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INVESTIGATIONS OF THE AE SIGNAL PROPAGATION IN THE VESSELS AND TANKS IN-OPERATION.

Arkady KAMYSHEV, Igor RAZUVAEV, Eugeny SUCHKOV

Alcor Corp., 48 Lenin Str., Dzerzhinsk, 606023, Russia
Tel. +7 8313 252 610
E-mail : IRazuvaev@alcor.pro

Abstract: Researches of decay of AE signals in operated large-sized thin-walled steel vessels and tanks with integrated structural health monitoring system «Resource-2000» are executed. Researches were spent at AE monitoring a technical condition of the vessel working under pressure in volume 70 m^3 and wall thickness of 20 mm, and also the vertical tank in volume 20 000 m3 with the wall thickness changing on height from 17 mm to 10 mm. Features of distribution of the signals radiated by AE transducers were investigated, at consecutive turn of everyone transducer in a impulser mode. The decay of amplitude at path of a signal on distances from 2 up to 45 m was defined. Also, for an estimation of type of a wave rate of propagation of a signal from radiating to reception transducer was determined. Dependence of size of decay from the amplitude of the testing impulse submitted was investigated also. The estimations of decay obtained and rate of propagation of signals have allowed to optimize the transducers arrangement on objects of monitoring with the purpose of increase of the efficiency and reliability of the AE monitoring.

Keywords: AE, signal propagation, monitoring, vessels

1. Introduction

The report investigates the characteristics of acoustic emission (AE) signals attenuation in large-sized thin-walled steel structures: pressure vessels and reservoirs. The correct assessment of attenuation in the test object allows to design optimal arrangement of sensors for acoustic monitoring: on the one hand, too large number of sensors significantly increases the laboriousness of the control, on the other hand - the number of sensors must be sufficient in order to prevent missing of a developing defect.

The most pressing is the solution to this problem for such objects AE monitoring, as the reservoirs or system of vessels working under pressure. For such objects, the number of installed sensors can be quite large (from tens to several hundred) and optimization of their number allows not only significantly reduce the cost of installation and maintenance, but also significantly increase the speed of information processing system of the acoustic emission. Thus, knowledge of the characteristics of the AE signal attenuation allows to reduce essentially expenses for carrying out the AE control without reducing its quality.
A necessary condition for ensuring the quality of AE for any zone of the controlled object is the ratio of:

$$A>A_D+\delta A(l) \qquad (1)$$

where: A – amplitude of the signal from generator AE at any point of the control zone, A_D the discrimination level of at least one of the AE channels that control this area, $\delta A(l)$ is the attenuation of the AE signal at a distance (l) between the generator and the installation location of the sensor of this channel.
Knowledge $\delta A(l)$ allows, with a certain discrimination level to determine the maximum allowable size of the control zone and, accordingly, the minimum number of sensors required to ensure compliance with conditions (1) for the whole of the controlled object.

When monitoring large objects in conditions of unavoidable operational noise the main method of detecting defects is to calculate their coordinates according to registration times of the AE signals with known values of velocity. As is known, acoustic oscillations propagate in the control object of waves of different types: symmetric and asymmetric lamb waves, surface waves, etc., each of which is characterized by its range of values of group velocities. Thus, if you want to define the coordinates of the AE source, to perform the ratio (1) it is necessary to evaluate the attenuation of the desired wave type, which is used in the localization algorithm.

2. The attenuation of AE signals in the vessel

The following are the results of the evaluation of the attenuation of AE signals in a controlled pressure vessel, with a volume of 20 m3 (wall thickness 22 mm) and a reservoir with a volume of 15,000 m3 (side wall thickness 17 mm). The calculation of the coordinates is performed in the mode of planar location, with the size of the antenna transducers: of the vessel ~ 2 m and of the reservoir is ~ 5.5 m.

Control is performed by complexes of AE monitoring Resurs-2000, manufactured by JSC NPO Alkor, using transducers with a bandwidth of 30-300 kHz. A feature of this AE system is the ability to transfer the sensors in the radiation mode, i.e., each sensor mounted on the object may become a generator of AE signals. When working in a radiation mode to the sensor-generator was applied stimulating impulses with amplitude of 100 V and duration of 1 µs.

The attenuation was assessed by changes in amplitude during the propagation in the object control signals emitted by the sensors when operating in the generator mode. The measurements were carried out as in filling these objects with a liquid hydrofluoric acid in the vessel and liquefied propane in the reservoir) and no fill. The speed of sound was estimated by the ratio of propagation time between sensors (AE signal generator and receiver) to the distance between them. If the value of the sound speed below 2000 m/s (speed in a liquid medium) that it would be modified by substitution to calculate the shortest distances between the sensors in a straight line, not along the curved surface of the wall.

For vessel, as can be seen from figure 1, the speed of sound does not depend on the distance between the signal generator and receiver AE or the filling of the vessel and is of the order of 5000 m/s. This means that the recorded signal is transferred by a symmetric lamb wave.

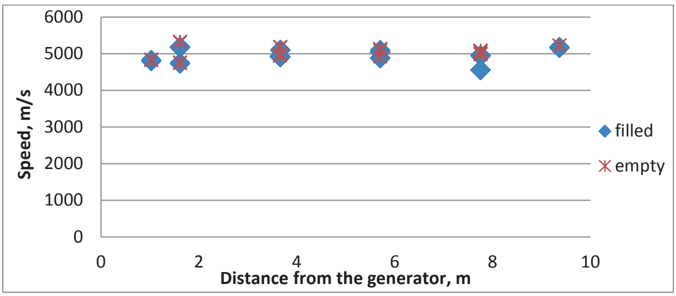


Figure 1. Speed of AE signal during its propagation in the vessel in the absence and in the presence of liquid fill.

Figure 2 shows the dependence of the amplitude of the signals received from the distance between the generator and receiver sensors for both an empty and filled vessel. The results show that the nature of the damping on the vessel there are two zones: the near field (up to ~5.5 m) and far field. Their features:

- in the near-field attenuation is not constant and decreases with increasing distance;
- in the far field attenuation is much less, there is even increase in the amplitude of the received signal compared to the sensors located closer to the generator.

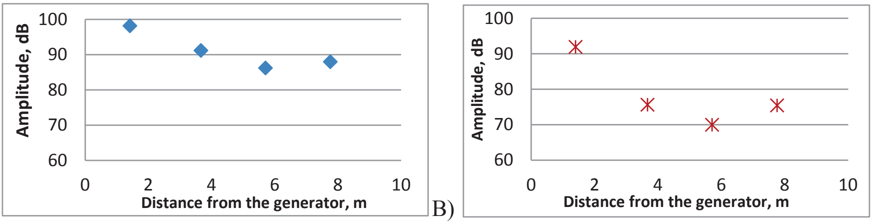
A) B)


Figure 2. The change in the amplitude of the AE signal during its propagation in the vessel in the absence (A) and (B) filled with liquid.

As seen from the above results, the feature dependence of attenuation on distance, as well as the speed of sound does not depend on the filling of the vessel: there are near and far area. At the same time, attenuation in the near field on the unfilled vessel is approximately two times lower than in the filled.
The change in the amplitude in the near field (up to 6 m) can be approximated by a polynomial of second degree (the attenuation linearly decreases with distance). This approximation gives a more conservative estimate of attenuation within an acoustic emission array, than the linear approximation. The results of measuring the attenuation of the obtained dependence of the amplitude change (ΔA, dB) on distance (L, m) in the near zone:

$$\Delta A = 0,4L2 - 5L \text{ - for an empty vessel;}$$

$$\Delta A = 1,1L2 - 14L \text{ – for a filled vessel.}$$

The value of the attenuation in the far field could not be assessed because there is the effect of increasing the amplitude of the signal. The observed "lack" of attenuation in the far zone can be explained by the combined effect of the following factors:

- formation at distances much larger than the diameter of the vessel (more than 3 diameters), flat wave front, propagating without elastic scattering;
- dispersion of lamb waves, resulting in large distances to the imposition of modes propagating with different speeds.

