VPS VIBRATIONS IN PHYSICAL SYSTEMS
DOI: 10.21008/j.0860-6897.2024.1.13
Vibrations in Physical Systems, 2024, 35(1), 2024113

Experimental tests of selected damping and sound-absorbing materials to determine their suitability for sound attenuation of hydroacoustic measuring tank

Aleksander M. SCHMIDT, **Lech KILIAN**, **Jacek MARSZAL**

Gdańsk University of Technology Faculty of Electronics, Telecommunications and Informatics, Department of Sonar Systems, ul. Narutowicza 11/12, 80-233, Gdańsk, Poland

Corresponding author: Aleksander M. SCHMIDT, e-mail: aleksander.schmidt@pg.edu.pl

Abstract The article contains a description and results of the measurements necessary to select the optimal material for damping two hydroacoustic measuring tanks according to simple suitability criteria, i.e. obtaining minimal sound reflections from the water surface, walls and bottom in these pools by covering the surfaces with sound-dispersing materials or acoustic absorbers. One will be larger (15x10x10 m) for measurements in the range of possibly low ultrasound frequencies and the other smaller (4x3x3 m). The frequency characteristics of these materials, but also the price, ease of assembly and cleaning, and ageing, are decisive for their usefulness. Attractive (according to these criteria) patches of 'synthetic grass' and plates made of various plastics were selected for the measurements. The obtained results were compared with the measurement results of the long-used curtains made of dissipative brushes for dampening the measuring tank of the Department of Sonar Systems (DSS) and with those presented by a specialized manufacturer of commercial absorption plates.

Keywords: hydroacoustic measuring tank, damping and sound-absorbing materials, frequency characteristics of material properties.

1. Introduction

Several scientific institutions from the Gdańsk community are participating in the implementation of the grant from the Ministry of Education and Science 'Concept of building metrological infrastructure in the area of underwater acoustics at the Central Office of Measures'. In practice, the concept includes designing two measuring tanks: one large (around 1500 m^3 in volume) for measurements in the range of possibly low ultrasound frequencies (from several dozen kHz) and one smaller (around 36 m^3, for measurements from the order of several hundred kHz).

There are many measuring tanks and pools, exploited both by producers of hydroacoustic and ultrasound systems as well as scientific institutions and measuring laboratories. There is even a European standard in this matter, referring more to high-frequency ultrasonography, but universal in the fundamental problems [1].

The methodology for conducting measurements in tanks has been developed and used for a long time (e.g. [2, 3]). The basis here is to minimise the possibility of interference of significant, measured signals with interfering signals such as parasitic reflections from the walls, bottom and surface of the water in the measuring tank. Since in practice it is not possible to completely eliminate these reflections, it remains to use impulse methods of measuring signals transmitted or reflected from the target on a direct path – before the appearance of parasitic echoes. As is known, these methods impose limitations on the length of measurement pulses in water (i.e. their allowed duration) and thus on the minimum frequency of the envelope-filling signal, because the pulse should contain at least a dozen or so wave periods. The possibility of conducting measurements in the near field should also be eliminated due to the rapid variability (and thus spatial instability) of the value of the measured sound pressure in this field. It must be taken into account that the near field may arise not only in front of a radiating surface, but also in front of a reflecting obstacle.

In this way, numerous but quite simple relationships were created between the size of the tank and the parameters used to measure the signals, especially at their lowest frequencies. These dependencies displace measurements of systems with operating frequencies below several dozen kHz from closed reservoirs to open waters or force the use of a different measurement technique with the use of special, damped acoustic systems. It therefore seems reasonable that parasitic echo suppression in a typical measuring tank could be neglected in such circumstances. Unfortunately, this is a false hope, because without damping you can expect unstable multiple reflections, lasting a long time and sometimes creating an frustrating background for measurements. Therefore, in the design and operation of tanks, care should be taken to suppress background interference, although without hope of achieving complete success.

2. Selection of materials

The selection of materials that provide suppression of parasitic echoes should be made on the basis of their acoustic properties, but also other practical features, such as ease of assembly and disassembly on the covered surfaces of the tank, convenience in keeping it clean, resistance to ageing when immersed in water and price, which is especially important for large tanks.

