# NON-CONTACT ULTRASONIC TESTING USING EMAT TRANSDUCERS

**Ing. Stanislav Štarman**
*STARMANS Electronics, s.r.o., Praha, www.starmans.net*

***Abstract:***
*The article gives a brief description of basic principles used in electromagnetic acoustic transducers (EMAT). Main configurations of EMAT transducers and wave types generated are described, as well as most common applications of non-contact ultrasonic testing. The article presents some results of development of electromagnetic acoustic transducers and necessary instrumentation – improved pulse generator and preamplifier. The developed system is capable of thickness measurements of metallic products. However, defects equivalent to 3 mm DSR are already detectable as well.*

## 1 EMAT Principle

### *1.1 Classic Piezoceramic Transducers*

Classic piezoceramic transducers have a limitation, that in order to transfer the ultrasonic energy, they need a contact with material under inspection. The contact can be provided by down-force, immersion, pressurized air..

Air-coupled method operate with air as a coupling medium and are adequate for composites. However, for metals, there is so great difference in acoustic impedance, that a signal, reflected from materials having a thickness greater than approx. several millimeters, is virtually inaccessible.

### *1.2 EMAT — Electromagnetic Acoustic Transducer*

EMAT works only in conductive and ferromagnetic materials. compared to classic piezoelectric transducers, it enables series of applications, which are rather problematic.

The EMAT principle consists in the Lotentz’s attractive force in magnetic field. The magnetic field orientation influents principally on generated ultrasonic wave type.

### *1.3 EMAT in the World*

EMAT techniques are developing intensively in the world now. Basic application branches are:

Testing of steel bars and rods

Bars of round and square shape; inspection at high temperature in the production process.

Testing of tubes

Thickness measurements on hot tubes in production process; testing of tubes for defects.

Testing of pressure vessels

Hot pressure vessels in manufacturing process.

Survey testing

Portable instruments for testing especially heat exchangers in power plants. Testing of tubing and piping, hot or with very bad surface.

Testing on the orbit

NASA and ESA opened a competition for testing equipment — portable EMAT flaw detector for international space station, because immersion cannot be used in weightlessness.

Testing of non-metallic products

Composites may be inspected, provided, if coated with thin conductive layer.

Measuring of modulus of elasticity

EMAT most easily generates shear wave, which is, on the other hand, hardly transferable into the material with classic piezoceramic transducers, since shear wave does not propagate in immersion.

Thickness measuring at high temperatures

Classic piezoceramic transducers lose their function, when Curie's temperature had been reached.

EMAT enables measuring at high temperatures. Projects had been opened for testing at temperatures of 700-1200 °F. Results were compared using CSCAN: 90 % of tests were possible at room temperature, 80 % of tests were possible to at 700 °F.

### *1.4 EMAT Principle*

A current *I* in the coil, which is parallel to the surface of conductive sample, will generate magnetic field $\overline{B}$. Alternating magnetic field in the sample surface induces eddy currents, which generate alternating magnetic flux, which acts against initial current in the coil.

Force vector tries to rotate the coil in the static magnetic field. Since the coil and test sample are firmly fixed and changes in the field are alternating in frequency band of hundreds kHz up to tens MHz, the result is alternating suspension of atoms in crystal grid.

For EMAT coil, only first term of the basic Maxwell equation is applied.

$$\oint \overline{B}.d\overline{l} = \mu_0 I + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} \tag{1-1}$$

Considering zero value of electromagnetic field vector, the Lorentz's force vector will be defined by following equation.

$$\vec{F} = q\left(\vec{v} x \vec{B}\right) \tag{1-2}$$

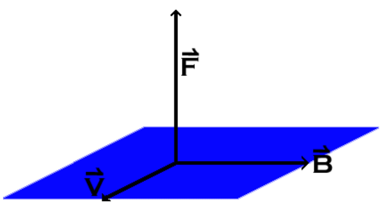



**Fig. 1. Orientation of force vector, magnetic induction and velocity**

Since crystal grid is bound with coil current by means of magnetic field as elastic system, vibrations of the grid will cause its vibration at its specific frequency, which is defined by the wave type generated in the sample.

