MODERN MEASUREMENT TECHNIQUES IN THE RUSSIAN UNDERWATER ACOUSTICS STANDARDS

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The State Metrological Institute of Underwater Acoustics Measurements (GMIGI) is one of the major departments of the All-Russian Scientific Research Institute for Physical-Technical and Radiotechnical Measurements (VNIIFTRI).

The mainstream of scientific research in GMIGI is metrological maintenance of underwater acoustical and hydrophysical measurements in Russia.

Main tasks of GMIGI in the area of underwater acoustical measurements are:

- to create, maintain and improve the National primary and secondary standards of sound pressure unit in water;
- to create precise and stable instruments for underwater measurements and reference standards for their calibration;
- to disseminate the unit of sound pressure in water to working measurement instruments;
- to develop and improve the methods of precise measurements and traceability techniques in order to provide accuracy and uniformity of underwater measurements in Russia;
- to take part in the international and key comparisons of the primary standards of sound pressure unit in water.

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The measuring facility of primary standards features:

- the highest accuracy of reproduction and transfer of the sound pressure unit in water in the frequency range 0.01 Hz - 1.0 MHz ;

- uncertainty of hydrophone sensitivity measurements does not exceed 3 % - 7 % with confidence coefficient 0.95 (corresponds to the best world results achieved nowadays in this area of measurements).

- metrological characteristics of standards were repeatedly verified by the international comparisons:

International comparisons of IEC (1967),
Bilateral Russian-Chinese comparisons (1998, 2004),
CIPM Key comparisons of free-field hydrophone calibrations
(CCAUV.W-K1, 2000 - 2004).

Methods used in the secondary and working standards for hydrophone calibrations:

- method of comparison in a closed coupler (frequency range: 0.1 – 3.15×10^3 Hz)
- free-field comparison method
- free-field reciprocity method

(1.0×10^3 - 2.0×10^5 Hz)

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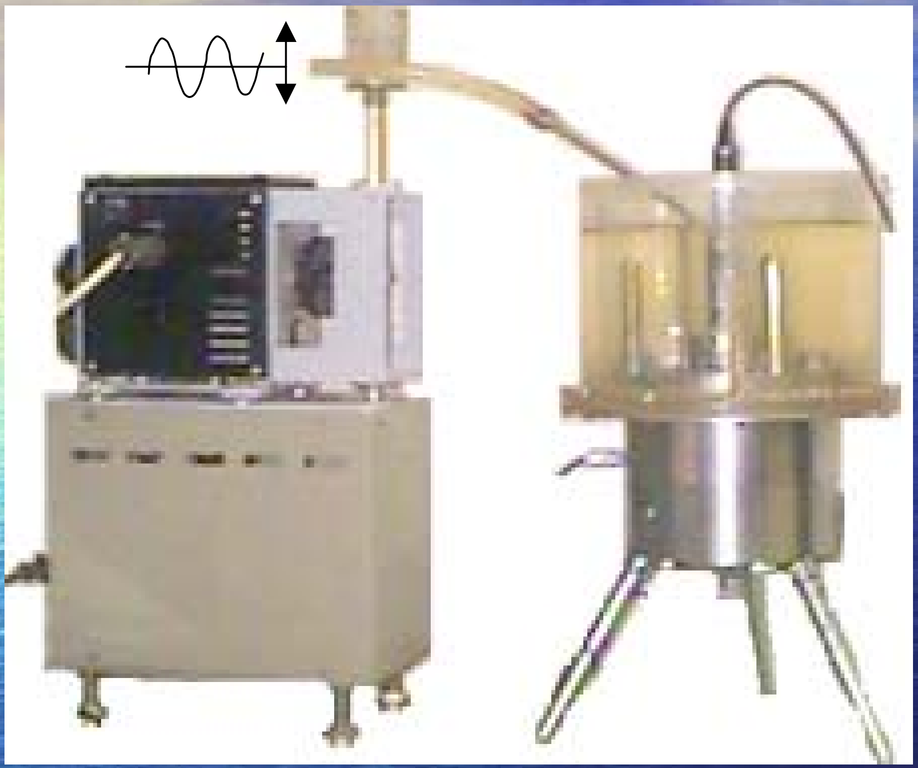
ABSOLUTE METHOD FOR THE REPRODUCTION OF UNIT OF SOUND PRESSURE IN THE WATER

Frequency (Hz)	Method of reproduction	Written Standard, author of the method
0.01 – 1.0	Method of hydrostatic exciter	A.N. Golenkov VNIIFTRI, IEC
$0.8 – 4.0\times10^{3}$	Reciprocity technique in closed coupler with excess static pressure up to 50×10^{6} Pa	S.F. Nekhrich, VNIIFTRI
$0.1 – 1.0\times10^{3}$	Method of piezoelectric compensation in a closed coupler	L.E. Pavlov, VNIIFTRI, IEC
$0.5\times10^{3} – 2.0\times10^{5}$ $2.0\times10^{5} – 1.0\times10^{6}$	Free-field reciprocity method in a water tank with the size $6.0\times10.0\times6.0$ m in a water tank with the size $1.0\times1.5\times1.0$ m	IEC

FACILITY OF PRIMARY STANDARDS FOR THE REPRODUCTION OF SOUND PRESSURE IN THE CLOSED COUPLER



Electromechanical hydrostatic exciter and closed coupler

Frequency range 1.0×10^{-2} - 1.0 Hz

Method of the hydrostatic exciter

- pressure in the coupler is created by vertical oscillations of a vessel filled with water;
- oscillations created by the electro-mechanical hydrostatic exciter;
- frequency of vessel oscillations is synchronized by the quartz generator.

