

Acoustic emission signal attenuation in the waveguides used in underwater AE testing.

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In the paper presented are the results of study of the acoustic waves' propagation via waveguide lines of various lengths. Defined is the value of attenuation in the waveguide lines at normal conditions and in water.

The acoustic-Emission (AE) testing method for evaluation of metal structures integrity is based on the AE signal parameters analysis and makes it possible to reveal dynamically developing flaws.

AE method assumes that the AE sensor picking up the AE signals is placed on the surface of examined structure. If the structure under testing is in normal conditions, the sensors can be mounted directly on its surface. This provides the best AE equipment sensitivity. However in many cases it's not possible to place the sensor on the surface due to several reasons or factors. Among these are: high temperature, radiation, chemically aggressive medium as well as difficulty (and in some cases impossibility) of the sensor replacement if it is damaged. When examination of heated surfaces is performed, it is possible to use high temperature sensors, but their sensitivity is less than that of standard ones. Another way is to remove standard sensors out of the extreme the area and use waveguides for AE signal transmission. The most effective waveguides have the form of the long thin rods or plates.

Waveguide (in general) is the part of medium limited in one or two directions and used for transmission of waves, for instance, tube filled with liquid or gas; rod or plate (solid waveguides).

When the elastic wave is propagating in the body which transverse size is comparable or compatible with the wave length or smaller, the influence of side

boundaries on which mechanical stresses are disappearing should be taken into account. As a result of this phenomenon the following happens:

1. Only the elastic waves are propagating and their displacements vector field satisfies the condition of the elastic stresses on the lateral surface disappearance. At each frequency in given waveguide this is fixed and corresponding wave is called the normal one. In such a manner only the normal waves are propagating in the waveguide.

2. For given excitation frequency several normal waves can exist simultaneously differ in the distribution of displacement field over cross section. The oscillation amplitude in the resulting wave equals to the vector sum of the oscillations in each normal wave.

3. The elastic waves' propagation velocity depends on the frequency and, so called, sound velocity dispersion takes place in this case. The dispersion causes distortion of any nonmonochromatic signal which is the AE pulse. In a case of narrow-band signal its waveform will change while waveform' envelope will stay unchanged. When the wide-band signal is propagating – both waveform and its envelope will change and it may cause the problems in AE source location.

The resonant frequency of homogeneous waveguide with one free end can be determined from the formula [1]:

$$F_0 = C \cdot k / 2 \cdot L, \quad (1)$$

where L – waveguide length;

C – sound velocity;

$k=1, 2, 3 \dots$ – harmonic index.

For reasons to achieve compromise between necessity of noise filtration and minimize AE signal attenuation in the tested structure, the signals pick up frequency range, as a rule, is selected to be in the limits of 0.1 – 2.0MHz. Depending on the specific conditions of signal propagation, noise level and sensors parameters the operating frequency range is selected more narrow than stated above, i.e. 100 - 300kHz.

More often used are waveguides in the shape of rods or wires in which excited are longitudinal waves. Consideration of those waves type demonstrates that in the frequency range where the following formula is correct:

$$d \cdot f / C \leq 0,4, \quad (2)$$

where d – waveguide diameter;
 f – frequency;
 C – sound velocity,

only one longitudinal wave is propagating [2]. As this takes place the distribution of oscillations' amplitude along cross section is uniform enough, i.e. waveguide section effectively provides signal transmission.

The design of waveguides used for AE signals transmission shall provide operating frequencies range to be much higher above its lowest resonant frequency. For example, for the 0.5m waveguide made of steel the lowest frequency of natural longitudinal oscillations calculated using the formula (1) equals $F_1 \approx 5\text{kHz}$.

If the signal registration range corresponds to the frequency band of 100 - 200kHz it will mean that in the process of signals transmission the basic frequency harmonics with numbers from 20 to 40 will be generated. Excitation of the waveguide at such high frequencies provides significant advantages: separate resonant peaks, imposed one upon the other, provide obtaining of the relatively smooth curve of impedance-waveguide transfer function against frequency response [3].

With taking into account condition (2) as well as constructive and technical considerations, it is appropriate to use waveguides with diameters of 0.8 ...3.0 mm for transmission of informative AE signals. The practice of implementation of proposed above solution demonstrated only some wave package diffuse that does not have influence on the process of AE information receiving and processing.