In terms of acoustic properties, two types of materials can be considered. The first type are materials with a structure that effectively dissipates the energy of sound waves in the desired frequency ranges. The second type are acoustic absorbers operating on the principle of a so-called. ρc rubber, invented to protect submarines from sonar. This rubber has an acoustic resistance very close to that of water, so it does not create the impedance barrier necessary to reflect sounding signals. They willingly penetrate inside the coating and are immediately suppressed here, because this special rubber's internal structure is very lossy. It is obvious that it is best to first disperse the wave and then absorb it, that is, to use both types of materials together. However, the costs and construction and operational difficulties (especially the weight of the curtain) of such a solution may decide to use only one type of material. This may be indicated by satisfactory measurement results of the appropriate acoustic properties, especially in the above-mentioned conditions, without the need to completely destroy the parasitic field.

Therefore, designing the damping of the new measurement tanks does not require any special discoveries at present, but rather a review of the currently available materials, not necessarily strictly acoustic ones, and checking them in terms of the aforementioned acoustic and utility criteria.

A 'historical' example of the effects of such a procedure is the nearly forty-year-old, but still in good condition, tank of the Department of Sonar Systems of the Gdańsk University of Technology (GUT) [4]. It was dampened with curtains painstakingly made in a craftsman's workshop from plastic brushes sewn with copper wire on vinidur plates. Today, there are almost no such workshops, but there is a previously unavailable wide range of other materials, potentially very attractive for the purpose in question.

Figure 1. Damping curtains with plastic brushes in the tank of the Department of Sonar Systems GUT.

Therefore, the following materials were prepared for the measurements:

- dissipative – patches of synthetic grass with dimensions of 2 x 2 m and blades of various lengths: 27, 35 and 60 mm; additionally – for comparison – 2 sheets of 47 mm were used, but with different weight (density): 2.3 and 2.6 kg/m²;
- damping – 5 plates made of various plastics with dimensions of 1.4 x 2 m and a thickness of 2 cm: PU (polyurethane), NBR (acrylonitrile butadiene rubber), SBR (styrene butadiene rubber), EPDM (ethylene-propylene-diene rubber), CR (chloroprene rubber);
- brush fittings from the DSS pool (80 mm PVC bristles on 10 mm vinidur boards) – although tested many times, this time they were used to perform measurements in the same conditions as the measurements of the 'new' materials, which provided a reliable comparison of the results.

3. Infrastructure of the measuring station

Due to the external instrumentation enabling easy mounting, movement or replacement of samples for measurements, a rather large towing tank was selected in the building of the Faculty of Ocean Engineering and Ship Technology GUT [5], with internal dimensions of 40 x 4 x 3 (depth) m.

Although the basin is not dampened, it is large enough that for the applied method of impulse measurements and in the expected lower frequency range of suitability of the tested material samples, it can be treated as a quasi-free field – with the possibility of eliminating parasitic reflections of waves interfering with the measurements.

The following typical set of apparatus was used for the measurements:

- KSEM SN2014-03 transmitting transducer driven by a B&K 2713 power amplifier controlled by a TEKTRONIX AFG 3011 function generator;
- RESON TC 4014-5 hydrophone with preamplifier;
- KEYSIGHT DSO-X 4034A oscilloscope to control the amplitudes and shapes of the transmitted and received signals.

Another very important task of the oscilloscope was to enable a constant view of the geometric distribution of the transmitted, received and echo pulses in the measuring space for control and possible elimination of parasitic wave interference during measurements.

During the measurements, the VALEPORT miniSVP meter was used to control the distribution of sound velocity and the distribution of water temperature as a function of the water depth in the pool. The recorded differences did not exceed 0.3 m/s (at the level of 1477 m/s, i.e. approx. 0.2 ‰) and 0.1°C (at the level of 18.3°C, i.e. approx. 0.5 ‰), so their possible impact was neglected.

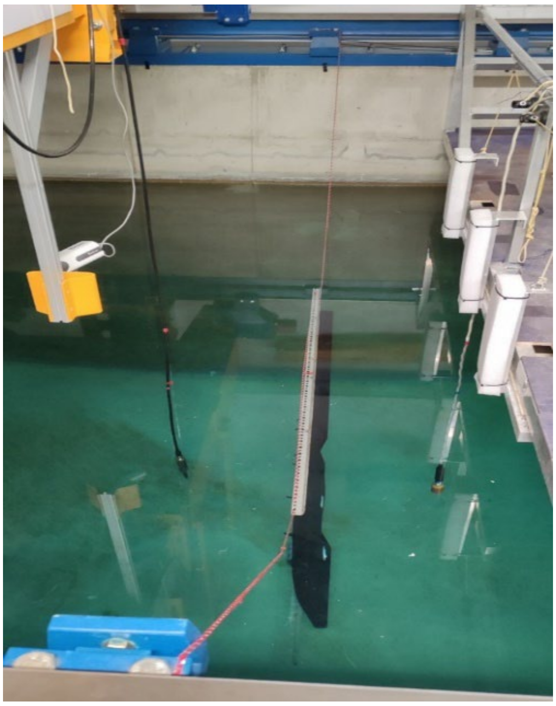

Figure 2. Infrastructure of the measuring station. Optical reflections of elements above the surface can be seen in the water.

