research limitations/implications: In the future, more combination of "pipe material – preservation medium" should be explored to establish pain of general regularities.

Practical implications: The probabilistic curves of the pipeline non-destruction are constructed, which will be used for practical calculations of the reliability and durability of the 13G1S-U steel pipelines.

Originality/value: Mathematical model is made that describes non-stationary oil moves in oil pipeline, that has been caused by jump like changes of oil supply in oil pipeline, on this basis was defined, that oil pressure in oil pipeline provides within non stationary process in a range of 0.4-0.6 Hz frequency and amplitude fluctuation of pressure is 0.1-0.5 MPa.

Keywords: Oil pipelines, Conservation, Temporary decommissioning, Probability of non-destruction, Pipeline steel 13G1S-U

Reference to this paper should be given in the following way:

L. Poberezhny, R. Martyniuk, A. Stanetsky, L. Poberezhna, O. Tkach, A. Hrytsanchuk, Estimation of temporary decommissioning impact on reliability and durability of oil pipelines, Journal of Achievements in Materials and Manufacturing Engineering 94/1-2 (2019) 22-31.

ANALYSIS AND MODELLING

1. Introduction

Construction quality including main oil pipeline has been determined by the materials quality and construction work quality. Specific quality level is estimated within pipeline construction period with defining systems functioning reliability. By exploitation process quality assimilation takes place, its looks like it is dissipation connected to construction and materials ageing. The reliability level lowering within system's exploitation loads to failure frequency raising and so on technical system resource defines. Thus, its necessary to define the origin reliability level, character its failure after system exploitation and a measure after system exploitation is not reasonable as an aftereffect of higher frequently failures [1-4].

Origin (high) reliability level is to be defined by the material quality, done quality work and metal dynamic quality change by time (degradation of a material). Towards material characteristics which have influence to oil pipe system reliability lowering, first of all necessary to define a value of yield strength and crack resistance [5-7].

The researches of strength and pipe metals crack resistance were described in the works of native and foreign scientists [8-13]. The common methods of experiments were made in the above-mentioned researches, its results had been presented and pipe metals degradation regularity characteristics are defected. Nevertheless, being pointed out that each metal is a unique system, which mechanical characteristics ties and its changes in time can be well different from the same characteristics another metals [9]. Due to incomplete loading, the Odessa Brody pipeline is not constantly operated, which is why the pipe material is subjected to cyclic loads due to pressure fluctuations and corrosion during temporary decommissioning. To ensure trouble-free operation, it is necessary to evaluate the impact of these factors on the durability of the pipeline material. The purpose of the work is theoretical and experimental study of pressure fluctuations during operation of oil pipelines and their impact on the durability of the pipeline material in work state and after temporary decommissioning (conservation). To achieve it, in the first stage, develop a mathematical model that will allow you to calculate the frequency for the amplitude of stresses caused by fluctuations in the pressure of the working environment. In the second stage, fatigue and corrosion tests should be carried out, the results of which determine how the cyclic loads and temporary decommissioning affect the oil pipeline (in the solution of lime milk) on durability of the pipeline material.

2. Modelling of pressure fluctuation in oil pipeline by oil supply change

The oil flow in oil pipeline moves in the terms of turbulence regime, that is why for it is typical speeds and pressure turbulence pulsations. Unite of pressure pulsations amplitudes is so minor, so is not able to cause pipe metal fatigue. But in case of often non-stationary process in the oil flow a low frequent pulsation could appear. Its amplitude could cause a metal fatigue process. With a purpose to define pressure floatation frequency and amplitude in oil pipeline a non-stationary process is considered, that process was caused by intermittent change of oil supply in oil pipeline.

