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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

MICROCRACKS DIAGNOSTICS IN-PIPE OF SILICON COATING

Speciality: 3337.01- Information-measuring and control systems
(Oil industry)

Field of science: Technical sciences

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GENERAL DESCRIPTION OF THE THESIS PAPER

The subject relevance and research degree. The pipelines of oil-mining and oil-processing equipment operating in high temperature, pressure and chemically active environment become defective after a short period of operation. Intensive corrosion processes, deviations, cracks are formed on the inner surfaces of such pipelines, and they fail.

To avoid defects, the inner surfaces of the pipes are covered with various metal (non-metal) and organic (inorganic) materials. The most effective of such coatings, silicate coatings differing in their modernity and prospects are more widely applied. The quality of the silicate coatings resistant to chemical and thermal environments is an essential issue.

Experimental studies and procedures have shown that the main defects in silicate coated pipes are irregularities on the inner surface of the pipe, small bubbles, macrocrystalline layers, which greatly reduce the life of their operation. The causes of such defects are due to improper selection of the technological mode upon laying silicate-enamel coating on the inner surface of the pipes. The choice of the technological mode upon laying the coating depends on the geometric dimensions and technological parameters of the pipes. Such technological processes are operated automatically.

Nevertheless, microcracks are formed on the surfaces upon laying silicate coating inside the pipes of various geometric dimensions. The formation of such microcracks is due to the non-accuracy of the process of laying silicate coating, automatic adjustment of technological parameters and failure of diagnostic analysis to meet modern requirements, so their solution proves the relevance of this thesis paper.

Despite the fact that the process of diagnostics of microcracks is being carried out, the issue of diagnostics of microcracks is still a problem.

The purpose of the thesis paper is to reduce the formation of microcracks through adjusting parameters in the technological process in high temperature conditions and their diagnostics upon the purchase of silicate coated pipes. At the same time, it is an automatic adjustment of the cooling mode and the diagnostic analysis of the formed cracks of the silicate coating obtained through high temperature.

It is known that the non-accuracy upon the laying silicate coatings inside the pipes causes the formation of the microcrack layers. Taking this into account, the main tasks of the research are the automatic adjustment of the parameters of the technological mode of the device and the control system determination, the improvement of the automatic adjustment of the cooling process of the pipe coating in order to avoid microcracks upon the laying procedures for ensuring the purchase of quality coatings.

Research methods. The research methods of the paper are the following:

The support and design of the automatic adjustment and control system for the laying of quality (flawless) coating inside the pipes of the furnace device is based on the use of software in the "Matlab" environment. Computer modeling used in the Matlab environment was performed

Arduino microcontroller software was used to measurement of the parameters of cracks with a defectoscope to detect the microcracks formed upon the technological process of silicate coating in oil and gas mining pipes and operating conditions of silicon coating in oil and gas mining pipelines. The results of the received diagnostics were processed by the software called "Diagnostics of microcracks" is written in C # programming language.

Main issues for review. The main issues to be considered for the performance of the thesis paper are as follows:

1. To design an automatic regulation and control system of the technological mode for the devices used to apply silicate coatings on the inner surface of the pipes.

2. To design the microcontrolling management system of an electric spark defectoscope for determination of micro and macro-cracks on the silicate coating surface inside the pipes

3. To make mathematical modelling of the cooling mode of the silicate coating pipes exposing to cooling from high temperature (600-800^{0}C) to room temperature, and to provide the automatic adjustment of cooling parameters

4. To specify the economic efficiency with analysis of macro-/ micro-cracks and faults upon application of silicate coating pipes in the oil and chemical industry

The scientific novelty of the paper:

1. To design the automatic adjustment system for technological parameters upon laying high-quality silicate coating in the furnace devices under high temperature conditions (600-800C).
2. To make mathematical modelling of cooling mode of high temperature pipe coatings, automatic adjustment and diagnosis of cracks.
3. To improve the electric spark defectoscope for micro and macro-cracks on the silicate coating surfaces.
4. To design the "Microcracks diagnostics" software and algorithm and to determinate the coordinates and geometric parameters of microcracks

Personal presence of the author. Problem statement in the dissertation work, experiment, analysis of the obtained results, generalizations were made by the author.

Theoretical and practical significance of the paper.

1. The methods of solving the problems laid down are based on the theory of automatic regulation and the application of mathematical model with the programs of the management system. The results obtained from the classical method solution of the differential equations of heat conduction of the double cylinder are fully reflected in the stability of the study.

2. On the basis of observations conducted at SOCAR, CPC and its results, the process of laying the coating on the surface of pipes has been improved. Thus, the forward movements with the rotation of the pipes in the newly developed and applicable device are regulated depending on their geometric dimensions.

3. Due to the precise modelling of this control system, the technological parameters are automatically adjusted. As a result of the

modelling and management system developed, accurate results have been obtained in technological mode with a decrease in errors from 5-8% to 1-3%.

4. Economic efficiency is calculated as a result of the application of high-quality silicate coating. As a result of reliability, the longevity is increased by 1.5-2.5 times. The companies have introduced the reports of application.

Approbation and application. 19 scientific articles on the volume and content of the dissertation were published. 14 of them are articles. 9 of them are co-authored and 9 have been published abroad (2 articles are included in the Wos: SCI / SCIE database). 5 thesesis of reports made at international and national conferences were published.the main results and content of the thesis paper were presented at the following conferences:

- The X International scientific practical conference of young researchers, Bulgaria, Sofia, 2014.
- The XIX Republican Conference of doctoral students and young researchers, Baku, 2015
- The Republican scientific and technical conference of youth and scientific innovations, Baku 2017.
- The XXI Republican scientific conference of doctoral students and young researchers, Baku 2017.
- The Opportunities and prospects of application of information technologies and systems in construction, Baku 2018.
- The Modern information, measurement and control systems: Problem and perspectives, Baku 2019.

The name of the thesis paper preparation institution;

The studies were conducted at the "Electronic and automation" Department of the Azerbaijan State University of Oil and Industry.

Defectoscopic measurements were performed at the new training center of the State Oil Company of the Republic of Azerbaijan. At the same time, the laboratory of the SOCAR training center carried out the determination of the coordinates and dimensions of defects on the surfaces of pipes with silicate coating of different sizes, including cracks.

The thesis paper volume and scope. The thesis paper consists of introduction, 5 chapters and the list of reference and appendices. The main volume of the paper consists of 191 pages, including 26 figures, 17 tables, 11 grapics, 120 references and 16446 simvols without tables, pictures, grapics and bibliography.

THE PAPER SUBJECT

The İntroduction substantiates the relevance of the dissertation work, the purpose and issues of research have been identified. The scientific work and practical significance of the obtained results are shown.

Chapter one deal with the analysis and interpretation of the automatic adjustment of the technological mode of the device designed to apply the silicate coating to the inner surface of the pipes. These coatings are resistant to corrosion and increase the reliability and longevity of the pipe. The analysis of the method of elimination of defects on the surfaces of the coating in the technological process is described.

One of the factors affecting the quality of the coating is that the pipes are very uneven, rough, and sticky, etc. as a result of poor quality coating is in a state.

Despite the introduction of automatic adjustment and control system in the technology of obtaining silicate coatings, the emergence of defects, including macro-microcracks, has been observed. Since accuracy is not taken into account in the current management systems, a sudden violation of the technological process has resulted in formation of defects.

In the automatic adjustment process, the laying of the coating on the surface of the pipes is completed by heating the pipe to a high temperature (600-800°C), entering the oven with a forward and simultaneous rotational motion. At this time, the formation of cracks on the surface of the coating and metal pipe as a result of stress and compression caused by thermal stresses and deformations has been investigated.

Since the automatic adjustment procedures have been carried out within a certain framework of investigations of Skvortsov, B.V., Prokurenko, Y.A., Jornik, V.A., some of the forming defects have been eliminated[1].

The technological process of pipes is executed at 600-800 ^{0}C temperature with automatic regulation and control system. After that popes must be cooled naturally and artificially.

