VERSATILE USAGE OF ELECTROMAGNETIC ACOUSTIC TECHNOLOGIES FOR IN-LINE INSPECTION OF AGEING PIPELINES

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The urgent need to increase reliability of stress corrosion cracking detection in ageing trunk pipelines served as a powerful incentive to active development of electromagnetic acoustic technologies (EMAT) by Spetsneftegaz scientists.

Due to extensive experience of using MFL and TFI in-line inspection tools during many years, it became evident that extra small shallow cracks with nearly zero opening were beyond detection capability of magnetic ILI tools. There are certain restrictions, which make detection of such defects impossible with required reliability.

It is noteworthy that “reliability” notion includes such notions as “reliability of detection”, “reliability of identification” and “reliability of defect sizing” (including its depth measurement). Regarding that any detected crack is considered as severe defect, which must be immediately cut out of the pipeline, two reliability constituents must work without failures, i.e. a crack defect must be detected and correctly identified.

In practices, at least two classes of stress corrosion cracking damages of pipelines can be determined, being seriously problematic for magnetic in-line inspection.

Fig.1. SCC combined with pitting corrosion.

1. The first class is represented by stress corrosion cracks with nearly zero opening, which are weakly detected by magnetic ILI tools (due to their minor opening, but not depth), so called high pH SCC. In fact, reliability of SCC detection by magnetic ILI tools is disputable. As a rule, even longitudinal cracks with nearly zero opening can give anomaly on the TFI tool record, though its amplitude is insufficiently high. Huge quantity of anomalies with similar amplitude, not associated with SCC, are recorded by TFI tools as metal structure features, and neither resources of ILI data treatment specialists nor machine time will be enough to treat such quantity of anomalies.
2. The second class is also represented by stress corrosion cracking zones, which are spacious enough to be detected by TFI tools. However, it is difficult to identify them correctly, because they are covered by general corrosion defects. It is necessary to remind that the most reliable criterion of identifying longitudinal cracks is ability to be detected by TFI tools and invisibility for MFL tools. Other criteria, such as parameters of form, amplitude of signal, gradient of signal are insufficiently reliable and can be considered only as supplementary ones. Thus, when magnetic anomaly initiated by a crack becomes smaller than anomaly initiated by general corrosion that is spread on a crack, which is encountered quite often, the main identification criterion stops to work, and uncertainty appears.

Multiple attempts of Spetsneftegaz scientists to solve the above mentioned problems, using only magnetic in-line inspection methods, did not have reasonable success. So it was decided in 2005 to start developing and inculcating ultrasonic technologies. Electromagnetic acoustic method of ultrasound generation was chosen for in-line inspection of gas pipelines, because of extreme complexity to use ultrasonic technology that requires liquid contact with pipe walls.

Fig.2. Crack detection by EMAT tool & TFI tool

There are two mechanisms of electromagnetic acoustic generation of mechanical oscillations. The first one is the eddy current Lawrence mechanism. The second one is magnetic striction mechanism. Sometimes it is called piezo magnetic mechanism. It is not noteworthy to describe advantages and disadvantages of each of them. This topic was already discussed many times. It should be just mentioned that Spetsneftegaz uses magnetic striction method. Mechanism of magnetic striction becomes apparent in deformation of elementary volumes of a ferromagnetic subject under magnetic field impact. There is reverse effect of this mechanism: magnetic field appears as result of ferromagnetic subject deformation. Thus, if alternating magnetic field is locally initiated in a metallic subject, then that subject itself will become source of deformations, which are later transformed into a wave. Coils, called transmitters and receivers, are used to induce magnetic field into a subject and then to receive it.

Electromagnetic acoustic transmitter is a special coil, through which special impulse of ultrasonic frequency current with amplitude of about 100 amperes is induced as so called “acoustic shot”. Ultrasonic wave is formed as packet of mechanical oscillations with duration of several (from 2 to 6 as a rule) periods, under the transmitter in the moment of impulse as result of electromagnetic acoustic transformation. Wave packet is propagated along a wall of inspected pipeline with velocity of about 3 km/sec. and received by EMA receiver. The receiver is a special coil, in which electric signal is formed as result of reverse electromagnetic acoustic transformation. Acoustic wave, in the process of its propagation in a pipe section, acquires specifications that can give important information (for example, information on abundance of defects in an inspected pipeline section).

Efficiency of EMA transformation (both direct and reverse one) is considerably lower than contact piezoelectric method and makes up 10^{-4} as compared to it. This fact was taken into consideration, when determining the scheme of creating ultrasonic in-line inspection system based on electromagnetic acoustic method.

