INCREASING INFORMATION DENSITY OF ULTRASONIC TESTING OF PLATES WITH THE USE OF THE EMAT

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Abstract: The report considers theoretical and practical aspects of increasing information density of ultrasonic testing of plates with the use of the EMAT. It gives principles of construction of multi-channel systems for detection of internal and surface defects and mechanical properties homogeneity estimation in a wide range of temperatures: from -40 to + 650 degrees Celsius.

Introduction: The report is devoted to the application of electromagnetic acoustic transducers (EMAT) as part of an automated multi-channel UT-system intended for plates and strips testing. However, the results can be extended on many other types of simple-shaped metallurgical products, such as bars, billets, pipes and tubes.

There are several fundamental characteristics of the EMAT that facilitate some additional capabilities of ultrasonic testing.

The most important of the characteristics are as follows:

1. The EMAT can operate in a very wide range of temperatures (from - 40 to + 650 degrees Celsius).
2. The EMAT can generate and receive polarized shear waves.
3. It can do that strictly normal to the surface of the material to be tested, regardless of the probe inclination. That involves obtaining extremely stable back-wall echoes from all defect-free probe position areas.
4. A polarized transverse wave is extremely sensitive to many types of surface defects including vertical cracks.
5. The velocity of polarized shear wave propagation in rolled materials depends on the direction of displacement in the wave relative to the rolling direction.

The mentioned above characteristics allow one to organize much more informative UT-process by using the EMAT.

There are at least two additional capabilities of a multi-channel UT- system equipped with electromagnetic acoustic probes. We can perform habitual UT-process of plates or strips using conventional piezoelectric probes. But simultaneously and additionally we can also do the following:

1. Detect unfavorable defects including surface cracks, which do not reflect ultrasound, but rather scatter the energy of transverse (shear) waves.
2. Estimate homogeneity of mechanical properties of materials to be tested.

Let us consider the capabilities in more detail by turns.

Results: Detecting crack-like defects that adverse to normal UT.

A polarized shear wave is able to interact with vertical cracks much better than a longitudinal one excited by a piezo-probe. It occurs if a crack is located mainly perpendicular to the polarization vector of a shear wave.

The influence of vertical cracks on scattering and attenuation of acoustic signals is represented in Fig.1 – 4.

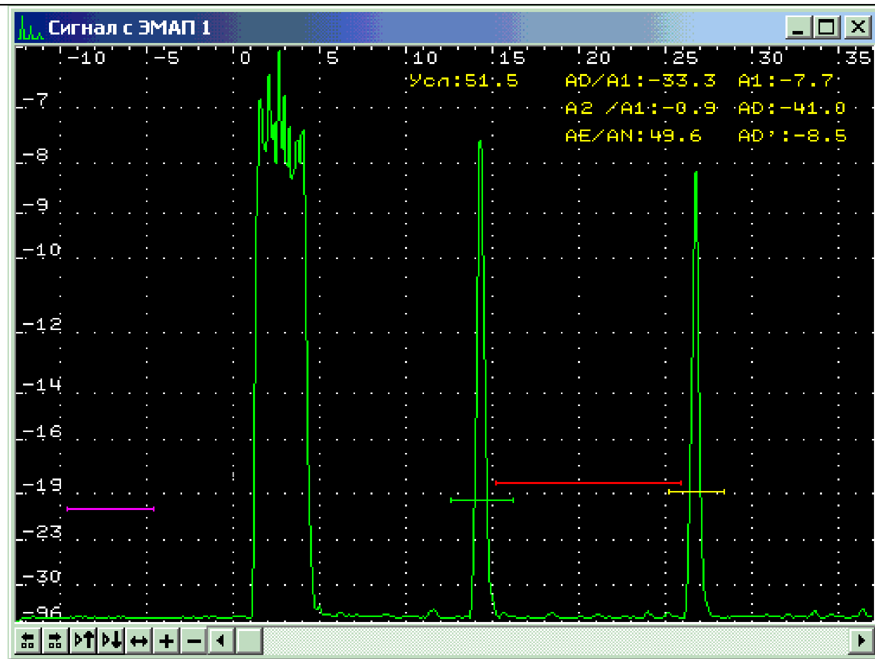

Fig.1. The signal from a defect free area of a plate 20 mm thick.