In this case, one of the most important issues is to accurately determine the cooling mode. Otherwise, depending on the geometric dimensions of the pipes on the surface of the coating, macro and micro cracks and bulges appear, rendering the coating unusable. Statictically silicon-coated pipes must be cooled in a special mode.

A mathematical model for the automatic adjustment of the operating mode of the device in the process of laying the coating based on the experimentally constructed curve of the temperature dependence of the voltage. Temperature dependence of coating tension during cooling is shown in Graphic 1.

At present, the meteorological and technical characteristics of the newly developed and commissioned “Korona-12” and “Korona-C” electric sparkling defectoscopes are considered more favorable to find out defects on the internal surfaces of the silicate coating pipes. However, the test voltage of defectoscopes is able to detect defects with the coating thickness from 5 to 30 mm in the range of 10 kV. Table 1 shows the comparison of the meteorological and technical characteristics of "Korona" type defectoscopes[2].

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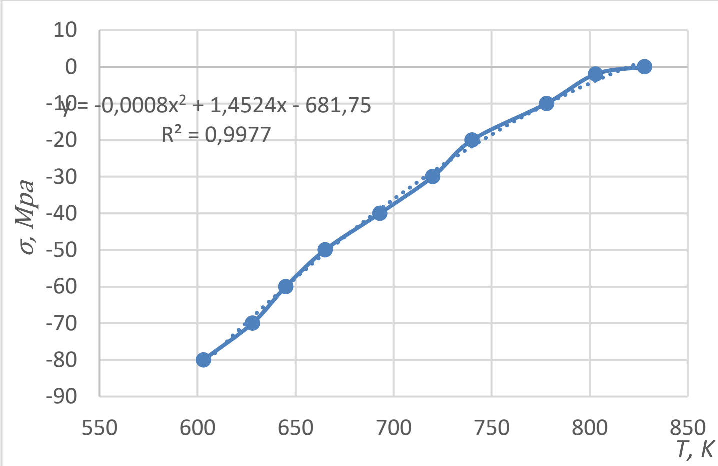
[1] Василин, В.А., Ивашов, Е.Н., Степанчиков, С.В. Автоматизация нанесения тонкоплёночных покрытий в современных вакуумных технологиях // Автоматизация и современная технология, 2011, №7, с. 19-21

[2] Прибор для контроля и обнаружения дефектов изоляционных покрытий Электроискровым методом «Корона С» руководство по эксплуатации, Вариант для использования в системах заводского контроля. УАЛТ.025.000.00ПС, Санкт-Петербург, 2014, 17 с.



Graphic 1. Temperature dependence of coating tension during cooling

Although macrocracks on the surface of silicate coatings of pipes were removed, the microcrack formation issues were not investigated.

The "Korona-C" prototype has been proposed to be applied to a new electric sparkling defectoscope to find out the macro- microcracks of the silicate coatings inside the pipes.

Chapter two deals with the minimization of macro-microcracks caused by the automation of technological process in silicate coated pipes and the adjustment of their technical parameters[1,2].

It was also taken into account that the technological process, which is the basis of the causes of cracks and defects, was not carried out accurately and the employees did not comply with the technolo gical regulations. With all this in mind, scratches on silicate coated pipes, star-shaped, wavy and groove cracks in the form of fish flakes, black dots, thin cracks with small holes, and etc. occur.

Geometric dimensions of such crack layers depending on the brand and thickness of the silicate coating accept the microcracks in the range of 0.3-3.0 mm and the macrocracks in the range of 3.0-5.0 mm, even the length of the cracks reaches up to 10 mm[3].

Thus, the pipe coating laying procedures consist of two stages. In the first stage, a device control system is built to draw a liquid silicon coating inside the pipe. Here, a certain thickness and smoothness of the coating is obtained by adjusting the flow rate of the liquid.

. The system operates in the following sequence. According to the picture 1, the device is covered with silicate material to absorb the liquid inside the pipe by using a 4-valve.

Then the liquid flow is controlled with the 5 valve support. It is

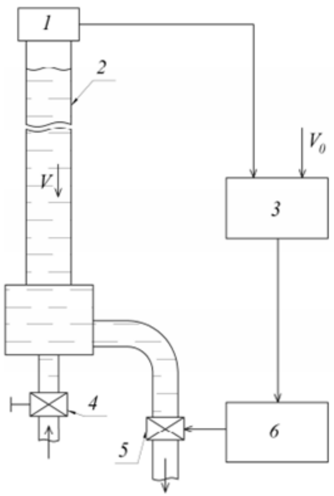


Figure 1. The pipe coating device flow chart

1-Liquid measuring transmitter, 2-pipe, 3-control and information block, 4-valve, 5-hose support, 6-electric motor.the device to apply the slurry coating inside the pipes.

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[3] Прибор для контроля и обнаружения дефектов изоляционных покрытий Электроискровым методом «Корона С» руководство по эксплуатации, Вариант для использования в системах заводского контроля. УАЛТ.025.000.00ПС, Санкт-Петербург, 2014, 17 с.

Table 1.

Technical characteristics of electrical defectoscopes manufactured by different companies

Device	Manufacturer	Country	U, kV	f, hs	d, kV	Δ, %	t, hour	T, °C	Dimensions	Crack determination interval	m, kg
Korona1.2	Konstanta	Russia	35	600(0.7-2kV) 50(2-4kV)	0.1	5%	20	40+50	240x149x52	3 mm	2
Elcometer 266	Elcometer	Britain	30	-	0.1	5%	40	0+50	520x370x125	5 mm	1.2
Elcometer 280	Elcometer	Britain	35	30	0.01-0.1	5%	30	0+50	603x219x193	5 mm	3
Inspect 8.0	Isotest	Germany	8	50	0.5	n.d	9	n.d	220x256x88	4 mm	3.9
Compact P	PCWI	Australia	20	50	0.1	n.d	n.d	n.d	260x160x70	5 mm	2.2
PHD pro	Buckley	Britain	6	-	0.01-0.1	1%	16	0+40	160x60x200	4 mm	1.6
AP/W	Tinker&Razor	USA	35	50	0.1	5%	n.d	10+50	171x216x203	4 mm	3.62

The silicon coated pipes are dried at 20-30 °C for some period and delivered to the furnace assembly to be heated at high temperature to obtain a full smooth coating [4]

The silicon coated pipes entered the oven are treated as double cylinders.

As the temperature in the oven is stable at 1000°C, it is accepted that the heat is evenly distributed along the surface of the pipes, since upon heating the temperature changes only in the radial direction of the pipe

The silicon coated pipes entered the oven are treated as double cylinders. As the temperature in the oven is stable at 1000°C, it is accepted that the heat is evenly distributed along the surface of the pipes, since upon heating the temperature changes only in the radial direction of the pipe.

By applying the differential equation of thermal conductivity of the double cylinder to the coated pipe, using the initial and boundary conditions of the heating of the pipes, the mathematical expression of the regulatory parameters is obtained as follows.

$$T=600+[200\frac{V_1^2}{n_1^2}\ln(\frac{D_2}{D_1})+(D_2^2-D^2)]k \qquad (1)$$

Where: D_2 is the metal pipe outer diameter;

D_1 is the coating outer diameter;

D is the coating inner diameter;

$k=10^1\text{-}10^3$°C/mm^2 is changeable conversion coefficient of measurement units;

n_1,V_1 is the system that is modelled in the technological process depending on the number of rotational cycles of the pipe, the speed of its progress and the diameter of the cover. The values for the

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[4] Скворцов, Б. В. Исследования и оптимизация параметров системы управления нанесением покрытия на внутреннюю поверхность трубы. // Вестник Самарский государственный аэрокосмического университета, 2013, №3, с.185-189.

construction of this model vary and are accepted within the following value range;

n_1 =1.0÷10 r/sec, V_1= $5.0 \div 20\frac{mm}{sec} = 0.005 \div \ 0.02\frac{m}{sec}$,
$D_2 = 50 \div 500\, mm = 0.05 \div 0.5m$.

