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GAUGING OF HYDROACOUSTIC TRANSDUCERS IN SMALL-SCALE MEASUREMENT POOLS USING CONTINUOUS SIGNALS

Igor Silvestrov

141570, State Research Institute of Physicotechnical and Radiotechnical Measurements VNIIFTRI,
Mendeleevo, Moscow Region, Russian Federation
e-mail address: igsilv@pochta.ru

Abstract

The majority of the modern graduation methods used for determination of the hydroacoustic transducers sensitivity in small-scale measurement pools is based on the use of the “tone-burst” signals. This approach leads to the limitation of the low graduation frequency and to the decrease of the signal to noise ratio for the measurements. A method of gauging based on the use of continuous signals and the segregation of the spectrums for the measurement pool and the hydrophone being graduated is proposed in the article. The method under consideration allows decreasing the low graduation frequency in small-scale pools and increasing the signal to noise ratio.

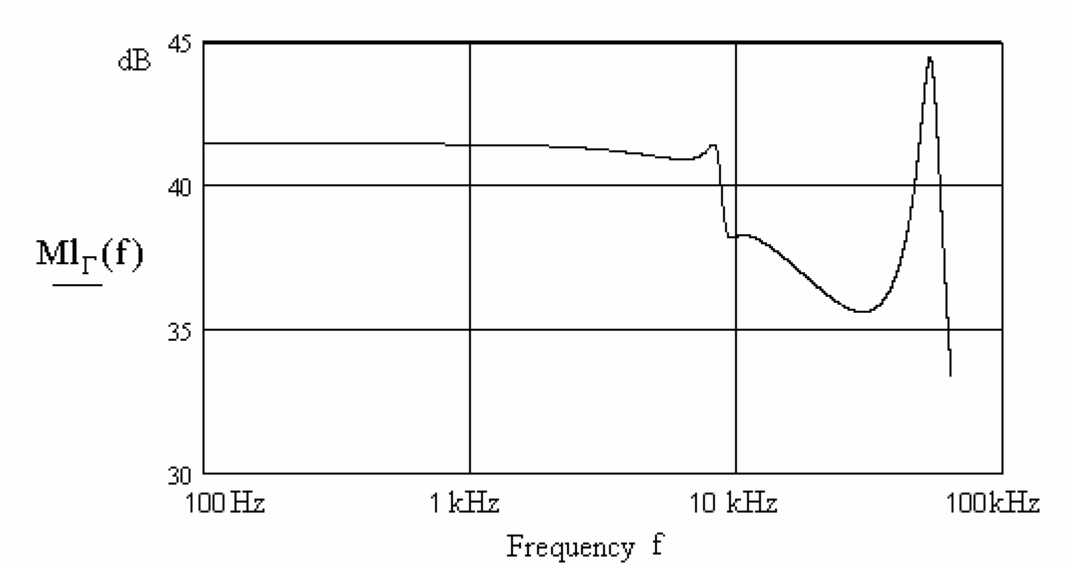
1. INTRODUCTION

At present graduation of hydroacoustic transducers (hydrophones) in measurement pools is usually conducted using “tone-burst” signals as the use of sound-absorbing covers does not provide the necessary coefficients of reflection, especially in the frequency range below 10 kHz. However, the use of such methods also has several disadvantages. The most serious of them is the transient process’s presence that makes it necessary to have at least 3 – 10 periods of the carrier frequency in the signal. This situation limits the low frequency of the graduation range and decreases the signal to noise rate for the measurements.

This article is dedicated to the consideration of an approach to the hydrophone’s graduation, based on the use of continuous signals and the segregation of the spectrums for the logarithmic frequency response of the hydrophone being graduated $Ml_{\Gamma}(f)$ and the logarithmic transfer characteristic of the measurement pool Pl(f).