EMA transformers can excite and receive all possible modes of acoustic waves. However, the method of excitation and reception of resonance waves is the most efficient one, being primarily prospective for further development. When such method is used, pipe wall plays role of wave guide, along which wave is propagated. Broad inspection spectrum is undisputable advantage of this method, besides its efficiency. Theoretically, one transformer pair is capable to scan full pipe length during ILI tool movement in a pipeline (excluding insignificant zone located in front of a transformer and shade zone). Increase of transformer pairs, regularly distributed on ILI tool circumference, does not increase resolution ability of an EMAT tool. Its operation is based on the resonance method, which is principally different from magnetic and contact ultrasonic ILI methods, being chosen due to necessity to overcome such unpleasant effects as wave attenuation in the process of its propagation, reverse dispersion effect (repeated reflection, etc.) that accompany guided wave ultrasonic sounding. Resonance ultrasonic sounding method has capability of echo shade method of pipeline defects sizing and check up of wave attenuation in the process of its propagation.

Ability to check up resonance wave attenuation degree enables to obtain new information layer (inaccessible for other inspection methods) for assessment of condition and type of pipeline coating. The physical principle that serves basis for disbanded coating detection technology is quite simple. As it was mentioned above, resonance wave attenuates in the process of its propagation. Attenuation is considerably associated with transfer of energy to pipeline coating. Various types of coating are characterized by various energy absorption factors. Application of EMA technology made it possible to identify type of pipeline coating. In case a propagating wave crosses disbanded coating zone, it is recorded as the zone with anomalously low attenuation, while anomaly value characterizes distortion degree.

Fig.3. EMAT ILI Tool. Detection of disbanded coating zones

However, resonance wave has its disadvantages, the main of which is relatively big wave length (as big as pipe wall thickness of an inspected pipeline), and as consequence, low frequency (as a rule, not more than 500 kHz). Contact ultrasound works at several MHz frequencies, wave lengths being several millimetres. It is well known from the ultrasonic inspection theory that the less wave length is, the higher is resolution ability of an ILI tool, and the smaller can be detectable defect. Thus, it could be expected that contact ultrasound considerably exceeds resonance electromagnetic sound, at least in sensitivity.

Fortunately for scientists that develop EMA in-line inspection methods, major quantity of longitudinally oriented cracks are encountered as zones of cracks. So interaction occurs not with a single crack, but with a group of cracks. Sizes of zones are, as a rule, bigger than resonance wave length. Moreover, stress corrosion cracking causes change of anisotropy of stresses in pipe wall, and, consequently, local change of resonance specifications of a pipe crack zone. It may also cause increase of amplitude of reflected signal. Spetsneftegaz scientists performed comparative statistic studies of efficiency of resonance and volumetric waves reflection from several stress corrosion cracking zones that proved the same sensitivity efficiency of EMA resonance technology as contact ultrasonic technology.

Fig. 4. EMA resonance technology. High pH SCC detected in 2007

Another disadvantage of a resonance wave is necessity to solve identification problem aimed to separate anomalies caused by cracks from anomalies caused by other pipeline features, predominantly not dangerous from the point of view of pipeline integrity. Such pipeline features can be insignificant corrosion defects or metallurgical defect.

In spite of the fact that resonance EMA technology as compared to magnetic ILI technology is much more sensitive to cracks and less sensitive to corrosion, the problem of their discrimination remains. It was reasonable to solve this problem by using a scheme of pipe wall ultrasonic sounding in two perpendicular directions. Anomalies of isotropic shape caused by corrosion give reflections in both ultrasonic sounding directions, while cracks give reflections only in one direction. Thus, the criterion of anomalies discrimination, which is applied in practices of magnetic in-line inspection (MFL, TFI), can be also applied in EMAT ILI tool.

Fig.5. SCC & corrosion. Bi-directional EMAT principle. EMAT ILI Tool (2009)

Laminations are also considerable hindering factor, when solving identification task. Due to the fact that they appear in the process of metal sheet rolling into a pipe, they acquire anisotropy of shape, like “tongues” elongated in rolling direction. Application of the mentioned criterion of bi-directional ultrasonic sounding does not give positive result and requires another approach.

Fig.6. Crack & lamination. Multimodal EMAT analyses (2009)

As result of tests in pull through test stand, containing SCC as well as laminations of natural origin, criterion of discrimination was developed on the basis of modal analysis. Certain correlations of amplitudes of signals obtained from various types of waves were used as criterion.