### *1.5 Principal Advantages of EMAT*

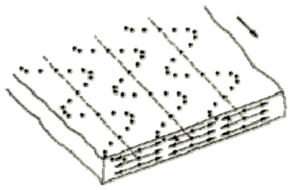
1. EMAT works without need of contact or liquid coupling. Typical distance between the transducer and material under test is tenths of mm up to number mm. A gap between the tested material and EMAT transducer prevents wearing of the transducer.
2. EMAT can work at high temperatures, where immersion evaporates and gaseous mixture of evaporated couplant causes deterioration or loss of coupling. The transducer can be cooled by cold air, with no influence on the US signal transfer.
3. EMAT enables generation of following wave types:
   a. SH shear horizontally polarized
   b. LH longitudinal horizontally polarized
   c. Rayleigh waves
   d. Lamb waves
   e. SH plate waves

### *1.6 Disadvantages of EMAT*

1. A disadvantage consists in, that EMAT principle works only in conductive environment and in ferromagnetic materials.
2. Very weak signal for testing to actually required defect criteria is another disadvantage. Therefore, for the present it is used only in specific applications and does not replace general classic US testing.
3. Great force attracting the transducer to material is the next disadvantage of EMAT transducer. However, permanent magnet can be replaced by electromagnet.

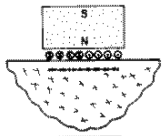
## 2 Types of US waves Generated by EMAT

### *2.1 Shear Wave*

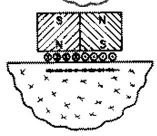


Shear waves have basic orientation of the polarization plane depending on the method of generation. Figure shows an example of horizontally polarized shear wave propagating along the plate.

### *2.2 Configuration of EMAT Transducers for Shear Wave*

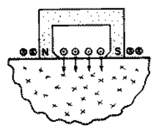



Spiral coil of EMAT generates radially polarized shear wave, which propagates perpendicularly to the surface.



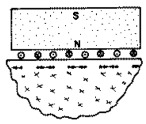

Configuration of EMAT for plane polarized shear wave, which propagates perpendicularly to the surface .

### *2.3 Configuration of EMAT Transducers for Longitudinal Wave*



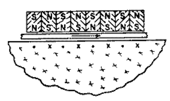

Magnetic field oriented parallel to the surface for generation of longitudinally polarized wave, which propagates perpendicularly to the surface.

### *2.4 Configuration of EMAT Transducer with Meander Coil*




Meander coil in this configuration enables generation of longitudinal, shear, Rayleigh, Lamb wave, plate wave, which propagates under an angle.

### *2.5 Configuration of EMAT Transducer with Periodic Magnetic Field*



Periodic magnetic field enables generation of planar or angled horizontally polarized shear wave or plate wave.

# 3 Generator for EMAT

Generators for EMAT constitute the key part for EMAT function.
Basic parameters of the developed generator are:

- Voltage 900 V
- Leading edge time 6 ns
- Current 30 A – 160 A
- Output pulse power 27 kW to 150 kW
- Number of output pulses 1 to 20