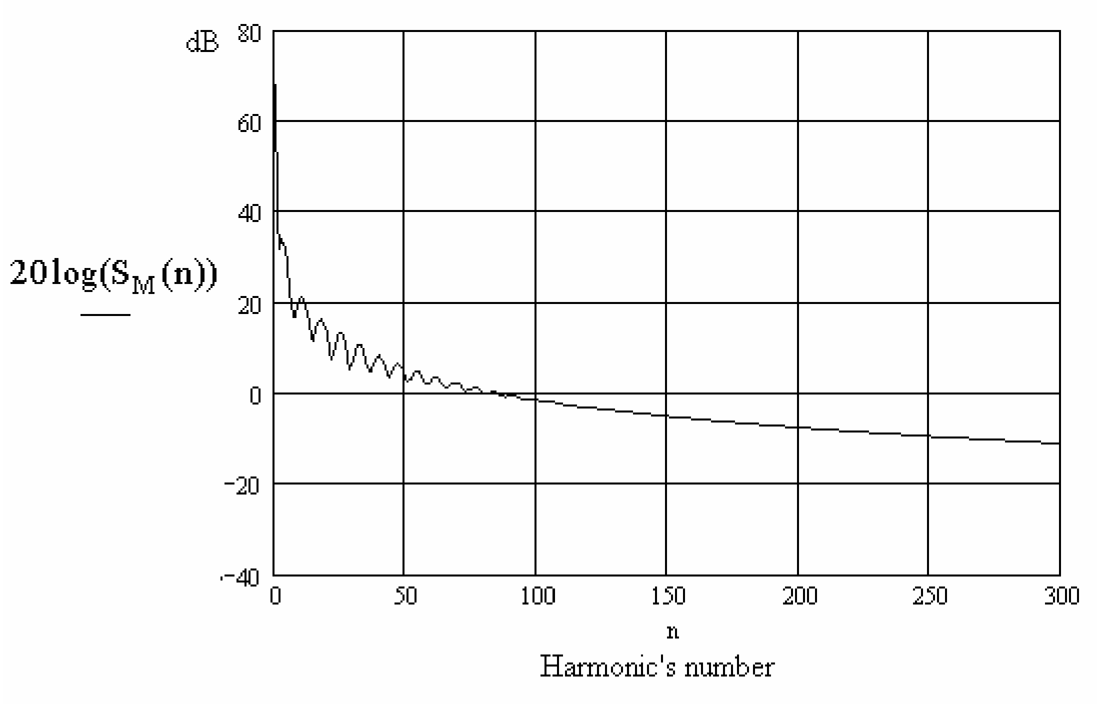
2. LOGARITHMIC FREQUENCY CHARACTERISTICS

Let the logarithmic frequency response of the hydrophone $Ml_\Gamma(f) = 20\log(M_\Gamma(f))$ ($M_\Gamma(f)$ is the frequency response of the hydrophone [1]) have the following form for the frequency range 100 Hz – 63000 Hz:



Pic.1. Logarithmic frequency response of the hydrophone $Ml_\Gamma(f)$.

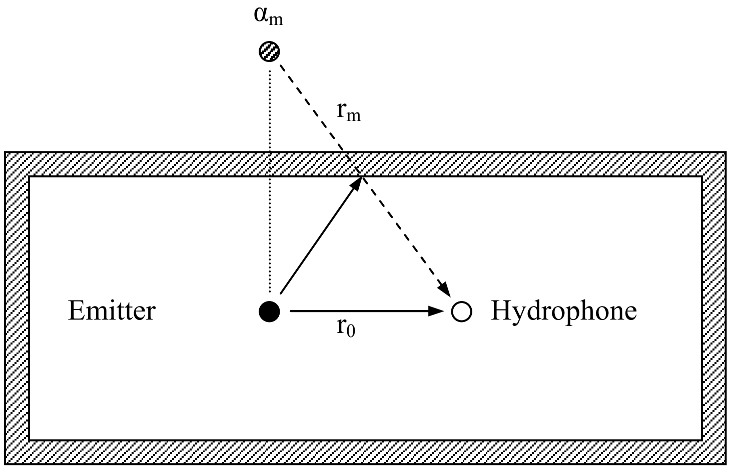
The spectrum $S_M(n)$ of such characteristic received using the Fourier transform is shown on the pic.2. The frequency step for the initial characteristic is 15.5 Hz. The received spectrum's harmonics are similar to the harmonics received using cepstral analysis [2].