4. Measured parameters

The measurements consisted in transmitting transducer sequences of pulses with a changed fill frequency and constant amplitude (controlled on an oscilloscope) into the water. Different amplitudes of signals (at different frequencies) received by the hydrophone were recorded. This was done in three spatial configurations of the transmitting transducer, hydrophone and the tested material shown in Figure 3.

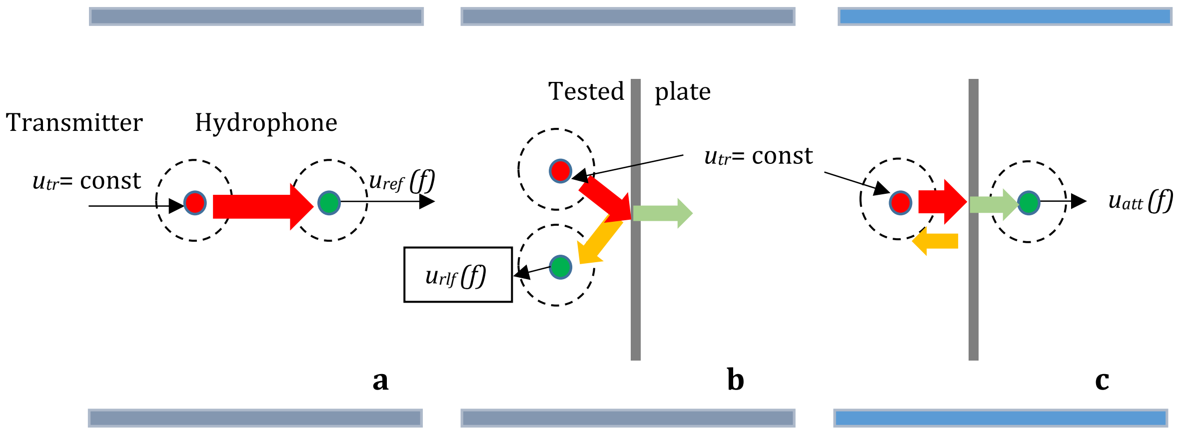

Figure 3. Configuration of the relative position of the transmitting transducer, measuring hydrophone and the tested material in the tank (top view): **a** – signal level without obstacles, **b** – signal reflection, **c** – signal attenuation. u_{tr} – voltage of pulses from the power amplifier (const – with adjustable amplitude for frequency changes), u_{ref} (*f*) – voltage of reference pulses on the hydrophone as a function of frequency, u_{rlf} (*f*) – voltage of echo signals from material samples, u_{att}(*f*) – voltage of signals attenuated in tested samples. Immersion depth of the transmitting transducer and measuring hydrophone: 1.5 m.

Measurements in configuration **a** provided reference levels of signals from the hydrophone at individual frequencies (taking into account the efficiency characteristics of the transmitting transducer and the hydrophone voltage response). They were used in the calculations of the following frequency characteristics [6]:

- echo reduction: $ER\,(f)\ [\text{dB}] = -20\log\left(\frac{u_{rlf}\,(f)}{u_{ref}\,(f)}\right)$, (1)
- insertion loss: $IL\,(f)\ [dB] = -20\log\left(\frac{u_{att}\,(f)}{u_{ref}\,(f)}\right)$, (2)
- fractional power dissipation FPD: $FPD\,(f) = 1 - \left(\frac{u_{rlf}\,(f)}{u_{ref}\,(f)}\right)^2 - \left(\frac{u_{att}\,(f)}{u_{ref}\,(f)}\right)^2$, (3)

where *u* are the voltages on the oscilloscope and the indices mean: *rlf* – reflected signals, *att* – signals after passing through the material, *ref* – references (on the direct path transmitter – hydrophone).