The fabrication and fixation of the AE sensors with the diameter equal to the waveguide one is rather difficult task in the context of necessity to achieve stability

of the production performance. It is also necessary to underline that it is preferable to use AE equipment in combination with standard commercial sensors. Since commercial sensors diameter is bigger than one of the waveguide it is required to use terminating concentrator to provide matching of both. So the concentrator transforms load applied at its input end to some value at its output end. The transformation coefficient is calculated as:

$$K = Z_{\text{inp}}/Z_{\text{outp}} = S_{\text{inp}}/S_{\text{outp}} , \quad (3)$$

where Z_{inp} – the load at the input end;

Z_{outp} – the load at the output end;

S_{inp} – the input end area;

S_{outp} – the output end area.

The concentrators of the following three types are mostly used: stepwise, conical and exponential (Fig. 1).

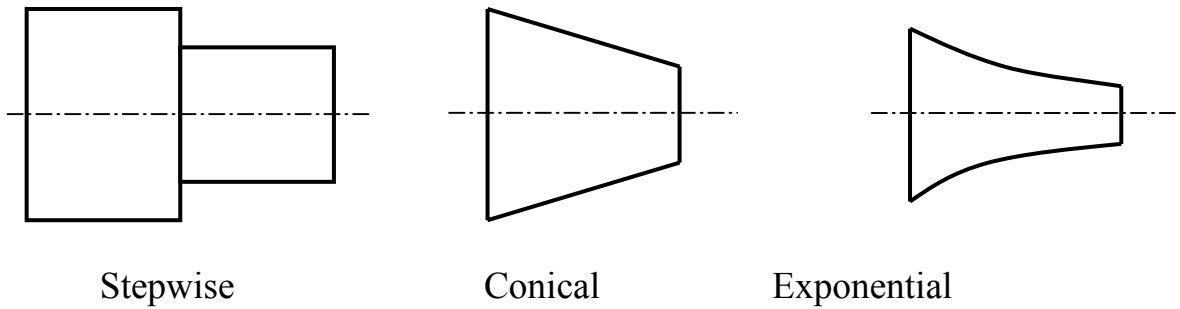


Fig. 1. Types of used concentrators.

The exponential concentrator provides minimal signal distortion and reflection but is difficult-to-make. The concentrator is fabricated from the same material as the waveguide and connected to the last one by means of welding.

In the process of studies were tested waveguides manufactured from steel wire (12X18H10T) with 3mm diameter and 10, 8, 6 & 5m length. The waveguides were made from non-tempered and tempered at 1050°C wire. Tempering was implemented to reduce signal attenuation. While one end of the waveguide was

welded to the steel plate the other one was welded to the exponential concentrator providing matching of the waveguide and sensor.

In the process of tests the AE system DiSP-8 (Physical Acoustics Corporation) was used operating in the mode of signal waveform acquisition with R15I sensors (150kHz resonant frequency, 40dB integral low noise preamplifier).

The wideband P113 (0,02 – 0,2) sensor was used as AE pulser and was excited by electric pulses from square-pulse generator of G5-54 type. Parameters of generated signals correspond to [4] and were as follows:

- Pulse rate – 10Hz;
- Generated pulses amplitude – 60V;
- Electric exciting pulse duration – 0.1us.

The test layout is shown on Fig. 2. Sensors were placed as follows: sensor #1 was mounted on the plate surface next to the point of waveguide welding to the plate; sensor #2 was fixed at the concentrator wide end and it's fixation was provided with the help of mechanical clamp. The pulser was mounted on the plate surface next to the sensor #1. To improve acoustic contact the Lithol grease was used.

During the tests the signals attenuation in waveguides was measured. Attenuation was defined upon comparison of amplitudes of signals picked up from sensors #1 and #2.