This exploitation type is typical for oil pipeline “Odessa-Brody”. For this line oil supply is define by a sea supply and casual type of unit supply. Non-stationary process in oil pipeline has been described by system of differential equations [14].

$$-\frac{\partial p}{\partial x} = \lambda \frac{\rho \cdot w^2}{2d} + \frac{\partial(\rho \cdot w)}{\partial t}, \qquad (1)$$
$$-\frac{\partial p}{\partial t} = c^2 \frac{\partial(\rho \cdot w)}{\partial x}$$

where,

$p = p(x,t)$ – oil pipeline pressure as a function of linear coordinate and time;

λ – hydraulic resistance coefficient;

ρ – oil density;

w – oil pipeline speed;

d – oil pipeline diameter;

c – sound spread speed in liquid.

The term is defined as a stationary allocation of pressure by oil pipeline length.

$$p(x,0) = p_1 - \frac{p_1 - p_2}{L} \cdot x\,, \tag{2}$$

where,

p_1 and p_2 – pressure in the beginning and in the end of oil pipeline by the length L.

Obviously, pressure distribution by the length of the oil pipeline with complex of oil pipeline characteristics and physical oil properties define oil expenses value for stationary regime conditions. Let's say in one moment of time oil expenses value has changed in the beginning of oil pipeline and be equal M_0, so boundary terms for (1) would be written as:

$$\frac{\partial p}{\partial x}\Big|_{x=0} = -\mu M_0;\ \frac{\partial p}{\partial x}\Big|_{x=L} = -\mu M_L\,, \tag{3}$$

where,

$\mu = \frac{2a}{F};\ 2a = \frac{\lambda w}{2d}$ – linearization coefficient;

$F = \frac{\pi d^2}{4}$ – oil pipeline square section.

After linearization moving equation in (1) by differentiating the system it can be made to equation:

$$\frac{\partial^2 p}{\partial x^2} = \frac{1}{\psi}\frac{\partial p}{\partial t} + \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}\,. \tag{4}$$

Due to move towards uniform boundary conditions; let's put a new function which connected to pressure function by the equation

$$p(x_1 t) = p(x_1 t) + \gamma_x + \gamma_1 x^2\,. \tag{5}$$

than,

$$\frac{\partial p}{\partial x} = \frac{\partial \varphi}{\partial x} + \gamma + 2\gamma_1 x$$

then, lets presume that

$$\frac{\partial \varphi}{\partial x}\Big|_{x=0} = 0$$

whence,

$$\gamma = -\mu M_0$$

on another edge $x = L$

$$\frac{\partial \varphi}{\partial x}\Big|_{x=L} = 0$$

than

$$\gamma + \gamma_1 L = -\mu \cdot M_L$$

from where

$$\gamma_1 = -\mu\frac{M_L - M_0}{L}$$

For unknown $U(x_i t)$ we have equation

$$\frac{\partial^2 U}{\partial x^2} = \frac{1}{\psi}\cdot\frac{\partial U}{\partial t} + \frac{1}{c^2}\cdot\frac{\partial^2 U}{\partial t^2}\,, \tag{6}$$

where

$$\psi = \frac{c^2}{2a}\,.$$

Decision (6) with congenerous boundary conditions will have been searching by Fourier method. Unknown function is to be presented in a look of equation:

$$U(x_1 t) = X_{(x)} \cdot T_{(t)}\,.$$

Then the equation could have a look:

$$\frac{d^2 X}{dx^2}T = \frac{1}{\psi}\cdot\frac{\partial T}{\partial t}X + \frac{1}{c^2}\cdot\frac{\partial^2 T}{\partial t^2}X\,,$$

or

$$\frac{1}{X}\frac{d^2 X}{dx^2} = \frac{1}{\psi}\cdot\frac{dt}{dT}\cdot\frac{1}{T} + \frac{1}{c^2}\cdot\frac{d^2 T}{dt^2}\cdot\frac{1}{T} = -\omega^2\,.$$

By this, two equations where received:

$$\begin{cases} \frac{d^2X}{dx^2} + \omega^2 X = 0 \\ \frac{d^2T}{dt^2} + 2a\frac{dT}{dt} + \varpi^2 c^2 T = 0 \end{cases} . \qquad (7)$$

From the first equation (7) have:

$$X_{(x)} = A \cdot \cos x + D \cdot \sin \omega x,$$

where

A, B –constants of integration

$$\frac{dX}{dx} = -A \cdot \omega \cdot \sin \omega x + B \cdot \omega \cdot \cos \omega x \cdot$$

First congenerous boundary condition gives $B = 0$.