Pic.2. Spectrum $S_M(n)$ of the logarithmic frequency response of the hydrophone $Ml_\Gamma(f)$. Only the first 300 harmonics are shown.

As it can be seen, the characteristic $Ml_\Gamma(f)$ is described mostly by the first 70 – 100 harmonics.

Now lets examine the logarithmic transfer characteristic of the measurement pool $Pl(f) = 20\log(P(f))$. Let the hydrophone be positioned in the laboratory measurement pool where an emitter is also positioned (pic.3).



Pic.3. Layout of the hydrophone and the emitter in the measurement hydroacoustic pool.

Then $P(f)$ can be described by the following formula:

$$P(f) = P_0(f)\left|1 + \sum_{m=1}^{L}\left(\frac{e^{jk(f)Rg_m} r_0}{r_m}\alpha_m\right)\right| \tag{1}$$

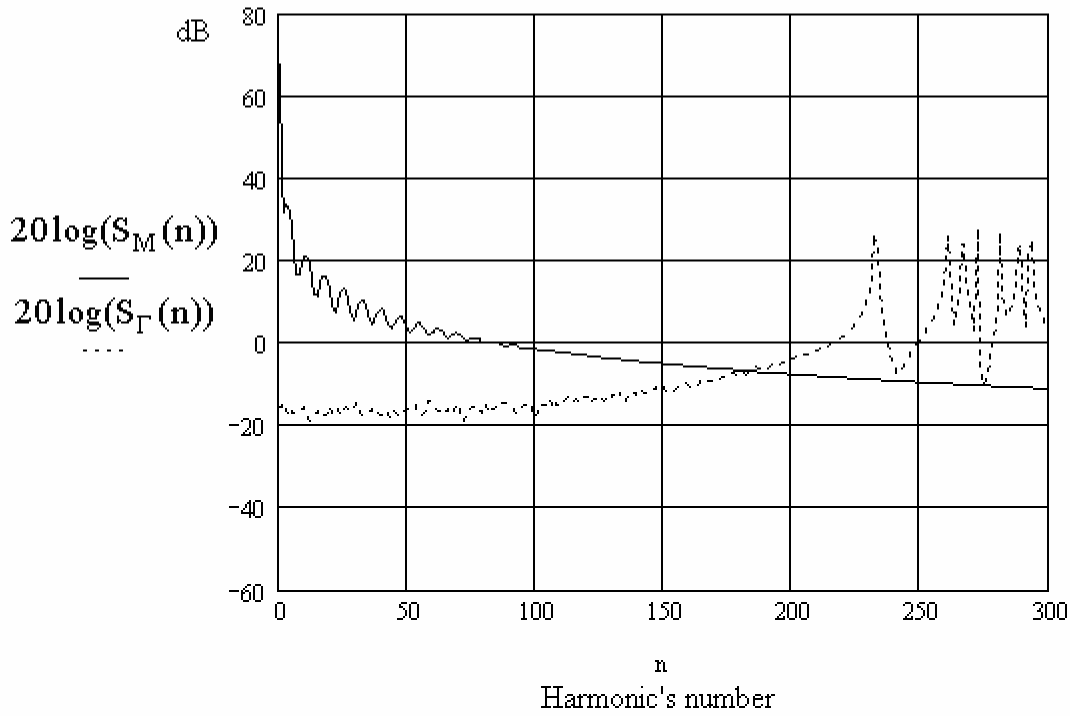
where k(f) is the propagation vector, $k(f) = \frac{2\pi f}{c}$, **c** is the speed of sound in water.