Measurement Equation:

$$P(w) = \rho gh \times \left(1 + \frac{w^2}{w_0^2}\right) \times \left(1 - \frac{w^2 He}{g}\right)$$

$P(w)$ - amplitude of pressure;
w - frequency of fluctuations;
w_0 - resonance frequency;
? - density of water;
g - gravity acceleration;
h - amplitude of vessel fluctuations;
He - equivalent height of water level.

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Frequency range 0.8 – 4.0×10³ Hz

Electromechanical hydrostatic exciter and closed coupler for piezoelectric compensation

Method of piezoelectric compensation in the closed coupler

- pressure in the closed coupler is created by piezoelectric projector

Measurement Equation:

$$P(w) = \frac{\rho g h \times \left(1 - \frac{\tilde{w}^2 He}{g}\right)}{U_c(\tilde{w})} \times U_c(w)$$

$\tilde{w}$ - frequency of determination of piezocompensation coefficient of the coupler;

$U_c(\tilde{w})$, $U_c(w)$ - voltage on compensator when the zero-indicator is completely blocked.

Variant of the reciprocity method in the coupler with excess static pressure up to 50×10^{6} Pa

Measurement Equation:

$$M_H(w)=\sqrt{A\times C_a\times \Phi_A}\ ,$$

$$C_a=\frac{V_0\times\chi_\beta}{C_0}\ ,\qquad A=\frac{U_{PH}\times U_{TH}}{U_{PT}\times U_{C_0}}\ ,$$

Pump station and coupler of the standard facility in frequency range 0.1 Hz – 1.0 kHz

U_{PH} - response of a hydrophone when the projector emits sound;

U_{TH} - the response of a hydrophone when the reciprocal transducer emits;

U_{PT} - response of the reciprocal transducer when the projector emits;

U_{C_0} - voltage on capacity C_0 in series with the reciprocal transducer;

C_a - compliance of the coupler;

V_0 - volume of water in the coupler;

χ_β - water compressibility factor;

Φ_a - wave distribution factor.

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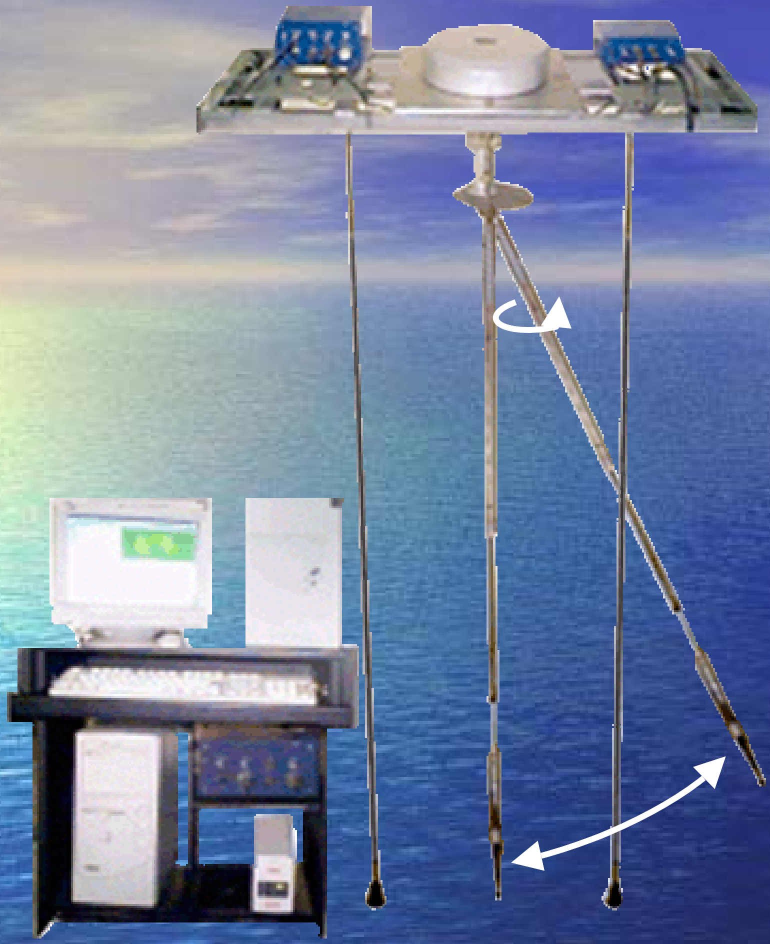
STANDARD FREE-FIELD RECIPROCITY PROCEDURE



Facility of working standard for hydrophones calibration in water tank with the size 3.0×4.0×3.0 m, frequency range 2.5 – 200.0 kHz, uncertainty of measurements below 0,6 .. 1 dB.

