КОНТРОЛЬ І ДІАГНОСТИКА ПРОЦЕСІВ ТА СИСТЕМ В ПРИЛАДОБУДУВАННІ

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TESTING TECHNOLOGY OF THE UNDERCOUPLING SPACE FILLING OF COUPLING ON THE MAIN PIPELINE

Tymchyk G. S., Podolian O. O., Serhiienko K. S.
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute",
Kyiv, Ukraine
Email: a.podolian@i.ua

Background. *Now actively used the method of repair with the use of coupling metal structure. It is use to restore the carrying capacity of active pipelines that are working for a long time.*

The coupling is installed on the defective area, and the undercoupling space is sealed and filled under pressure with a self-hardening mass. In this case, the stresses in the pipe walls and coupling are aligned with each other. The parameters of the filling process the undercoupling space determine the quality of the entire coupling repair and require precise testing.

Objective. *The purpose of this article is to analyze the parameters for testing the filling of the under-coupling space using ultrasonic non-destructive testing methods.*

Methods. *Strength improvement of the spots of the active pipeline is realized by installing an active main pipeline of couplings. Strengthening the pipeline with the coupling is to redistribute part of the load from the pipe to the wall of the coupling, which leads to a decrease of the stress level in the pipe wall. The reinforcement efficiency of the pipeline could be evaluated by the degree of reduction of circumferential stresses in the wall of the repaired pipe. The article describes the analysis of the possibility of testing the filling of the under-coupling space of the glues-welded and brazed-welded couplings using ultrasonic methods of non-destructive testing.*

Results. *The use of the most common piezoelectric transducers is ineffective. This is due to the high temperature of the brazed-welded coupling during working using molten metal, determined by its melting temperature. In this case, it is proposed to use an electromagnetic (EMA) transducer as a radiator and receiver of ultrasonic vibrations. The results of theoretical and experimental studies of the control of filling the undercoupling space of soldered-on sleeves with molten metal have confirmed the effectiveness of using the EMA-method for controlling the formation of the undercoupling space. It is shown that the proposed method of ultrasonic testing allows to achieve maximum efficiency in testing the filling of the brazed-welded coupling with the molten metal.*

Conclusions. *The analysis of the possibility of using an ultrasonic method of non-destructive quality control of filling a undercoupling space with a self-hardening substance showed the theoretical possibility of testing the filling of the undercoupling space of glueswelded couplings with both the compounded filling of the undercoupling space and the filling with molten metal.*

The results of experimental studies of the control of filling the under-coupling space of the glues-welded couplings with molten metal using the EMA-method confirmed the effectiveness of using the EMA-method for testing the formation of the undercoupling space.

Keywords: coupling; non-destructive; control; diagnostics; repair, gas pipeline; pipeline; pressure; gas, oil; refinable crude; transit; EMA; ultrasonic; maintenance; pipe; clutch.

Introduction

Now actively used the method of repair with the use of coupling metal structure. It is use to restore the carrying capacity of active pipelines that are working for a long time.

The coupling is installed on the defective area, and the undercoupling space is sealed and filled under pressure with a self-hardening mass. In this case, the stresses in the pipe walls and coupling are aligned with each other [1, 2]. The parameters of the filling process the undercoupling space determine the quality of the entire coupling repair and require precise testing.

Problem statement

The article objective is to analyze the parameters for testing the filling of the undercoupling space of the coupling using ultrasonic non-destructive testing methods.

1. Theoretical investigations of the testing undercoupling space filling

In the case of filling the undercoupling space of steel couplings with a self-hardening mass based on epoxy or polyurethane - glued-welded couplings [1, 2], as well as low-melting metal (for example, lead, tin or their alloys) – brazed-welded coupling [3, 4], the parameters of the formation of the undercoupling layer can be testing by ultrasonic method. In the case of filling the undercoupling space of steel couplings with a self-hardening mass based on epoxy or polyurethane [1, 2, 4], as well as a low-melting metal (for example, lead, tin or their alloys) [3], the parameters of the formation of the undercoupling layer can be testing by ultrasonic method. Taking into account the high temperature of the repair structure during the execution of works using molten metal (determined by its melting temperature), the use of the most common PET (piezoelectric transducers) is associated with known difficulties (limited temperature ranges, difficulty or impossibility to test soiled surfaces) [5, 6]. Therefore, in this case it is proposed to use an electromagnetic-acoustic (EMA) transducer as a radiator and receiver of ultrasonic vibrations.

