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Round-robin intercomparison of hydrophone calibration in Russia

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The results of an interlaboratories round-robin comparison of hydrophone calibration techniques in the frequency range 0,1 Hz – 200 kHz carried out in Russia in 1993-97 are described. Six hydrophones of two types were circulated to twelve laboratories involved in defence, education, shipbuilding, and state metrology activity. Both types of hydrophones were designed in All-Russian Scientific Research Institute for Physical-Technical and Radiotechnical measurements (VNIIFTRI).

Each laboratory determined the open-circuit end-of-cable hydrophone sensitivity using their normal calibration methods

The agreement between all the participants was within 1 dB at frequencies 0,1Hz –100 kHz and within 2 dB at frequencies 100 - 200 kHz.

1. Introduction

In 1992 in Russia the new hierarchy scheme for means of underwater acoustic measurements in the frequency range 0,01 Hz to 1 MHz was established. Its main feature is the existence along with the centralised part (which demands that all hierarchy levels must be used one after another – from primary standard through system of working standards to the working instruments) also the decentralised part.

Latter gives the opportunity of comparison of working standards of 2-nd accuracy directly with the primary standard. In order to investigate the possibility of such system proper functioning and the state of the art of underwater acoustic measurements the first All-Russian round-robin intercomparison of hydrophone calibration techniques in the frequency range 0,1 Hz to 200 kHz was undertaken in 1994 – 1997 years. All-Russian Scientific Research Institute for Physical-Technical and Radiotechnical measurements (VNIIFTRI) as a keeper of the primary standard launched this intercomparison.

The intercomparison that is made by calibration of measuring hydrophones is important for the estimation of uniformity and trueness of underwater acoustic measurements along with the correctness of uncertainty assessed by laboratory dealing with such measurements.

2. The hydrophones

Six hydrophones of two types (GI-20 and GI-21) were used for the calibrations – three of each type.

The hydrophones GI-20 and GI-21 were designed in our institute and have air-backed spherical piezoelectric ceramic active element, 20 mm and 10 mm in diameter respectively. Each one has a 10m long cable. The leakage resistance is greater than 200 MΩ, the GI-20's end-of-cable capacitance is 17-19 nF and the GI-21's - 4,5-5,2 nF. The nominal end-of-cable open-circuit sensitivity of the GI-20 is 200 dB (re

1 V/μPa) and of the GI-21 – 208 dB. The both types of hydrophone have no in-built preamplifier.

The hydrophones of GI-20 type were calibrated in the frequency range 0,1 Hz to 63 kHz, and of GI-21 type – 20 to 200 kHz.

Before intercomparison the work was undertaken in order to select the hydrophones. More than 30 hydrophones were investigated to satisfy the next criterions:

- the temporary instability of sensitivity was not to be more than ± 1 % per year
- the temperature instability of sensitivity was not to be more than ± 0,4 % per °C
- the frequency response was to vary less than 1 dB over any third-octave band
- the variation in sensitivity with angle was not to be more than 0,1 dB/ ° in any direction up to 15 ° from a reference axis.

All the hydrophones selected for the intercomparison exceed these criterions by 1,5 to 2 time.

3. Intercomparison procedure

All of the six hydrophones were circulated to twelve laboratories involved in defence, education, shipbuilding, state metrology activity. They determined the open-circuit end-of-cable sensitivity of the hydrophones on the third-octave frequencies using their normal calibration methods (most of the participants have several facilities using different calibration methods). These methods included [1-3]: variable pressure, hydrostatic exciter (one of the variable pressure type), piezoelectric compensation, air-water pistonphone, oscillating column, free-field reciprocity, comparison in a closed chamber.

The total frequency ranges for the methods mentioned are the next:

- variable pressure and hydrostatic exciter 0,1 Hz to 2 Hz
- piezoelectric compensation 0,8 Hz to 5 kHz
- air-water pistonphone 20 Hz to 200 Hz
- oscillating column 2 Hz to 500 Hz
- free-field reciprocity 500 Hz to 200 kHz
- comparison 0,1 Hz to 3,15 kHz.

It also should be noted that not all the facilities cover the whole frequency range for the method they use.