From another point it has $\sin \omega L = 0$.

By this

$$\omega_n = \frac{\pi \cdot n}{L} \cdot$$

For another equation of the system (7) is a character equation:

$$k^2 + 2ak + \left(\frac{\pi \cdot n \cdot c}{L}\right)^2 = 0 \cdot$$

Its decision is

$$k_{1,2} = -ka \pm i\sqrt{\left(\frac{\pi \cdot n \cdot c}{L}\right)^2 - a^2} \cdot$$

Then total decision of the second equation of the system (7) has a look:

$$T(t) = a_n e^{-at} \left(\begin{array}{l} \cos\sqrt{\left(\frac{\pi \cdot n \cdot c}{L}\right)^2 - a^2} \cdot t + \\ + \sin\sqrt{\left(\frac{\pi \cdot n \cdot c}{L}\right)^2 - a^2} \cdot t \end{array} \right) \qquad (8)$$

Integral constant a_n can be found from equation:

$$a_n = \frac{2}{L}\int_0^L U(0,t) \cos\frac{\pi \cdot n \cdot x}{x} dx, \qquad (9)$$

where $U(x_1 0)$ – first function of distribution

$$U(x,0) = P(x,0) - \gamma_x - \gamma_1 x^2 =$$
$$= p_1 - \frac{p_1 - p_2}{L}x + \mu \cdot M_0 x + \mu\frac{M_L - M_0}{L}x^2$$

After integration we receive

$$a_n = \frac{2}{\pi^2}\sum_{i=1}^{\infty}\left[\begin{array}{l} \frac{2}{n}\left(M_L - M_0\right) - \frac{1-(-1)^n}{n^2} \times \\ \times\left(p_1 - p_2 - \mu \cdot Ì_0 \cdot L\right) \end{array} \right].$$

Thus, term for function $U(x_1 t)$ has an appearance:

$$\begin{array}{l} U_n(x,t) = \frac{2}{\pi^2}\sum_{n=1}^{\infty}\left[\frac{2}{n}\left(M_L - M_0\right) - \frac{1-(-1)^n}{n^2}\left(p_1 - p_2 - \mu \cdot M_0 \cdot L\right)\right] \times \\ \times \cos\frac{\pi \cdot n \cdot x}{L}\left(\begin{array}{l} \cos\sqrt{\left(\frac{\pi \cdot n \cdot c}{L}\right)^2 - \left(\frac{\lambda \cdot w}{4 \cdot d}\right)^2} \cdot t \\ - \sin\sqrt{\left(\frac{\pi \cdot n \cdot c}{L}\right)^2 - \left(\frac{\lambda \cdot w}{4 \cdot d}\right)^2} \cdot t \end{array} \right) \times \\ \times \exp\left(-\frac{\lambda \cdot w}{4 \cdot d}t\right) \end{array} \qquad (10)$$

By this way, the assigned task realization on Fourier method has an appearance:

$$\begin{array}{l} P(x,t) = P_n - \frac{P_n - P_k}{L}x - \frac{\lambda \cdot w}{2dF}M_0 x - \\ - \frac{\lambda \cdot w}{2dF} \cdot \frac{M_L - V_0}{L}x^2 + \\ + \frac{2}{\pi^2}\sum_{n=1}^{\infty}\left[\begin{array}{l} \frac{2}{n}\left(M_L - M_0\right) - \frac{1-(-1)^n}{n} \times \\ \times\left(P_n - P_k - \frac{\lambda \cdot w}{2 \cdot d \cdot F}\right)M_0 L \end{array} \right] \times \\ \times \cos\frac{\pi \cdot n \cdot x}{L} \times \\ \times\left(\begin{array}{l} \cos\sqrt{\left(\frac{\pi \cdot n \cdot c}{L}\right)^2 - \left(\frac{\lambda \cdot w}{4 \cdot d}\right)^2} \cdot t \\ + \sin\sqrt{\left(\frac{\pi \cdot n \cdot c}{L}\right)^2 - \left(\frac{\lambda \cdot w}{4 \cdot d}\right)^2} \cdot t \end{array} \right) \times \\ \times \exp\left(-\frac{\lambda \cdot w}{4 \cdot d}t\right) \end{array} \qquad (11)$$

Based on received by (11) results graphical dependence of pressure level fluctuation were designed for oil pipeline within non-constant process, which had been caused by oil changed supply in the oil pipeline. The presented dependence has been designed to the terms of "Odessa-Brody" oil pipeline by 674 km length and by diameter 1020 x 9.5 mm [15].

The results of calculation are testifying, that amplitude pressure changes are in wide range (in diapason 0.1-0.5 MPa) and with getting down by a time. Above mentioned diapason confirms to diameter of cycling tensions changes in oil pipeline walls 5.35-16.74 MPa. Extinction decrement of oscillatory process in time $D = e^{-\frac{\lambda w}{2d}}$ for real conditions is 0.005 –0.015 $\frac{1}{s}$.

Part of oscillatory process as a sum of frequency harmonics is to be presented by dependence:

$$\omega_n = \sqrt{\left(\frac{\pi \cdot n \cdot c}{L}\right)^2 - \left(\frac{\lambda \cdot w}{2 \cdot d}\right)^2}. \quad (12)$$

Obviously, by a long time of oil pipeline exploitation the hydro resistance coefficient has been changing, that will influence toward frequency of oscillatory process. Also, changes of regime work will be caused speed of oil move in oil pipeline this caused a change of oscillatory frequency simultaneously. But the first member value in (12) for real conditions is higher than a second member value, because frequency of oscillatory process basically being defined by sound spread speed in a liquid environment.

$$c = \sqrt{\frac{E}{\rho}},$$

where,
E – oil resilience module;
ρ – oil density.

As oil resilience and oil density are physical properties of pumping environment and can change with receiving a new oil consignment.

But a gas chase existence impact toward oil resilience model and medium pumping density, that is used to takes place in a way of the bubbles or gas jam.

Those comprehensive analyses factors influence toward oscillatory process character of oil pipeline pressure presented that frequency sinusoidal oscillation of pressure is within 0.4-0.6 (1/s).

The results of oil pressure fluctuation research have given a chance to choose the terms of experimental research providing of the pipe metal mechanical features changes research during oil pipeline exploitation.

3. Experimental research and discussion

The pipe metal 13G1S-U trademark had been taken as the researched object. This pipe metal was used for construction of “Odessa-Brody” oil pipeline. Chemical composition of pipeline steel is shown in Table 1.

In present time “Odessa-Brody” pipeline has been working by reverse regime, namely pump oil toward oil pumping complex “Pivdennyj”. A part of the oil pipeline had not been used by the reverse regime. Conditionally, oil pipeline can be divided into next parts:

- oil pipeline that had not been working and was not under pressure;
- oil pipeline that had not been working and was filled with lime water.

With a purpose of the samples research from these parts of oil pipeline and compare it with the samples from new pipe had been used:

- oil pipeline metal research samples made from new metal;
- oil pipeline metal research samples which had been under exploitation within 6 years (1);
- metal oil pipeline research samples which were cut off from pipe which had been conserved inside of lime milk for 3 years and had been exploited within 6 years (2).

Due to research samples that were cut off from oil pipeline were over worked till appropriate dimensions.