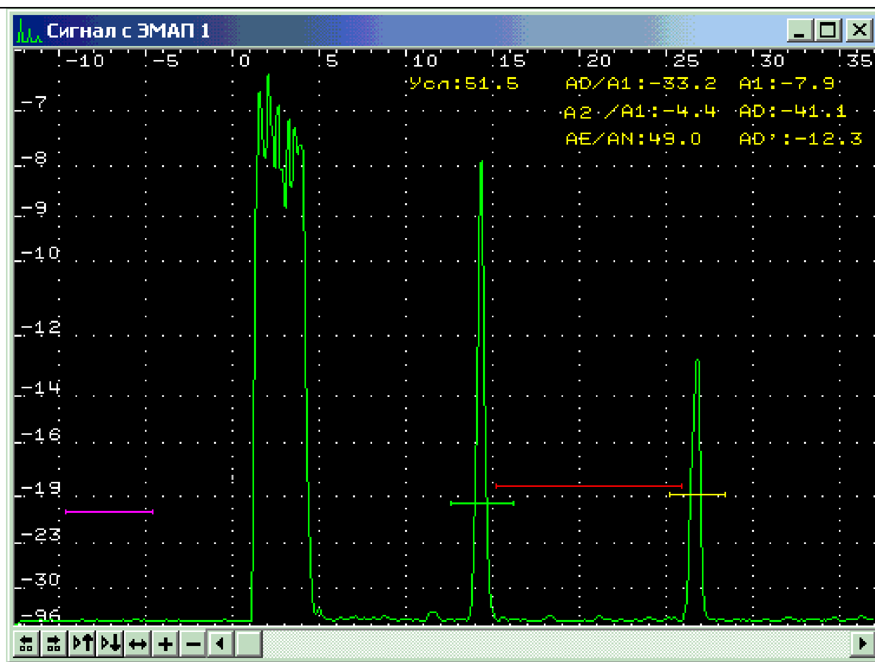

Fig.2. The signal form an area containing an artificial scratch 0.3 mm deep in the same plate 20 mm thick.

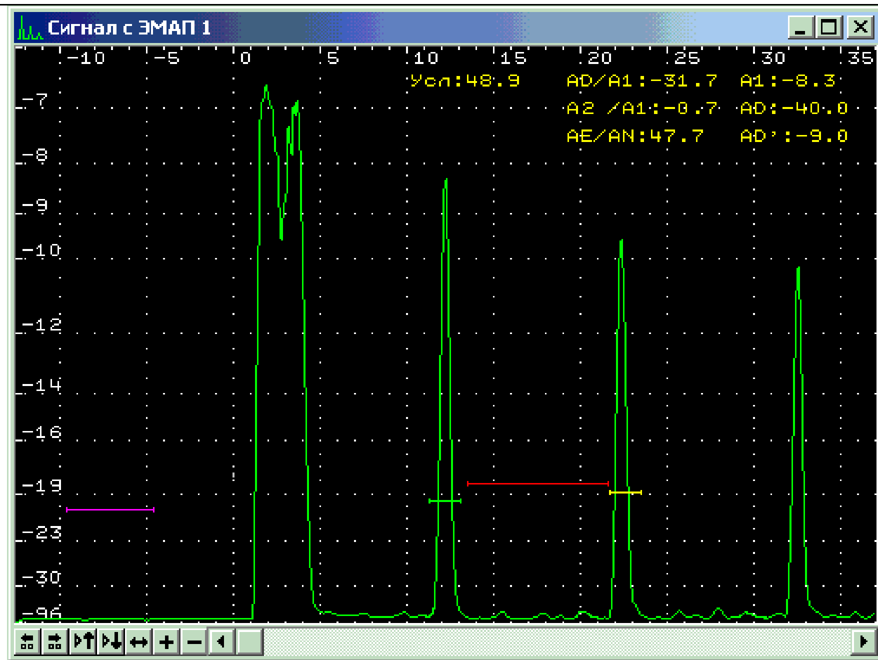

Fig.1. The signal from a defect free area of a plate 16 mm thick.