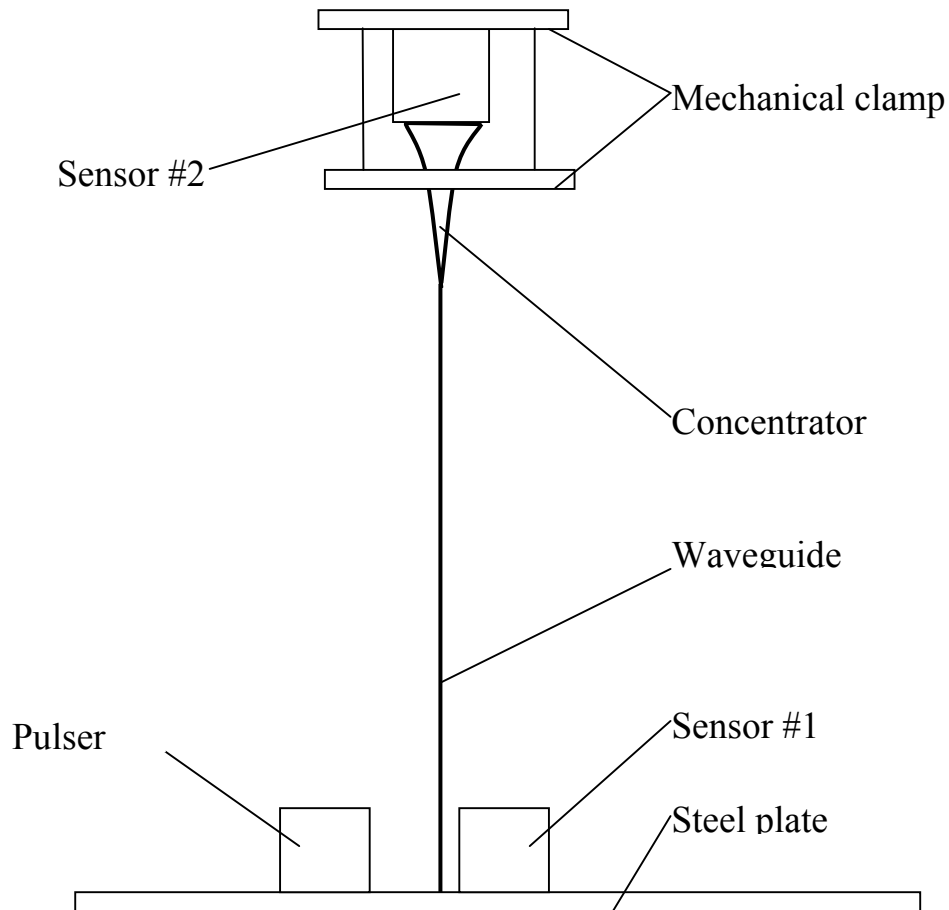
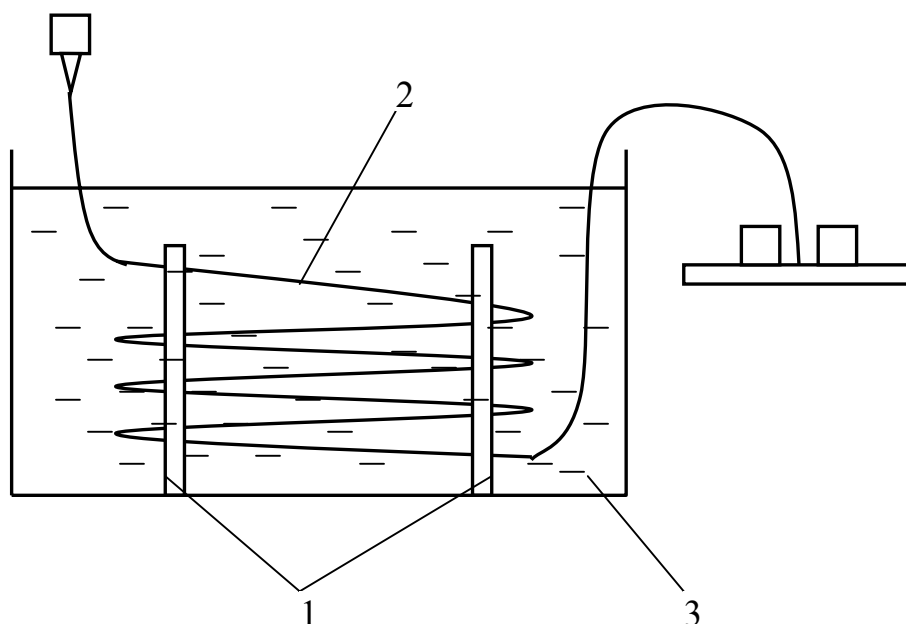


Fig. 2. Test layout with waveguide line and allocation of sensors.

All waveguide lines were tested both in normal conditions (in air) and in bath with water. Before placing in the water the waveguides were twisted as spiral with the help of textolite stands – insulators preventing contacts of spiral coils between each other (see Fig. 3).



- 1 – Insulating stands;
- 2 – Waveguide line under test;
- 3 – Bath with water.

Fig. 3. Layout of waveguide line test in water.

To imitate acoustic noise in the process of tests in water and while the square-pulse generator was switched off the Hsu-Nielsen pencil lead breaks were made at the bath wall.

The results of AE signals attenuation measurements in the process of propagation in waveguide lines of various lengths are presented on Fig. 4.