For the research of fatigue cracks growth kinetics, a set УКИ 7И was used. This set gives a possibility to provide fatigue research of drill pipe strength. Thus, for the research of fatigue cracks growth of oil pipeline samples the set had been re-equipped.

The samples were cut off from welded pipe. A scheme of experimental setup is presented in Figure 1 and dimensions researched samples that were used for experiments is in Figure 2.

The re-equipped experimental setup УКИ 7И consist of power and supporting unit. The power unit includes electric motor 2 for system drive, auto gear box connected with motor by clutch 1 and designed for load forming which connected with arm 7 with striker 8 which acts toward researched sample 9. Support 5 are related to supporting unit and console jamming 10. The sample is fixed with a help of upper and down “sponge”.

Table 1.
Chemical composition of pipeline steel

C	Si	Mn	Cr	N	Ti	Al
0.11-0.15	0.4-0.6	1.25-1.55	up to 0.3	up to 0.012	0.015-0.035	0.02-0.05

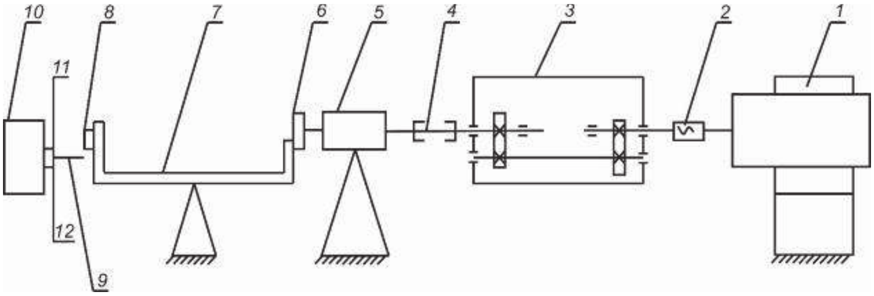


Fig. 1. Principles scheme of re-equipped experimental setup for research tests УКИ 7И

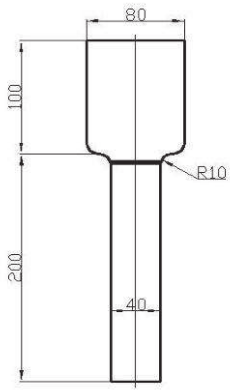


Fig. 2. Experimental sample for research providing

The set gives a possibility to provide experiment by console turn method. Fixing of the experimental sample is presented in Figure 3.

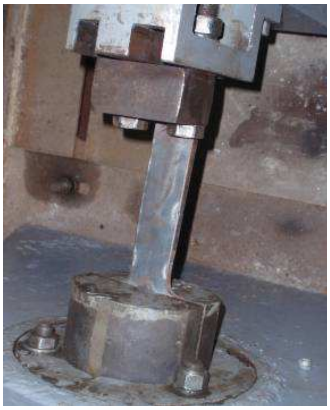


Fig. 3. Sample unit fixing

Due to avoid danger situations, manager panel is equipped by blocking automatic. Except the blocking automatic necessary control measurement equipment were situated on the management panel.

Amplitude dimension was provided with help of a micrometre with edge measurement accuracy 0.01 mm installed under experimental sample. Amplitude regulation was made by the striker moves up or down (Fig. 4).

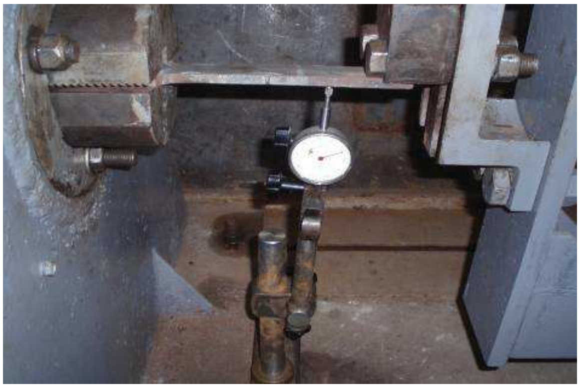


Fig. 4. Sample deflection measurement

Measurement of the pipe metal sample trade mark 13Г1СУ that have been in the different conditions of exploitation with cycling frequency f was defined on the basis of pressure fluctuation analytical research ω_n, where $f=2\pi\omega_n$. Calculations demonstrate that cycling frequency must be in between from 3 to 5 hertz. As the terms of experiments providing 3.8 hertz of frequency had been taken. For fatigue experiments a base $2{\cdot}10^6$ cycles was selected.