The physical meanings of the above parameters are contained in their names. Echo reduction ER means the weakening of the echo level after reflection from a sample of material in relation to the full, specular reflection from a smooth wall, i.e. the better the material, the higher the number of decibels at a given frequency. Similarly, the IL insertion loss parameter means the attenuation (suppression) of the signal level after passing through the tested sample in relation to direct transmission, without an obstacle. Again, the better the material, the higher the number of decibels at a given frequency. The fractional power dissipation parameter FPD combines both effects. It can be given as a fraction or percentage. With a complete lack of reflection and complete absorption of the wave after passing through the sample, FPD = 100 % (ideal material), i.e. the higher the percentage, the better the material.

5. Measurement results

The parameters of all materials listed above in Sect. 2 were measured and recorded. For the sake of clarity of this presentation, however, the best samples were selected from among them and the measurement results of only these materials are presented in the charts below.

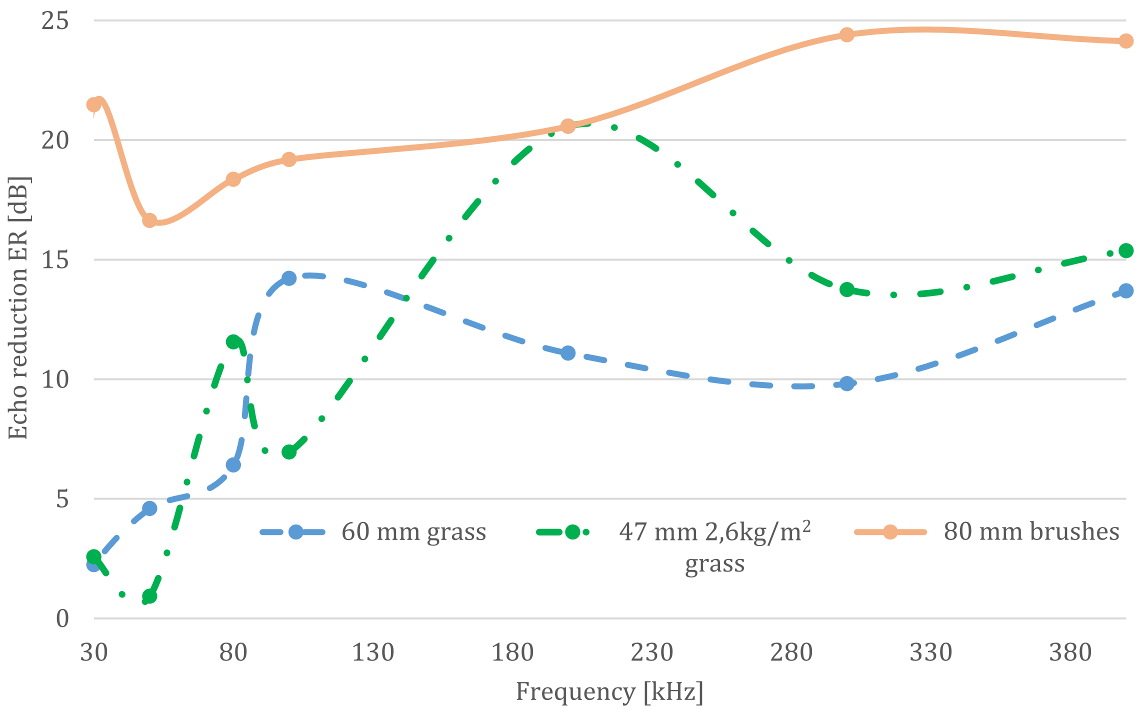

Figure 4. Echo reduction – according to Eq. (1) – for synthetic grasses with the longest blades compared to brushes from the DSS tank.

