NDE2002 predict. assure. improve.
National Seminar of ISNT
Chennai, 5. – 7. 12. 2002
www.nde2002.org

Phase Controlled EMAT Antenna for the Inspection of Coated Pipes

Andrei Boulavinov, Michael Kroening, George Nikiforenko

Fraunhofer Institute for Non-Destructive Testing, Saarbruecken, Germany

Jakov Smorodinsky

RAS Institute for Metal Physics, Ekaterinburg, Russia

Introduction

Pipe inspection in the production and inspection of pipeline systems during maintenance are tasks, which require improvement of NDE-techniques. The reasons are the unification of norms according to technical progress and increased understanding of quantitative contribution of NDE to the reliability and safety of industrial objects. The modern trends in NDE are in the automation of the inspection processes and in automated documentation of data. This follows the maintenance strategy, which should be able to quantify the current condition of the industrial equipment under consideration.

Some of the diverse inspection tasks may demand an original technical solution, which is optimized for special conditions, such as defect type, material and geometry of object, inspection speed etc. The development and application advantages of such an optimized technique can be achieved by an appropriate platform.

In this article we present such an optimized inspection system that allows the detection of corrosion damage as well as fatigue cracks in coated pipelines by use of an innovative inspection technique.

Inspection task

Gas-pipelines made of ferritic steels must be inspected for corrosion damages by ultrasonic technique. The pipeline is covered with 3 mm bitumen which can hide corrosion damage. The pipe diameter can be up to 0.5 m having wall thicknesses up to 12.5 mm. A 20 to 50 % loss of wall thickness must be revealed.

For the detection of corrosion damage and evaluation of the residual life of a pipeline, selective wall thickness measurements are performed, usually in location of assumed maximum wall reduction [1]. Radiography can be used as well as magnet particles testing and penetrant testing for the detection of corrosion cracks, which are open to the pipe surface. However, the mentioned methods require the removal of coatings prior to the tests leading to significantly higher inspection time and cost.

An other ultrasonic method for detection of corrosion is based on "guided waves" [2, 3, 4]. The ultrasonic waves are transmitted and received by the sensor system that laps the pipe circumferentialy. The defects can be detected up to distance of 50 meters [5]. However, for pipe surfaces coated by a layer of bitumen or polymere the high attenuation of surface waves does not permit this testing mode.

Our inspection technique allows to detect corrosion induced defects without removal of coating. Components, which are not accessible for surface scanning such as pipes or plates embedded in concrete, can also be inspected by this technique.

Solution

We have developed a novel automated ultrasonic pipe inspection system, employing a modified sensor technique. The sensor system is based on the use of shear horizontal (SH) ultrasonic waves [6, 7] generated by one electromagnetic transducer (EMAT) and received by an optimized EMAT antenna consisting of up to four individual sensors. A real-time averaging module is used to improve the signal to noise ratio.

The inspection is to detect corrosion induced defects according to the requirements of relevant regulations and procedures. A significant reduction of inspection time and reduced cost to prepare the pipe for inspection - the coating has not to be removed - provide significant cost saving. Rather than a full scan of a pipe's surface, only two circumferential scans (from both welded joints) can complete the inspection of one length and thus reduce cost. In the regions of interest the axial line scan can be performed without removing bitumen, since the EMAT-principle allows for scanning through the coating.

Sensor system design

The sensor system consists of one transmitter and two or four receivers (receiving channels). The receivers represent a multi-element antenna. The transducers are protected against mechanical damages by a layer of austenitic steel. The EMAT-sensor design [8, 9], which is optimized for high sensitivity is shown in Fig.1.