The temperature of the pipe to be coated depends on the thickness of the coating, the pipe rotation speed and the speed at which the pipe moves into the furnace through computer generated modelling.

At this time, the calculations of both MATLAB simulating software are used that allows to build a model of visual imitation of the process and to perform computer experiments, and it is shown in Figure 2.

Computer experiments were conducted in the following manner. In the T- range, modelling and calculation of the pipe cover temperature changes, i.e. at different rates of pipe rotation speed around its axis, gradually variable values of the pipe forward speed were performed.

In the second stage, the calculation of the temperature of the coating and the construction of suitable parametric dependences were carried out using the mathematical model of gradual change of both parameters within the relevant interval.

As we can seen from the figure, the simulation model uses constant blocks to include the initial values of the parameters, limited integration blocks to ensure that these parameters change continuously within the interval, and the necessary computational operations, such as multiplication, division, addition, subtraction, multiplication, and natural consists of appropriate multiplier and divisor, summation, amplification, and logarithmic blocks to perform logarithmic operations, and finally, appropriate blocks to check intermediate results and obtain graphical representations of the final result of the calculation. A result of the imitation model are shown in Graphic 2.

As demonstrated from the graph, the temperature of the pipe remains constant after the rotation speed reaches 8 m/sec. So, this speed is optimal at the given values of the parameters and ensures the correct conduct of the process.

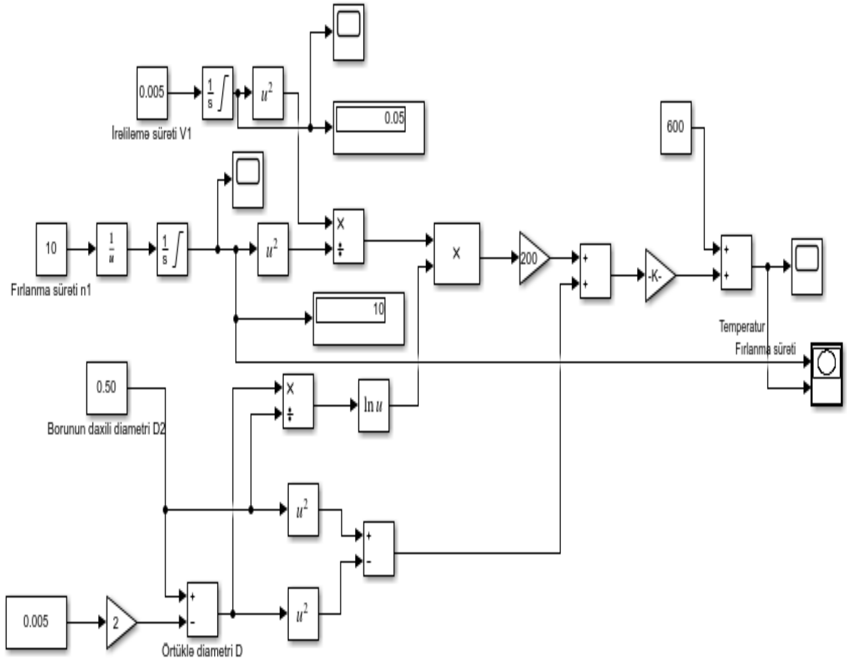
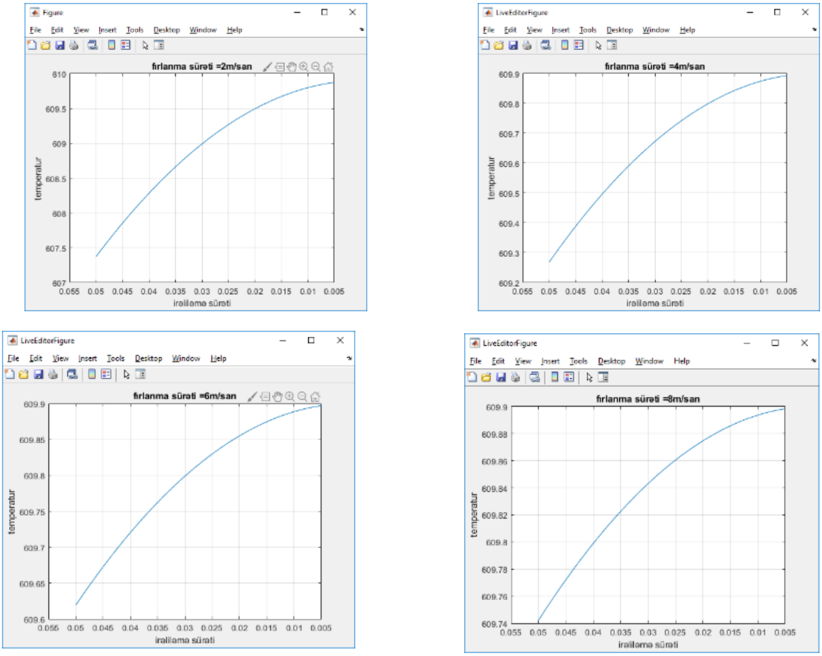


Figure 2. The simulating model in the simulating environment scheme



Graphic 2. The temperature of the pipe at different rotational speeds

The technological process control system consists of transmitters and performance units, as well as indicators and signalling ALCM measuring the speed of the pipe forward V, the number of rotation cycles n and the temperature T on the surface of the pipe outgoing from the oven[4] .

The functional diagram of the device is shown in Figure 3.

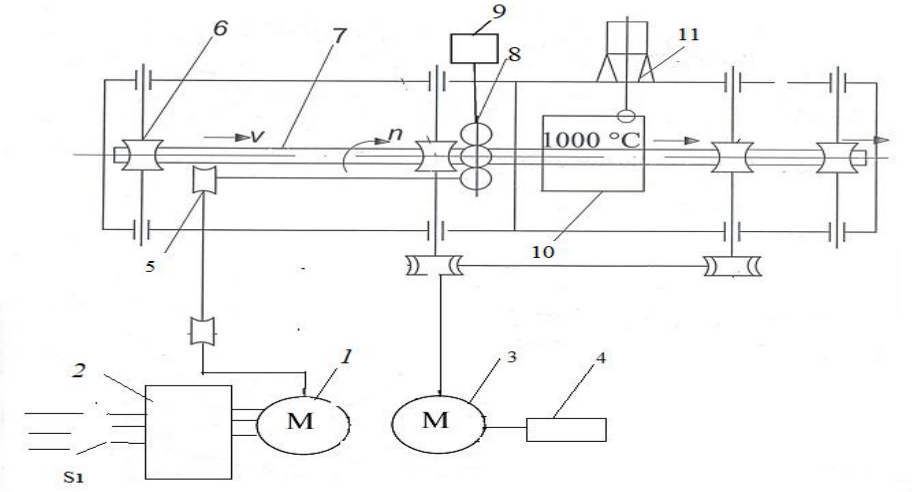


Figure 3. The furnace device flowchart

1-rotation regulating electric motor; 2-invertor; 3- forward movement regulating motor; 4-tachometer; 5-mechanical transmission; 6-conical bearing; 7-pipe; 8-rotating unit; 9-encoder; 10-oven; 11-pyrometr.

The adjustment parameters of the 2nd stage of the coating drawing process and the model of the control system are shown in Figure 4. The pipe (7) moves towards the oven with a certain speed of rotation and forward through conical rollers of different diameters and angles (6). Rotation and forward movement (5) are performed using special (8) rotating units and electric motors. Additional mechanical displacements are carried out using mechanic agitators (1) and electric motors (3). The forward and rotation movement of the devices is one of the main parameters of the technological process.

The moving pipe enters the oven (10) after a certain time. In the oven with a temperature of up to 1000℃, the coating heating process takes place. At this time, the temperature change on the surface of the coating (11) is determined by the pyrometer[3,16]

The pyrometer measures the temperature on the surface of the pipe by absorbing rays from the surface of the coating and transmits the result to PLC.

The red indicator shows that the pipe is of improper quality, and the green indicator shows that the pipe is of proper quality. If the pipe transmission speed is V=5.0÷20.m/sec and the temperature is in the range of 600-800 ^{0}C, the pipe is considered to be of proper quality[2,4].