As it is seen from the graphs, the attenuation of AE signals propagating through waveguide line which is in water is bigger than when the last one is in the air. This is due to the fact that the acoustic impedance of water is higher than of air and part of signal energy goes to water.

Preliminary tempering of the waveguide line to some extent made it possible to reduce attenuation that is important in case of long waveguides.

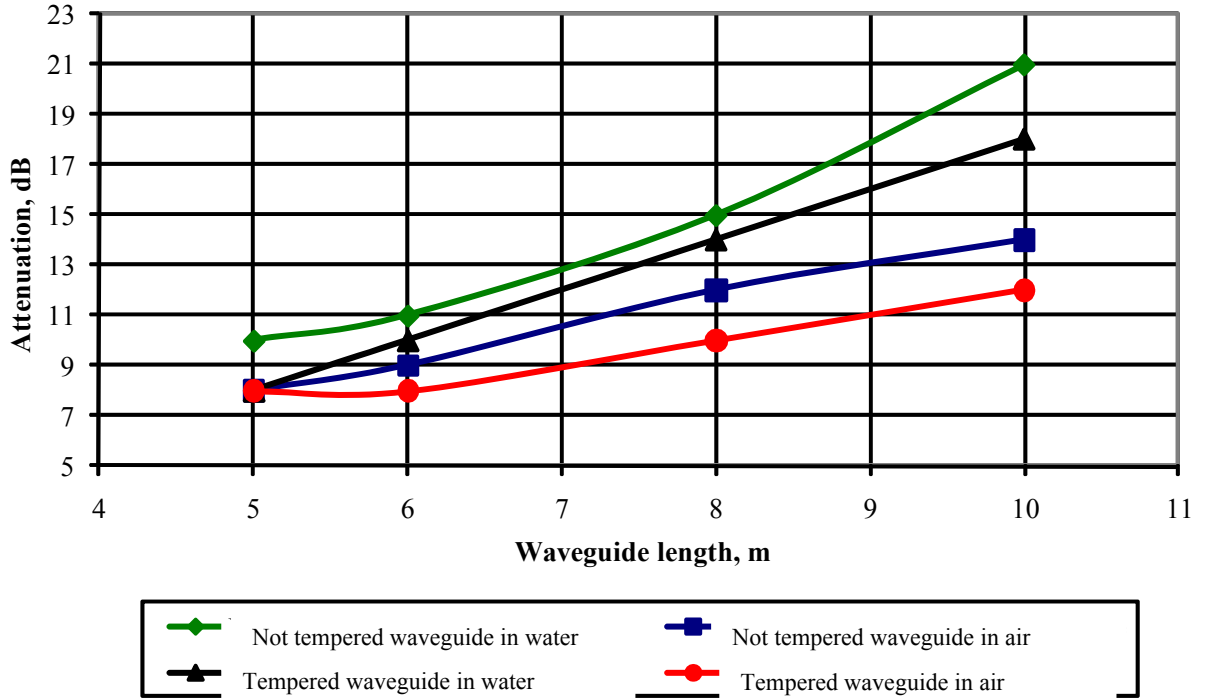


Fig. 4. AE signals amplitude attenuation dependent on the waveguide line length

When pencil lead was broken, while been pressed to the wall of bath with water, signals were registered in both acoustic channels and this verifies that acoustic noise easily pass through water into the waveguide and further on to the sensor. To avoid such influence it is required to protect the waveguide from contact with water. It can be done with the help of cover tube.

The pictures of signals waveform picked up from sensors #1 & #2 are presented below.

On Fig. 5 are presented the waveforms of signals obtained in the process of tests in water of the 10m long waveguide manufactured from non-tempered steel. The first waveform related to the signal, which passed through the waveguide (sensor #2) and the second one was picked up in the point of waveguide weld to the plate (sensor #1). As it seen from the figure the pulse passed through waveguide has flat front edge while the pulse maximum shifts to the right along time axe and this will have negative impact on the process of signal source coordinates determination.