Measurement Equation:

$$M_H = \sqrt{J_{sf} \frac{U_{PH} \times r_{PH} \times U_{TH} \times r_{TH}}{U_{PT} \times r_{PT} \times I_R}}$$

U_{PH}, U_{TH}, U_{PT} - output voltage of transducers;
I_R - current in series with the reciprocal transducer;
r_{TH}, r_{PT}, r_{PH} - distances between transducers;
J_{sf} - reciprocity parameter.

Improvements:

- Optimized tone burst radiation and receiving technique;
- Extended low frequency range;
- Adaptive cancellation of random disturbances;
- “Sound streamline” design of underwater units;
- Reduction of “shadowing” by central transducer.

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A modified free-field reciprocity procedure

- in water tank with the size $6.0\times10.0\times6.0$ m in the frequency range $0.5\times10^3 - 2.0\times10^5$ Hz;
- in water tank with the size $1.0\times1.5\times1.0$ m in the frequency range $2.0\times10^5 - 1.0\times10^6$ Hz.

Facility of the primary standard in the frequency range $0.5\times10^3 - 2.0\times10^5$ Hz
Coordinate framework for precise transducer positioning in the water tank with the size $6.0\times10.0\times6.0$ m

Measurement Equation:

$$M_H = \sqrt{J_{sf} \times \frac{<Z_{PH,sf}> \times <Z_{TH,sf}>}{<Z_{PT,sf}>}}$$

$\left.\begin{array}{l} <Z_{PH,sf}> \\ <Z_{TH,sf}> \\ <Z_{PT,sf}> \end{array}\right\}$ - estimations of free-field reduced transfer impedances (RTI) of transducers

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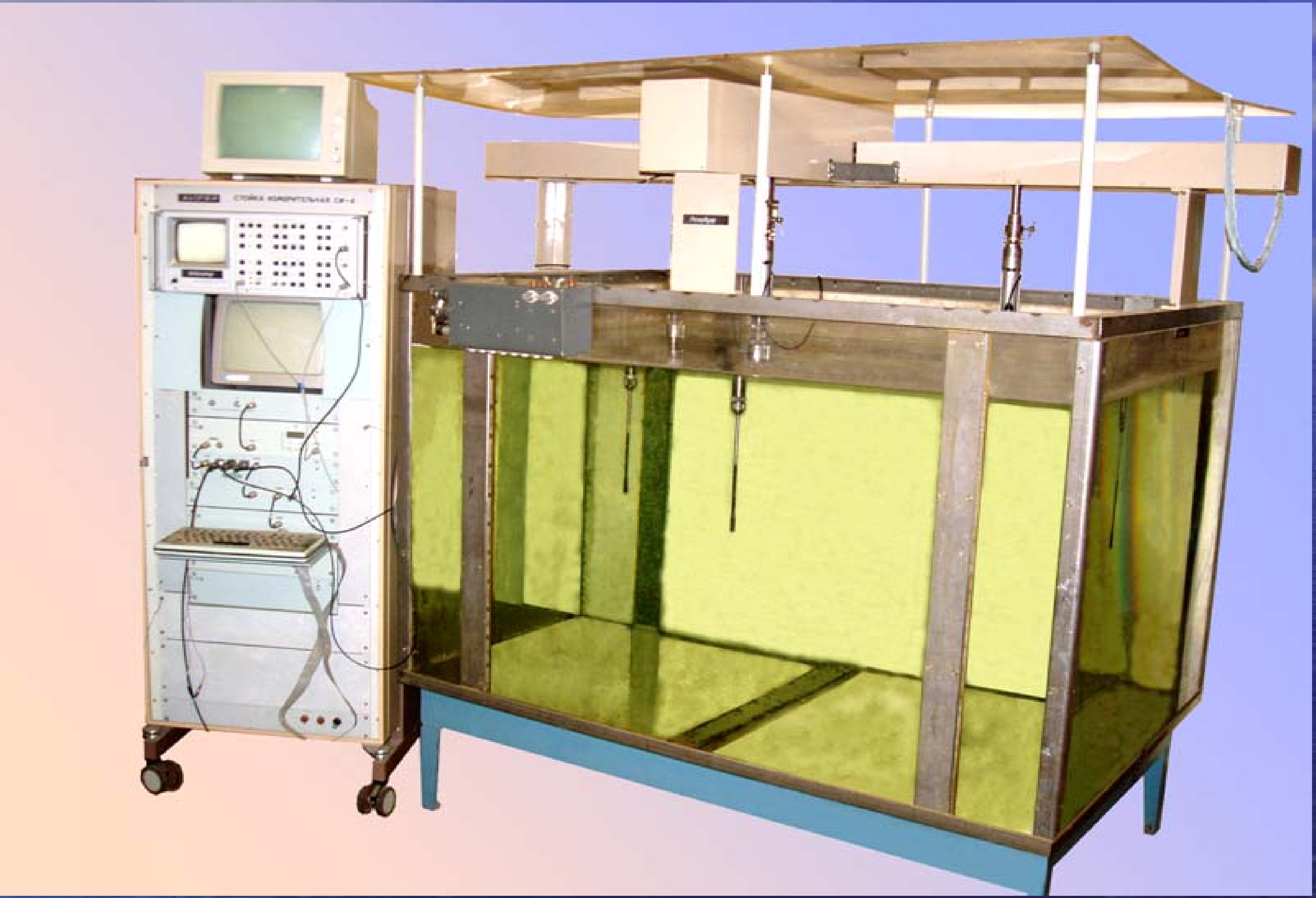