The Encoder transmits the number of circuits that the electric motor makes per a minute to the PLC in the form of an electrical impulse, allowing the operator to simultaneously adjust the V–forward speed of the pipe and the rotation number (n). To adjust the number of rotational cycles of the pipe in the calculated mode, an electromechanical tachometer and a converter are provided. The PLC control flowchart, which has been applied to ensure that the parameters shown are within the specified value range, is shown in Figure 4.

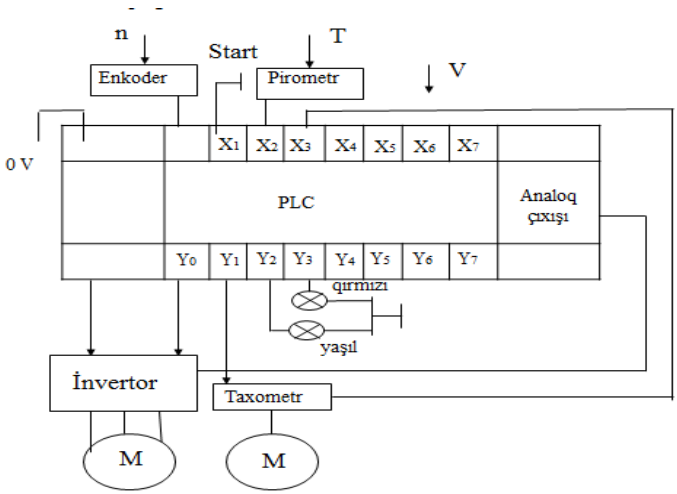


Figure 4. PLC-based technological process control flowchart

Chapter three deals with the diagnostics of local spots, scratches and circular (screw-shaped) crack layers arising from temperature changes during cooling on the surfaces of the coating and their cooling regime are covered in high-temperature silicon-coated pipes. The cause of cracks is the tensile and tensions caused by various temperature drops on the surfaces of the coating. Therefore, these defects arisen can be eliminated by temperature regulation.

At high temperature of 600-800°C, the heated coating pipes come liquid environment. Otherwise, it causes macro–microcracks, blisters and roughness on the surfaces of the coating.

The tests and practical experiments show that in order to ensure the quality of the coatings inside the pipe, it is necessary to create a certain temperature regime to cool the coatings, as they are heated to a high temperature. So, when laboratory experiments were conducted, it became known that since silicon coatings are fragile, it is necessary to cool them only at constant drop temperatures, depending on their brands and thickness. According to the studies as described in the known reference, such constant drop temperatures

According to the experience as described in the known reference, this corrected temperature drop depends on the coating brands (EP-1, EP-2, EP-20, EP-30), so the change of the cooling and drop temperature within the range of ΔT=5-10°C causes positive results. Since these quantities are practical, so depending on the geometric dimensions of the coating and the time period, the exact temperature drop should be determined according to the brand of each coating.

As a result, the temperature drop in the coatings of different brands should be determined in the operating conditions, and the characteristics of the coatings of different brands widely used are given in Table 2.

On the basis of the experiments, the optimized heating and cooling time in all branded silicon coatings is considered appropriate for the purpose in the interval τ=25-50 minutes. In order to fully implement these modes, the coating inside the pipe is cooled to a constant drop temperature, and the air is adopted as a cooling agent. Depending on the intensity of the air supplied to its surface with a special cooling apparatus, the cooling process is carried out.

The cooling temperature of the refrigerator is determined by the following formula as known.

Table 2.

Thermal and physical properties of the coatings

Thermal properties of the coating	The coating industry brands				
	ЭП-1	ЭП-2	ЭП-10	ЭП-20	ЭП-30
Linear expansion coefficient λ, $10^{-7}C^{-1}$	103	89	50	32	64
Coating softening temperature ℃	520	580	620	650	690
Heat transfer coefficient 20℃, Vt/m ℃	0.63	0.92	0.89	0.91	0.98
Coating density 10^{-3}kg/m^3	1.1	1.29	1.38	1.41	1.48
Special heat capacity Cal/kg ℃	1.7	1.8	2.1	2.8	3.2
Constant temperature drop in cooling (overheating) ΔT, ℃	8.2	7.5	5.0	10.0	9.5

$$T_2 = \frac{Q}{c\rho} \tag{2}$$

Where: c is the special heat capacity of the coating,

ρ is it the coating material density,

Q is the heat amount received by the refrigerator based on the coating material density.

Thus, when cooling the coated pipe, the temperature area of the coating is obtained by solving the initial and boundary conditions of the differential equation of non-stationary heat conduction of the double cylinder. The temperature during cooling on the surfaces of the pipe coating according to the solution is determined by the following formula.

$$T_1 = 9.81\exp(\frac{a\tau}{R}) \qquad (3)$$

Where: T_1 is the temperature on the coating surface upon cooling;

a is the coating temperature transfer coefficient;

τ is the cooling time.

$R = \frac{R_3^2 - R_2^2}{R_2^2 - R_1^2}$ is the relative coefficient of cross-section of the pipe and the coating. So, the temperature drop is determined in the cooling process as follows $\Delta T = T_1$-T_2.

Based on this formula, automatic adjustment with the control system depending on R1, R2, R3, Q, T1, T2 parameters was carried out by adopting the temperature fall of the cooling process in the single time, i.e. τ=1 min in the interval of t_0=5-10°C.

This study was carried out in the sequence as indicated in the "Matlabin" simulating package. The task of the system is to adjust the cooling process (5 -10°C), keeping the fixed given values of the cooling speed with the help of the cooling agent, as a result of the inclusion of high-temperature coated pipes into the cooling chamber. Figure 5 shows the adjustment system model.

The following elements are used to build the system. The inertial element (3) and the algebraic aggregator (5) are used to model the temperature drop of the heat conductivity pipes. The input of each of such elements is influenced by the signal source (1) push. The output (5) of the camshaft indicates the change in T1 temperature over time, and oscillograph (9) is used to observe its change.

The monitor shows the dependence of time on the cooling process obtained upon modelling procedures. The regulator (6) and the corrective element (4) are used to model the elements of the cooling channel. The elements (4) and (6) play the role of automatic regulator together. The cooling temperature should be changed so that $\Delta T = T_1 - T_2 =$ (5-10°C) temperature drop should be kept constant.

The element (2) is used to create the required temperature differences[2,3].

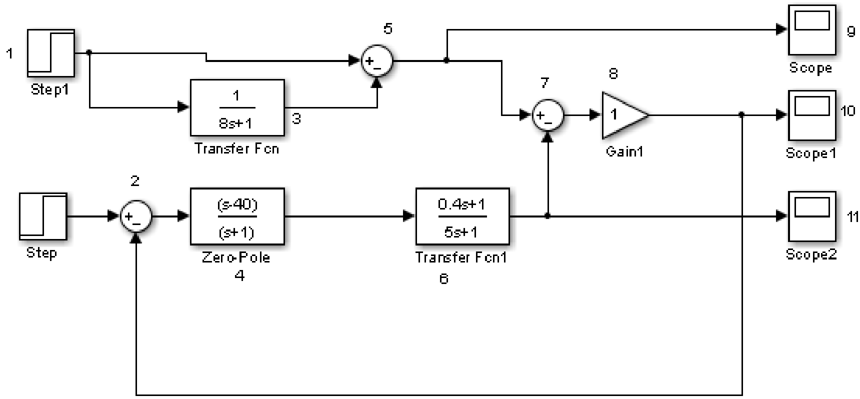


Figure 5. The regulatory system model

1 - boost signal; 2, 5, 7 - concentrating elements; 3 - inertial element; 4 - corrective element; 6 - automatic regulator; 8 - amplifier; 9, 10, 11 - oscilloscopes

Through it, the amplitude of the boost function ΔT_1 (2), (7) compare the actual cooling temperature velocity on the concentrator element with ΔT, the pre-determined T, and the differences between them are given to the elements (4) and (6) to create a profile of the T_2 temperature area.