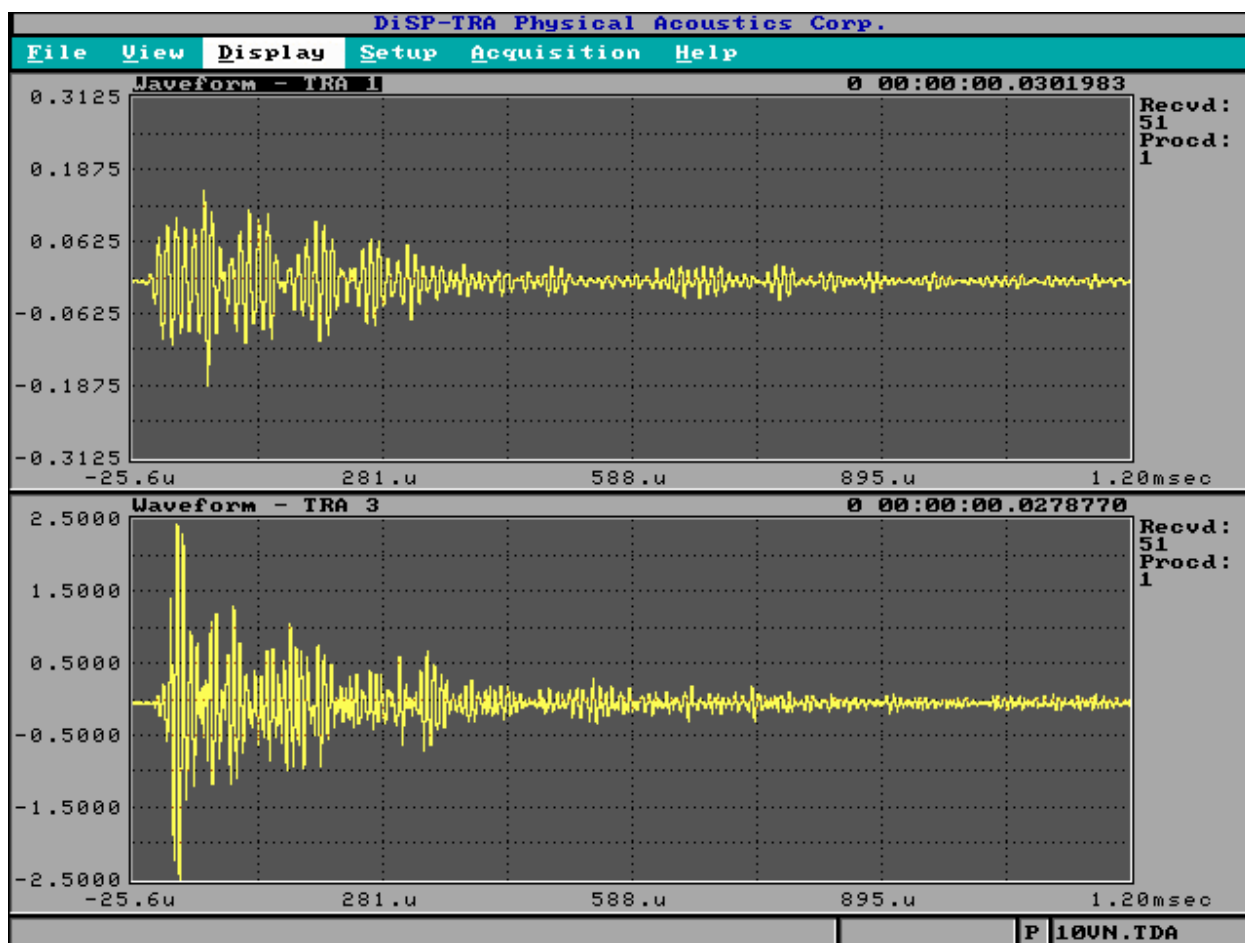


Fig. 5. The waveforms obtained in water tests of 10m non-tempered steel waveguide.

The waveforms obtained in the process of tests of the 8m long waveguides are presented on Figs. 6 & 7. The shape of pulse passed through the waveguide line also has flat front edge and its maximum as well shifts in time.