# 4 Instruments for EMAT Signal Processing

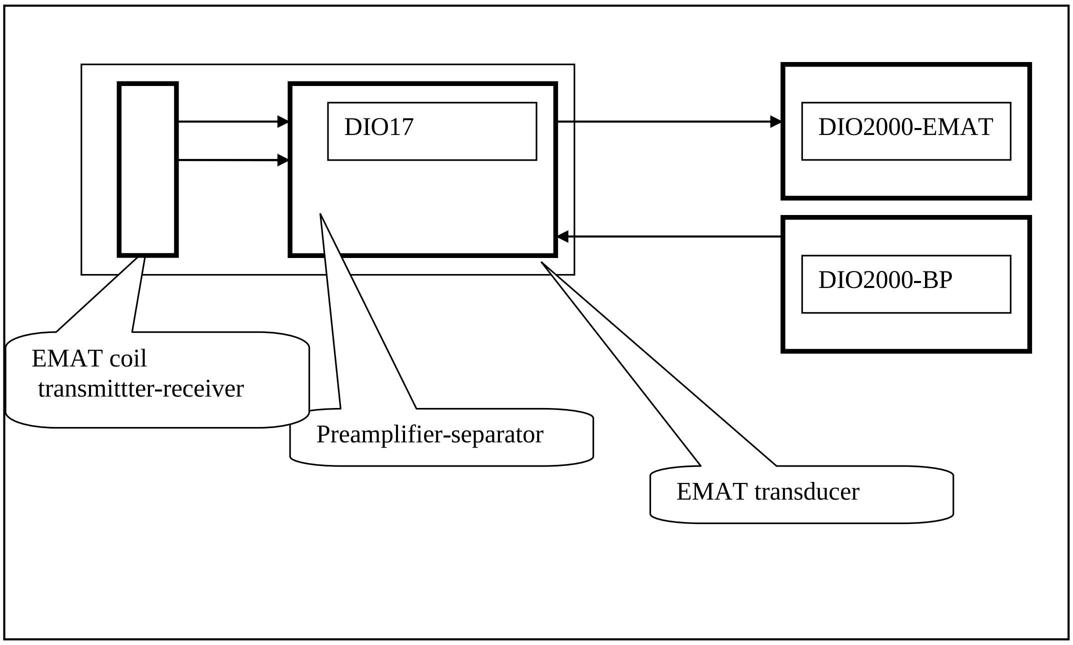
## *4.1 HW DIO2000*

<u>Basic characteristic of the ultrasonic channel</u>

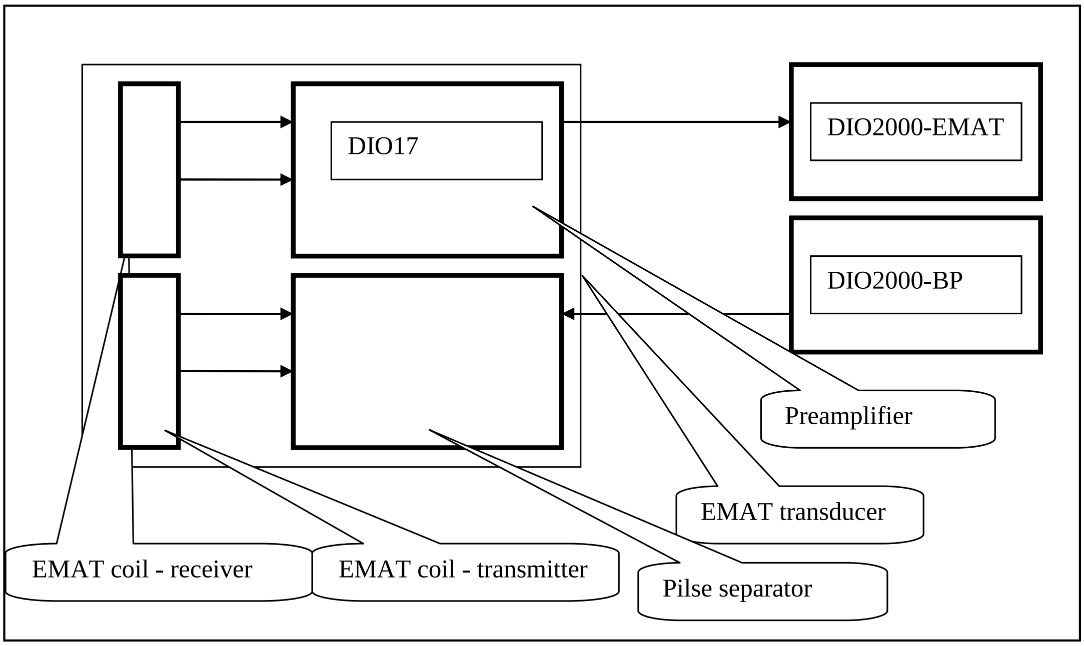
Each channel consists of autonomous electronic module (board) and contains all circuits as complete ultrasonic flaw detector:

- adjustable pulse repetition rate;
- adjustable gain and frequency band filters;
- digital signal processing DSP (digital filters, averaging and other functions);
- three monitor gates with adjustable threshold level;
- measuring of echo amplitudes, mean, relative and absolute echo position and its graphic presentation;
- 2 analog outputs (amplitude and time) for C-scan;
- automatically refreshable freeze mode, freezing of maximum values;
- external and internal synchronization with adjustable time shift;
- external power pulse generator can be connected to each channel;
- transducers with internal dynamically excited preamplifier can be connected.