3. The attenuation of AE signals in the side wall of reservoir

For the reservoir having a considerably large size, the dependence of velocity of propagation of test signals from the distance in the filled and empty state differs significantly. As shown in figure 3, the speed of sound in the side wall of filled reservoir corresponds to symmetric lamb wave only on the distance from the generator not more than 10 m. This means that at large distances the amplitude of the lamb waves is reduced below the level of discrimination. Sensors, remote at a distance of 10 m receive signals propagating with velocities of the order of 1500 m/s and below. This means that they only accept signals propagating in a liquid medium.

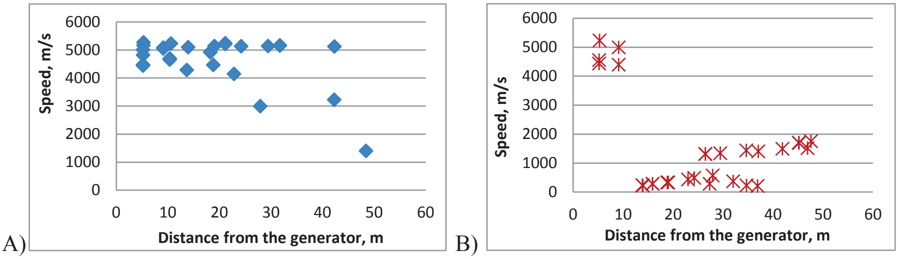


Figure 3. Speed of AE signal during its propagation in the side wall of reservoir in the absence (A) and (B) filled with liquid.

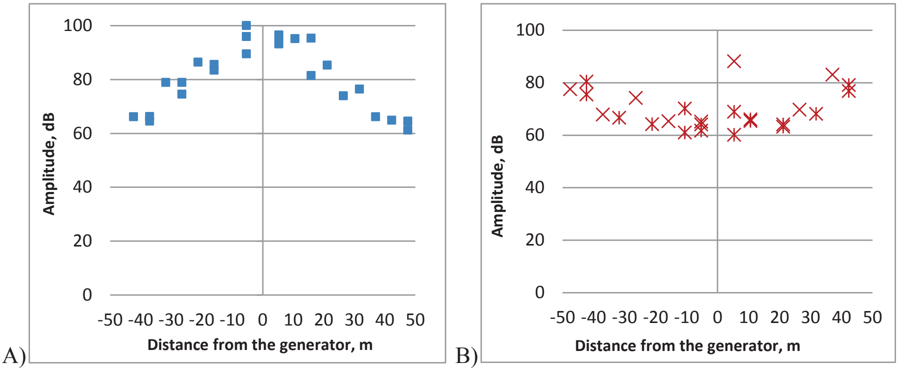


Figure 4. The change in the amplitude of the AE signal AE signal during its propagation in the side wall of reservoir in the absence (A) and (B) filled with liquid.

It should be noted that the values of the amplitudes of the impulses taken by the sensors on the reservoir, located at a distance of ~5.5 m correspond to the values of the amplitudes taken at the vessel, at the same distance from the emitter: 87 and 70 dB for filled and unfilled objects, respectively. From this we can conclude that on the reservoir also features near field attenuation of signals, and the distance between the closest sensors in the reservoir corresponds exactly to its border. Thus, there is reason to believe that the presence of the near and far zones of attenuation is not due to the peculiarities of the geometry (which of the vessel and the reservoir is significantly different), but the uneven attenuation of high - and low-frequency harmonic components of the signal.

As shown in figure 4(A), in the side wall of empty reservoir at distances up to 40 m from the transducer (where, judging by the magnitudes of the velocities are taken mostly symmetrical lamb waves – see figure 3(A)) the amplitude depends linearly on the distance. Thus, in the far field attenuation of the lamb waves is constant and equals ~ 1,3 dB/m.
For the side wall of filled the reservoir the dependence of the amplitude on the distance from the emitter has a paradoxical character: with increasing distance the amplitude is increased, see figure 4(B). However, this "paradox" is easily explained by the fact that at a distance of about 10 m (figure 3(B)) the amplitude of the lamb waves due to high attenuation in the near zone (see figure 2B) is reduced below the discrimination level (~40 dB) and recorded only signals coming in the liquid. The distribution of signals in a liquid has its own features: in particular, due to narrow the directivity pattern of the sensors, the signal with the greatest amplitude have been the

most remote sensors, located on the opposite wall from the generator (the speed of sound is ~ 1500 m/s – see figure 3(A)), the other sensors located closer to the generator, taking only multipath signals of smaller amplitude. Shown in figure 3B, the values of sound velocities for them are low (less than 1000 m/s), since the actual propagation path multipath signals are unknown.