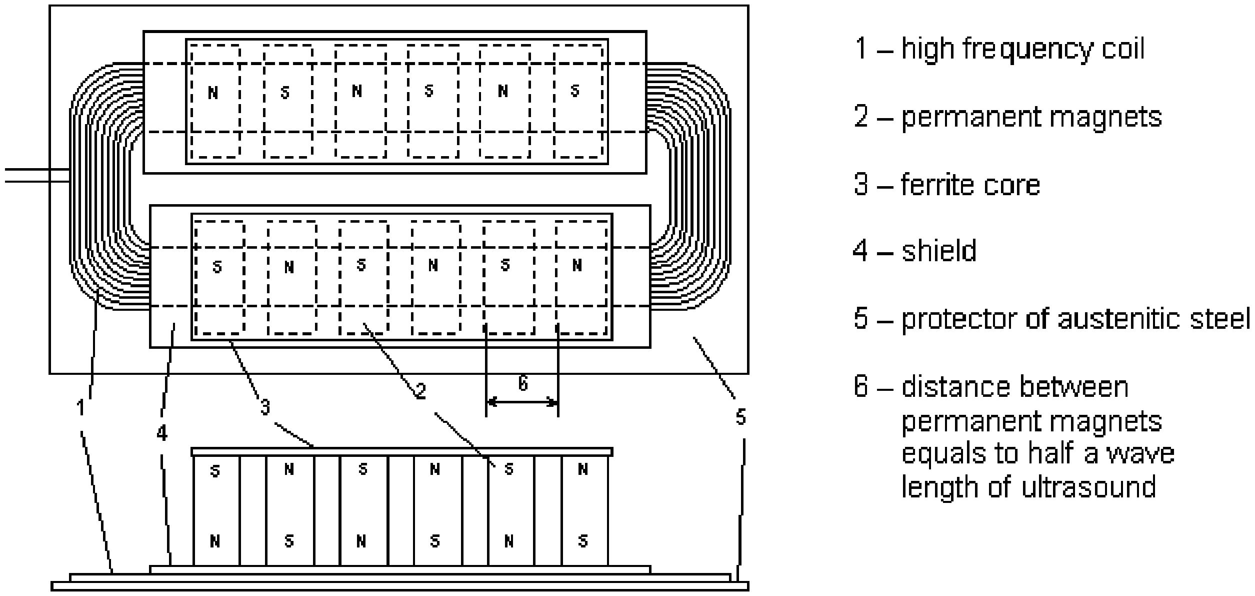


Fig. 1 Design of EMAT-probe

The distance between permanent magnets must be much bigger than the gap between magnet and material. Ferrite cores reduce the magnetic flux and concentrate the magnetic fields. Electrical shields reduce eddy currents induced in magnets that are the sources of acoustic noises due to interaction with magnet field inside of magnet. Protector of austenitic steel extends EMAT-sensor life.

The ultrasonic waves from transmitter interact with discontinuities of the inspection object. Parts of the reflected ultrasound pulse are picked up by the EMAT-receivers. The received signals are added with optimal phase delays.

Inspection procedure

For calibration of the inspection system a pipe specimen with artificial defects is used. The test specimen is shown in Fig. 2. The required sensitivity is adjusted on the side-drilled holes that represent the corrosion damage.