## *4.2 Preamplifier EMAT for Single Transducer*



### *4.3 Preamplifier EMAT for Dual Transducer*




### *4.4 DIO2000 Software*

Software DIO2000 serves, first of all, to setting up the hardware, display, database management, saving data, displaying of simulated data, displaying of real-time processed signals by the DIO2000 hardware. For off-line signal processing, for investigation of EMAT signal processing, DIO2000 enables data export in several formats.

<u>Software DIO-2000</u>

- is intended for control of ultrasonic units, database and signals display;
- individual activation and deactivation of each channel;
- A-scan of ultrasonic signals for each channel can be displayed in one or more windows and by groups;
- graphic display of the measured values process, depending on time or space co-ordinates;
- process of measured and calculated values;
- B-scan and their combinations, combined values from several channels, statistics, minimum values, maximum values etc.;
- outputs for automated marking;
- maximum poss9ible number of channels 1 to 64.

### *4.5 ON-LINE Methods of Signal Processing*

In order to process the signal in real rime, measured signal passes through cascade of analog modules and digital algorithms.

The cascade of analog circuits serves for limiting of usable signal spectrum and interference.

The digital signal processing cascade serves for processing from several sections of signal time realization.

# 5 Results of EMAT Signal Measurements

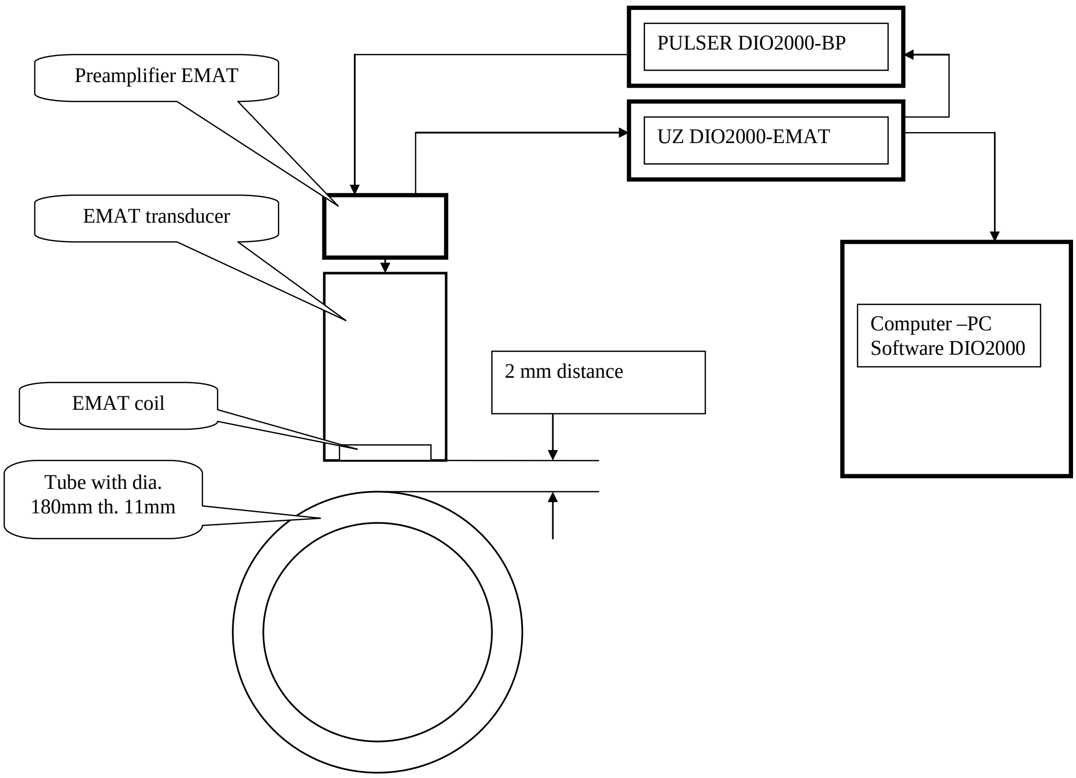
## *5.1 Block Diagram of the Measuring System*