Being the experiments provided for 3-th samples a moment cracks appear has been fixed (for experimental sample from metal (1) presented in Fig. 5). The experiment results presented in Table 2. A fatigue curve has been made according of the results.

The fatigue tests of samples of pipeline steels were carried out in the state of supply and after exposure to lime milk (Tab. 2).

Fig. 5 Moment of crack appear in the experimental sample from metal (1)

For fatigue curve design three paramedic nonlinear equation of E.K. Pochtenny had been used as following [14]:

$$N = \frac{N_0 \sigma_0}{\sigma} \ln \left\{ 1 + \left[\exp\left(\frac{\sigma - \sigma_0}{V_0} \right) - 1 \right]^{-1} \right\}, \quad (13)$$

where,
N – cycles quantity till samples breakdown;
σ – maximum tension of cycle from 0 loading;
V_0 – parameter curve incline with dimension tension;
N_0 – parameter which characterize cycles quantity to down level of fatigue curve turn.

The following parameters were obtained by the minimum squares' method: for the samples from new metal: the limit of endurance is 120 Pa, cycles quantity to down curve turn N_0=300000 cycles, parameter that characterize angle of inclination of fatigue curve is V_0=500 MPa; for the oil pipeline that had been cut off from a pipe which was in exploitation and inside of lime milk environment, limit of endurance is 90 Pa; cycles quantity to down curve turn N_0=300000cycles, parameter that characterize angle of fatigue curve inclination isV_0=520 MPa; for oil pipe samples that were cut off from a pipe which was in exploitation (1), the limit of endurance is 120 Pa, cycles quantity to down curve turn N_0=300000 cycles, parameter that characterize angle of fatigue curve inclination isV_0=510 MPa.

Table 2.
Experiment values for pipeline material fatigue tests

Metal type	Cycles for destruction	Tension value σ , MPa
New metal samples	192000	250
	297000	223
	490000	176
	741000	139
	1004000	125
	1396000	125
	1578000	124
	1709000	125
Samples from metal (2)	165000	229
	270000	193
	343000	168
	622000	120
	1008000	97
	1200000	96
	1500000	92
	1731000	92
Samples from metal (1)	151000	183
	200000	162
	265000	136
	476000	95
	1007000	70
	1170000	65
	1529000	62
	1735000	63

Fatigue curve in half-logarithm coordinate system and experiment results were presented in the Figure 6.

As seen from the Figure 6 fatigue strength for the samples made from new metal is more for 20-25% than for the metal that contacts with lime milk and for 30-40% more than for the metal which had been under exploitation. The fatigue curves for probability non-braking 0.9 and 0.95 for the metal samples made from new metal were presented on fig Figure 7 and for the experimental metal samples which were cut off from pipe which were under exploitation and inside of lime milk environment (2) in the Figure 8 and for experimental oil pipeline metal samples that were cut off the pipe that was under exploitation (1) in the Figure 9.