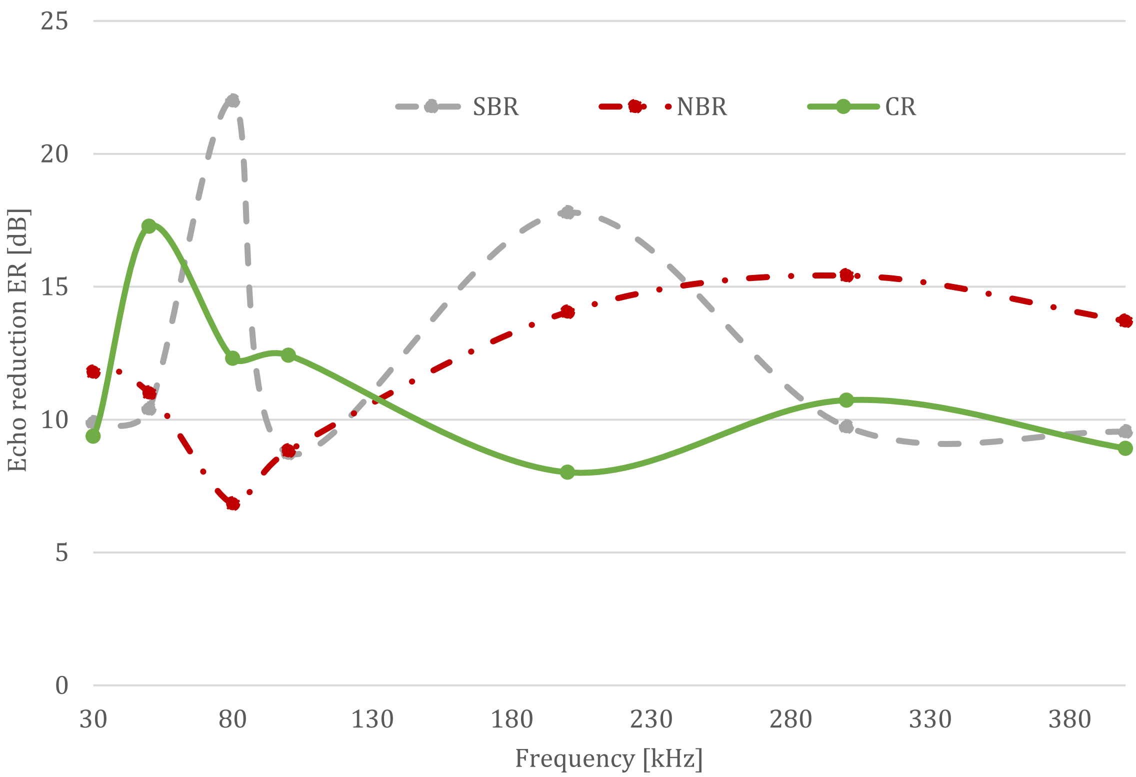

Figure 5. Echo reduction – according to Eq. (1) – for the least reflective plastic plates.

The presented ER(f) graphs indicate a clear advantage of the brush curtain over grass curtains and plates. Plates show higher attenuation than grass for lower frequencies (around 50 kHz) which is important.

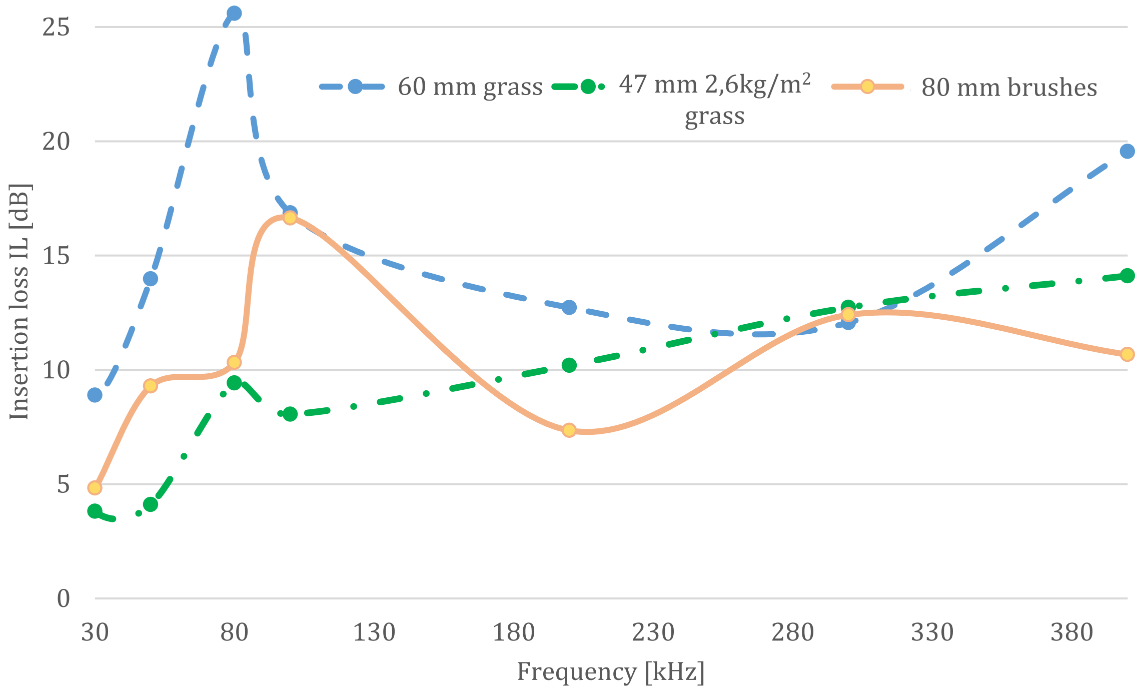

Figure 6. Insertion loss IL – according to Eq. (2) – for synthetic grasses with the longest blades compared to brushes from the DSS tank.