Facility of primary standard in frequency range $2.0\times10^{5} - 1.0\times10^{6}$ Hz. Coordinate framework for precise transducer positioning in the measurement water tank with the size 1.0×1.5×1.0 m

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THE BASIC DIRECTIONS OF STANDARDS IMPROVEMENT:

- increase of accuracy of reproduction and transfer of sound pressure unit in the water by means of:

- using new technologies for the development of instruments for precise measurement of sound pressure in closed couplers;
- using the information on acoustic field amplitude and phase distribution in free-field measurements;

- use of the continuous frequency band test signals for calibration of hydrophones and underwater measuring modules;

- use of the frequency band sensitivity applicable to random processes measured in natural conditions for characterization and calibration of hydrophones and underwater measuring modules;

- creation of reference facilities and primary standards for calibration of oscillation velocity measuring instruments used for measurements of vector parameters of sound fields in water.

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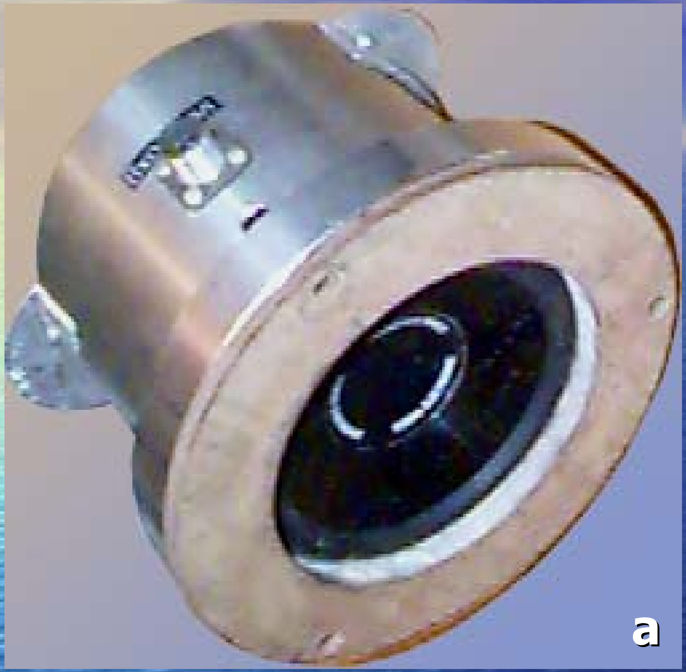
THE STANDARD MEASURING COUPLER AT FREQUENCIES 0.1 – 3.15×10^3 Hz BASED ON THE TENSOMETRIC SENSOR



a – electrodynamic projector;
b – chip of tensometric sensor and acoustic pressure measuring instrument made on its basis;
c – the ready-mounted measuring coupler.