If the model is connected through the start button, the results obtained are displayed with 9, 10, 11 oscillographs. Thus, oscillograph 9 indicates cooling of the heated pipe coating, T1 curve, oscillograph 10 indicates the changes of the cooling speed over time, and oscillograph 11 indicates the cooling temperature changes over time created by the cooling agent.

Studies have shown that changes in the R value of R_1, R_2, R_3 are observed. Thus, the increase in R value varies with the decrease in these expressions.

On the basis of the report, it is possible to visually review the reports as shown in Table 3.

Table 3.

The coating temperature drop upon the coated pipe cooling procedures

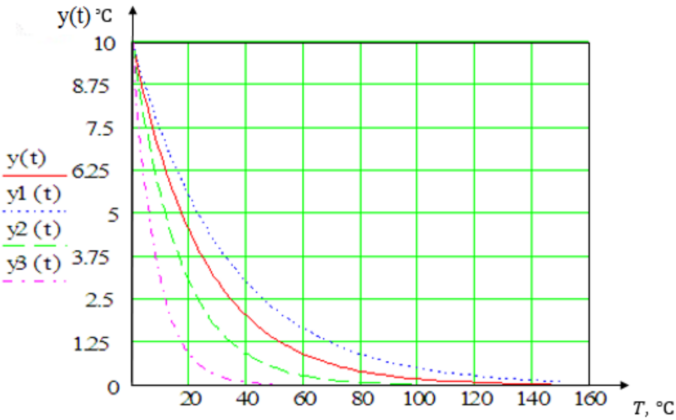
№	$y(t)$	$y_1(t)$	$y_2(t)$	$y_3(t)$
1.	10	10	10	10
2.	9.608	9.704	9.418	8.939
3.	9.231	9.413	8.839	7.866
4.	8.839	9.139	8.363	6.977
5.	8.521	8.939	7.833	6.188
6.	8.187	8.607	7.408	5.488
7.	7.833	8.363	6.977	4.936
8.	7.658	8.103	6.67	4.317
9.	7.261	7.933	6.198	3.829
10.	6.977	7.634	5.827	3.396
11.	6.703	7.408	5.488	3.012
12.	6.44	7.189	5.139	2.671
13.	6.188	6.977	4.933	2.369
14.	5.945	6.771	4.594	2.101
15.	5.712	6.67	4.317	1.934

Calculation of quantities is carried out through the program. The main task is to practically determine the thickness of the coating on the basis of the outer and inner diameters of the metal pipe in accordance with the standard, which is created by automatic adjustment in the cooling and heating processes.

Taking these into account, all its characteristic parameters, depending on the brand of the coating and the area of application were modelled with the Simulink program and achieved certain results.

The dependence of the metal and coating cooling process on pipes of different geometric sizes is shown in Qraphik 4.

To build such diagrams, at first, the diameter of both the metal pipe and, most importantly, the coating is determined. The temperature change characteristics are directly proportional to the change in the coating thickness. Thus, it is possible to make the temperature change characteristics for all coatings in the crack formation interval (20-150°C) based on the graphical dependence and
described in figure 7.



Graphic 4. The silicon coated pipe cooling process characteristics

Here, $y(t)$, $y_1(t)$, $y_2(t)$, $y_3(t)$ is depending on the radius of the coated pipe (R, R1, R2, R3), temperature changes are characteristic upon the surface cooling process, ΔT is the coating surface temperature drop within τ-period, and, as a result, $\Delta T=T1-T2$ is obtained.

Here, $y_0(t)=10 \exp (a\frac{\tau}{R_0})$; $y_1(t)=10 \exp (a\frac{\tau}{R_1})$; $y_2(t)=10 \exp (a\frac{\tau}{R})$; $y_3(t)=10 \exp (a\frac{\tau}{R_3})$.

Chapter four. The diagnostic algorithm of defects on the silicate coated pipes surface, i.e. macro-microcracks, has been developed. Based on the current diagnostic methods, the electric spark defectoscope was used to determine defects. The defectoscope penetrates the coating surface through the electrode to 40 KV by penetrating into the crack layers, passes through the pipe according to the metal thickness and forms an electrical sheath.

The "Korona" defectoscope applicable for the studies was improved. The measuring range has been expanded, while the working principle of the selected defectoscope remained. The device is operated through the remote control. The parameters measured through transmitters connected to the Arduino microcontroller are processed by the software installed. As a result of the diagnostics, the coordinates and geometric parameters on which the crack locations are determined.

Let's consider the functions of the microcontroller control system in the following sequence. Figure 6 shows the technological and functional scheme of the electrical defectoscope device. Before starting the measurement, the threaded electrode (5) is transferred to the test tube (6). The defectoscope is connected to the network and initial settings are adjusted. One end (3) of the threaded electrode (4) is connected to the defectoscope, the other end (10) is connected to the drum (9), and the other to the electrical circuit (12). Thus, it is required to regulate the movement of the electrode along the test tube (6). For a pipe of different diameters and lengths, the moving speed

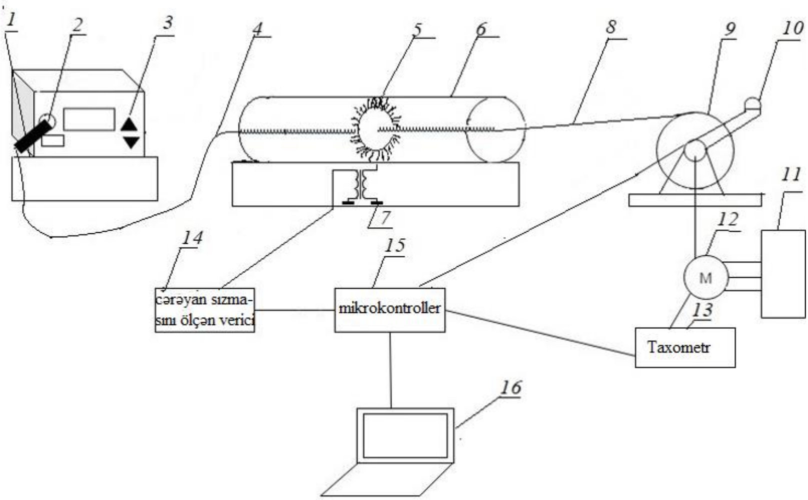


Figure 6. Technological functionality of the defectoscope

1-VT-1 transformer; 2–transformer connection slot; 3– ВИЭД-1 high performance electrical defectoscope; 4– connecting wire; 5- threaded electrode; 6–silicate coated pipe; 7-TU3B series transformer; 8–insulated tension wire; 9 - rotating drum; 10 - KY-040 series encoder; 11- AO-2 series electric motor movement speed inverter; 12-electric motor; 13- FC03 tachometer; 14- light current measuring transmitter; 15- microcontroller; 16- personal computer regulation of the number of rotation cycles of the rotor (11) of the electric motor (13). If there is a crack in the pipe, the electric circuit is moved by transmitters (14) due to the leakage occurred between the pipe and the electrode.

of the electrode is different and is calculated in advance[5, 6]. To determine the crack, the high-precision electrode (5) is moved along the pipe at a certain speed. The rate of this speed is determined by regulation (12) of the number of rotation cycles of the rotor (11) of the electric motor (13).

If there is a crack in the pipe, the electric circuit is operated by means of transmitters (14) due to the leakage occurred between the pipe and the electrode. The rate of this speed is determined by (12). The rate of the speed (12) is determined by the regulation of the number of rotational cycles of the rotor (13) of the electric motor (11). If there is a crack in the pipe, the parameters of the electric circuit are measured by transmitters (14) through the current leakage between the pipe and the electrode, and consequently the microcontroller detects the crack inside the pipe.

The defectoscope control and measurement scheme consists mainly of three operations and it performs functions for the detection of microcracks inside the silicon-coated pipes. The electric current permeability occurs upon the movement of the threaded electrode inside the pipe, and the two operations shown below are performed:

a) measurement of leakage current passing through the threaded electrode into the pipe;

b) determination of the distance of the electrode inside the pipe to determine the coordinates where the cracks are located in the pipe of the corrugated electrode;

c) control of the number of cycles of the asynchronous motor governor according to the conditions and at the same time regulation of the speed of movement of the electrode inside the pipe;

The defectoscope adjustment and measurement processes are controlled by a personal computer (16) based on the software installed to record the sequence of certain commands in the Arduino microcontroller database.