At present, the theory of EMA excitation of an ultrasonic wave is well-developed [5], which makes it possible to consider questions of the practical application of the EMA methodology for testing the process of formation of the undercoupling layer.

To solve this problem, it is necessary to determine the characteristic differences in the signal obtained when probing sections of the coupling with a continuous under-coupling layer and areas containing air bubbles or foreign matter (for example, liquid remaining after hydraulic testing of the coupling [4]). This task can be effectively solved by using the echo method.

Despite it seems simplify, the implementation of the EMA-testing of the under-coupling space has a number of features that must be taken into account in the present investigations.

In the simplest case, an ultrasonic wave excited in the upper layer of the coupling shell with EMAT or PEP is included perpendicular to the boundary of the shell and undercoupling space (Figure 1). If there is air in the undercoupling space, then the steel-air boundary can be equated to the border with vacuum, since gaseous substances have extremely small acoustic resistances compared to steel.

For air $Z = 0{,}0004 \cdot 10^6\ N \cdot s / \mathrm{m}^3$, therefore, at the steel-air boundary, the reflection coefficient differs only by $2 \cdot 10^{-5}$ [7]. Thus, with sufficient accuracy for practice, we can assume that the wave does not pass such a boundary and returns to the medium. The pulse reflected from the boundary can be registered by an EMAT connected to the recorder input.

If the testing spot of the undercoupling space is filled with a self-hardening substance based on epoxy or polyurethane [4], or with a molten metal (for example, tin or lead) [3], the nature of the wave propagation mode, as part of the wave will propagate into the undercoupling layer and from it into the body of the pipe.

Due to the fact that the input of a plane ultrasonic wave is considered perpendicular to the boundary, then the reflected and transmitted waves will propagate in the same way perpendicular to this boundary.

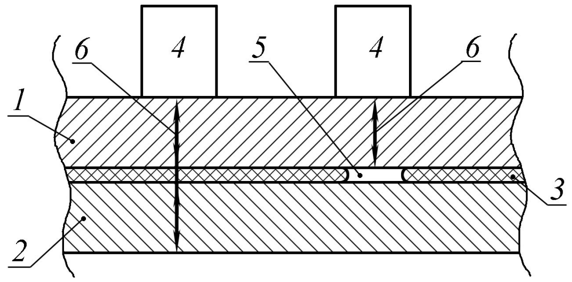


Fig. 1 Testing of formation of the under-coupling layer by ultrasonic echo method: 1 - coupling sheath, 2 - reinforced pipe, 3 - undercoupling layer, 4 - ultrasonic trandusers, 5 - air bubble, 6 - ultrasonic wave

Taking into account the small depth of the undercoupling space, limited by the height of the roller of the longitudinal and circumferential welds, which, according to the current regulatory documents should not exceed 3 mm, we can distinguish three typical options for the formation of the undercoupling layer (illustrated in Figure 2).

Option (a) corresponds to the presence of an air bubble in the undercoupling space or unfilled undercoupling space at the point of measurement. Option (b) is characterized by the absence of adhesion of the substance of the undercoupling layer to the inner surface of the coupling, which creates an obstacle to the passage of the ultrasonic wave. Option (c) corresponds to a partially filled undercoupling space.