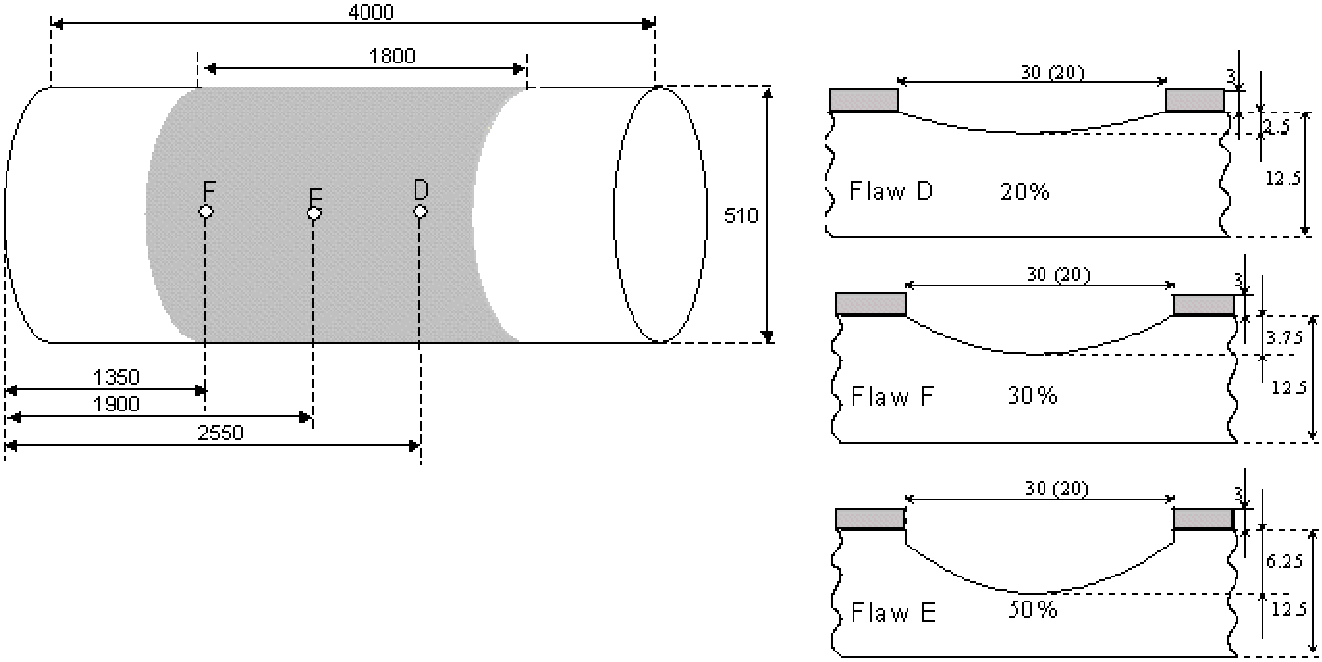


Fig. 1: Test-specimen of pipe with calibration flaws

Detection of corrosion damages by circumferential scanning

Fig. 3 presents the principal arrangement of EMAT-sensors for the inspection of pipeline sector by circumferential line scanning. The ultrasound is coupled with the pipe at the pipe end, which must be free of coating. Commonly the coating in the weld area is removed for weld inspection purposes. This area can be used for inspection with the EMAT-antenna. The pipe section between two circular welds is enough to be inspected by linear circular scans from both welded joints.

The optimal design of sensor and their arrangement for different pipes geometries can be calculated by special algorithm. This algorithm as well as the design of the sensor are proprietary information of the “Institute for Non-Destructive Testing” – IZFP.

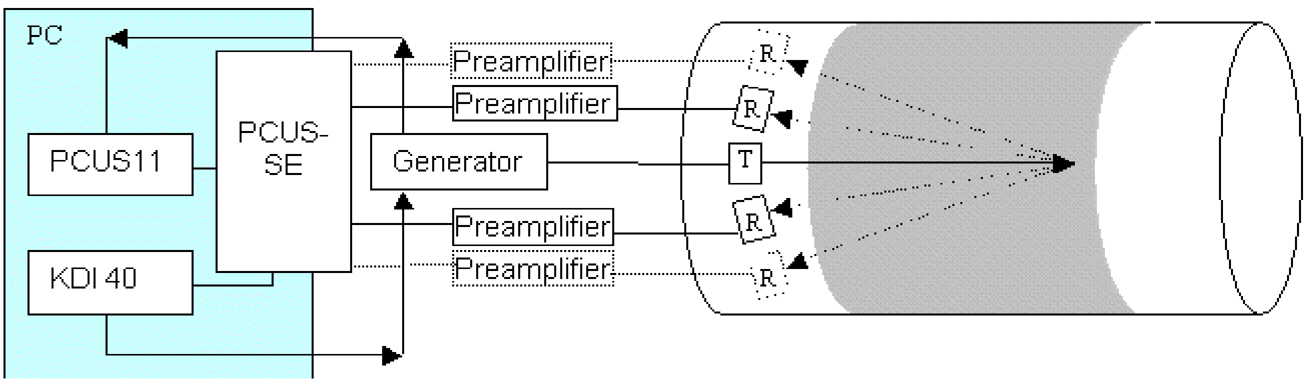


Fig. 3: Inspection scheme by circumferential scanning

Detection of corrosion damages by axial scanning

For safety relevant locations of the pipeline, an additional axial scan can be done (Fig. 4). In this case one can carry out the inspection directly through the coating. By one linear scan in axial direction all calibration flaws in the test-specimen can be detected. The coating thickness can change up to 30% of the relative average value without significant influence on the inspection sensitivity.