Measuring of signal characteristics was carried out on different samples of different materials with different thicknesses.

The system consists of the following main parts:

- EMAT transducer with internal preamlifier
- pulser DIO2000-BP
- US board DIO2000-EMAT
- computer PC with software DIO2000

Measurement were carried out with the distance 2 mm between the transducer coil and surface of measured material, using a mechanic adapter with guide rolls.

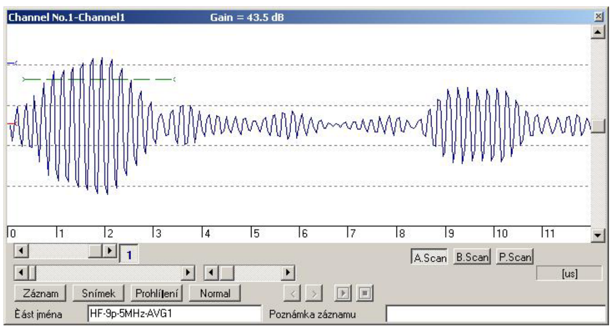



## *5.2 Results of Signal Characteristics and Spectrum Measurements*

Resulting signal had been principally affected by:

- pulser setting 1-9 pulses,
- setting of analog input circuits,
- consecutive DSP processing in real time,
- reflected signal of the transducer in P-E mode.

HF EMAT signal at 5 MHz frequency and 8 transmitted pulses produces energy aggregation with dominant energy matching with transmitted frequency.