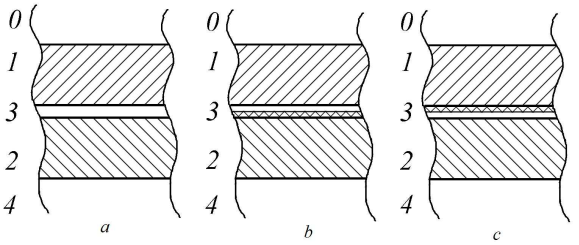


Fig. 2 Basic options for filling the undercoupling space: 0 - air, 1 - coupling sheath, 2 - reinforced pipe, 3 - undercoupling layer, 4 - transported product; a - no filling, b and c - partial filling, d - fully filled undercoupling space

Option (c) is characterized by a good acoustic contact between the inner surface of the coupling and the undercoupling layer and a poor one between the undercoupling layer and the reinforced pipe. The option is possible, for example, when using the pretinned inner surface of the coupling during filling the undercoupling space with molten metal and no filling, or good filling of the undercoupling layer, but poor acoustic contact with the pipe due to poorly prepared in field conditions of the pipe, the presence of rust, or places of putty defects. Option (d) corresponds to the undercoupling space completely filled with a substance with good adhesion of the surfaces of the coupling and the pipe to the substance of the undercoupling layer, which creates high-quality acoustic contact between the layers of the structure.

Thus, the ultrasonic wave excited by the ultrasonic transducer in the layer of the coupling 1 must overcome the border 1-3, pass through the undercoupling layer 3, the border 3-2 between undercoupling layer 3 and the pipe 2, reflect from the inner surface of the pipe (border 2-4) and return in a similar way to the wall of the coupling, after which it will be registered by the ultrasonic transducer. Obviously, passing through the layers and the boundaries between them, the acoustic wave (impulse) will undergo known changes (reflection, absorption, scattering). As a result of multiple divisions and reflections of the wave at each boundary, in the presence of an infinite input wave, superposition and interference of secondary waves occur.

If the undercoupling space is filled with air (option (a)), there will be a total reflection of the acoustic wave from the border 1-3, which is characterized by the presence of a damped pulse sequence at the output of the ultrasonic transducer caused by the effect of multiple wave reflection between the boundaries of the coupling wall.

After a high-quality filling of the undercoupling space with a self-hardening substance or a molten metal (option (c)), the ultrasonic impulse is divided at the boundary 1-3, and the acoustic pressures of the separated waves will be determined by the acoustic properties of the material under the pitchwork. In this case, if the acoustic pressure of the wave incident on the boundary 1-3 is designated as p_{11} reflected, as p_{12}, and transmitted as p_{31}, then the reflection coefficient k_ρ of the boundary 1-3 can be defined as

$$k_\rho = \frac{p_{12}}{p_{11}}, \tag{1}$$

and transmission coefficient k_τ as

$$k_\tau = \frac{p_{31}}{p_{11}}. \tag{2}$$

In this case, the values of the reflection k_ρ and transmission k_τ coefficients of the boundary 1-3 can be determined from the expressions [7]:

$$k_\rho = \frac{Z_3 - Z_1}{Z_3 + Z_1}, \tag{3}$$

$$k_\tau = \frac{2 \cdot Z_3}{Z_3 + Z_1}, \tag{4}$$

$$Z_1 = \rho_1 \cdot c_1, \tag{5}$$

$$Z_3 = \rho_3 \cdot c_3, \tag{6}$$

Z_1, Z_3 - acoustic resistance (impedance), respectively, of the wall materials of the coupling and the undercoupling layer; ρ_1, ρ_3 - density of the materials of the coupling wall and the undercoupling layer; c_1, c_3 - speed of sound (for longitudinal waves) in the materials of the wall of the coupling and the under-coupling layer.

In most cases, couplings are made of the same material as the reinforced pipe. or gas pipelines it is steel, characterized by a resistance to $Z_1 = Z_2 = 45 \cdot 10^6 \; N \cdot s / \mathrm{m}^3$ resistance. For example, self-hardening polyurethane-based substance SZLAST (NPIP “KiATON”, Ukraine) can be widely used for coupling repair as a material under the muted space. Included in the expression (6) the value of the sound speed c_3 for a longitudinal ultrasonic wave can be calculated by the parameters that determine the strength properties of the material, according to the formula proposed in [7]:

$$c_3 = \sqrt{\frac{E_3}{\rho_3} \cdot \frac{1 - \mu_3}{(1 + \mu_3)(1 + 2 \cdot \mu_3)}}, \tag{7}$$

E_3, μ_3 are the modulus of elasticity and Poisson’s ratio of the material of the under-coupling layer.

The Poisson's ratio μ_3 and the modulus of elasticity E_3 of the self-hardening substance SZLAST was determined experimentally on the TIRA-test equipment of the Department of Materials Resistance of the Kiev Polytechnic Institute [8], their values were $\mu_3 = 0.487$, $E_3 = 64.9 \; MPa$. The density in accordance with the passport data is $\rho_3 = 1.5 \cdot 10^3 \; \mathrm{kg/m}^3$. Based on the expressions (6), (7), in the material SZLAST the sound speed is $c_3 = 2.75 \; km / \mathrm{s}$, acoustic impedance is $Z_3 = 4.125 \cdot 10^6 \; N \cdot s / \mathrm{m}^3$

In the case of filling the undercoupling space with tin, the acoustic resistance of the material of the undercoupling layer will be equal to $Z_3 = 24 \cdot 10^6 \; N \cdot s / \mathrm{m}^3$.

For the compound undercoupling layer formed from the SZLAST material, for the boundary 1-3, $k_\rho = -0.832$, $k_\tau = 0.168$, that is -83.2 %, the acoustic pressure of the reflected acoustic wave is incident and transmitted 16.8 %. For the border 3-2 (the transition from the undercoupling space into the pipe wall, these values will be $k_\rho = 0.832$, $k_\tau = 1.832$, (the acoustic pressure reflected from the border 2-3 waves is incident on it 83.2 %, and passed 83.2 %). The increase in acoustic pressure when passing the border 2-3 is explained significantly large, compared with polyurethane, the acoustic resistance of steel.

In gas pipelines, the inner surface of the pipe is bordered by gas, so the border 3-4 can be considered free, the reflection coefficient $k_р$ of which is equal to one.

For an undercoupling layer formed of tin, for border 1-3, $k_р = -0.3$, $k_τ = 0.7$, that is, the acoustic pressure of the reflected acoustic wave is -30 % incident and transmitted 70 %. For the border 3-2 (the transition from the undercoupling space to the pipe wall, these values will be $k_р = 0.3$, $k_τ = 1.30$, (the acoustic pressure reflected from the border 2-3 waves is incident on it 30 %, and transmitted 130 %).

In the process of propagation of an ultrasonic wave in the layers as a result of scattering processes on inhomogeneous structures of the layers and absorption of a part of the energy by the material of the layers, its attenuation occurs. Both types of losses limit the practical use of the ultrasonic method to control the process of forming the undercoupling layer. Difficulties in testing may arise due to the appearance of numerous reflections that correspond to different arrival times of the waves.

The change in acoustic pressure in an ultrasonic wave that has passed a certain distance l in a homogeneous medium is described by an exponential equation of the form [8]:

$$p = p_0 \cdot e^{-\alpha l}. \tag{8}$$

Where, p - acoustic pressure at the exit of the section with a length l of a homogeneous material, p_0 - acoustic pressure at the beginning of the section, α - attenuation coefficient.

Thus, the acoustic pressure of the p_0 wave passing through section 1 (coupling) at the boundary 1-3 will decrease to the value $p_{11} = p_0 \cdot e^{-\alpha_M \cdot \delta_M}$, where α_M is the coefficient of attenuation of the coupling material. The wave that passed through the border 1-3 will create an acoustic pressure $p_{31} = D \cdot p_{11}$, which will decrease to the value $p_{32} = p_{31} \cdot e^{-\alpha_{PP} \cdot \delta_{PP}}$, where α_{PP} is the attenuation coefficient of the material of the undercoupling space at the boundary 3-2.

That is, the acoustic pressure will change at the boundaries of the media and decrease as the layers spread in the materials.

If we neglect the attenuation in the layers and confine ourselves to considering only the main maxima, then we can single out four main characteristic echo impulses, on the basis of the analysis of which one can judge the quality of the formation of the undercoupling layer (Fig. 3).

Figure 3 shows: I - an echo pulse reflected from the boundary of the coupling-undercoupling layer, II - an echo pulse reflected from the inner boundary of the undercoupling layer (options b and in Fig. 2), III - an echo pulse reflected from undercoupling layer-pipe, IV - an echo pulse reflected from the boundary of the pipe-transported product.