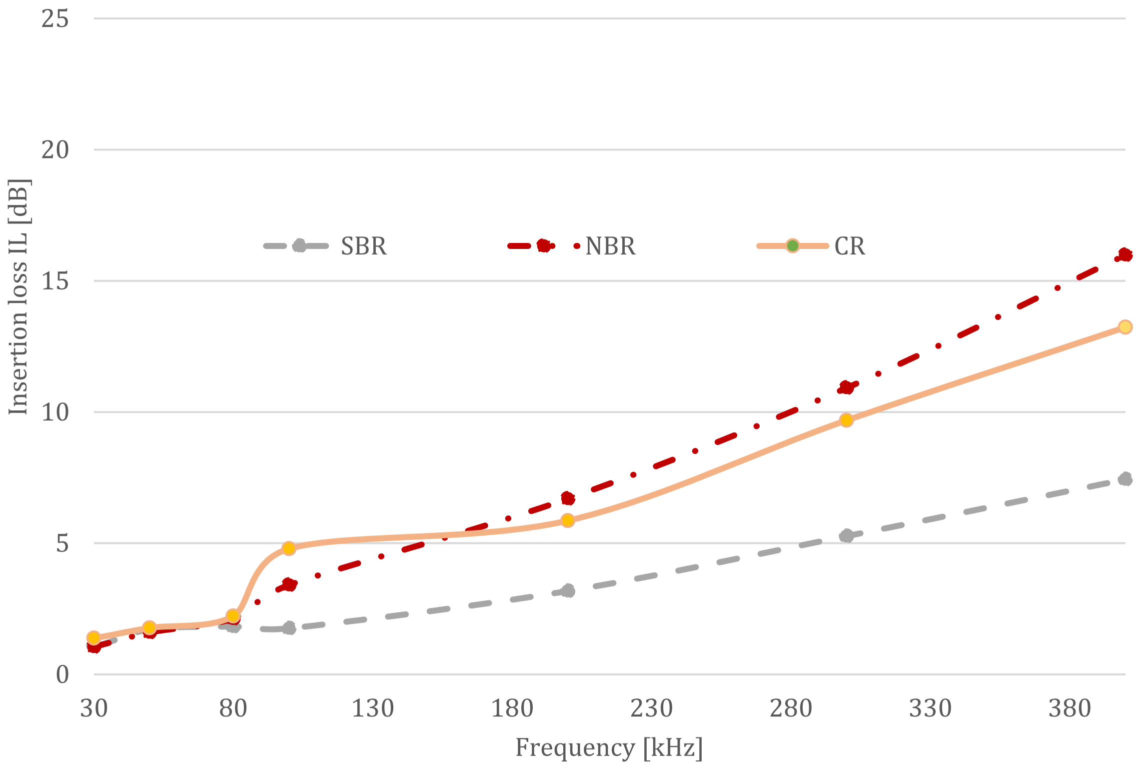

Figure 7. Insertion loss IL – according to Eq. (2) – for the least reflective plastic plates.

IL losses - attenuation of waves inside the structures of the samples are clearly lower in the plates, probably due to the elasticity of their materials.