$P_0(f) = e^{jk(f)r_0}/r_0$ is the pressure that would be created by the emitter in the area of the hydrophone's location in absence of the additional reflected signal's sources (free field).

$Rg_m = r_m - r_0$.

α_m is the reflection coefficient.
L is the quantity of the reflected signal's sources.

Let L = 50, the reflected signal's sources are situated so that Rg_m has values between 4.58 m and 20 m according to the uniform distribution law. The reflection coefficient α_m is equal to 1. Examples of the spectrums for the logarithmic transfer characteristic of the measurement pool $S_\Gamma(n)$ and the logarithmic frequency response of the hydrophone $S_M(n)$ are shown on the pic 4.



Pic.4.The spectrum $S_M(n)$ for logarithmic frequency response of the hydrophone $Ml_Γ(f)$ and the spectrum $S_Γ(n)$ for the logarithmic transfer characteristic of the measurement pool in the area of the hydrophone's location. Only the first 300 harmonics are shown.

It can be seen that for $n < n_0$, $n_0 = 170$, the harmonics of the spectrum $S_M(n)$ transcend the harmonics of the spectrum $S_Γ(n)$.

3. GRADUATION OF THE HYDROACOUSTIC TRANSDUCER USING CONTINUOUS SIGNAL

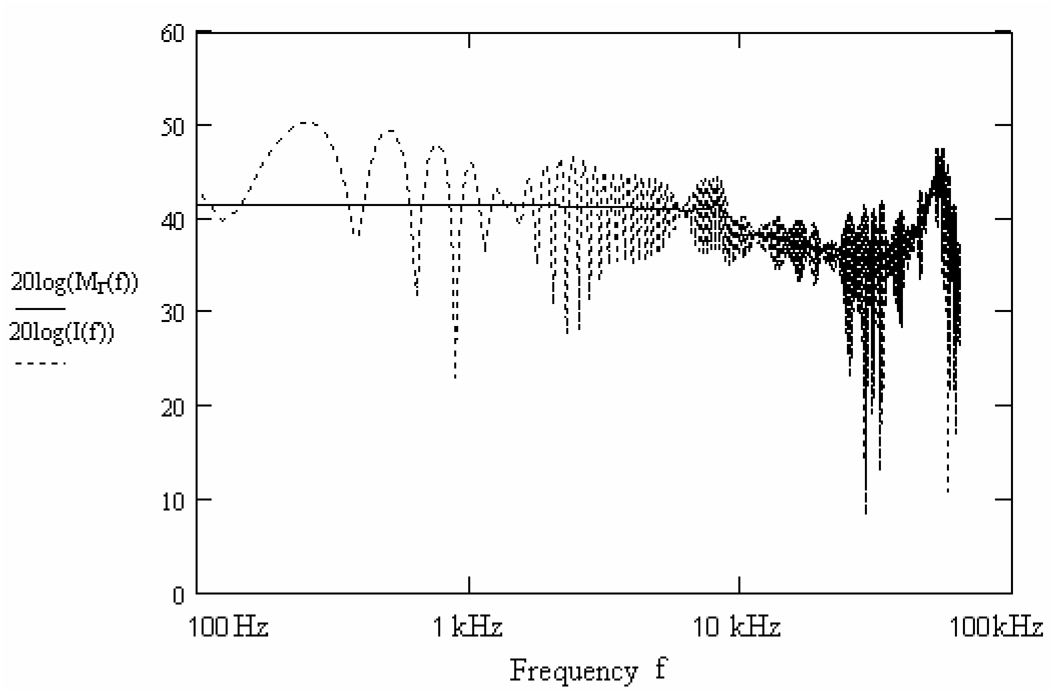
The following formula is correct for the output voltage $U_Γ(f)$ of the hydrophone measured using continuous signal:

$$M_Γ(f) * P(f) = U_Γ(f) \tag{2}$$

Lets carry out the normalization of (2) relative to $P_0(f)$:

$$M_Γ(f) * \left| 1 + \sum_{m=1}^{L} \left(\frac{e^{jk(f)Rg_m r_0}}{r_m} \alpha_m \right) \right| = \frac{U_Γ(f)}{P_0(f)} = I(f) \tag{3}$$