The control system scheme is shown in Figure 7. So, the threatened electrode is provided with voltage of 40 kV, and the process of fixing cracks takes place. If there is a crack in the pipe, a current leakage occurs. According to the measurement scheme (the part indicated by a broken line) the current passes through the threatened electrodes to the pipe, and from there through the 1st loop of the transfurmtor (ТСЗИ series).

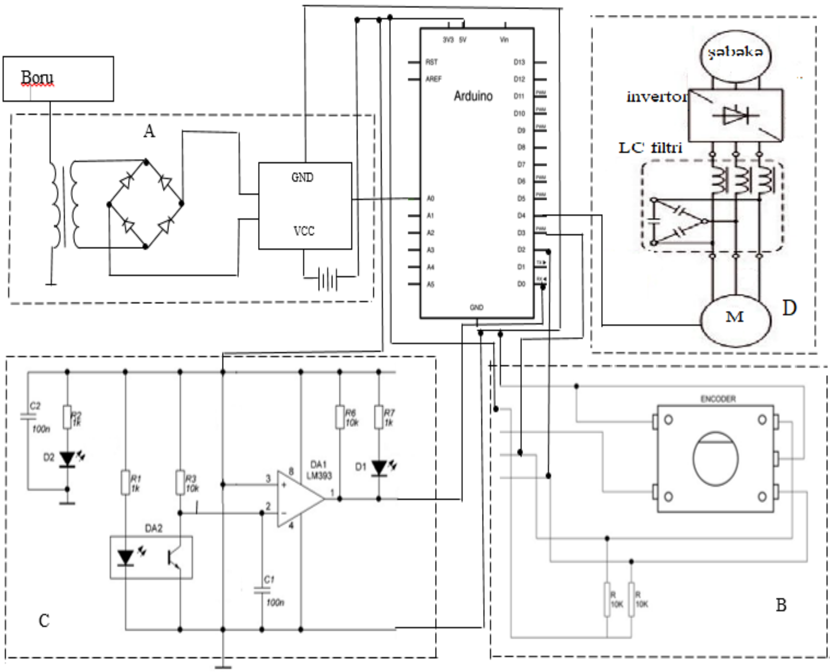


Figure 7. Arduino microcontroller-based control scheme

a) current leakage measurement;
b) electrode pass distance determination;
c) asynchronous motor movement speed regulation

The applicable humiliation transformer (7) nominal power is 30 W and it allows to receive 12V voltage at the output. According to the scheme, the current passes through the second loop of the transformer, and then through the rectifier, and the alternating current turns into a constant current. As a result, the analogical signal is transmitted to the input of the voltage transmitter. The voltage transmitter in turn sends the analogical signal to the A_0 analogical input of the Arduino microcontroller

The electric spark defectoscope allows to measure the coating cracks upon the current passage through the high-voltage electrode inside the pipe.

Based on the resistance measured *(r)*, the geometrical parameters are calculated as follows[13,17].

$$r = \rho\ l/s \tag{4}$$

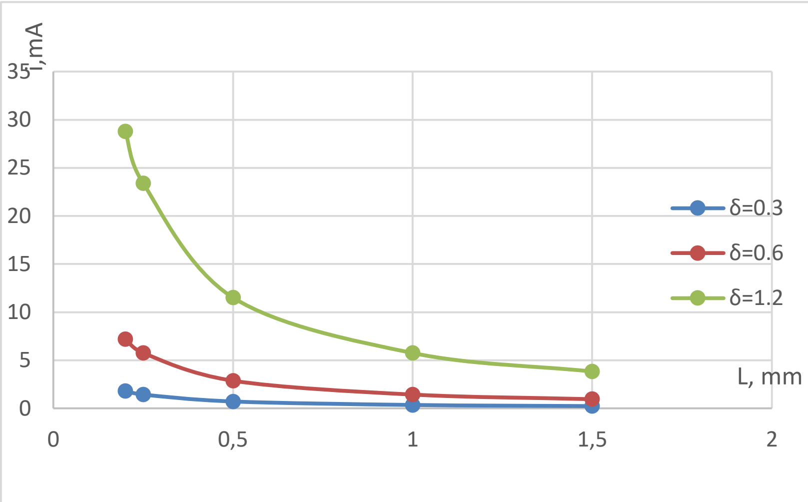
$$S=b\ \delta \tag{5}$$

Here, b is the crack width and the maximum value is considered as b=1.0 mm, δ is the coating width. Subject to U=40 kV and finding the resistance *(r)* in formulas *(4)* and *(5),* using the coating thickness according to Om's law the current strength is calculated as follows.

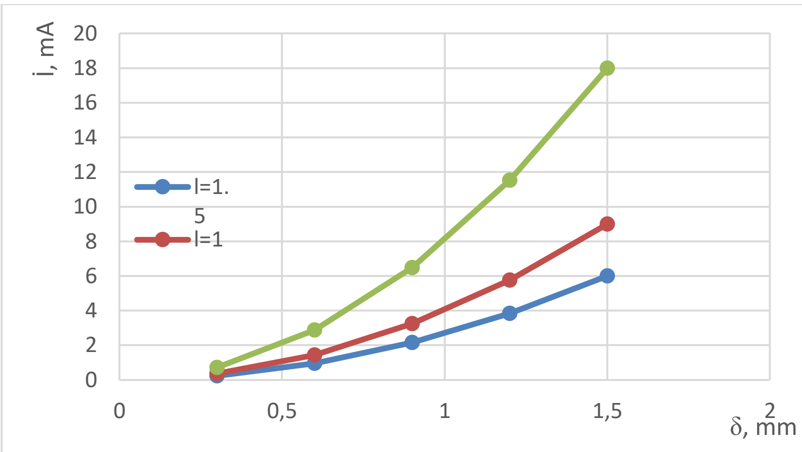
$$I = 40\ \frac{b\delta^2}{\rho l} \tag{6}$$

Here, *r* is the eclectic resistance of the crack, and it is determined according to the leakage current and density as measured during the tests; *ρ* is the special resistance of the coating, and it is changeable within 1.0-10 interval, *l* is the crack length, *S* is the crack cross-section surface area.

So, according to formula (6) the diagrams showing the dependence of the current strength *(I)* on the silicate coating thickness and the crack length *(δ)* are made. As a result of the measurement procedures, depending on the crack length *(l)* in the coating thickness of δ_1=0,3 mm, δ_2=0,6 mm, δ_3=1,2 mm, the leakage current decreases as shown in Diagram 2.a. Diagram 2.b shows the instant changes of the current leakage upon increase in the coating thickness of the crack of $l_1 = 0.5$ mm, l_2=1,0 mm, l_3 =1,5



a)



b)

Graphic 5. The dependence of the silicate coating leakage current on the crack parameters

a) the dependence of the leakage pipe on the inside coating thickness;
b) the dependence of the leakage crack on the length;

mm length. Such changes are considered to be caused by the adhesion process between the pipe inner metal and silicate coating.

To determine cracks, the C# software has been designed by using specific technologies to find out the cracks existing inside the pipes. The functions operated through the software allow to determine the microcraks occurring in the silicate coated pipes. The software determines the positioning coordinates and geometric dimensions within the crack pipe on the screen as a result of processing the measurement results of the transmitters connected to the Arduino microcontroller.

The functional algorithm of the Arduino microcontroller and the program "Diagnostics of microcracks" is shown in Figure 8.

Block A - enables the flaw detector and converters to start the measurement.

Block B - regulates the movement of the ci electrode inside the tube.

Block C - Control of the movement of the electrode at a certain speed, depending on the thickness of the tube. Adjusting the engine speed with a tachometer.