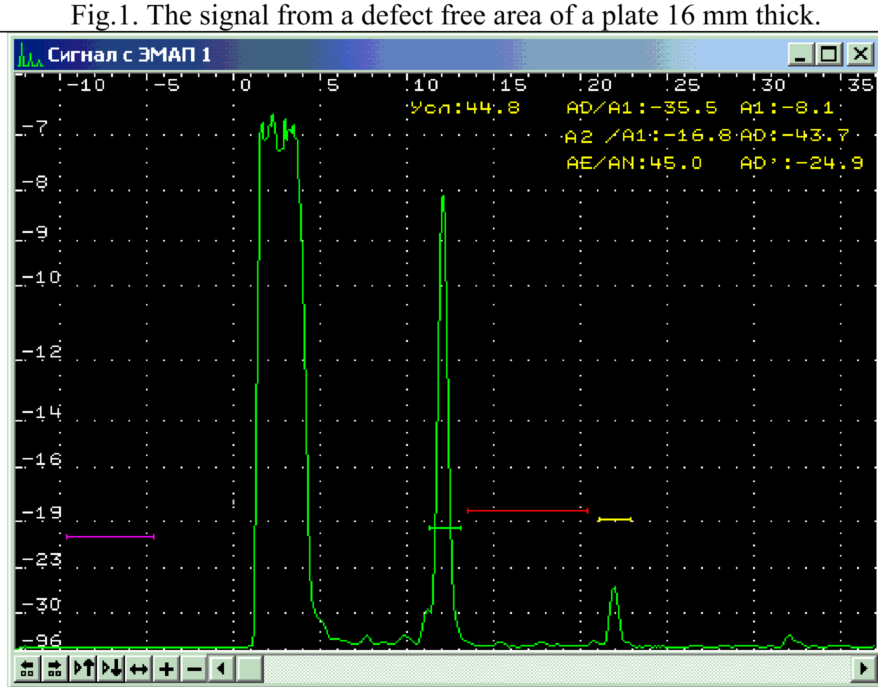

Fig.4. The signal from an area with an original vertical surface crack in the same plate 16 mm thick. The depth of the crack had been estimated by an eddy-current gauge as about 1 mm.

Discussion: Mechanical Properties Homogeneity (Uniformity) Estimation.

There are only two possible stable modes of polarized shear waves propagating in rolled plates. One of the waves can be polarized parallel to the direction of rolling, and the other one – perpendicular to it.

The velocity of polarized shear wave propagation in rolled materials depends on the direction of displacement in it or, in other words – on the mode of a shear wave.

One can excite both modes simultaneously or separately depending on the design of the EMAT and (or) its orientation relatively the direction of rolling.
The oscillogram of a signal picked up by the EMAT which coil's active zone had been rotating at the angle of about 45 degrees to the rolling direction is shown in Fig 5.