Determination of depth of crack zone is not trivial task. Both for magnetic and resonance EMA methods, amplitude of anomaly caused by SCC depends first of all on opening of cracks, then on density of cracks location and their interaction in the zone and only then on depth. So it is impossible to develop certain monotonous depth function with desired accuracy for anomaly amplitude. Uncertainty is too high. In case resonance EMA method is applied, solution can be found in modal analysis. Various modes differ by distribution of oscillations by thickness. Knot surfaces are available in modes higher than zero, where stresses are equal to zero, and defects that coincide with them are badly detectable. Thus, analysing correlation of amplitudes of signals initiated by modes of various orders, it is possible to obtain significant information on depth of cracks.

Since 2005, Spetsneftegaz NPO JSC has produced two generations (G1 and G2 types) of EMAT ILI tools. Now the third generation (G3) of high resolution EMAT ILI tool is being produced.

EMAT ILI tool of G1 type (2007) demonstrated principal capability to perform in-line inspection of trunk gas pipelines, using electromagnetic acoustic technology without requirement of super clean inner pipe walls (that problem was solved by finding compromise in choice of proper wave length). It was proved that G1 tool had much higher sensitivity to high pH stress corrosion cracking detection, than magnetic TFI ILI tools. Nevertheless, it was found out that G1 tool required further development of more reliable system of pipeline defects identification and more power.

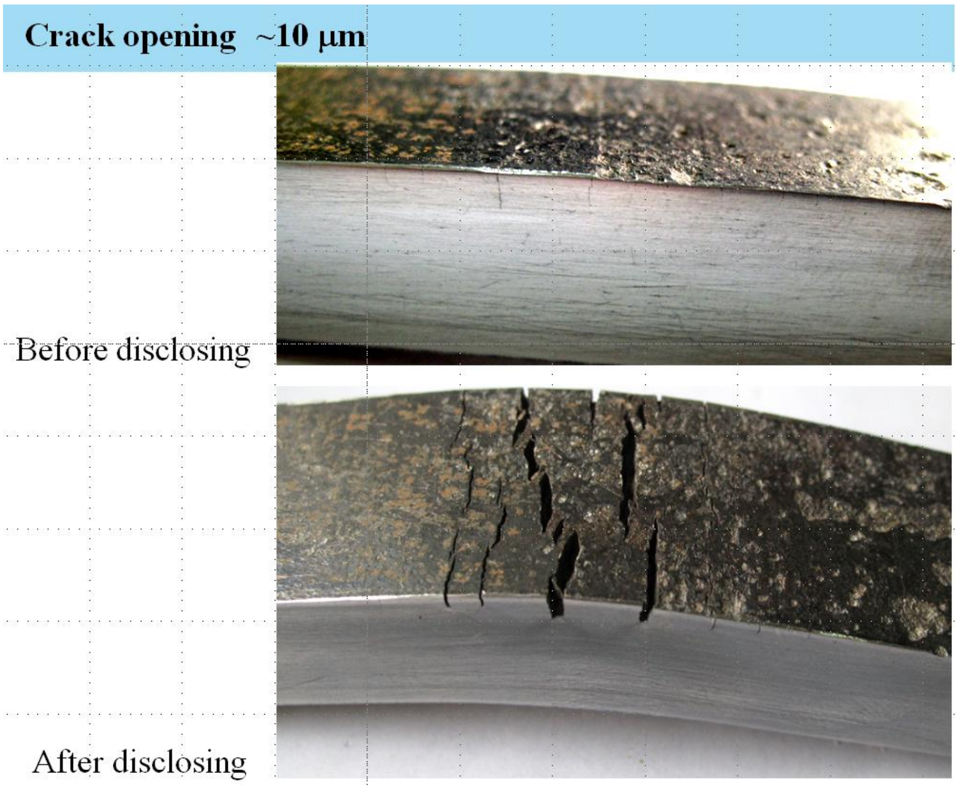
Development of EMAT ILI tools of G2 type continued till 2009. Sensor system was considerably upgraded, ultrasonic sounding in perpendicular directions was inculcated, the tool became several times more powerful. Number of sensors was increased.

Fig.7. Generations of Spetsneftegaz EMAT ILI tools

EMAT ILI tool of G3 type is being produced now. It is planned to be ready in 2010. Sensor system was upgraded to increase reproducing ability of in-line inspection results (obligatory requirement of criteria identification analysis). System of modal analysis was inculcated.

Thus, creation of G1 generation of EMAT ILI tool solved the problem of reliable SCC detection in gas pipelines. Creation of G2 and G3 generations of EMAT ILI tools solved both problems of SCC detection and identification. It is expected that accuracy of EMAT ILL tool of G3 generation to size crack depth will be much higher.