When a crack is found in the pipe, the maximum point of the recorded signal indicates the part of the graph where the crack is present. Otherwise, the signal is represented in the form of a straight line and indicates. The operator can set the micro cracks based on the signal recorded and described on the monitorş

The program interface consists of 2 sections.

The main section and archival section. The description of the main section is shown in Figure 9. According to the functions performed, the software can be conditionally divided into three parts.Taking these into account, the pipe length and diameter, the silicate coating thickness and the number of engine cycles are added to the relevant parts as the initial data. Then, through the C# software with the COM3 port, the information setting occurs, and the second main function of the software is executed. The information reception

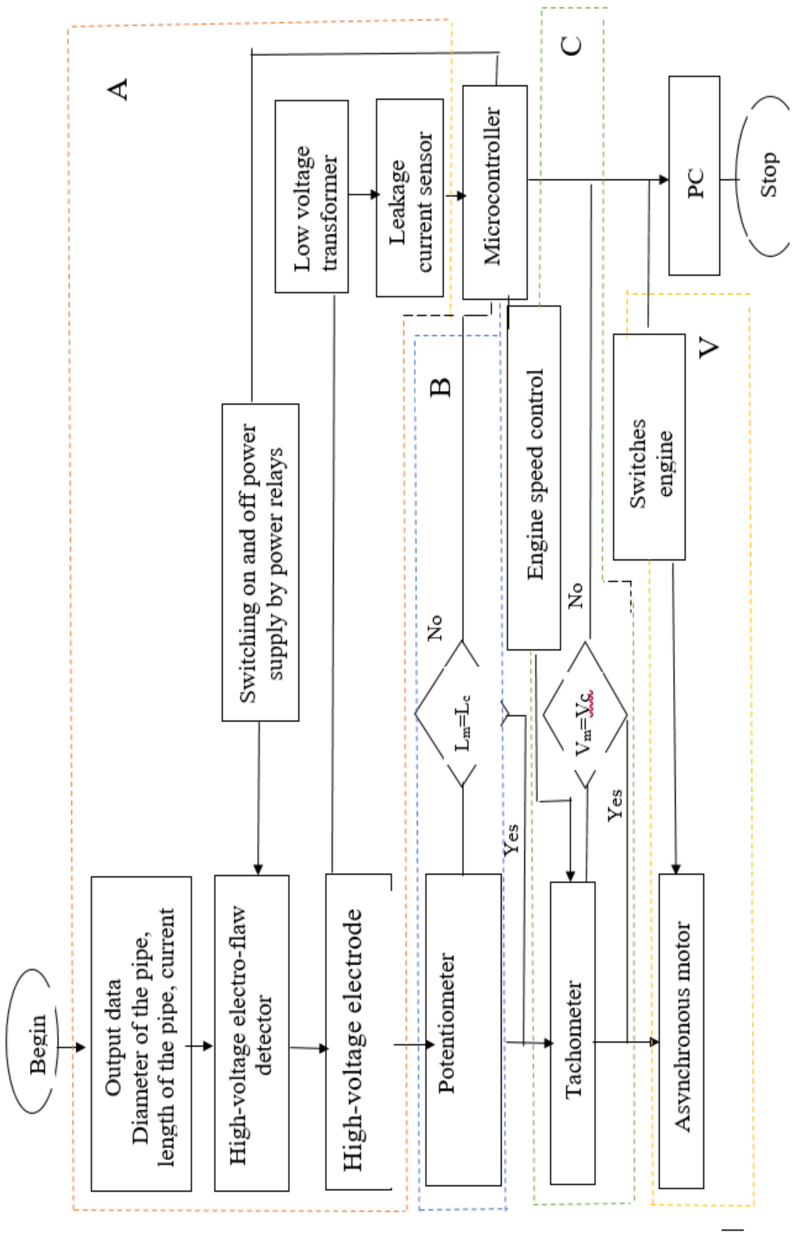


Figure 8. Functional algorithm of the program "Diagnostics of micro cracks"

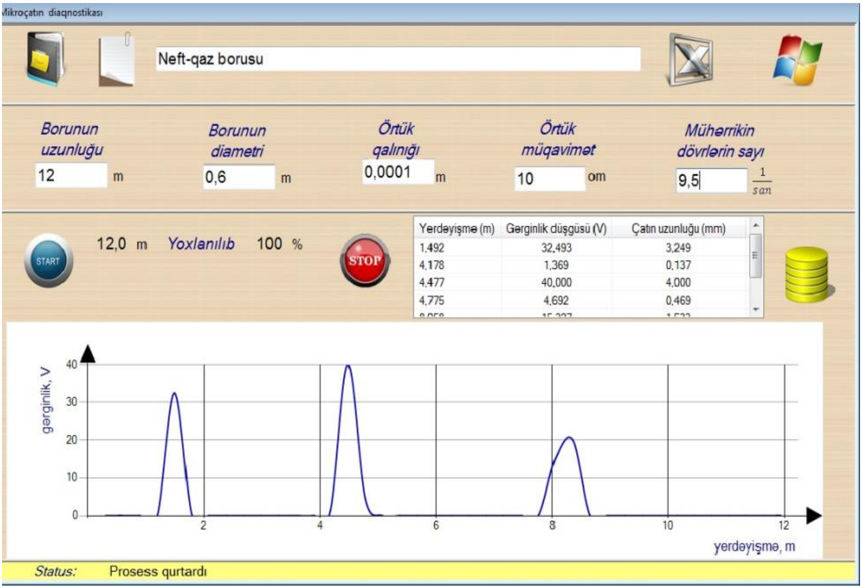


Figure 9. "Microcrack diagnostics" software

block reflects the following sequence of commands, and this process is controlled via the start button.

The information obtained through Arduino microcontroller is described in graphical dependencies in real-time mode of the result.

When the crack is detected in the pipe, the maximum point of the recorded signal indicates on the diagram the part where the crack exists. Otherwise, the signal is described in the form of a straight line and indicates that no crack is found. The operator is able to determine any crack based on the signal recorded on the monitor. Due to the current leakage in the point of any crack the signal is transmitted to the Arduino microcontroller and, then, to the software

Based on the information received, the coordinate of the crack is found. So, since we get the information about the instantaneous displacement of the electrode with the encoder, we determine the coordinate of the crack according to the maximum value of the current leakage based on the diagram obtained.

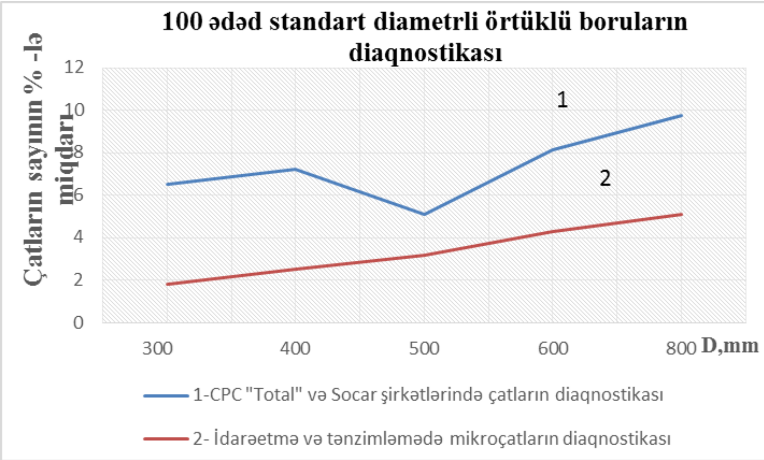
Chapter five. To diagnose the cracks in silicon coated pipes in offshore oil fields, proper organization of the work of the naval fleet, ensuring the silicon pipe strength and durability, the complete dependence of the region on the wave regime were studied. The wave quantities that characterize the wave mode are wave elements. To the wave elements include the wave height, length, period, the wave peak state according to the sea level, and etc.

The studies were carried out in the Neft Dashlary reservoir. The studies of the location of the large oil field office in the open sea in this district helped to create the necessary conditions. In addition, it should be taken into account that hurricane wind waves approach ocean waves with a speed up to 40 m/sec.

