Eddy Current Nondestructive Testing of Large Diameter Pipes Through Thick Protective Coatings.

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Abstract. During production of large-diameter pipes (LDP) considerable attention is paid to non-destructive testing (NDT) of those pipes. Ultrasound and X-ray are widely used NDT methods. In the article there is information about the usage of eddy current NDT tools for detection of the areas of local hardening and micro cracks, as well as through the insulating coating with the thickness up to 10 mm.

LDP for oil and gas pipelines should be of high quality and reliability, LDP for subsea transitions require even higher attention. Traditionally used ultrasound and X-ray methods can’t reveal such metallurgical defect as the local hardening areas. It is not possible to use dynamic hardness testers for hardness measurement because of the huge number of measurements and low speed.

Multi-channel flaw detector VD-91NM was designed for automated nondestructive testing of hardness of the inner and outer surface of LDP and for detection of other surface defects. In multi-parameter eddy current NDT method for elimination of the gap influence, the complex plane and “phase turn” are usually used. In this case the voltage projection from the gap on one of the axes is minimized, but it leads to the significant reduction in the useful signal from the defect. Moreover, the existing equipment in the world, implementing the classical amplitude-phase method is not able to find defects through the considerable gap. The system of separate measurement of amplitude and phase of the signal with its subsequent mathematical treatment is implemented in VD-91NM, it has no analogues in the world. It allows to inspect through the insulation coating of variable thickness (up to 10 mm), and the sensitivity of flaw detector to defects remains unchanged.

Introduction

In metal-roll production the different methods of non-destructive testing (NDT) are widely used [1]. Eddy current NDT method plays an important role in the control of pipes up to 220 mm. It has a number of advantages: non-contact, high sensitivity and control speed, the ability to control the product with a high surface temperature, low quality requirements for surface preparation [2]. At the same time, the eddy current method has a number of disadvantages: detection of only the surface and subsurface defects in ferromagnetic materials, difficulties in determining the geometric parameters of the defects, the significant influence of the spread of electromagnetic properties of controlled object (OC) on the results of testing [3-5]. The last disadvantage can be eliminated by applying OC biasing to saturation [6].
Therefore, X-ray and ultrasonic methods are more often used for control of large diameter pipes (LDP). Their main advantage over the eddy current method is the ability to detect internal defects. To control the pipe ends, magnetic particle method is often used, it is highly sensitive and makes it easy to visualize defects. However, recent experience showed that there was a number of manufacturing metallurgical defects that could be detected only by eddy current NDT method [7]. In slab production the technological process can take the wrong way, which leads to the appearance of high temper zones on the surface. Later on, when rolling the slab into a plate (Figure 1), these areas become the spots of local surface irregularities with greater hardness than the base metal. During pipe manufacturing (especially heavy-wall) the plate is subjected to considerable strain (Fig. 2), as a result, microcracks appear in areas of higher hardness, they can penetrate into the entire depth of the hardened layer. Based on the practical experience, the depth of the cracks seldom exceeds 0.2-0.3 mm, but the area of such zone doesn’t exceed several tens of mm. Taking into account the pipe roughness and surface condition, these cracks can’t be detected by X-ray or ultrasound methods. Magnetic particle inspection can be used only for the pipe ends testing, so the cracking zones are not detected during the traditional output quality control. Local hardening areas of the metal surface layer can’t be detected by these methods as well. After covering the pipes with insulation or protective coatings it becomes impossible to detect these defects by any method except eddy current one, and finally, the defective pipes are shipped to the customers. During operation microcracks grow more and more, the pipes can be destroyed much earlier than the expected life cycle. Therefore, we can make the conclusion that hardness control should be made not only at some points of several samples of the lot, as it is made now, but along the whole surface of the plates or finished pipes.

Today several methods of hardness measuring and monitoring are applied. Among them, the most widely used are contact methods. The choice of measuring method of metal hardness depends on the mechanical properties of metals and constructive and technological features of the products. There are several ways to measure the hardness; they differ by the tip impact. Hardness can be measured by indentation (indentation method), by blow or by ball-tip rebound. Hardness, defined by scratching, characterizes resistance to rupture, by rebound - elastic properties, and by indentation - resistance to plastic deformation. Advanced and high-precision method is the method of continuous indentation when the movement diagram is recorded from the indenter, with the simultaneous recording of force. Depending on the speed of the pressure on the indenter, the hardness can be static (force is applied smoothly) and dynamic (force is applied by blow). Contact-impedance (ultrasonic) method is to control hardness by the change of vibration frequency of the probe indenter during its introduction to the testing surface. For periodic inspection of durometer readings, the control samples can be supplied (etalons of hardness), which are produced according to certain hardness scales (Rockwell, Brinell, Vickers).

The methods, stated above, have a number of drawbacks which limit their usage. First of all, we talk about labour content, which makes it impossible to control the whole surface of the objects. Also, none of them can be used to control metal with protective or insulating coatings.