The data for calculating the acoustic pressure generated by characteristic echo pulses with different variants of the formation of the undercoupling layer are presented in the form of graphical diagrams (Fig. 4).

The data obtained allow us to conclude that the ultrasonic method can be used to test the parameter formation of the undercoupling layer, both from the liquid compound and from the molten metal. At the same time, it should be noted that its use to control the process of filling the undercoupling space with a compound is associated with the difficulty of isolating the useful signal against the background of multiple reflections of the ultrasonic wave from the walls of the coupling shell, which in this case is noise. This question requires the correct circuit design of the ultrasonic device.

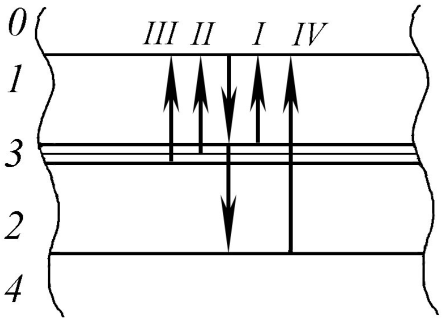


Fig. 3 Formation of characteristic echo pulses: 0 - air, 1 - coupling sheath, 2 - reinforced pipe, 3 - undercoupling layer; 4 - transported product

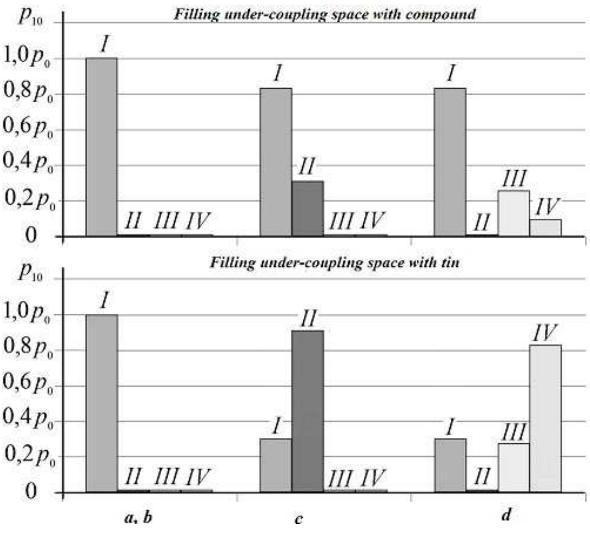


Fig. 4 Acoustic pressure generated by characteristic echo pulses

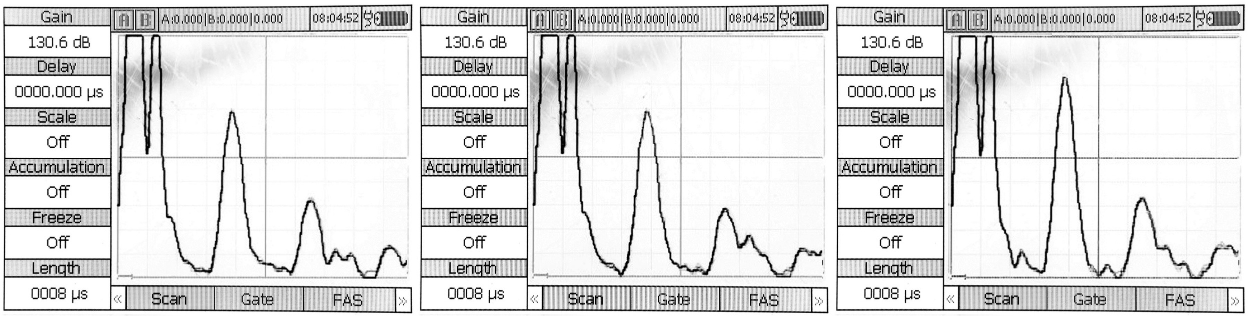
The quality control of the formation of a undercoupling layer of molten metal should not cause difficulties because of the ease of registration of pronounced signals that characterize the state of undercoupling space. For control, an ultrasonic thickness gauge can be used, built, for example, on the basis of an EMA [9] transducer operating at elevated temperatures. In the case of measurements using an echo pulse having maximum amplitude, an EMA thickness gauge will provide reliable information on the state of the undercoupling space. To excite the ultrasonic wave in the wall of the coupling, which has a higher temperature, an alternative method can be used that does not require the use of external magnets.