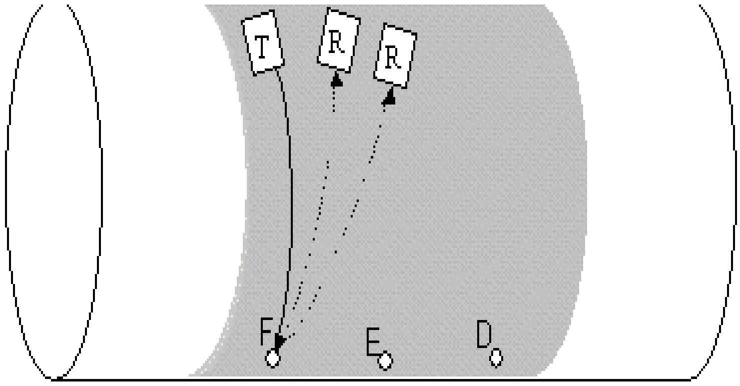


Fig. 4: Inspection scheme by axial scanning

Inspection system

Since the inspection system has several receiving channels, multi-channel electronics are required with some features concerning ultrasound transmission and signal processing. For the development of a laboratory system the PCUS-platform was applied (product of IZFP) [10, 11]. The 4-channel analog unit PCUS-SE (transmitter-receiver board) multiplexes the receiving channels. The analog signals are digitalized and processed by digital electronic PCUS11. Since high power for the excitation of EMAT-transmitter is needed, we used special signal generator.

The presented inspection system is a laboratory model. The industrial application system with parallel digitalization of signals can provide a sufficient inspection speed even for high averaging factors. For a repetition rate of for example f_r = 200 Hz and averaging factor N = 128 the sampling time in one position of EMAT-antenna is:

$$t = N / f_r = 0.64 \text{ s}$$

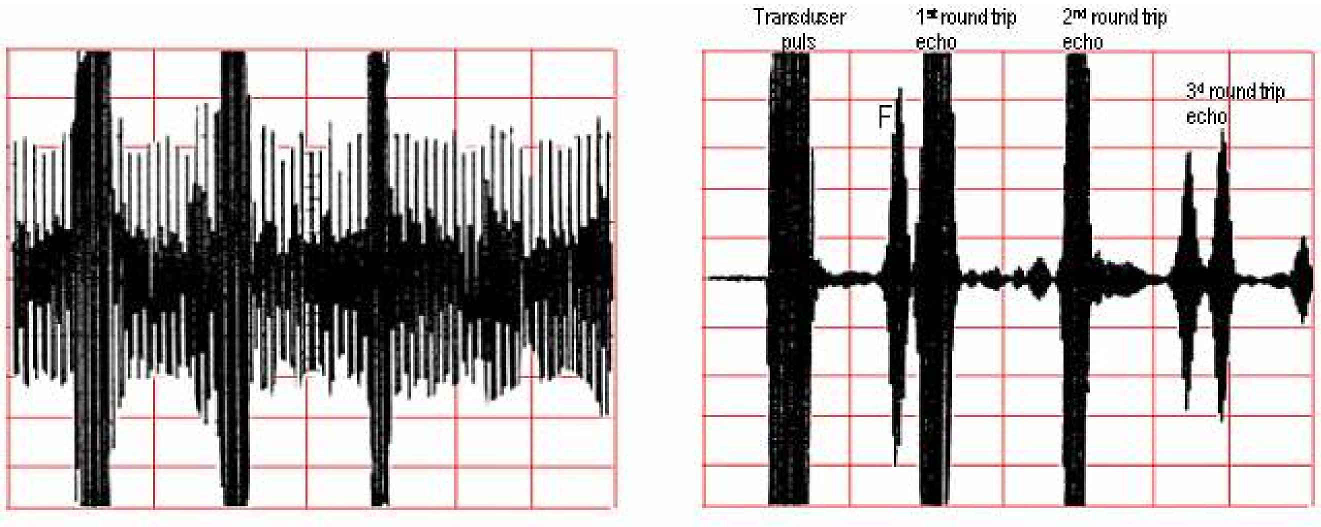
Considering the possible large scan index (up to 8) on pipe the circumference, the inspection of one pipe sector between two circumferential welds can be performed in a short time.

System modules of ultrasound electronic PCUS from IZFP can be used for the development of inspection systems according to industrial specifications. Customer’s requirements for the presentation of results can be taken into account. In particular the individual signals of all channels as well as the sum signal can be presented on the screen during inspection and documented for later evaluation.

Signal processing

It is well known that the EMAT-signals generally have a high level of noise. So long as the noise signals are of stochastic nature, averaging algorithms can be applied for their suppression [12]. The improvement of signal-to-noise ratio is proportional to the averaging factor. The algorithm can be implemented into the hardware nearly to real time measurement.