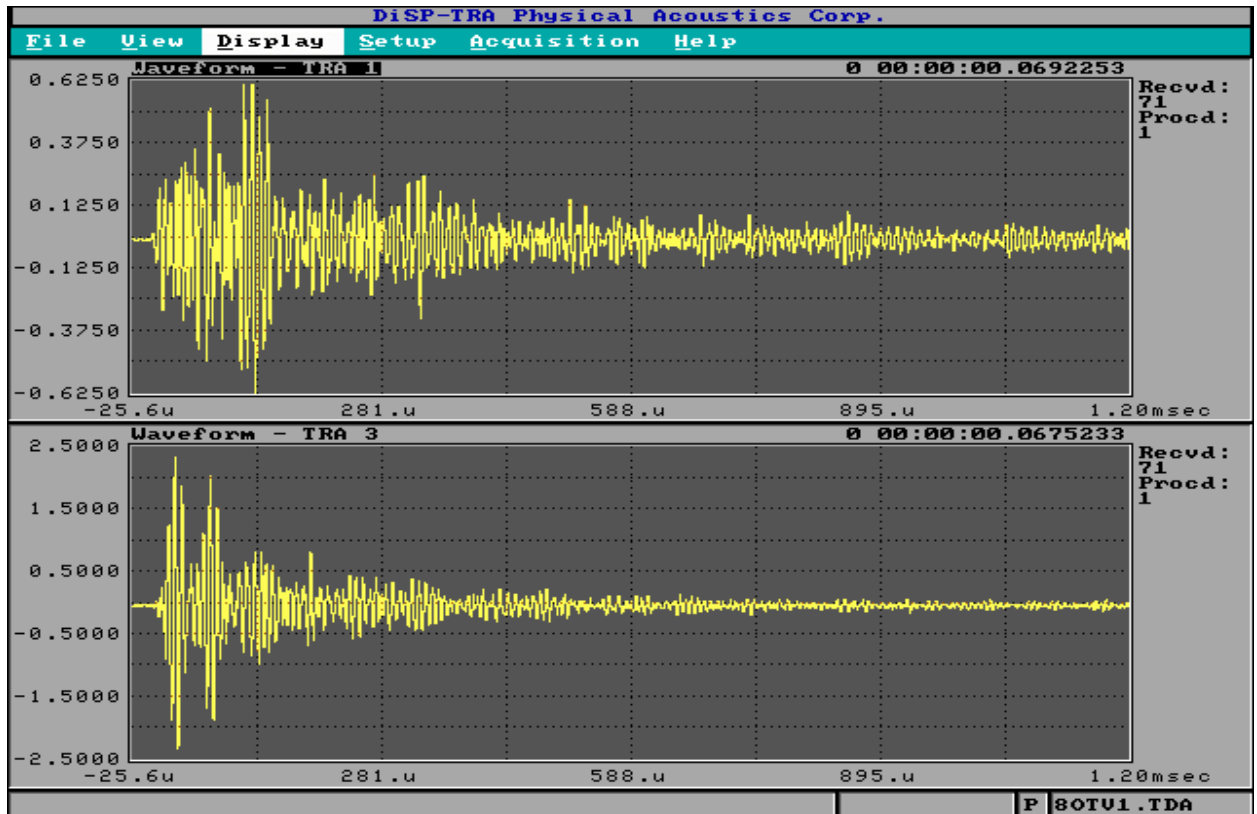


Fig. 6. The waveforms obtained in the process of tests in water of the 8m long waveguide fabricated from tempered steel.