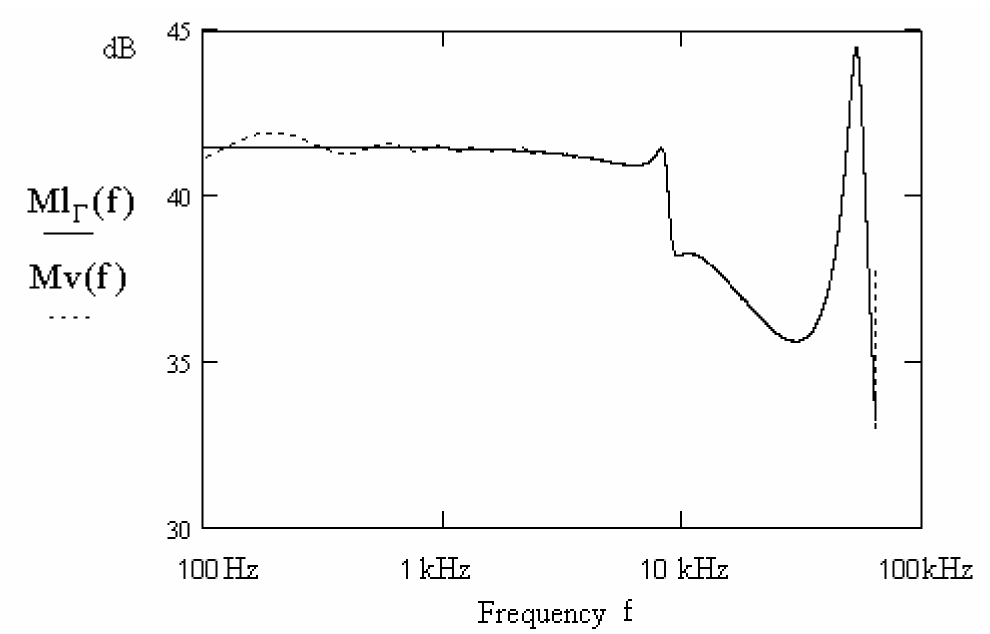
An example of the dependence 20log(I(f)) that can be measured using continuous signal is shown on pic.5.



Pic.5. The initial characteristic $20\log(M_\Gamma(f))$ and the characteristic $20\log(I(f))$, measured using continuous signal.

The logarithmic frequency response of the hydrophone being graduated $Ml_\Gamma(f)$ can be restored using the result of the I(f) according to the following algorithm. First, the logarithm of the expression (3) has to be found. Next, the spectrum for the received expression has to be calculated. And then the inverse Fourier transform has to be conducted using only the first n_0 harmonics.