The main task for the specialists of JSC "RII MSIA "SPECTRUM" was to detect local hardening zones on LDP body, also through the protective and insulation coatings of thickness up to 10 mm. This article shows the main results of experimental researches and description of the designed equipment.
Fig. 1. Slab at the rolling site

Fig. 2. Forming of large diameter pipe (LDP)
Experimental researches.

At the first stage the experimental research of sample with natural defects was made (Fig. 3) (Pallet, cut from a single seam pipe, made of steel grade X65 (API 5L), diameter 813 mm, wall thickness 39 mm, strength class K60). This sample was cut from the pipe, successfully passed the quality control. Defects were detected visually prior to applying the protective coating. Flaw detector VD 90NP with converter type-2 (coil diameter- 5 mm, excitation frequency of 70 kHz) was used as the control equipment. The purpose of the experiment was to estimate the possibility of identification of increased hardness area and determination of its borders. During research, the testing was carried out directly on the sample surface, and also through the maximum possible operating clearance of eddy current probe (ECP), because of protective coatings.

![Fig. 3. Pallet with local hardening area](image)

The Fig. 4 shows graphical view of the output signal of flaw detector VD 90NP. Zones marked in red correspond to the metal structure changes in the heat affected zone, appeared in the result of pallet cutting by gas welding. The blue color corresponds to the pipe base metal (hardness 200-230HV). Local hardening area (280-300HV) is marked in green. The results were confirmed by measurements from dynamic durometer Elite-2D.
On the second stage the influence of operating clearance on signal increase of eddy current flaw detector, caused by the local hardness increase, was investigated. Operating clearance varied from 0 to 7 mm. Indications were taken at point "A" (local hardening area with the maximum signal from flaw detector) relatively to the point "O" (compensation area corresponding to zero signal from flaw detector). Fig. 5 shows the received data.

Fig. 4. Graphical indications of pallet inspected by VD-90NP

Fig. 5. Indications of flaw detector VD 90NP in maximum local hardening area
At the third stage the pipe surface testing during production was simulated. The sample surface was scanned along the line A-B (Fig. 6), crossing the local hardening area with the true defect in it. Fig. 6 shows the trace of scanning, signal is on the screen of flaw detector. In the low left corner of the pallet we can see cracking in local hardening area.

Fig. 7 shows the signal of the eddy current flaw detector, received at A-B area and passed to personal computer (PC). The indications change in local hardening area and there is specific signal caused by crack-like defect existing in this area.

![Fig. 6. Indications from VD 90NP along A- B line](image)

![Fig. 7. Indications from VD-90NP along A-B line, transmitted to PC](image)
• Eddy current flaw detector VD-90NP with standard probe confidently distinguishes increased hardening zone from the base material of OC up to operating clearance of 7 mm.
• Further development of flaw detector software can reduce the influence of operating clearance changes on the output signal.
• It is possible to increase control speed by the use of multi-channel eddy current testing system and by partial or full mechanization and automation of this system.

**Practical implementation of research results**

Based on the analysis of the experimental data we come to conclusion that it is possible to apply eddy current NDT method for detection of defects such as crack and local hardening, also through the thick insulation and protective coatings. JSC "RII MSIA "SPECTRUM" and JSC "ULTRAKRAFT" developed the system of eddy current non-destructive testing of LDP. Multi-channel eddy current flaw detector VD-91NM is the main component of the system. It makes 32-channel amplitude and phase control of the inner and outer surface of the pipe through the insulating coating of variable thickness (up to 10 mm). Practical tests show that after shot-blasting of the surfaces during pipes production, the surface becomes "quasi-homogeneous". VD-91NM can detect defects from 0.3 mm depth and local hardenings which differ from base metal by 20% hardness. Control time of the pipe of 12 m length and 813 mm diameter is not more than 5 minutes. Final protocol contains developed views of pipe with color coding of signal level and the table of detected defects.

![Image](image.png)

*Fig. 8. Automated eddy current testing system of LDP on the basis of VD-91NM*
Hardware and software solutions in VD-91NM allow to skip the nuisance parameter such as operating clearance of the probe. Today VD-91NM is the only eddy current system in the world that allows to work with variable clearance up to 10 mm without sensitivity loss to crack-like defects and local hardenings. These characteristics allow to control pipes, and also within weld seam area. Wide range of operating clearance makes it possible to test pipes for subsea transitions, the insulation thickness is up to 8 mm [8]. Fig. 8 shows the carriage with transducers during control of the pipe outer wall through the insulation protective coating of 8 mm thickness. The operator screen with pipe developed views is shown in Fig. 9. It has operating control panel of flaw detector VD-91NM and configuration parameters for outer wall control of LDP.

Conclusion

Theoretical and experimental researches show that eddy current method is the only NDT method for identification of local spot hardenings through protective and insulation coatings. It has high sensitivity and control speed and it should be applied for output quality control in pipe industry. As the other methods can’t find the specified defect types, without eddy current method the accuracy of NDT results in LDP production significantly reduces.
References:


