INDUSTRIAL ULTRASONIC EXAMINATION OF PLATES WITH EMAT

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Abstract

Mass application of steel plates is one of the key factors that stimulate development of world metallurgy. The new multi-channel, fully automated ultrasonic testing equipment EMATEST-PL works successfully in Russia and Japan. The equipment contains hundreds of independent channels, allows one to annually perform reliable in-line test of millions tons of flat material. High sensitivity and excellent noise immunity, 100% coverage with overlapping as well as other features fully meet the requirements of all contemporary international and domestic standards. Technical and environmental aspects and advantages of the EMAT-based solutions, modern development and achievements in the non-contact ultrasonic testing technology, vast and positive field experience including examination of high-temperature (up to + 650 ºC) plates, are considered in this report.

Keywords: EMAT, ultrasonic testing, plates

1. INTRODUCTION

Nordinkraft NDT-group has a vast experience in the development, production and practical maintenance of equipment for industrial automated ultrasonic testing of plates, pipes, tubes, bars and billets. When possible, we equip our systems with so-called "electromagnetic acoustic transducers" (EMAT). This modern and environmentally friendly technology allows one to perform a very convenient and reliable non-contact ultrasonic examination of semi-ready materials.

Plates are commonly used for extremely important industrial purposes as raw-material for building gas/oil pipelines, ships, bridges, tanks for chemical industry and so on. Mass application of steel plates is one of the key factors stimulating development of the world metallurgy.

On the other hand, plates seem to be one of the best applications for the EMAT-based industrial ultrasonic testing technology. Apart from the great number of very distinct technical advantages, the EMAT-technology of ultrasonic testing does not require water or any other couplant, allows one to economize a huge amount of drinking water, and prevents corrosion both of a material to be tested and the surrounding technological equipment.

Today 18 non-contact plate testing machines of high capacity have been implemented into a practical use only by Nordinkraft. The percentage of EMAT-based plates testing systems in the world ferrous metallurgy is already considerable, and is constantly increasing.

2. EMATEST-PL – THE FIFTH GENERATION OF ULTRASONIC TESTING MACHINES FOR PLATES BASED ON THE EMAT-TECHNOLOGY

The first ultrasonic testing machine of new (5-th) generation was produced by Nordinkraft and put into industrial application at the end of 2006 at TOKYO STEEL. Since then we have built and are currently building at least 6 sets of this kind of ultrasonic testing equipment, which is called "EMATEST-PL".

Ten most important points of performance data are given below.

2.1. Number of independent channels – up to 400.

2.2. Test object's temperature range – from -20 to +650^{o} C.

2.3. Inspection time for one 24-meter long plate (testing cycle) – about 34 seconds – several million tons of plates annually.

2.4. Test process (including calibration and recalibration) is fully automated (testing team is not required).

2.5. Range of plate thickness – 4 – 100 mm.

2.6. Sensitivity – FBH2 (which is much stricter than the requirement of most international standards).

2.7. Density of testing – 100% except for natural untested zones.

2.8. Calibration and recalibration – normally not required.

2.9. Testing configuration – two lines of 4-channeled EMA-probes that excite and receive shear waves normal to the plate surface.

2.10. Probes do not normally touch the surface as the gap is provided by means of air cushion.

The explanation of main features of the EMAT-based ultrasonic testing equipment EMATEST-PL is given in the movie-presentation.

3. RESULTS OF PRACRTICAL EXPERIENCE OF THE EMATEST-PL INDUSTRIAL APPLICATION.

One of the biggest Russian steel-plants named "NOSTA" has two machines for testing plates with ultrasound. One of them is EMATEST-PL, the other one is based on conventional TR-piezo-probes application.

For Nordinkraft and the plant, it was an attractive opportunity to collect, summarize and compare the results of ultrasonic test to be performed with ultrasonic probes of so different physical basis.

More than 40.000 plates were put into trials. EMATEST-PL carried out the initial test, where the test object's temperature was 400 – 650 ^{o}C. Then the material was cooled down to the room temperature and tested with a conventional ultrasonic testing machine that uses TR-piezo-probes.

As it is shown in the movie, the results were basically identical. The only exception was – hydrogen cracks, which could appear much later while cooling down the plates, or while keeping them, or transporting, forming pipes, or even in the field, when the pipe-line is already put into industrial use.

The results of comparison of EMATEST-PL and the conventional UTM are given below. The number of stars reflect our subjective estimation of the respective ultrasonic testing equipment features.