In conclusion it is noteworthy to mention that the main “brake” of development of electromagnetic acoustic technologies for in-line inspection application, involving huge expenses, is that most problems arising in the process of EMAT tool development can be solved only after this tool is fully produced and tested in a real pipeline. Many processes can’t be observed during laboratory tests. It is extremely difficult to chouse optimum ways of solving certain problems. In fact, EMAT technology is very young. However, we hope that soon EMAT ILI tools will be serially produced, be accessible and wide-spread as MFL ILI tools.



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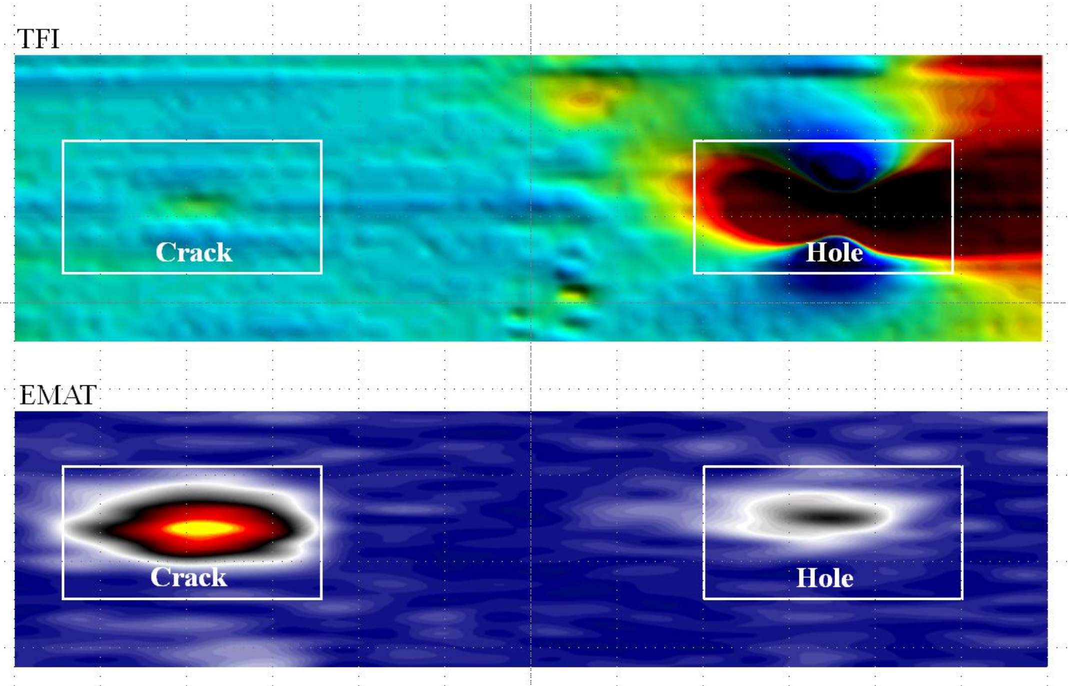

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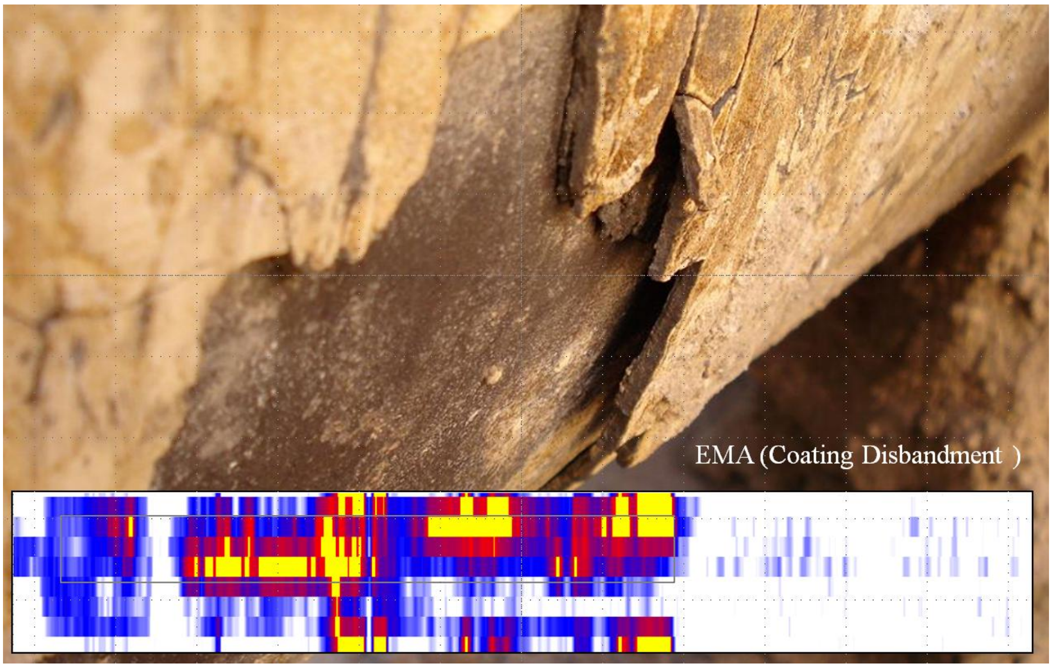