4. The influence of the amplitude of the excitation impulse

It should also be noted that the magnitude and nature of the attenuation does not depend on the amplitude of the excitation impulse generator. As can be seen from figure 5, the decrease in the amplitude in the range from 100 to 25V does not change the nature and magnitude of attenuation: it remains constant and its value corresponds to the value characteristic of the far zone (~1,3 dB/m in an empty reservoir and ~2.5 dB/m (filled). It should be noted that the signals from the generator when the amplitude of the excitation impulse 25V in a filled reservoir is practically not registered at a distance of more than 5 m, so to reduce the amplitude of this magnitude is not recommended.

A) B)

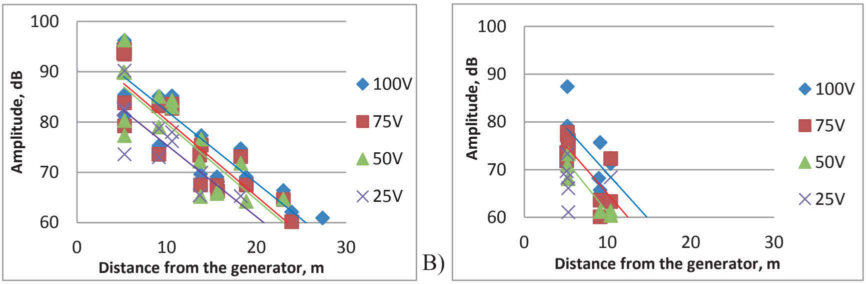


Figure 5. The amplitude of the signal from a distance in the side wall of reservoir while reducing the amplitude of the excitation impulse in the absence (A) and (B) filled with liquid.

5. Practical recommendations

The analysis of the attenuation allows to develop practical recommendations on the optimal distances between sensors for pressure vessels and reservoirs. As the limit of distance you can receive that, which the amplitude of the signal from the generator is reduced to a value of 50 dB (in accordance with [1] for vessels and reservoirs from carbon steel criterion for the presence of developing defects is the occurrence of amplitude above 55 dB). These distances correspond to the maximum allowable size of acoustic emission arrays. These recommendations relate to is made of carbon steel thin-walled vessels controlled in the range of 30-300 kHz.

In accordance with the obtained results:

- for objects filled with a gaseous medium, it is possible to mount sensors at a distance of 20 m, this provides confidence in a lamb waves with an amplitude greater than 60 dB;
- for objects filled with liquid, the distance between the sensors should not exceed 5.5 m, otherwise the effective positioning of the sources is impossible due to the high attenuation of lamb waves and registration of the AE impulses with different velocities and uncertain pathways;
- for this distances between sensors the amplitude of the excitation impulse should be not less than 50V.

6. Conclusion

1. Investigated the attenuation of AE signals during their propagation in large, thin-walled steel structures: vessels and reservoirs using sensors as generators of AE signals.
2. It is shown that regardless of the medium filling (liquid or gaseous) qualitative regularities of changes in the amplitudes of the signals are the same: there are near and far zones. In each of which the character of change of attenuation are the same, but in the near zone, its value is much higher. Filling the liquid medium leads to an increase in attenuation in the near-and far-field.
3. When determining the coordinates of AE sources must be considered that due to attenuation (especially when filling the liquid medium) more remote sensors may receive signals from waves propagating in a liquid medium with lower speed. This can lead to significant errors in determining the coordinates of the sources. To evaluate the performance of attenuation and velocity of wave propagation it is recommended to use the generators of the AE signals.
4. Determined maximum allowable size of the acoustic emission sensors arrays for objects filled with liquid and gaseous medium.
5. For this distances between sensors the amplitude of the excitation impulse should be not less than 50V.

7. References

1. ASME "Acoustic Emission Examination of Metallic Vessels During Pressure Testing" Article 12, Subsection A, Section V, Boiler and Pressure Vessel Code (December 1988 Addendum and later editions).