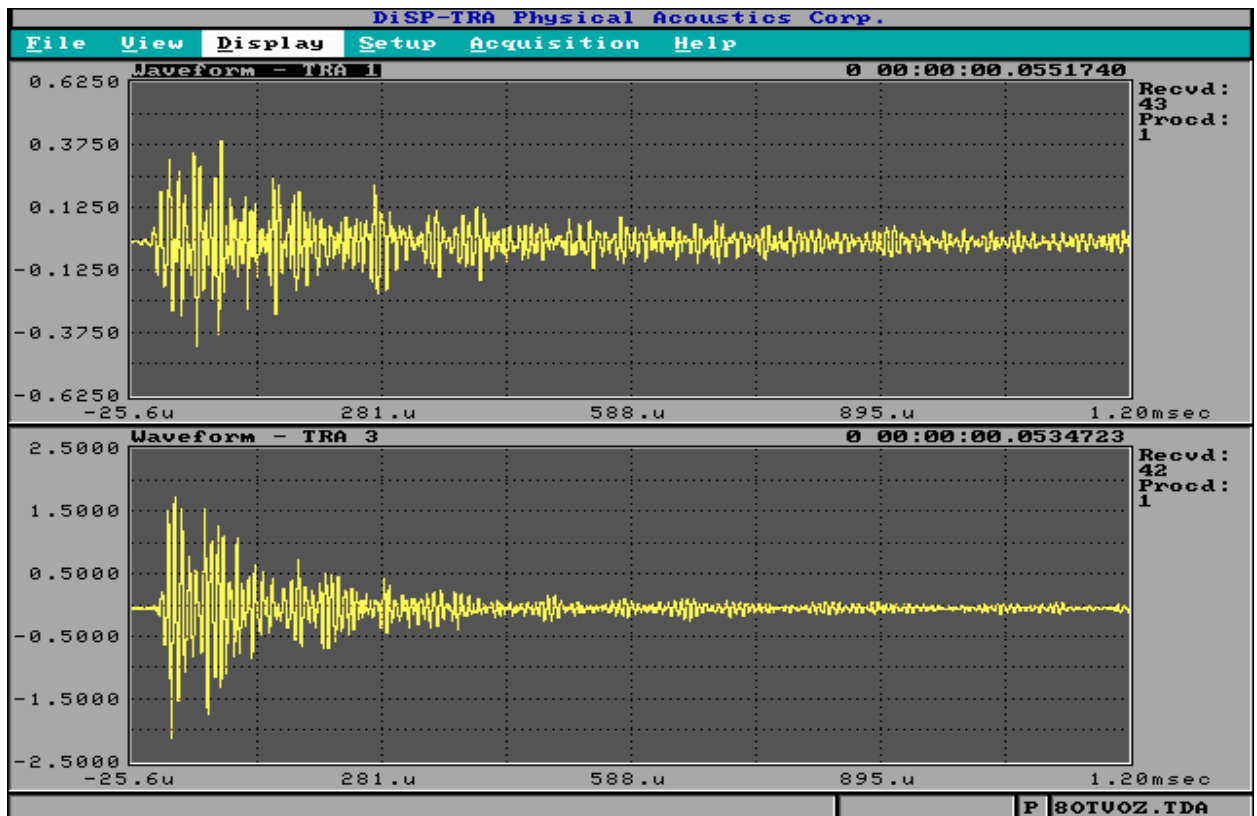


Fig. 7. The waveforms obtained in the process of tests in air of the 8m long waveguide fabricated from tempered steel.

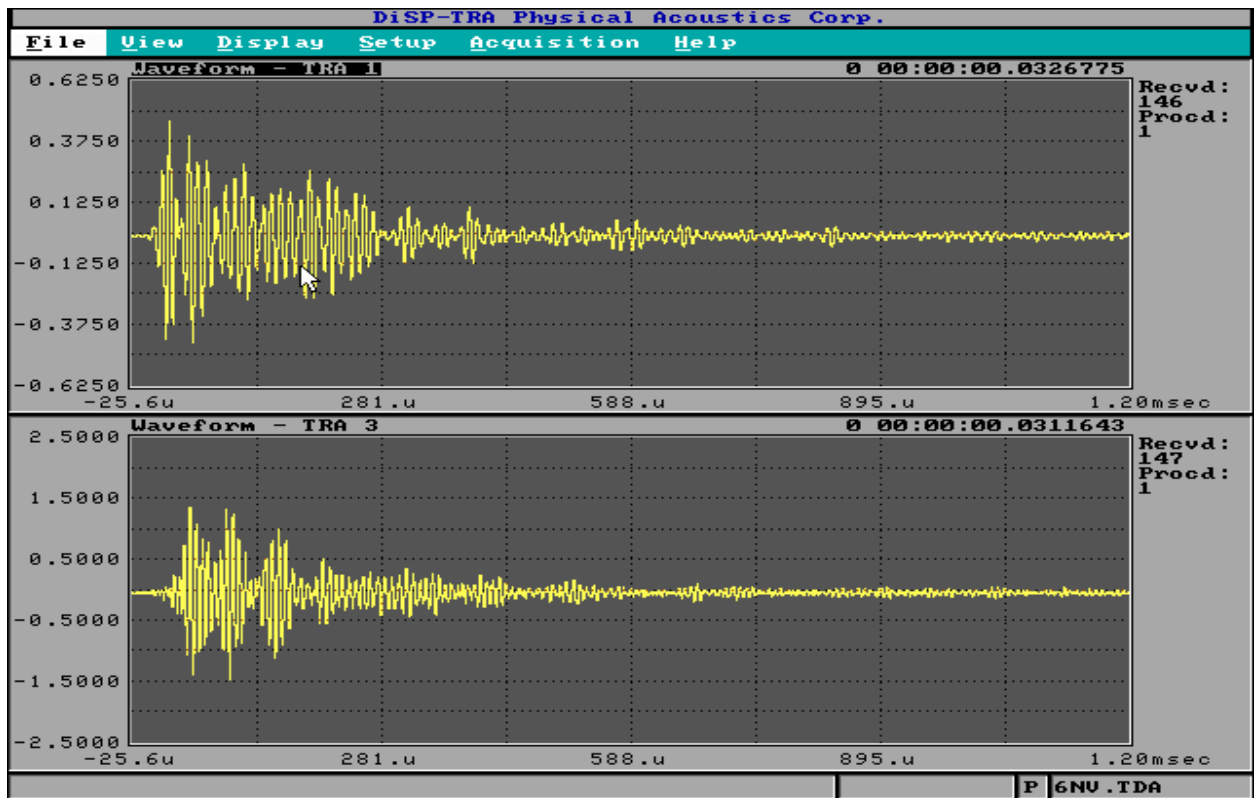


Fig. 8. The waveforms obtained in the process of tests in water of the 6m long waveguide fabricated from non-tempered steel.