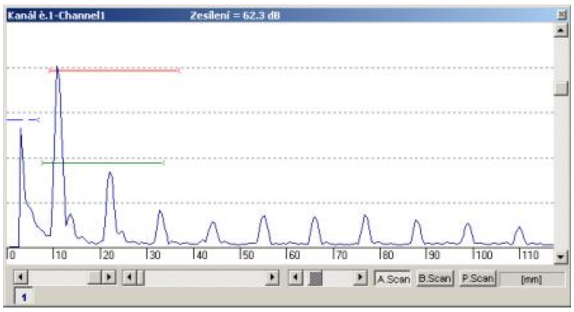


*Plate thickness 10 mm, steel.*

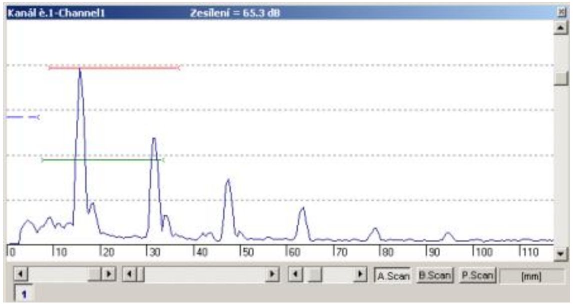


*Plate thickness 15 mm, steel.*

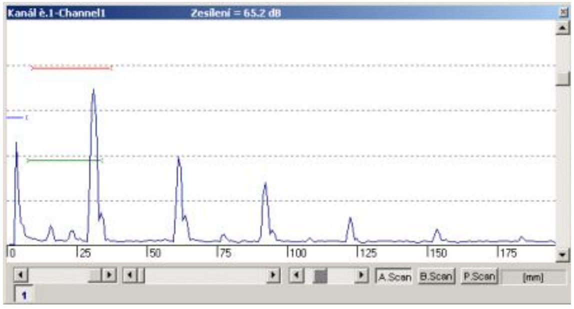


*Plate thickness 30 mm, steel.*

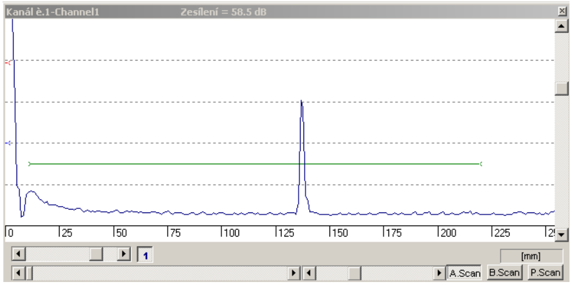


*Plate thickness 135 mm, steel.*

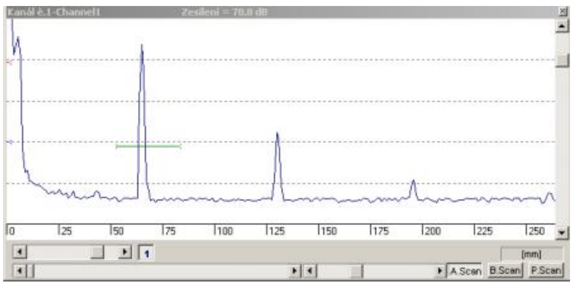
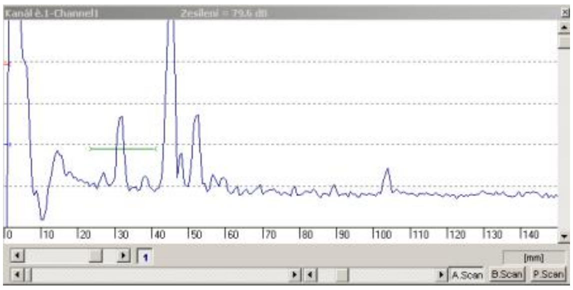


*Plate thickness 60 mm, aluminium.*



*Defect in 30mm depth, DSR 3 mm.*

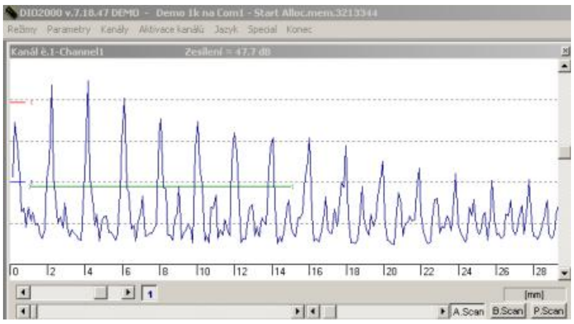
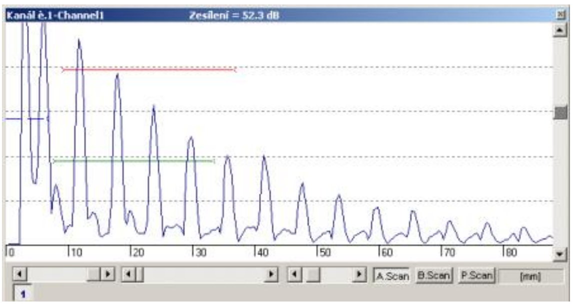


*Plate thickness 2 mm, aluminium.*



*Tube, t 6 mm diameter 200 mm.*

### *5.3 Conclusion*

Present state

At present I have developed, experimentally tested and implemented in operation in ISPAT Ostrava EMAT 4 channels operating in real time.

System had been designed for thickness measurements. Thickness measuring does not require such sensitivity as detecting small size defects. For testing according to most strict actual standards, required sensitivity is up to 1-2 mm DSR.

At present, defects with 3 mm DSR sensitivity had been identified.

Plan of further work

Decreasing the noise is one of evident ways. Present instruments enable signals collection to MATLAB and simulating of other methods for noise reduction. One of these methods will be several EMAT coils for parallel signal processing using DSP algorithms. DIO2000 enables processing and simultaneous measuring from up to 32 channels. The board enabling 4 channels synchronously and transfer to PC via USB 2.0 had been developed. A board with 16 channels for real time processing is in stage of preparation.

## 6 Literature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