3.1. KIND OF NDT.

Both types of probes transmit and receive ultrasound.

Thus, in both cases we are talking about ultrasonic test.

3.2. WORKING FREQUENCY.

For both types of probes the working frequency selected normally from the range of 3 – 10 MHz is available.

Result:

EMAT - *****

TR - *****

3.3. FREQUENCY OF PULSE REPETITION.

For both types of sensors – up to 10 kHz is available.

Result:

EMAT - *****

TR - *****

3.4. TYPE OF ELASTIC VIBRATIONAS TO BE USED.

Both types of probes are able to transmit shear and longitudinal ultrasonic waves. However, 'normal to the surface of plate' piezo-probe is able to transmit longitudinal waves only. According to physical research data, shear waves have better performance in terms of plates testing. This kind of acoustical waves can be easily obtained with EMAT.

Result:

EMAT - *****

TR - ****

3.5. UNIFORMITY OF ACOUSTIC FIELD UNDER THE PROBE.

A TR-probe for industrial plate inspection must have several receiving crystals. Drop of sensitivity in the areas between the crystals is inevitable. To compensate this drop (which is minimum 6 dB), sensitivity increase may be required. This results in over-

rejection, when good plates can be rejected. The field uniformity in the beam-direction for a TR-probe is also not well.
Uniformity of acoustic fields created by EMAT can be extremely smooth because of design specific. So, practical overlapping is easily available.
Result:

EMAT - *****

TR - ***

3.6. SENSITIVITY.

Most of international and local standards require detection of laminations in plates that reflect ultrasound as FBH-5. But both modern EMAT and piezo-probes allow one to reach much higher sensitivity – up to FBH-2 or even better. For multi-channel in-line systems real sensitivity is restricted by different kind of interferences, or noise, typical for the respective type of probe (see further).
Result:

EMAT - *****

TR - ****

3.7. UNTESTED ZONES.

The best TR-piezo-probes and the best EMATs show the same untested zones at plate edges.
Theoretically, new TR-probes with plastic prisms allow one to achieve a little bit better result in terms of dead zones in the direction normal to the surface. But practically, the situation is totally different. As TR-probes are very critical to their mutual position adjustment, and all the probes in a multi-channel system obtain inevitable and random deviations from their initial properties, the beam resolution in automatic piezo-based UT-systems is worse than in the case of EMAT.
Moreover, as the best TR-probes working surface is made of plastic, after a certain number of kilometers of working run, 'scale + water + scratches' factors create erosion of the prism surface. So, TR-probes lose their performances very fast. That makes very necessary to calibrate piezo-probes-based system at least two times a day. Every calibration may require to make adjustment of TR-probes. The adjustment time depends on personnel qualification and number of probes used.
Practically, as adjustment of EMATs is not required and the properties of EMATs stay stable, EMAT is better than TR-probe in terms of untested zones in multichannel in-line systems.
Result:

EMAT - *****

TR - ***

3.8. SERVICE REQUIREMENTS.

Almost all important properties of TR-probes with plastic prisms (this is the best type of TR-probes) are gradually worsening. It happens because of erosion, scratching, water and temperature influence.

Therefore, to be on the safe place, TR-probe-based systems need calibration at least two times a day (up to two times during every working shift). Automatic calibration of TR-probe-based system can be very limited only because change in TR-probes

properties (including change of their acoustic field and directional properties) is unpredictable.

EMAT of the modern design is a very stable device, very well protected against damage and temperature. It does not need any adjustment or calibration as its properties do not worsen. It is double-protected against rubbing: by hard ceramics and air cushion. Theoretically, EMAT can work forever without losing its properties. So, the total check (we would not call it calibration!) of an EMAT-based system can be made once a year. Automatic calibration in the case of EMAT is very effective and fully reliable.

So, TR-probes are always an object of service and calibration. A water supply system is another weak point of piezo-based multi-channel systems. Any change in water-related parameters may require new adjustment and re-calibration. It also takes some time to transport the reference plate with the crane. The roller-conveyor should have reverse movement to make calibration and re-calibration easier.
At this EMAT has a great advantage. No probe adjustment, calibration and recalibration are required.
Result:

EMAT - *****

TR - **

3.9. NOISE IMMUNITY.

There are 5 kinds of noise or disturbances typical for ultrasonic testing of plates. Some of them are typical for TR-only.
1). Electromagnetic noise. Advanced electronics of an EMAT-based system and special algorithms of signal processing make this kind of noise absolutely negligible. The same thing can be applied for a TR-probes-based system. But every system should be checked for electromagnetic noise immunity in advance.

2). Acoustic noise in coupling water (so called: reverberation). For piezo-probes only! It can be very strong and unpredictable in the case of TR-probes. A qualified adjustment process and good quality of water and water supply system are strongly required. Staff should be very well trained.

For a multi-channel TR-system this kind of noise can be critical. Reverberation can result in the wrong decision about the plate quality (plate without defects can be rejected by mistake) when the adjustment of TR-probes is wrong, or when air bubble or loose scale get in between a TR-probe and the plate, or when the gap is a bit bigger than it is necessary, or erosion has spoiled the shape of the TR-probe prism.

For EMAT this kind of noise does not exist because water is not required. Change of gap is very seldom and does not create any noise. It just makes signals a bit smaller, but auto-calibration system will immediately correct the situation and the sensitivity will remain stable.

3). Microphone-effect. It is caused by broad-spectrum noise when the plate is transported along the roller conveyor. EMATs working with shear waves are not sensitive to this noise. If electronics and signal processing in a TR-probe system are good enough, it is not a problem for it as well.

4). Oil, or paint, or loose scale, or other substances on the plate surface that prevent good watering and coupling. For piezo-probes only!
This is a typical problem of piezo-systems.
EMAT does not have this kind of problem.

5). Random deviations in probe inclination during the test. For piezo-probes only!
Inclination of a piezo-probe for 2-3 degrees can cause substantial distortion of the acoustic field in the plate. The defect can be easily missed.

EMAT always transmits and receives ultrasonic signals strictly normal to the surface regardless of its position. So, it is not a problem for EMAT. Its signals are normally extremely stable.
Result:

EMAT - ****

TR - **

3.10. TEMPERATURE.

For TR-probes temperature should be within 0 – 100 degrees. For good watering it is better to have warm water and material. In this case coupling is better and the results are more stable.

So, it is very difficult to find a good position of the TR-based UT-system in the roller conveyor where the temperature of all plates of different thicknesses is always in the range above.

But even a lower temperature (e.g., only 70 degrees) can tremendously affect the result of the ultrasonic test and even spoil TR-probes.
Any position where the plate temperature is not more than 650 degrees is good for the EMAT.

Thus an in-line EMAT-based system, working in fully automatic mode, is much easier and cheaper to be applied and installed.
Result:

EMAT - *****

TR - **

3.11. WATER CONSUMPTION AND INVIRONMENT PROTECTION.

A TR multi-channel system with 100% coverage may consume about 10 liters of first class water (free of gas and foreign particles) for every ton of product. To inspect 1 000 000 tons of production, one needs to shower 10 000 000 liters of drinking water on the floor.
EMAT works without water.

Result:

EMAT - *****

TR - *

3.12. CORROSION.

Scale is a natural protector against corrosion. After tests with TR –probes the plate gets rusty and loses its marketable state. All the equipment around is also under the risk of corrosion.

EMAT keeps plates and the surrounding equipment in a good condition.

Result:

EMAT - *****

TR - *

3.13. AUTOMATIZATION OF IN-LINE TEST PROCESS.

As TR-probes always require calibration, adjustment and service, as they constantly and unpredictably change and lose their properties, it is very unlikely to design and build a fully automated in-line piezo-based system.

EMAT does not need any adjustment. So, only malfunction or accident can be a reason to bring the testing unit into a service-position. However all the parts of the EMATEST-V are very reliable.

Result:

EMAT - *****

TR - **

3.14. TEST SPEED.

Advantage of EMAT at performing high-speed test is obvious. Speed of test with a multi-channel piezo-based system has its natural limit (about 1 m/s) because of the risk of cavitation. Bubbles will kill coupling. For EMAT there are no physical limits as no water is required.

Result:

EMAT - *****

TR - ***

3.15. LIFE EXPECTANCY.

TR-probes can run 100 – 200 kilometers (if the maintenance is good and the temperature of the material is always low), before they are destroyed and should be replaced. Properties always worsen.

A block of EMATs “EMATEST-V” runs normally 500 – 2000 kilometers. Properties do not depend on the working time. It works or out of operation.

Result:

EMAT - *****

TR - **

3.16. THE TOTAL AVERAGE RESULT

EMAT - 4,8

TR - 2,8

4. SUMMARY

As for industrial inspection of plates EMAT has considerable advantages over conventional piezo-probes in terms of almost all parameters and practical aspects.

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