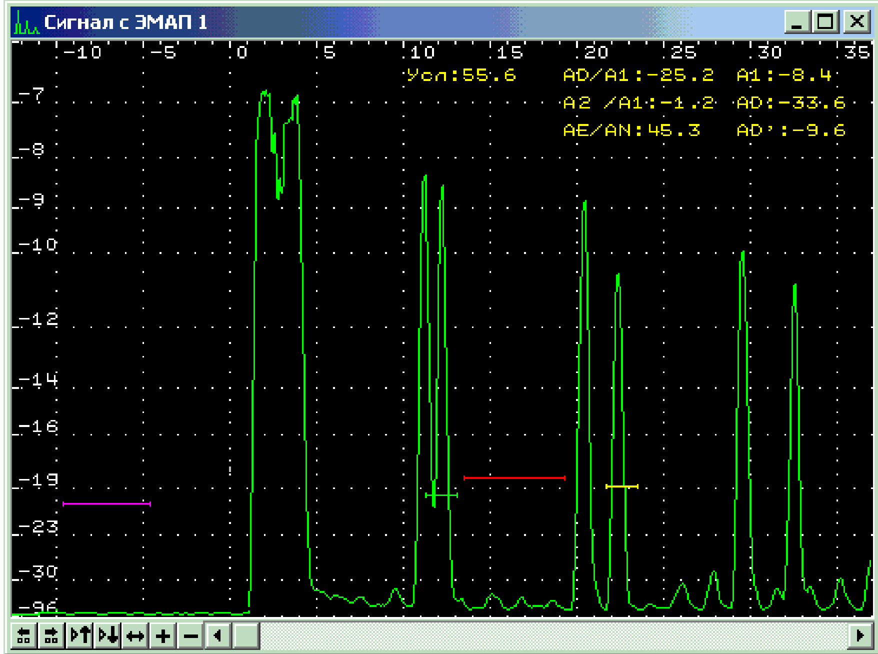

Fig.5. The signal picked up by the 45 degree turned EMAT from a defect free area of a 16 mm plate.

The signal contains divergent pairs of picks reflected from the bottoms of a rolled plate at a wall thickness of 16 mm.
The pairs of picks are caused by two modes propagating at different velocities.
The ratio of the shear waves velocities (or two respective times of flight that obviously do not depend on the wall thickness) defines acoustic anisotropy that in its turn correlates with the values of all mechanical properties (MP) of the material.

Specialists of "Nordinkraft" in cooperation with St. Petersburg electro-technical university, EUT-department, have developed the method of automated on-line ultrasonic testing of MP uniformity of strips and plates. The MP uniformity testing can be performed with one of the Nordinkraft's standard multi-channel UT-systems - "SEVER-10" or "SEVER-6-08", containing lines of electromagnetic-acoustic probes. Every probe has two active elements (coils) that are turned at an angle of 90 degrees to each other.

The essence of the method is in realization of the following algorithm.

1. Performing measurement of the Z (x,y) parameter all over the plate:

$$Z\,(x,y) = \frac{C_{t1}}{C_{t2}} = t1/t2,$$

Where C_{t1} and C_{t2}– velocities of a shear wave polarized across /along the rolling direction in the position with coordinates ***x*** and ***y****;*

t1, t2 – respective times of flight of differently polarized shear waves.

2. Finding areas of the plate where the Z (x,y) - parameter value exceeds the allowed limits:

$$Z_{min} > Z\,(x,y) > Z_{max}$$

The values of the limits should be determined previously, in the course of preliminary studies including the use of destructive testing methods.

3. Creating a map of the suspect areas of the plate, where the Z(x,y)- parameter values are beyond the allowed scope.
   The example of the MP homogeneity estimation results, obtained from an original plate, is shown in Fig. 6. Black spots on the plate's image indicate areas where the ratio t1/t2 is out of the scope of acceptance, namely for the case being described:
   $$1.1 < t1/t2 < 1.15$$
4. The total suspect area calculation. Making a comparison with the value of the ultimate-acceptable area. Making decision on the plate's status (good or bad).
5. Sampling on the suspect zones, determination values of real mechanical properties, corrections values of Z_{min} and Z_{max} – parameters for the next lots of material to be tested.

The algorithm above can be performed simultaneously with the flow-detecting process.

So the idea is not to determine the MPs themselves, but to pay attention to all plates of the lot where the ratio t1/t2 is beyond the range of typical values for the material. If the t1/t2 – ratio value is smooth and does not exceeds the allowed limits, the MPs are most likely homogeneous all over the plate.

Conclusions: Thus, the opportunity to realize the program of integrated assessment of plates and strips according to the scheme: "Precise Flow-Detection + Mechanical Properties Homogeneity Estimation) is a very important advantage of multi-channel automatic UT-systems equipped with electromagnetic acoustic transducers.

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