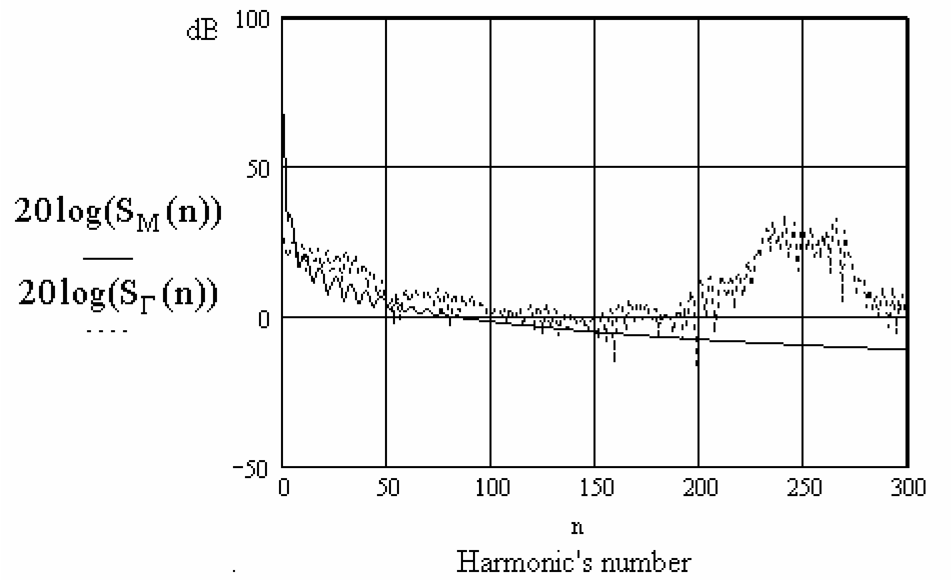
The result of this algorithm's usage is shown on pic.6 for the conditions described above.



Pic.6. The initial characteristic $Ml_\Gamma(f)$ and the characteristic $Mv(f)$, restored using the first n_0 harmonics.

As it can be seen, the proposed method allows restoring the logarithmic frequency response of the hydrophone nearly in all measurement range with the results of the measurement received using continuous signal.

In the example considered above the information about $P_0(f)$ was required in addition to the output voltage U(f). However, in some situations this information is very difficult to obtain. To avoid the usage of this information the method of graduation based on the substitution method can be used. In this method an additional hydrophone with a known frequency response is exploited. Such method also allows conducting of the hydroacoustic transducer's graduation using continuous signals for the cases when the logarithmic frequency response of the hydrophone and the logarithmic transfer characteristic of the measurement pool are similar. Examples of such characteristics are shown on pic.7.



Pic.7. The spectrum $S_M(n)$ for logarithmic frequency response of the hydrophone $Ml_\Gamma(f)$ and the spectrum $S_\Gamma(n)$ for the logarithmic transfer characteristic of the measurement pool in the area of the hydrophone's location. Only the first 300 harmonics are shown.

In this case the amount of harmonics that can be used according to the algorithm described above is not enough to restore the logarithmic frequency response of the hydrophone in the wide frequency range.

While using the substitution method, the function I(f) employed to restore the logarithmic frequency response of the hydrophone $Ml_\Gamma(f)$ is described by the following formula.

$$M_\Gamma(f)\frac{\left|1+\sum_{m=1}^{L}\left(\frac{e^{jk(f)Rg_m}r_0}{r_m}\alpha_m\right)\right|}{\left|1+\sum_{m=1}^{L}\left(\frac{e^{jk(f)Rgs_m}rs_0}{rs_m}\alpha_m\right)\right|}=\frac{U_\Gamma(f)}{U_{\Gamma c}(f)}M_{\Gamma c}(f)\frac{r_0}{rs_0}=I(f) \qquad (4),$$