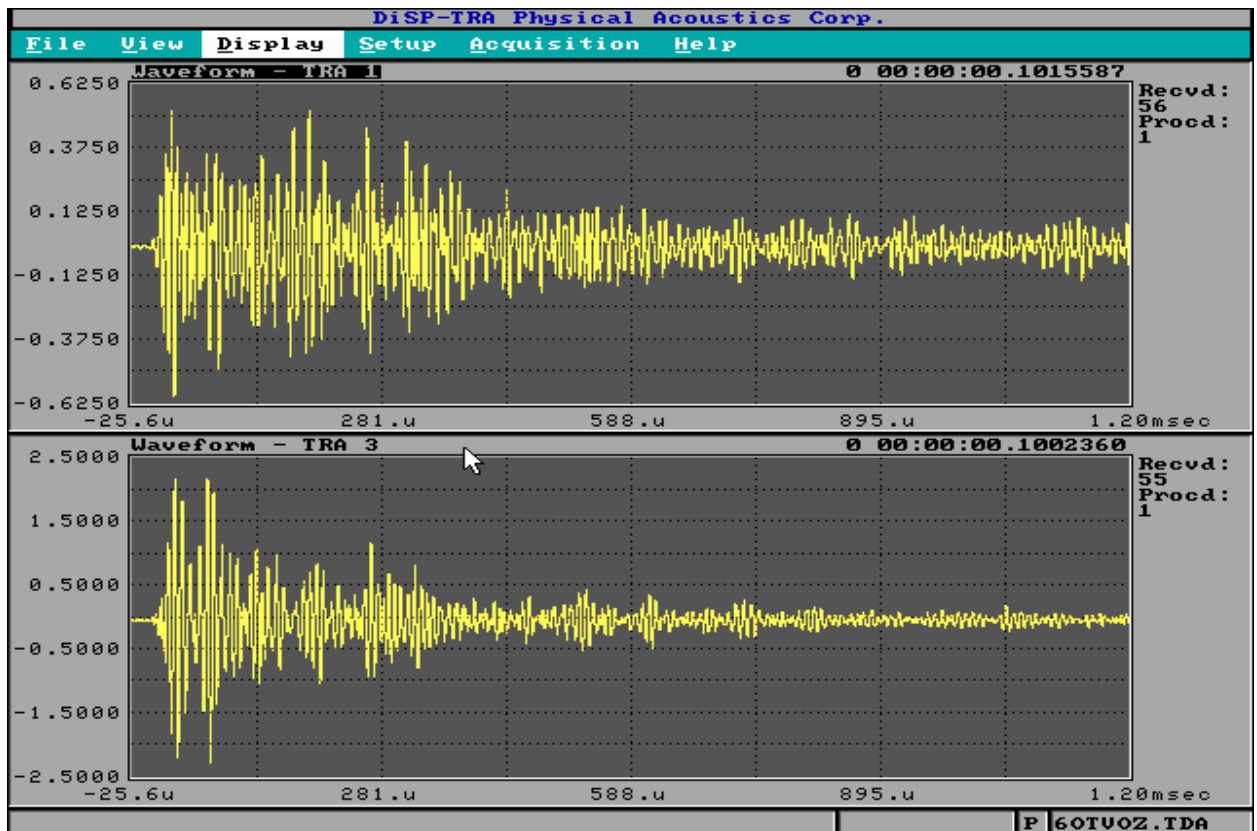


Fig. 9. The waveforms obtained in the process of tests in air of the 6m long waveguide fabricated from tempered steel.

The waveforms obtained in the process of tests of the 6m long waveguides are presented on Figs. 8 & 9 (the waveforms obtained for the 5m long waveguides are similar). In this case the difference of waveform of pulse that passed through the waveguide and one registered on the plate surface is small. If to take into account small amplitude attenuation (about 8dB) it can be said that registration of AE signals done with the help of 5-6m long waveguide lines, in principle, is not much different from the direct signal registration on the tested structure surface and does not have strong influence on the process of the AE source location accuracy.

References.

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