2. Experimental investigations of the testing of the undercoupling space filling

The UD-4T ultrasonic flaw detector was used in conjunction with the PET P111-2,5-K12 for experimental verification of the method for testing the quality of filling the under-coupling space using the ultrasonic method of non-destructive testing. As a control object, parts of the shell of the coupling and the pipe were used, on which the options for filling the undercoupling space, shown in fig. 2.

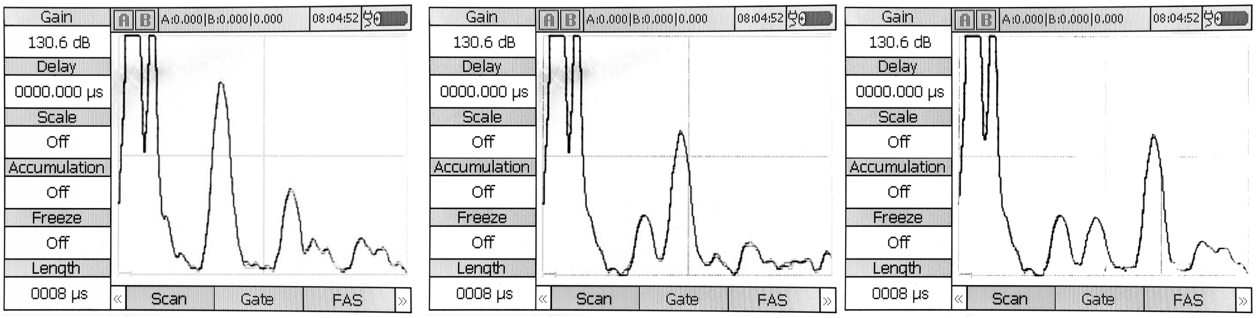
As a material for the formation of a undercoupling layer used composite material based on polyurethane SZLAST and tin. The results of the experimental verification are shown in the photographs presented in Fig. 5 and Fig. 6.

For further experimental verification of the quality of the formation of the undercoupling layer with the molten metal [6, 13], an experimental EMA sensor was connected using the EMA-method with the UD-4T ultrasonic flaw detector, and the flaw detector was switched to the “thickness gauge” mode. The results of thickness measurements are illustrated in Fig. 7.


Gain 130.6 dB
Delay 0000.000 µs
Scale Off
Accumulation Off
Freeze Off
Length 0008 µs

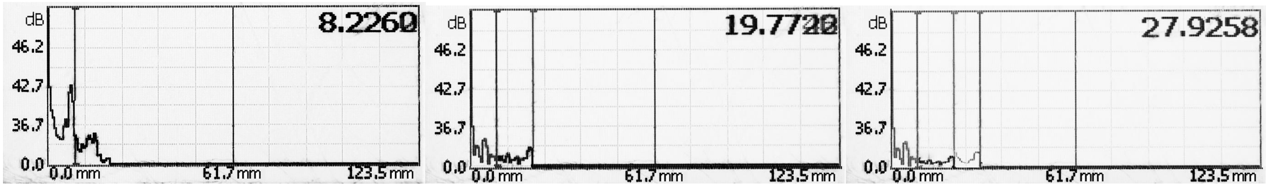
Option a, b Option c Option d

Fig. 5 Photos of the flaw detector screen with echo pulses with ultrasonic sounding of a coupling with an undercoupling space filled with a composite substance SZLAST


Gain 130.6 dB
Delay 0000.000 µs
Scale Off
Accumulation Off
Freeze Off
Length 0008 µs

Option a, b Option c Option d

Fig. 6 Photos of the flaw detector screen with echo pulses with ultrasonic sounding of the coupling with under-coupling space, filled with molten tin



Option a,b Option c Option d

Fig. 7 Photos of the flaw detector screen in the “Thickness gauge” mode when filling undercoupling space tin

Option (a,b) - lack of the filling undercoupling space, option (c) - tin is deposited on the inner surface of the coupling, there is no contact with the reinforced pipe, option (d) - tin has filled the coupling sleeve, good acoustic contact with the pipe and coupling.