Fig. 5 shows the effect of averaging for the example of corrosion damage inspection by axial scan (inspection through the coating). In Fig. 5a one can see the initial unprocessed signal. Fig. 5b demonstrates the signal after filtering and averaging with a factor of 128. The significant improvement of signal-to-noise ratio is evident. All relevant signals are recognisable.



a) Initial signal

b) Signal after filtering and averaging

Fig. 5: Averaging effect

The averaging algorithm is implemented on the PCUS11-board. The received signals of individual channels are averaged separately. Then the signals are added. An algorithm is used to optimize focusing to increase the amplitude of the resultant signals.

Fig. 6 shows the digitalized and averaged signals of two receiving channels for the case of inspection in circumferential scan (Fig. 3). Fig. 7 demonstrates the result of addition of two signals with an optimal phase delay.

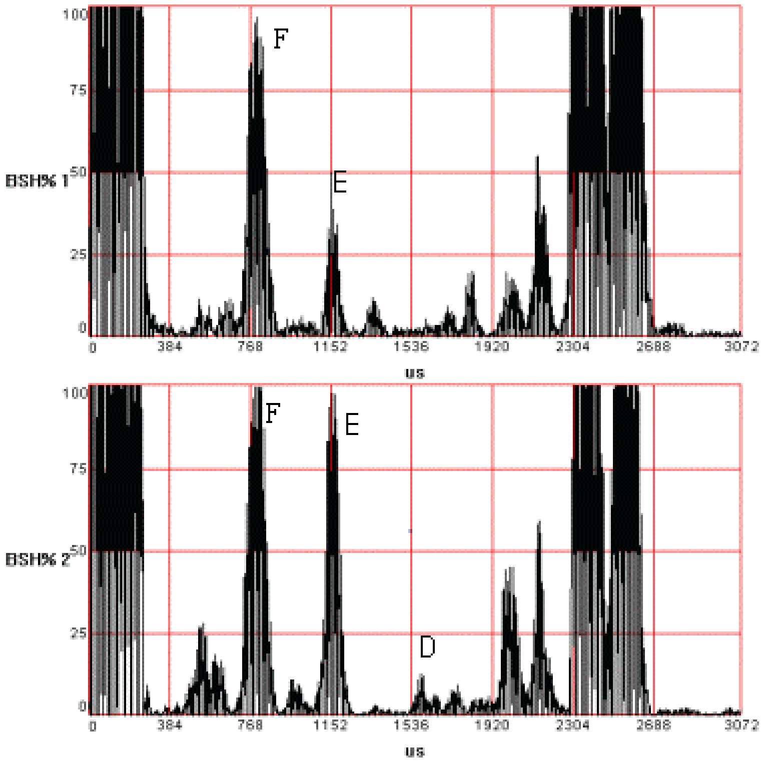


Fig. 6: Averaged and digitized signals of two receiving channels

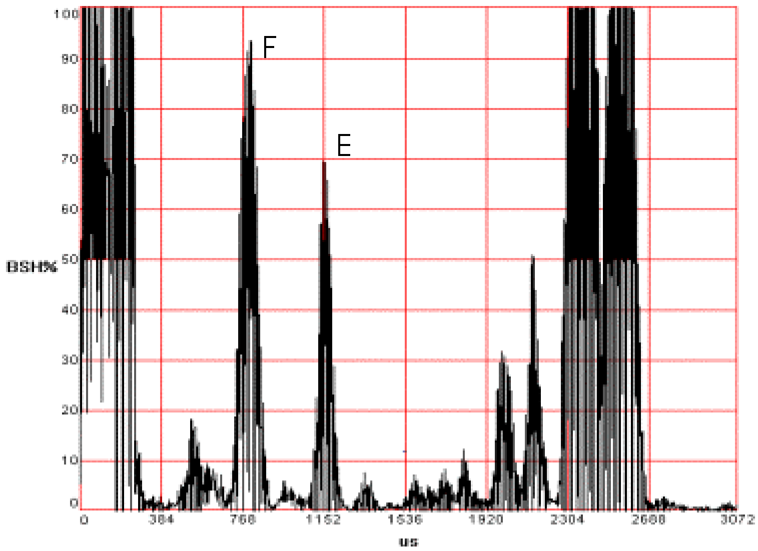
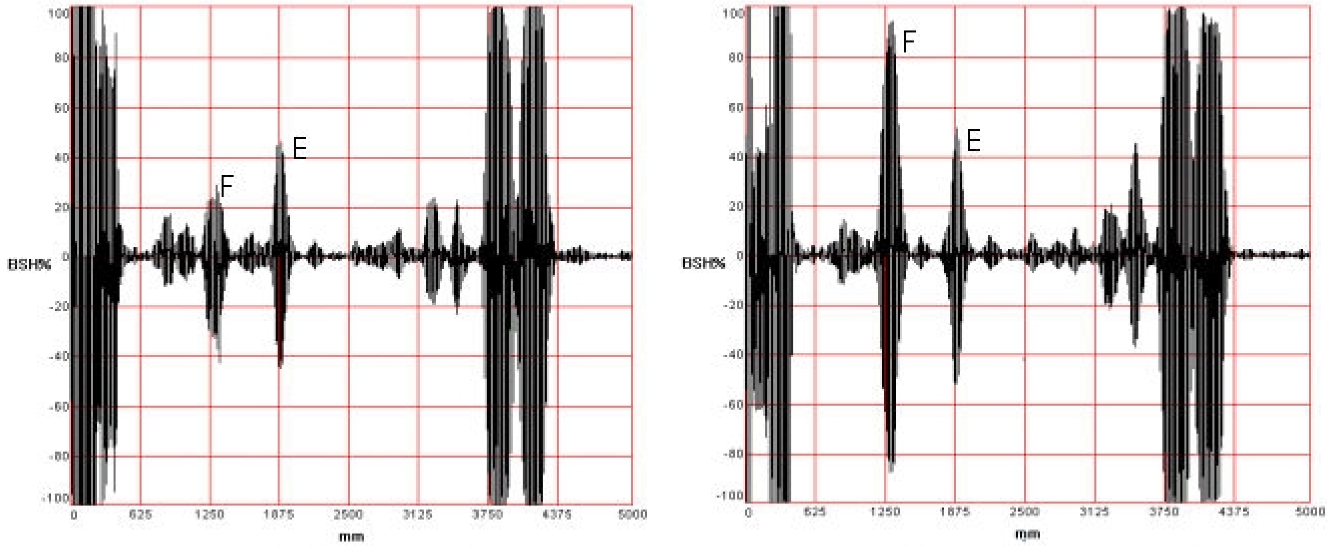


Fig. 7: Sum signal of two channels with optimal phase delay

Defects might be poor scatters for some receivers and good scatters for other. This technique enhances the probability of detection of the defects, which are not optimally oriented relative to the direction of sensors. Thus, sum signal of EMAT-antennas provides good amplitude for all defects as demonstrated also by Fig. 6 and Fig. 7.

The exact phasing of signals plays an important role (Fig. 8).



a) non-optimized phase delay

b) optimized phase delay

Fig. 8: Sum signals for optimized and non-optimized phase delays

It should be noted that the coating make the inspection tasks especially difficult owing to damping by bitumen. Whereas the attenuation in ferrite steel of pipe at a test frequency 100 kHz is less than 1 dB/m, the attenuation in a pipe with 3 mm of bitumen coating is about 15 – 20 dB/m.

Fig. 9 shows the A-scan that demonstrates the detection of two saw cuts at the distance 4 meter and 5 meter as an example of the inspection of non-coated pipes. Since the attenuation of ultrasound is not so strong compared to the coated pipe, the signal-to-noise ratio is significantly better.