At present, the defects found in Ø400x20 mm pipelines of 35 km length drawn from Neft Dashlary to the shore are in the range of 1.5-3.5% and have created the basis for better quality of the installation process. It is recommended to use a relatively inexpensive programmable controller Panasonic FPWIN pro7 for the control system. A mathematical model of the process of the coating laying on the surface of pipelines with a diameter of Ø630x30, Ø300x20, Ø800x40 mm is specifically made. The technological process is carried out with the application of the defectoscope to ensure more accurate diagnostics of cracks in pipe coatings.

Graphic 6 shows the results of diagnostics of cracks in pipes of different sizes. In this Diagram, the surface of steel pipes of any geometric size is reflected in the diagnostics of cracks formed in silica concrete and processing coatings.

Table 4 shows the diagnostics of cracks with the laid coatings in percentage of 100 units of the coated pipes. The research is based on an automatic regulation and control system by measuring the heating temperature on the surface of the pipe cover with a pyrometer during the technological process in the technological device.



Graphic 6. Pipe coating crack diagnostics

Comparative meteorological characteristics of the flaw detector are shown in Table 5.

The accuracy of the heating temperature in the pipe coating is determined depending on the rotational, forward and geometric dimensions of the pipe in the technological installation. Errors in repeated measurements of the heating temperature of surfaces in pipe coatings of different diameters (x1, x2, x3...xn) fully depends on the given voltages, leakage current, the size of the crack and its thickness and electrical conductivity. In the same way, in cooling mode the errors of repeated measurements (x1, x2, x3) depend on the geometric size of the coating, the thickness of the coating, the cooling mode, that is, the brand of the coating and the cooling time when the temperature drops...xn) is appointed. Therefore, the average calculation of these parameters is defined as follows.

Table 4.

Determination of the pipe coating cracks through a diagnostic device

Pipe diameter and thickness, mm	The number of cracks arisen in the coating of 100 pipes (%)	The number of microcracks arisen through control in the coating of 100 pipes (%)
Ø300x20	6.51	1.8
Ø400x25	7.23	2.5
Ø500x30	5.12	3.2
Ø600x35	8.14	4.3
Ø800x40	9.75	5.1

Table 5.

Metrological characteristics of the flaw detector

Defectoscope parameters	Defectoscope	
	Korona C	Advanced performance defectoscope
Test pipe diameter, mm	100	350
Pipe coating thickness, mm	2	4
Electrode movement speed, m/sec	0.15	0.25
Defect detection interval	0.4	0.2-1.0
Joint defect distance	15	9
Test tension value, kV	1-30	1-40
Test tension discretisation, kV	0.1	0.1
Test tension tolerance, %	5	2
Acceptable tolerance, %	9.75	5.1

$$x_c = \frac{x_1 + x_2 + x_n}{N} = \frac{1}{N}\sum_{i=1}^{n} x_i \qquad (7)$$

Here, x_i is the fault of the parameters of the technological regime upon making the coating in each pipe.

n is the number of cracks formed inside pipes.

N is the number of pipes with a common coating. Table 5.

Metrological characteristic of a defectoscope

The number of absolute errors in the determination of cracks in any pipe coating is calculated as follows:

$$\Delta x_i = x_c - x_i \qquad (8)$$

i= 1 2 3 ..n

Thus, the average absolute errors in measurements are calculated as follows:

$$\Delta x = \frac{1}{N}\sum_{i=1}^{n} \Delta x_i \qquad (9)$$

The nominal faults are found by the formula $\varepsilon = \frac{\Delta x}{x_c}$.

At the same time, the error of mid-quadratic inclination is determined as follows.

$$S = \sqrt{\frac{\sum (x_c - x_i)^2}{n}} \qquad (10)$$

At the same time, the different faults of geometric dimensions of coordinates of the cracks were reported through the electric spark defectoscope via formulas (7), (9) and (10), and they are provided in Table 6.

The table shows the characteristics of the coatings observed in steel pipes of 100 different diameters.

As a result of the reports, the crack origin and fault values are shown below[17,18].

Table 6.

Complete fault characteristics in measurement of cracks

Pipe diameter and thickness	Coating thickness δ, mm	Average fault value, $\Delta x, \%$	Quadratic value of faults, s, %	Crack number, n
$\emptyset 300x20$	1-1.5	2.78	2.63	1-3
$\emptyset 400x35$	1.5-2.0	3.24	3.12	2-3
$\emptyset 500x30$	1.5-2.5	3.68	3.54	3-5
$\emptyset 600x35$	2.5-3.0	4.72	4.66	4-5
$\emptyset 800x40$	3.0-3.5	5.21	5.12	4-5

As the results of the research also guarantee the production of high-quality pipes by laying a silicon-coated coating inside the pipe. The quality of these coatings depends on the material and quality of the pipes and the high level of coating technology.

Thus, to obtain a quality coating, the pipes must be heated in the first stage. Then the surface of the heated pipe should be cleaned of dust and dirt. In the next stage, the liquid is coated into the silicon pipe and heated to a temperature of 600-800 0C and the cover is glued inside the pipe. Then, the coated pipe is cooled to room temperature under the cooling mode.

One of the main factor in the industry is quality coating. Quality coatings of pipes, that pipes which do not have defects and meet international standards. This can be done by smoothing the pipes, roughness, preventing cracks, and automatically adjusting the production process. By performing these processes, high-quality silicon-coated coatings can increase the reliability and longevity of pipelines.

Therefore, it is advisable to apply silicon-coated pipes in all industries. Studies show that the economic efficiency is calculated taking into account the minimum reduction of cracks on the surface of the coating. Percentage of micracrks inside the silicate coating pipe is decreased from 8-10% to 1-3%.

Economic experts believe that the use of silicon-coated pipes allows to obtain anti-corrosion and long-lasting pipes.

MAIN FINDINGS

1. The causes of macro-/ microcracks upon the process of laying silicate coating inside the pipe have been studied. A comparative explanation of the methods of determination of defects and m macro-/ microcracks on the coating surfaces via use of various defectoscopes is given. The methods of diagnostics of macro-/ microcracks caused by temperature increase and decrease during heating and cooling of the coating obtained at high temperature in the furnace have been studied. The SOCAR and CPC statistics of cracks in pipe coatings is presented.
2. Automatic adjustment of the technological process of the furnace device for the laying of silicate coating has been obtained. Depending on the number of cycles (n), speed (V) and diameter (d) of the rotating pipe during the technological process, Panasonic FPWINPro7 programmed logic controller automatic adjustment system, its algorithm and software have been developed.
3. To avoid cracks (minimum number) on the surfaces of the coated pipe in the heating range of 600-800°C gradually up to high temperature in the furnace device the mathematical modelling of N,v,d parameters has been performed and the graphical interpretation is obtained. Depending on the brand of the coating, the temperature of the heating is calculated.
4. It has been possible to determine the dimensions of the cracks by raising the voltage (up to 40kV) in the measurement mode for the diagnostics of microcraks via using Korona electric spark defectoscope and improving the device. Using this defectoscope, a special device has been developed to determine the coordinates and geometric dimensions of cracks on the surfaces of the silicate coating inside the pipes.

5. A special software has been developed to determine the coordinates of microchips by measuring the leakage current in the pipe coatings. The graphical interpretation of the dependence between the thickness of the pipe coating and the leakage current value has been obtained.

6. A mathematical model of the temperature field has been drawn in the cooling process of the heated pipe coating up to high temperature. The automatic control of the cooling mode of the pipe with silicate coating is shown via diagrams.

7. The reliability and longevity have been increased several times through reducing the defect probability tolerance on the surface of pipe coatings from 5-10% to 1-5% in the technological equipment applied by SOCAR CPC. On the basis of long-term statistical studies the economic efficiency is calculated through the comparative analysis of defects and cracks in pipes with different diameters of the companies mentioned above.

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The personal role of the author in the work with co-authors:

[1,3,10,12,14] – Determination of factors influencing the formation of microcracks in the process of laying the silicon coating. [5,6,11,17] – With the introduction of microcontroller control system
Improving the existing Electric Spark Defectoscope.

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