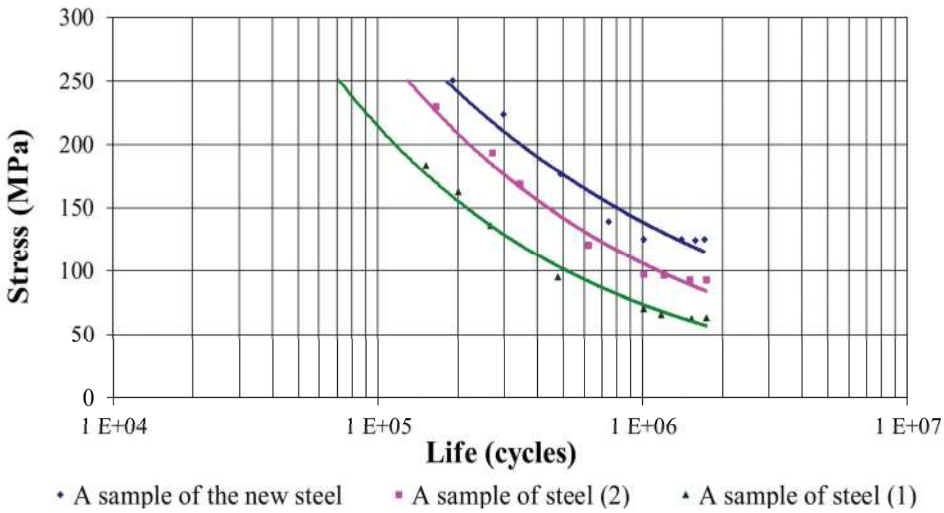
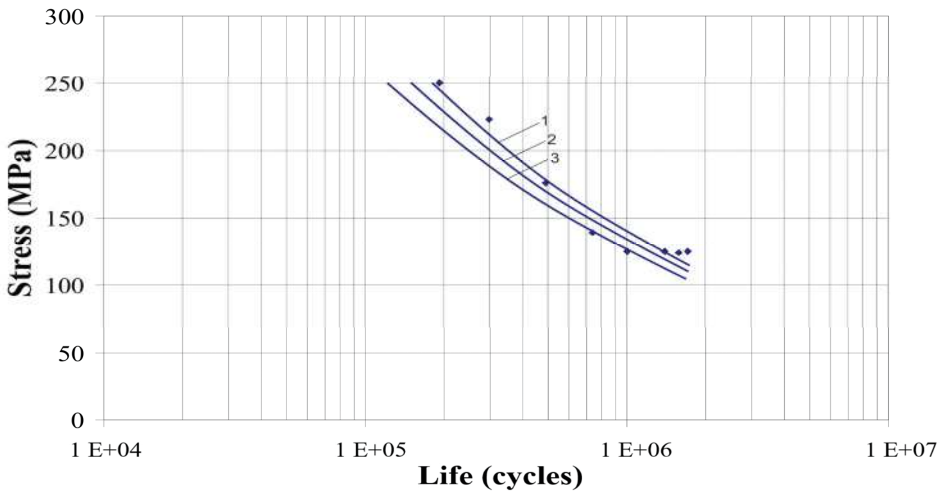


Fig. 6. Fatigue curves of pipeline steel samples



1 – median curve; 2 – probability of non-destruction 0.9; 3 – probability of non-destruction 0.95