Conclusion

The analysis of the possibility of using an ultrasonic method of non-destructive quality control of filling a undercoupling space with a self-hardening substance showed the theoretical possibility of testing the filling of the undercoupling space of glueswelded couplings with both the compounded filling of the undercoupling space and the filling with molten metal.

The experimental data do not allow the ultrasonic method to reliably control the quality of filling the undercoupling space with a polyurethane-based compounding substance due to the difficulty in extracting echo signals that carry useful information from the parasitic signals arising from the reflection of the ultrasonic wave from the surfaces of the coupling walls.

At the same time, the analysis of the echo signals gives reliable information about the state of the under-coupling layer in glues-welded couplings filled with molten metal.

The results of experimental studies of the control of filling the under-coupling space of the glues-welded couplings with molten metal using the EMA-method confirmed the effectiveness of using the EMA-method for testing the formation of the undercoupling space.

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Г. С. Тимчик, О. О. Подолян, К. С. Сергієнко
Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Київ, Україна

ТЕХНОЛОГІЯ КОНТРОЛЮ ЗАПОВНЕННЯ ПІДМУФТОВОГО ПРОСТОРУ МУФТИ НА МАГІСТРАЛЬНОМУ ТРУБОПРОВОДІ

Наразі активно застосовується метод ремонту з використанням муфтових конструкцій. Він використовується для відновлення пропускної здатності діючих трубопроводів, які працюють протягом тривалого часу.

Муфту встановлюють на дефектну ділянку, а підмуфтовий простір герметизують і заповнюють під тиском самотвердіючою речовиною під тиском. При цьому напруження в стінках труби і муфти вирівнюються. Параметри процесу заповнення підмуфтового простору визначають якість усього ремонту муфти і потребують контролю.

Метою цієї статті є аналіз параметрів контролю заповнення підмуфтового простору з використанням ультразвукових методів неруйнівного контролю.

Підвищення міцності діючого трубопроводу здійснюється шляхом встановлення на магістральний трубопровід муфт. Посилення трубопроводу муфтою полягає в перерозподілі частини навантаження з труби на стінку муфти, що призводить до зниження рівня напружень у стінці труби. Ефективність посилення трубопроводу може бути оцінена за ступенем зниження кільцевих напружень у стінці відремонтованої труби. У статті описано аналіз можливості перевірки заповнення підмуфтового простору клеєно-зварних і паяно-зварних муфт за допомогою ультразвукових методів неруйнівного контролю.

Використання найпоширеніших п'єзоелектричних перетворювачів неефективне. Це пов'язано з високою температурою паяно-зварної муфти під час роботи з використанням розплавленого металу, що визначається температурою його плавлення. У цьому випадку пропонується використовувати електромагнітний (ЕМА) перетворювач як випромінювач і приймач ультразвукових коливань. Результати теоретичних та експериментальних досліджень контролю заповнення підмуфтового простору муфти розплавленим металом підтвердили ефективність використання ЕМА-методу для контролю формування підмуфтового простору. Показано, що запропонований метод ультразвукового контролю дає змогу досягти максимальної ефективності під час контролю заповнення паяно-зварної муфти розплавленим металом.

Аналіз можливості використання ультразвукового методу неруйнівного контролю якості заповнення підмуфтового простору самотверднучою речовиною показав теоретичну можливість перевірки заповнення підмуфтового простору клеєзварних муфт як при компаундованому заповненні підмуфтового простору, так і при заповненні розплавленим металом.

Результати експериментальних досліджень контролю заповнення підмуфтового простору клеєзварних муфт розплавленим металом за допомогою ЕМА-методу підтвердили ефективність використання ЕМА-методу для контролю формування підмуфтового простору.

Ключові слова: муфта; неруйнівний; контроль;, діагностика; ремонт; газопровід; трубопровід; тиск; газ; нафта; нафтопродукти; транзит; ЕМА; ультразвук; обслуговування; труба; муфта.

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