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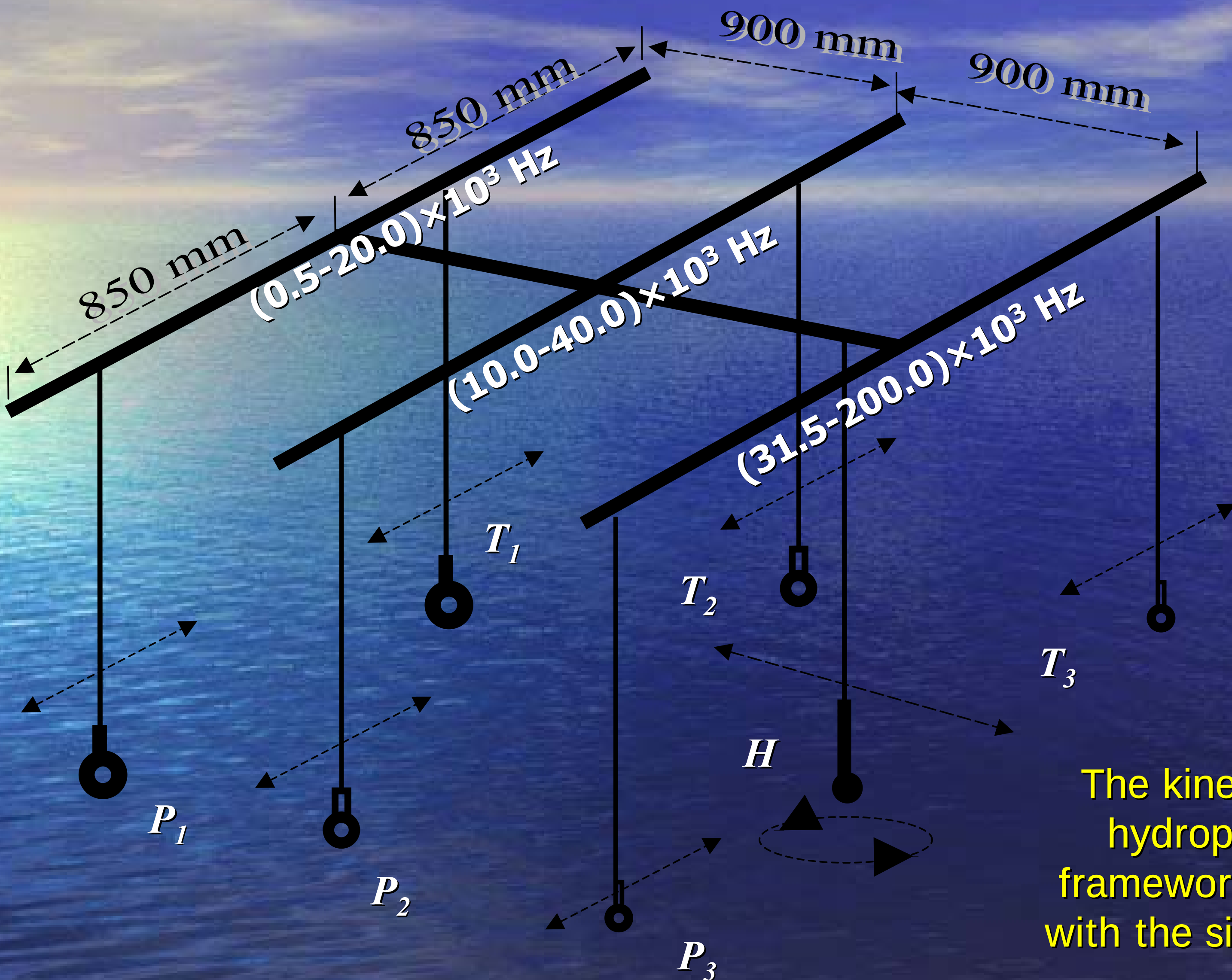
A FREE-FIELD MEASUREMENTS



The kinematics scheme of hydrophone coordinate framework in the water tank with the size 6.0×10.0×6.0 m

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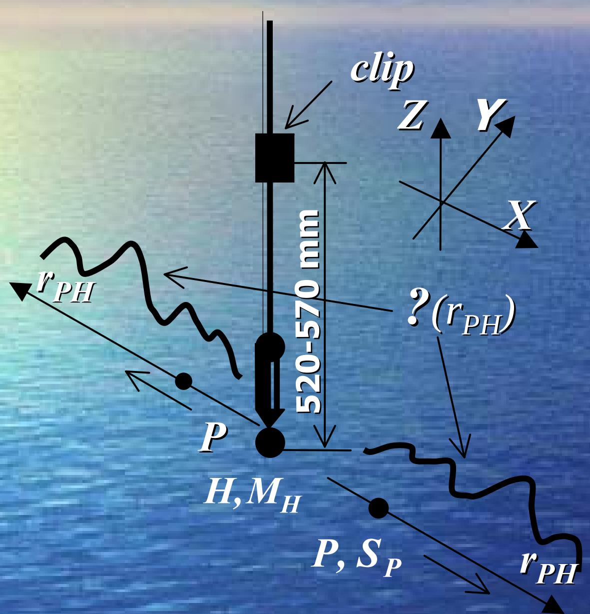
MODIFIED FREE-FIELD RECIPROCITY PROCEDURE



Measurement of spatial dependence of a transfer impedance of the projector and the hydrophone to be calibrated

Consequence of J. Babinet's principle for RTI in the sound field distorted by scattered wave:

$$Z'_{PH,sf}(r_{PH}) = Z_{PH,sf}\sqrt{1+\aleph(r_{PH})}$$

$Z_{PH,sf} = M_H S_P$ - RTI in free-field;

$\aleph(r_{PH})$ - transfer function of scattered inhomogeneity (TFI).