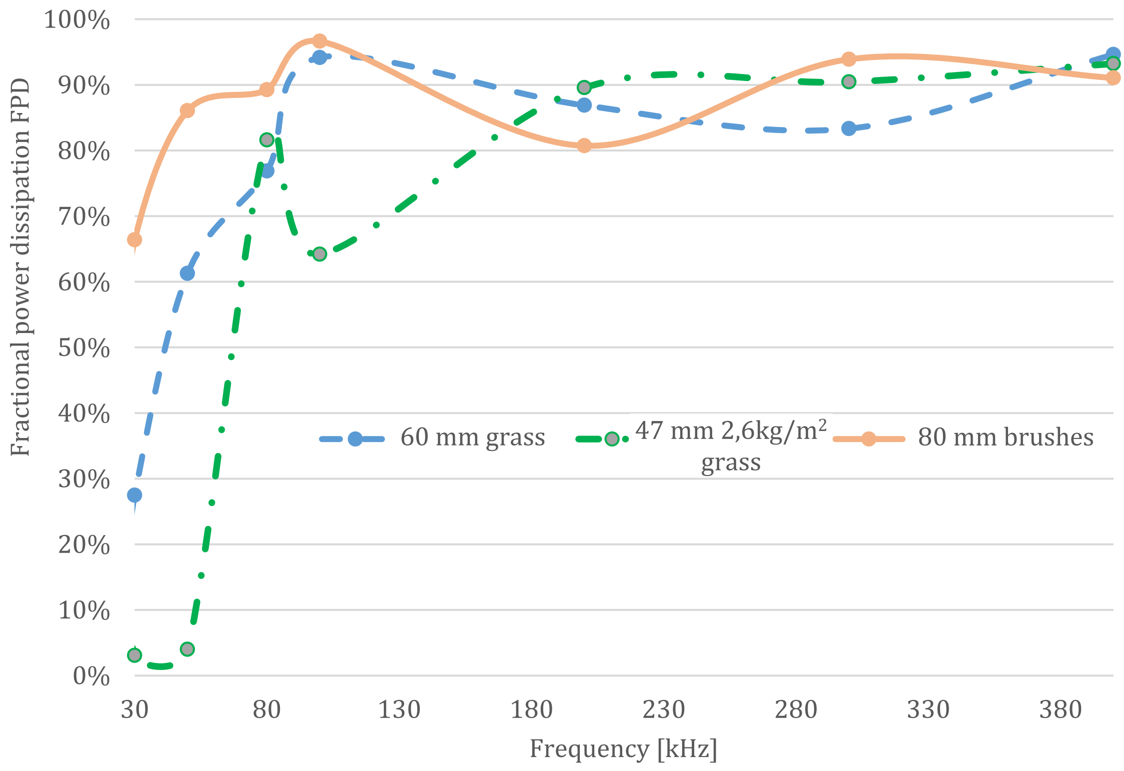

Figure 8. Fractional power dissipation FPD – according to Eq. (3) – for artificial grasses with the longest blades compared to DSS brushes