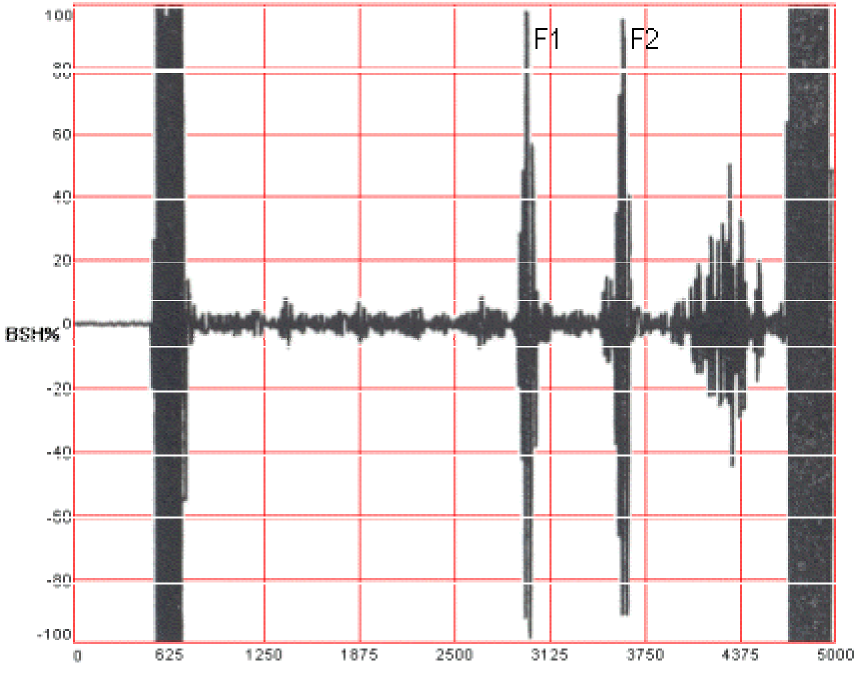


Fig. 9: Detection of two saw cuts at distances of 4 and 5 meters
Saw cut Nr.1 – 50% of wall thickness, saw cut Nr.2 – 30% of wall thickness

Fig. 10 demonstrates the detection of a saw cut at the distance 10 meter in a pipe of 12 meter length.