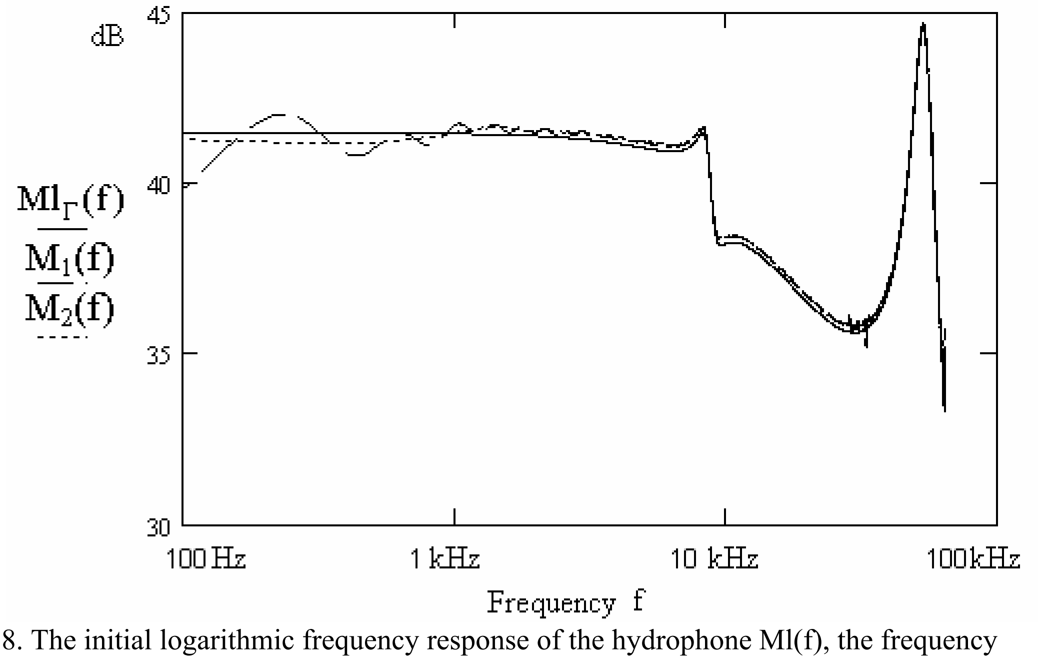
where $M_{\Gamma c}(f)$ is the frequency response of the substitution hydrophone.

$U_{\Gamma c}(f)$ is the output voltage of the substitution hydrophone measured using continuous signal.

$Rgs_m = rs_m - rs_0$, rs_m, rs_0 are the vectors similar to the vectors r_m, r_0 for the hydrophone being graduated.

Two components of error have to be analyzed to assure the more accurate choice of the amount of the harmonics used to restore the logarithmic frequency response of the hydrophone. The first component is the error related to the usage of a limited number of harmonics to restore the logarithmic frequency response of the hydrophone. This component can be estimated by comparing the initial frequency response (frequency response for a set of hydrophones) and the frequency response restored using the corresponding number of harmonics. The second component is related to the influence of the transfer characteristic of the measurement pool and to the fact that the substitute hydrophone and the hydrophone being graduated are positioned not exactly in the same area. This component can be estimated by using the same hydrophone with a known frequency response both as the substitute hydrophone and the hydrophone being graduated.

To decrease the fluctuations on the borders of the frequency range the methods of Gibbss effect's suppression are proposed to be used. The result of the proposed method's usage for restoring the logarithmic frequency response of the hydrophone in the measurement pool having transfer characteristic shown above are displayed on pic.8.



Pic.8. The initial logarithmic frequency response of the hydrophone Ml(f), the frequency characteristic $M_1(f)$, restored without the usage of the methods of Gibbs effect's suppression, and the frequency characteristic $M_2(f)$, restored using the methods of Gibbs effect's suppression.

Thus the proposed method allows restoring the logarithmic frequency response of the hydroacoustic transducer in all considered frequency range with low error.

6. CONCLUSIONS

The proposed method of gauging of hydroacoustic transducers using continuous signals allows to considerably decrease the low frequency of the graduation range in measurement pool by usage of the segregation of the spectrums for the logarithmic frequency response of the hydrophone being graduated and the logarithmic transfer characteristic of the measurement pool as well as increase the signal to noise rate for the measurements.

The conducted practical verification of the method showed the decrease of the low frequency of the graduation range to 200 – 300 Hz in the measurement pool having a size of 6x6x6 m.

However, it is necessary to note that the information about the transfer characteristic of the measurement pool and the information about the frequency response of the set of hydrophones including the hydrophone being graduated is needed for the correct realization of the method.

REFERENCES

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[2] Зверев В.А., Стромков А.А. *Выделение сигналов из помех численными методами.* – Нижний Новгород: ИПФ РАН. – 2001.