Fig. 7. Probabilistic fatigue curves for new metal samples

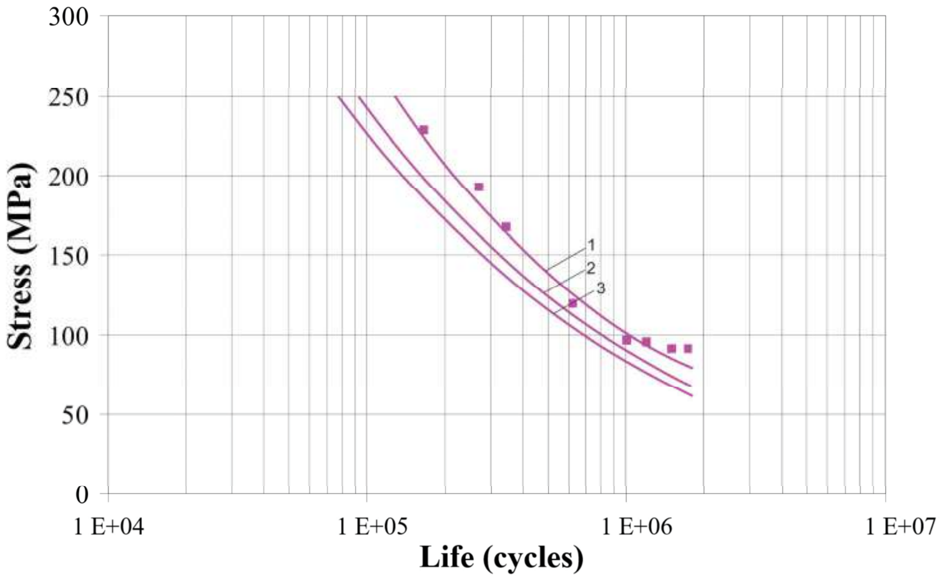
4. Conclusions

Mathematical model is made that describes non-stationary oil moves in oil pipeline, that has been caused by jump like changes of oil supply in oil pipeline, on this basis was defined, that oil pressure in oil pipeline provides within non stationary process in a range of 0.4-0.6 Hz frequency and amplitude fluctuation of pressure is 0.1-0.5 MPa.

Experimental studies of the dependence of the fatigue strength of the pipe material on the conditions of operation have been carried out, which made it possible to determine the parameters of the fatigue curve of the samples.

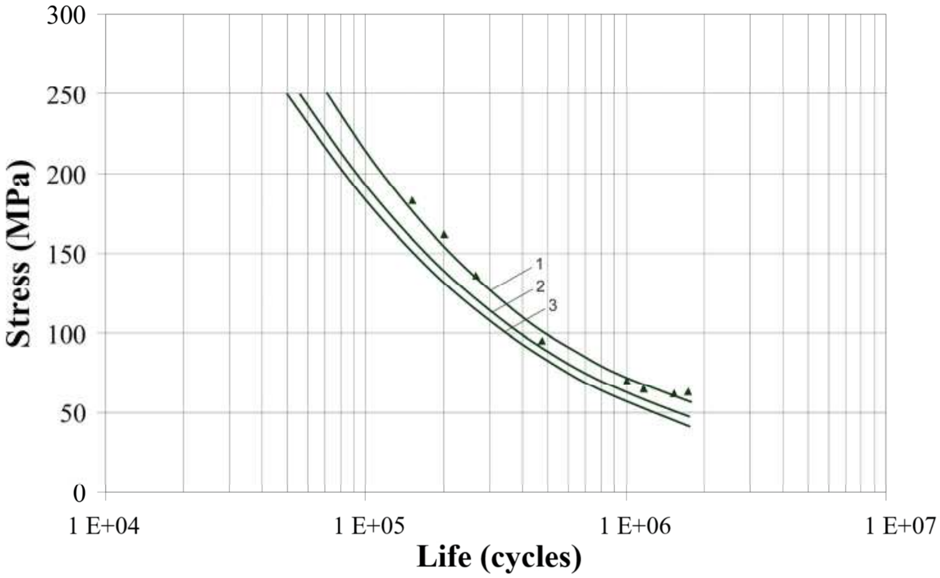
Has been defined that fatigue strength for the new metal pipe samples is more for 20-25% than for the metal samples which had the contacts with lime milk and for 30-40% more than for metal samples which were under exploitation.

The probabilistic curves of the pipeline non-destruction are constructed, which will be used for practical calculations of the reliability and durability of the pipelines.



1 – median curve; 2 – probability of non-destruction 0.9; 3 – probability of non-destruction 0.95

Fig. 8. Probabilistic fatigue curves for the samples cut off pipe that was in exploitation and inside of lime milk environment (2)



1 – median curve; 2 – probability of non-destruction 0.9; 3 – probability of non-destruction 0.95

Fig. 9. Probabilistic fatigue curve for the samples which were cut of the pipe which were in exploitation

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