Steps of modified procedure:

1 - measurements of RTI spatial dependence;

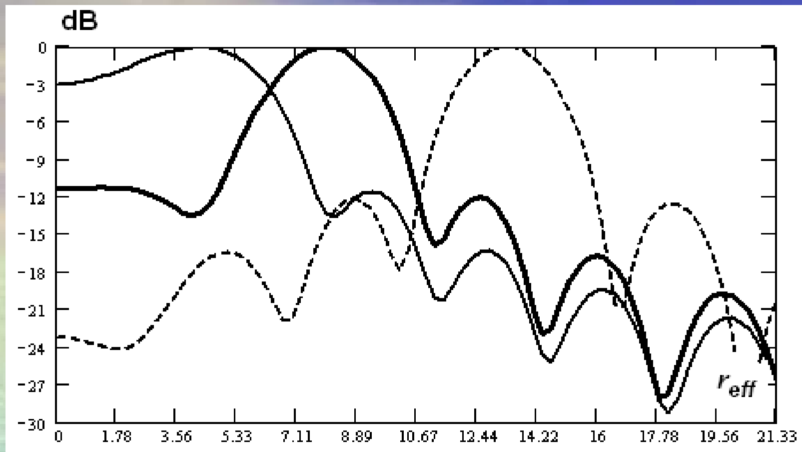
2 - selection of TFI;

3 - expansion of TFI in series of spherical source functions (reconstruction of scatterers spatial distribution);

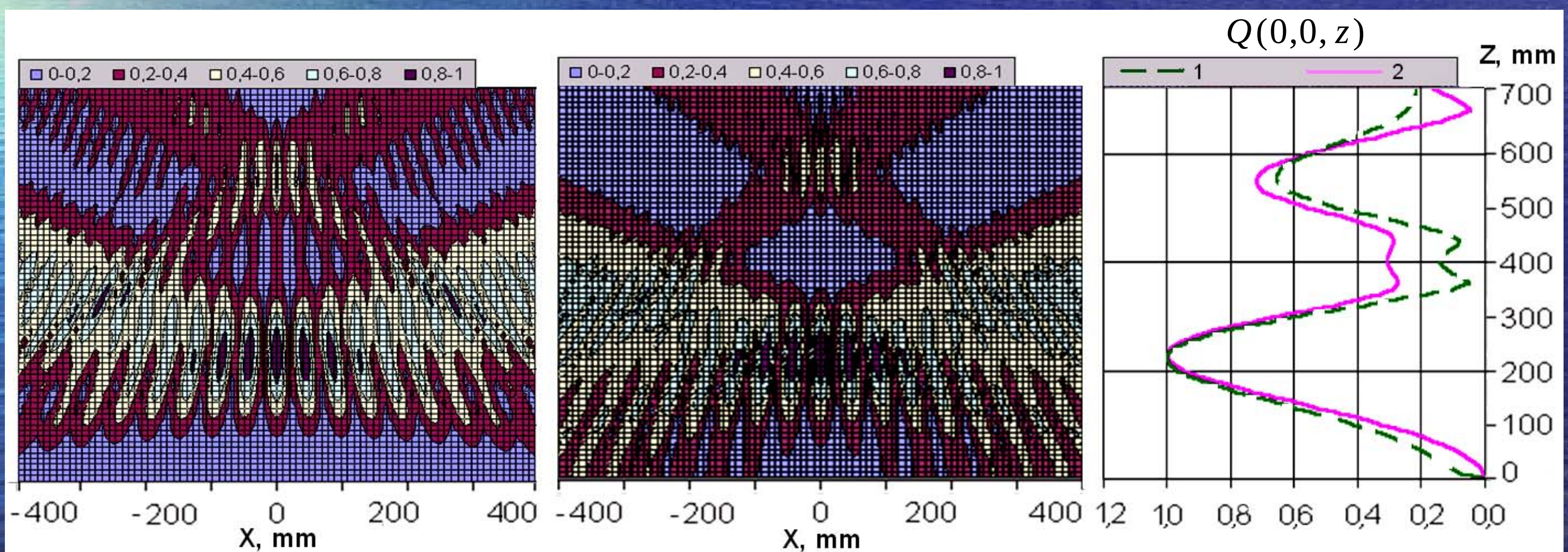
4 - estimation of free-field RTI $< Z_{PH,sf} >$ by least-squares method;

5 - insertion of RTI-s estimations to measurement equations.

RECONSTRUCTION OF SCATTERERS DISTRIBUTION BY MATCHED SPATIAL FILTRATION (MSF)



Degradation of spatial resolution of MSF with decreasing distance between a scatterer and the hydrophone active element



Improvement of sound scatterer images on the surface of clip and at area closed to hydrophone body at frequency 60 kHz