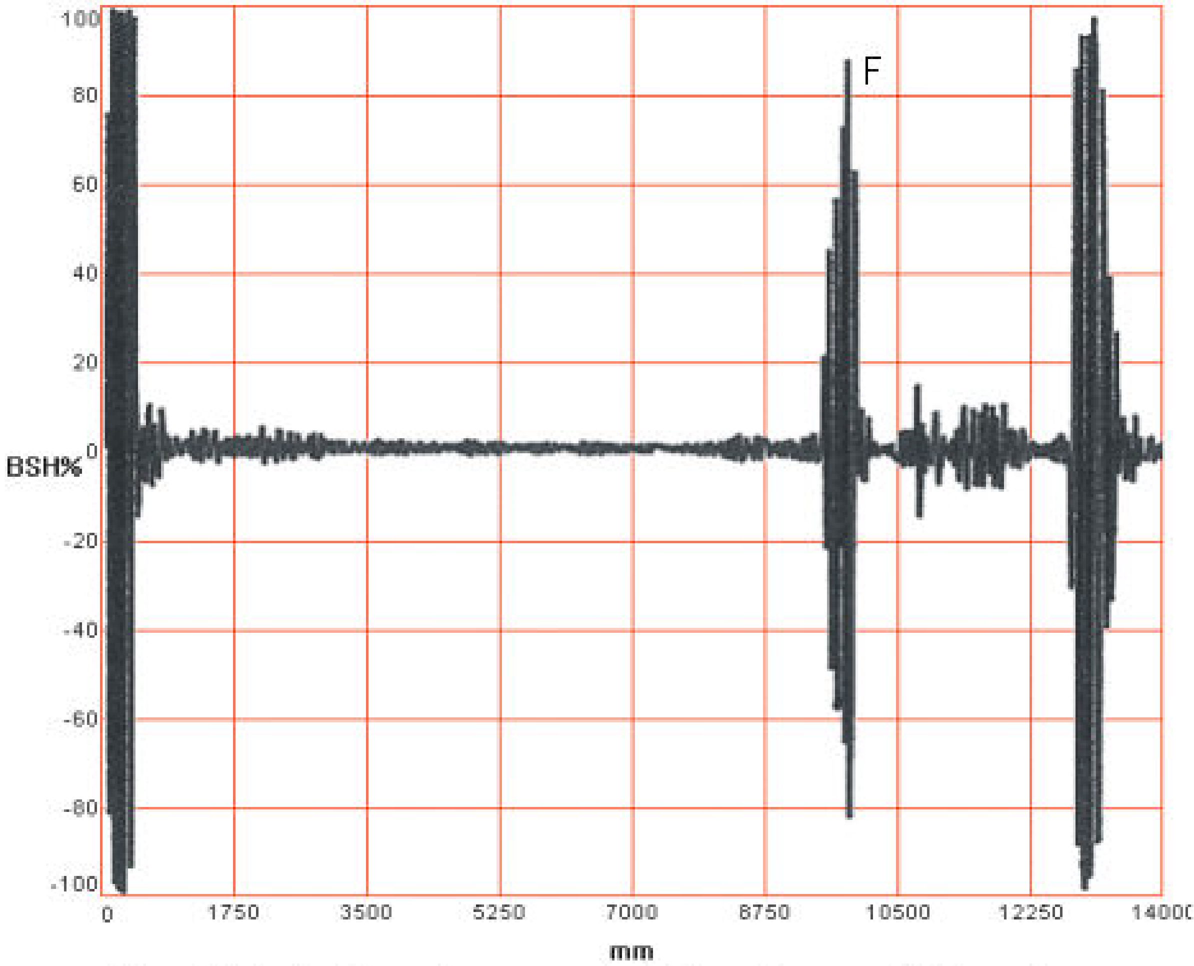


Fig. 10: Detection of a saw cut at the distance of 10 meters
Saw cut – 50% of wall thickness

Conclusion

The new inspection technique for the testing of pipes and pipelines by the EMAT-antenna was demonstrated. The technique allows carrying out fast pipeline inspection. It was shown, that the pipes with bitumen coating can be inspected without removal of the coating. Some advantages of presentation and documentation of inspection data were elaborated, which improve evaluation of inspection results.
The inspection technique can also be applied to pipes and pipelines with coating of polymers, concrete or bitumen of thicknesses up to 3mm.
The inspection system is optimised for the detection of corrosion damages. It is demonstrated that with proper design the sensitivity of EMAT-sensors can be improved. The necessary signal-to-noise ratio is achieved by the application of an averaging algorithm in combination with an optimised phased addition of signals from the receiving channels. Special algorithm for optimal focusing increases the amplitude of the resultant signals.
An inspection system for field applications using the described features is under development.

References

1. Dickenmessung mit Ultraschall / DGZfP, Deutsche Gesellschaft für zerstörungsfreie Prüfung e.V. Klaus Matthies u.a. - 2., überarb. Aufl. – Berlin: Verl. für Schweißen und Verwandte Verfahren, DSV-Verl., 1998
2. H.-J. Salzburger, Long Range Detection of Corrosion by Guided Shear Horizontal (SH-) Waves, 7th European Conference on Non-Destructive Testing, 26-29 May 1998

3. G. Hübschen, H.-J. Salzburger, Detection of corrosive defects in bottom plates of gas and oil tanks using guided ultrasonic waves and electromagnetic ultrasonic -EMUS-transducers, 9th European Congres on Corrosion. Vol.2 1990
4. Hegeon Kwun, Sang-Young Kim, and Glenn M. Light Long-Range Guided Wave Inspection of Structures Using the Magnetostrictive Sensor, Southwest Research Institute, San Antonio, Texas, 2001
5. Scott Lebsack Non-Invasive Inspection Method for Unpiggable Pipeline Sections, Pipe & Gas Journal, June 2002, p. 58 - 64
6. Шкарлет Ю.М., Бесконтактные методы ультразвукового контроля, Москва, „Машиностроение“, 1974, 57 с.
7. H. Salzburger, W. Mohr, Electromagnetic-Acoustic Generation of Ultrasound, 2nd Seminar on Characterization of ultrasonic Equipment. October 9-12, 1979. IZFP, Saarbrücken, Germany
8. Пашутин А. В., Харитонов А. В. Авторское свидетельство, 1973, № 380364
9. Пашутин А. В. Расчёт поля переодических магнитных систем электромагнитно-акустических преобразователей, Известия ЛЭТИ, Вып. 145, 1974, с.16 - 22
10. W. Kappes, B. Rockstroh, R. Weiss, E. Pridöhl, and M. Dalichow, “New Electronic Components and Software for Single and Multi-channel Ultrasonic Inspection of Piping and Components”. First Pan American Conference for Non-destructive Testing September 14-18, 1998, Toronto, Canada [conference]
11. J. Kretow, K. Pavros, W. Kappes, B. Rockstroh, R. Weiss, Neue PC- integrierte Geräte für die Ultraschall- Handprüfung und für die mechanische Ultraschallprüfung. Konferenz für moderne ZfP in der Industrie, März 98, Charkow, Ukraine
12. Справочник по радиоэлектронике под ред. А.А.Куликовского, том 1, Москва, „Энергия“, 1967, 640 с.