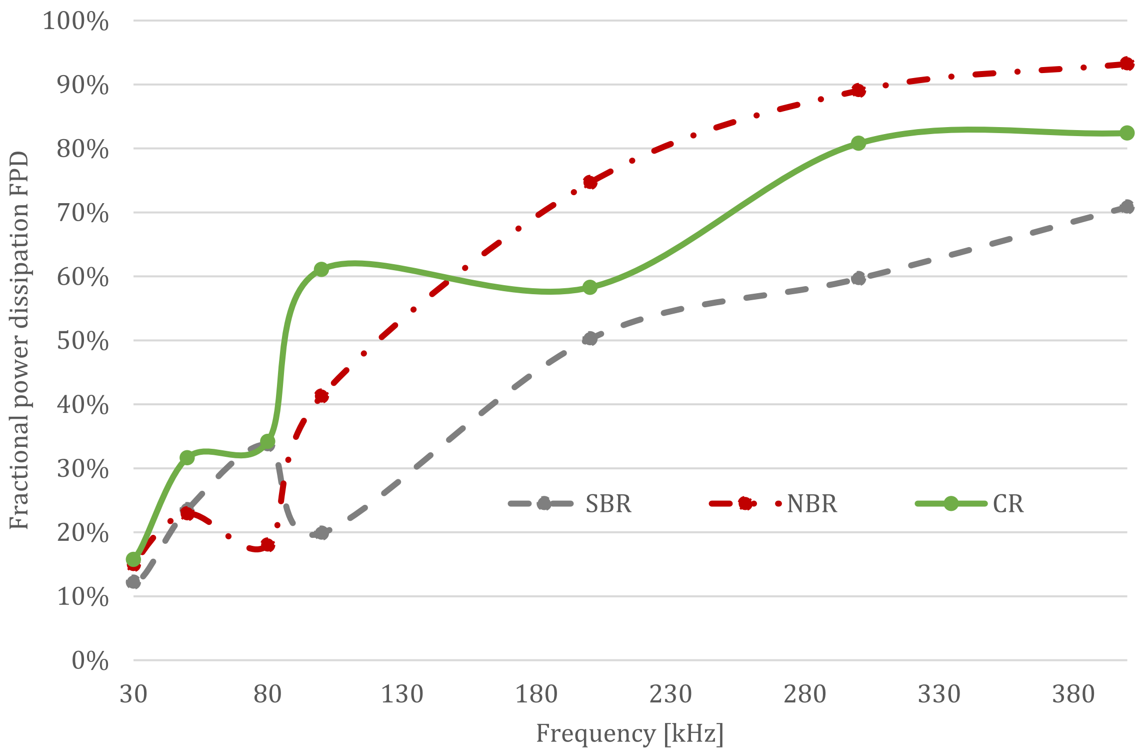

Figure 9. Fractional power dissipation FPD – according to Eq. (3) – for the least reflective plastic plates.

Again, the FPD parameter among the measured samples is best for the brush curtain in the low frequency region.

6. Conclusions

The obtained measurement results indicate that, as expected, for covering the walls, among all materials, the best, in terms of acoustics, are the long-used, dissipating and damping 'brushes'. However, the longest 'grasses' have important utility advantages – the ease of obtaining them and constructing light curtains that are convenient to hang and take down, as well as a low price. The measurements made help to make a decision - whether to choose worse (it is known by how much) but cheap and convenient 'grass' curtains, or look for a manufacturer of 'brush' curtains, or try to raise funds for special absorbers or their imitations. Therefore, the obtained characteristics of the tested materials were compared with their counterparts presented in Ref. [6] by a well-known manufacturer of specially developed absorbers. The characteristics in all respects indicate the acoustic advantages of these professional absorbers over the other tested materials. Their most important advantage seems to be extending their usefulness towards lower frequencies – up to single kilohertz. The measurement results presented in Ref. [6] by Precision Acoustics Ltd., carried out in conditions similar to those presented above for three different manufactured materials, differing in parameters mainly in the low frequency band (from several to several dozen kHz), show the possibility of achieving the IL parameter level of up to 60 dB from frequency approximately 150 kHz, and the FPD parameter approaches 100% from 10 kHz. The comparison of ER parameters is slightly better. Long grass is only about 10 dB worse. The only negative factor is their price, which is probably justified by the required technological studies and the costs of the technological processes involved in low-volume production, indicating the possibility of using these absorbers in rather small tanks. An alternative is efforts to internally develop a possibly imperfect absorber, but without the certainty of substantive and price success.

Continuation of the presented research should consist in measuring combinations of materials, such as complex layers of different (but always convenient) light 'grasses', and checking the effects of interference of waves reflected from hard structural walls with admittedly weakened, waves passing through the curtains at the tank walls.

Acknowledgements

The research presented in the article was carried out as part of the project "Concept of building metrological infrastructure in the area of underwater acoustics in the Polish Central Office of Measures" in the "Polish Metrology" program financed by the Ministry of Education and Science, Grant No. PM/SP/0057/2021/1.

Additional information

The authors declare: no competing financial interests and that all materials taken from other sources (including their own published works) is clearly cited and that appropriate permits were obtained.

References

1. IEC 61161:2013 Ultrasonics; Power measurement – Radiation force balances and performance requirements, 2013
2. S. Noguchi; Developments of Hydroacoustic Measurement Technology; Oki Technical Review, 2005, 202, 72(2), 38–41; https://www.oki.com/en/otr/2005/n202/pdf/otr-202-R12.pdf
3. I. Iliev, N. Kolev; Hydroacoustic stand for evaluating underwater sound systems in a measurement pool; IOP Conf. Series: Materials Science and Engineering, 2019, 664, 012017; https://iopscience.iop.org/article/10.1088/1757-899X/664/1/012017/pdf
4. L. Kilian, S. Kubica; Nowe opracowania aparatury pomiarowej i urządzeń w Zespole NB Systemów Hydroakustycznych IT PG; Proceedings of the VII_{TH} Symposium on Hydroacoustics (in Polish), Gdynia 1990
5. Towing tank – laboratory of hydrodynamics Institute of Naval Architecture, Faculty of Mechanical Engineering and Ship Technology GUT; https://wimio.pg.edu.pl/ibo/basen-modelowy (in Polish)
6. The National Physical Laboratory (NPL) is the UK's National Metrology Institute (NMI); https://www.npl.co.uk/products-services/ultrasound/acoustic-absorber-materials
7. Authorship and contributorship; https://publicationethics.org/authorship (accessed on 2023.01.01)