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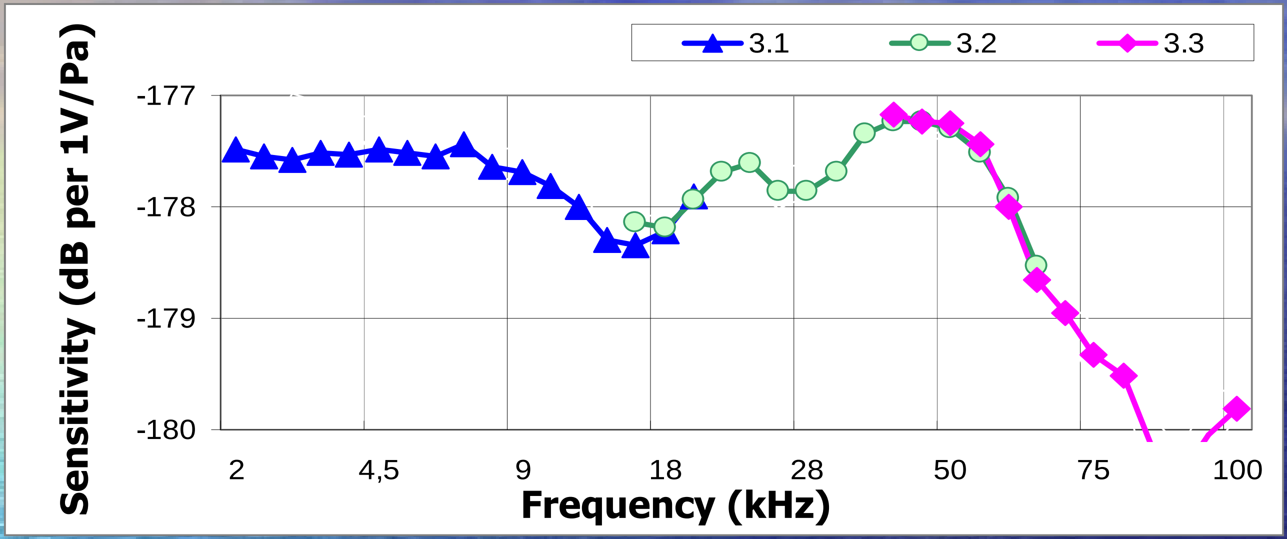
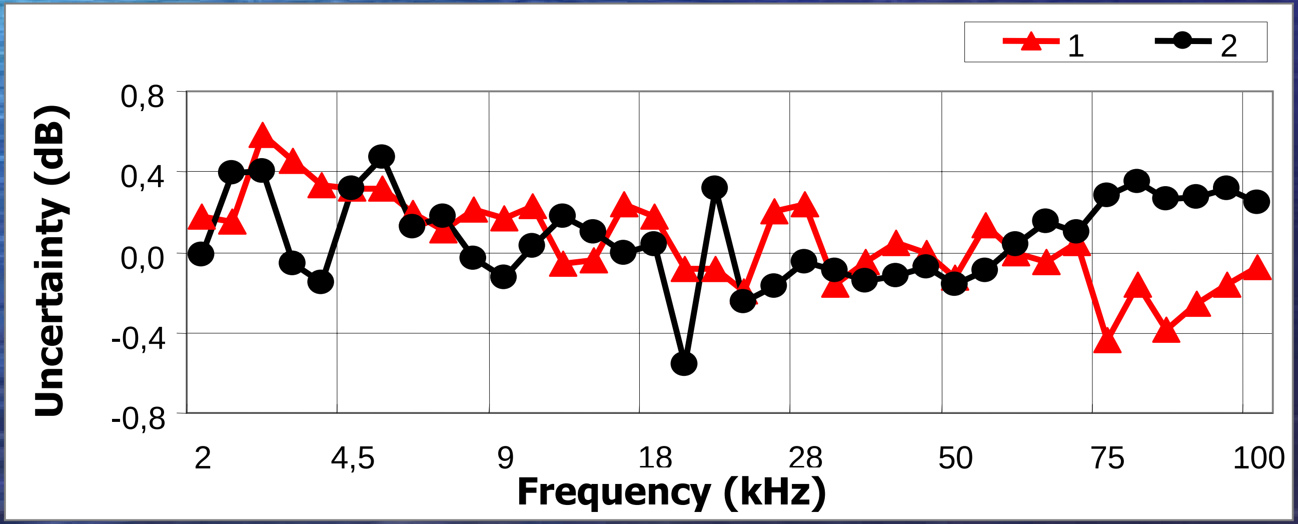
INCREASE OF ACCURACY OF FREE-FIELD CALIBRATION



Frequency response of a hydrophone type H 52-50, calculated with modify free-field reciprocity procedure



Influence of scatterers on the increase of uncertainty of standard free-field reciprocity procedure