Fig.3. EMAT ILI Tool. Detection of disbanded coating zones

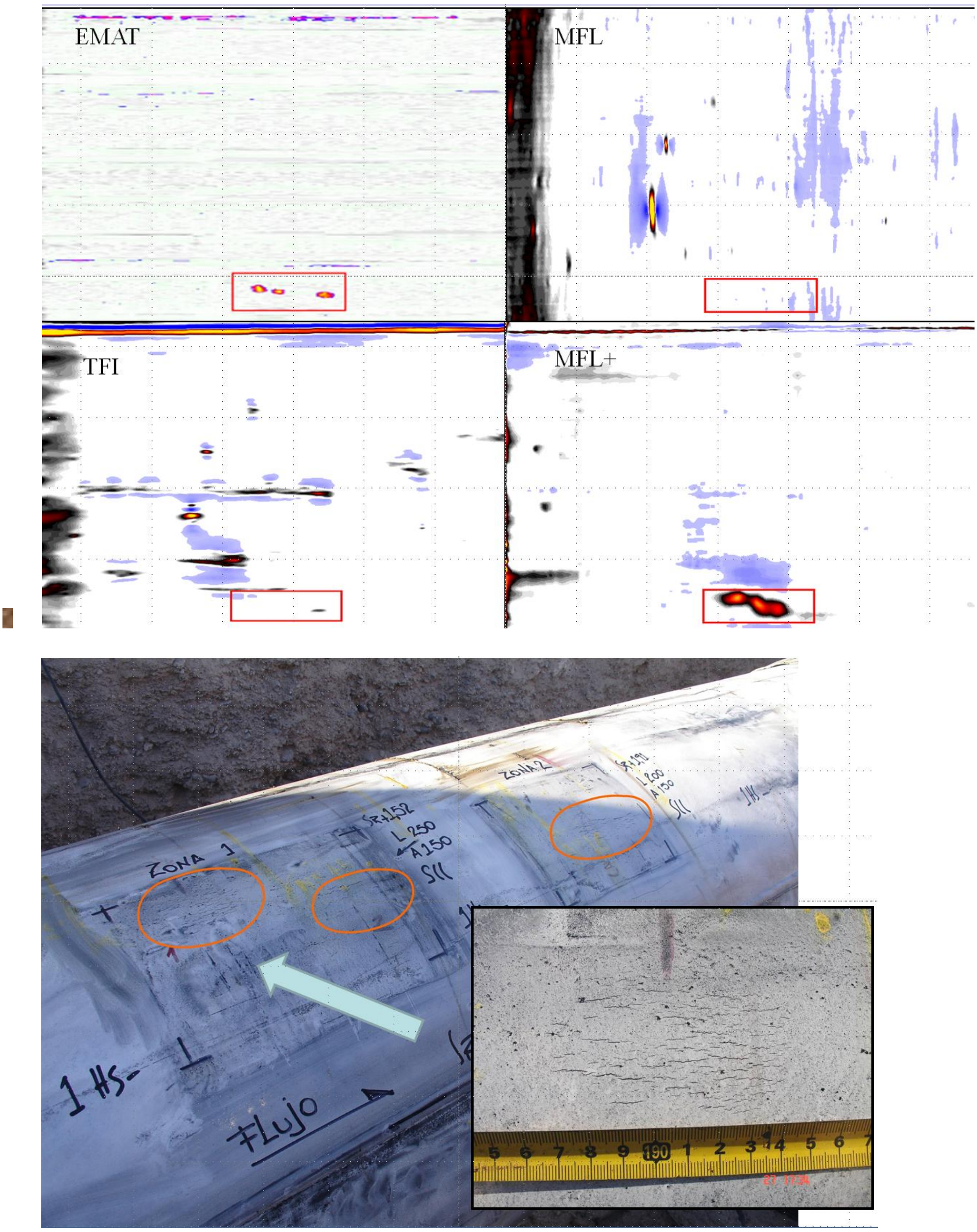

Fig. 4. EMA resonance technology. High pH SCC detected in 2007