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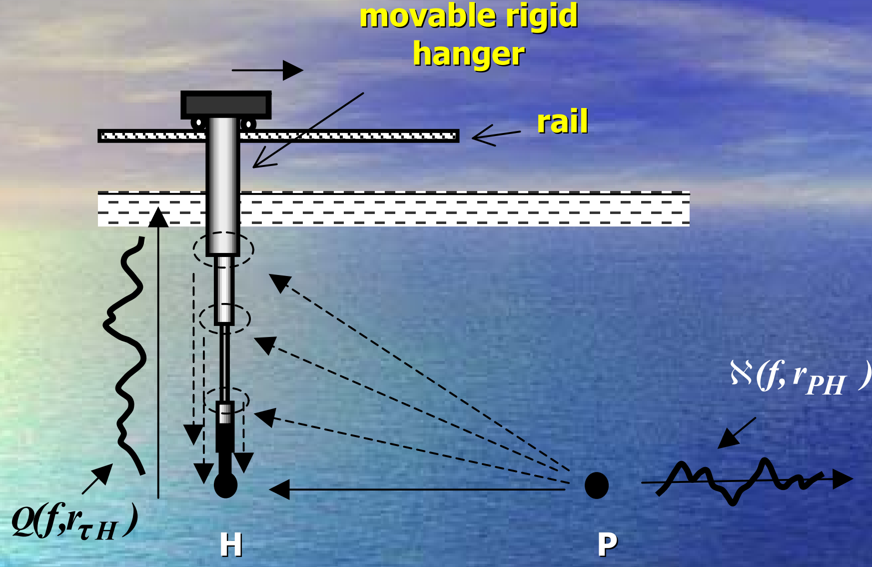
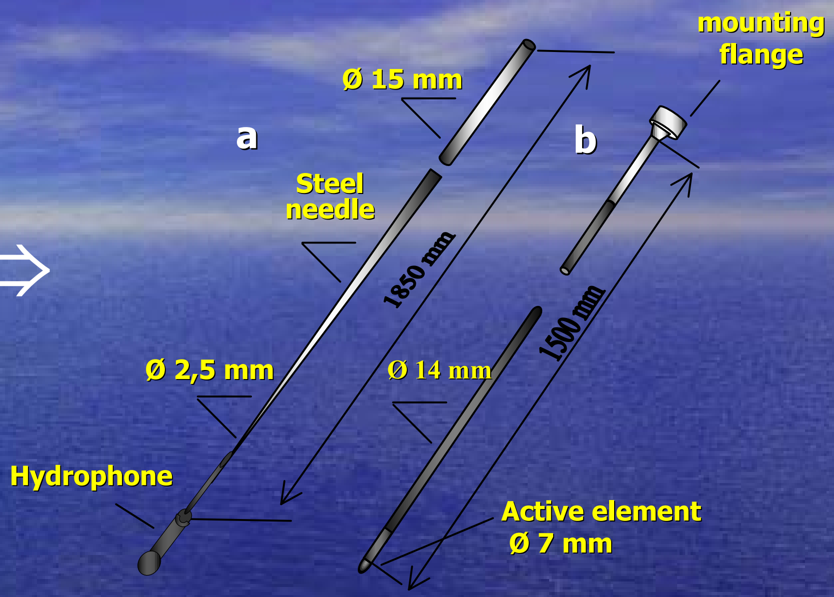
"SOUND STREAMLINE" UNDERWATER UNITS OF STANDARD



Distribution of diffraction scatterers close to cross-section jumps of rigid hydrophones mount



"Sound streamline" design:
a - needle-shaped rigid hydrophone mount;
b - projector and reciprocal transducer in form of straight uniform rod.

Response of MSF:

$$Q(f, r_{\tau H}) = \left| \frac{1}{\|V\|} \int_V \aleph(f, r_{PH}) \dot{\chi}_\tau (f, r_{PH}) dr_{PH} \right|$$

$\dot{\chi}_\tau (f, r_{PH})$ - spatial pulse function of MSF;

V - motion path.

Field distortion:

$var(Z'_{PH,sf}(r_{PH})) \leq$ 0,5 – 2,0 % in frequency range 31,5 – 200 kHz

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CONTINUOUS FREQUENCY-BAND TEST SIGNALS AT WATER TANK HYDROPHONES CALIBRATION

"Sound transparency" of measuring water tank:

RTI in water tank:

$$\dot{Z}'_{PH,sf}(f) = \dot{Z}_{PH,sf}(f)\left(1+\dot{\Omega}_{WT}(f)\right)$$

$\dot{\Omega}_{WT}(f)$ - transfer function of water tank.

$$\left|\frac{1}{\Delta f_{WT}}\int_{\Delta f_{WT}} \dot{\Omega}_{WT}(f)\,df\right| \approx 0$$

$\Delta f_{WT} = \dfrac{1}{\Delta\tau_{min}}$ - effective "frequency window" of water tank.

$\Downarrow$

$$\dot{Z}_{PH,sf}(f,\Delta f_{WT}) = \frac{1}{\Delta f_{WT}}\int_{f,\Delta f_{WT}} \dot{Z}'_{PH,sf}(f')\,\dot{\varpi}(f')\,df'$$

$\dot{Z}_{PH,sf}(f,\Delta f_{WT})$ - free-field RTI, averaged in "frequency window";

$\dot{\varpi}(f)$ - pulse response of low-pass (or rejection) spatial filter.

$\Rightarrow$

Sensitivity to RMS-value of sound pressure in a frequency band:

$$M_H(f_0,\Delta f) = \sqrt{\frac{\int \lambda^2(f_0,f)\,G_v(f)\,df}{\int_{f_0,\Delta f} G_p(f)\,df}}$$

$G_p(f)$ - spectral density of sound pressure;

$G_v(f)$ - spectral density of hydrophone response;

$\lambda(f_0,f)$ - frequency response of band-pass filter.

Applicable to random processes measured in natural conditions.

Enables the decrease of:

- the effective sensitive area ($a \le \beta_{\Delta f}\lambda_{f_0}$)
- the far-field distance at the calibration of underwater measuring module.

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