With the one exception all the participants performed the calibrations in laboratory tanks or closed chambers, in one case hydrophones were calibrated in the big lake.

Each participant was requested, alongside with the calibration data, to report the method, type of signal (single tone, noise, gated and so on), temperature during the calibration, signal-to-noise ratio, transducers arrangement, sound pressure value (if it was possible).

Each participant was to assess and report the measurement uncertainties both random and systematic. The uncertainties were to be estimated in accordance with the normative document.

Because of the large number of the participant and large number of the hydrophones the intercomparison had two sets each of approximately one year long. In order to check the hydrophones stability all of them was once more calibrated in VNIIFTRI between the sets.

4. Results and discussion

After all the reports was got the next values were calculated for each hydrophone: grand means averaged over all the facilities on each frequency, differences from the grand means for each facility, RMS differences from the grand means for each facility.

Table I shows the data calculated for each calibration facility (each facility has its own code, for example C2 means the 2-nd facility of the participant C): the mean differences averaged over the whole frequency range, maximum and RMS differences from the grand mean. Also the methods of calibration along with the total uncertainties (with 95 % confidence level) assessed by each participant are brought in this table.

It can be seen from the data presented in Table I that in the most of cases the maximum differences dodn't exceed the 1 dB. Only in five cases it was not so and it was only for the frequencies above 100 kHz where the hydrophones are at theirs most directional. This can be seen more clearly from Fig. 1. where the frequency dependencies of maximum and RMS differences from the grand means averaged over all the facilities are presented.

In general the low frequency methods reveal less differences than free-field reciprocity and it is not surprised because of the large number of difficulties that one meets in the last case. These difficulties is connected with the reflections from borders and from hydrophones mount elements, with the directional properties of hydrophones at high frequencies, with worse signal-to-noise ratio at frequencies below 10 kHz and some others.

Table I. The results of intercomparison for each facility given as the differences from the grand means averaged over all the facilities: the mean differences averaged over the whole frequency range, maximum and RMS differences. The total uncertainties are assessed with 95 % confidence level.

Facility code	Method of calibration	Mean Difference [dB]	Maximum Difference [dB]	RMS Difference [dB]	Total Uncertainty [dB]
A1	Method of hydrostatic exciter	- 0,15	- 0,21	0,04	0,2-0,3
A2		- 0,01	+ 0,28	0,14	0,2-0,3
J1	Method of variable depth	+ 0,17	+ 0,36	0,16	1,0
H3		- 0,12	+ 0,34	0,17	1,0
A3	Method of piezoelectric compensation	+ 0,10	+ 0,21	0,07	0,2-0,4
I1		+ 0,37	+ 0,51	0,09	3,0
H1		+0,01	+ 0,25	0,08	3,0
E1		- 0,28	- 0,41	0,15	1,0
C1		- 0,16	- 0,73	0,18	1,0
F1		+ 0,31	+ 0,44	0,08	1,0
G1		+ 0,17	+ 0,32	0,09	1,0
B1	Method of air-water pistonphone	+ 0,13	+ 0,15	0,01	0,2
K1	Calibration in a vibrating column of liquid	- 0,02	+ 0,29	0,14	1,5
A4	Free-field reciprocity method	+ 0,09	+ 0,82	0,22	0,2-0,4
A5		+ 0,26	+ 0,85	0,25	1,0
I2		+ 0,19	+ 1,66	0,60	3,0
H2		- 0,17	+ 0,55	0,27	3,0
E2		- 0,18	- 0,87	0,43	1,0
C2		+ 0,02	- 1,75	0,59	1,0
F2		+ 0,41	+ 1,09	0,22	1,0
D1		- 0,08	- 0,32	0,13	1,0
D2		- 0,17	- 2,04	0,62	1,0
L1		- 0,02	+ 0,44	0,28	1,0
A6	Method of comparison in small volume chamber	- 0,12	- 0,31	0,11	1,0

The mean difference can be treated as some estimate of systematic bias whereas RMS is the spread of this systematic bias. If it is so the sum and difference of mean difference and double RMS difference gives the idea about the borders of systematic shift the facilities with 95 % confidence level. As it follows from the data in Table I only for four facilities the value of borders exceeds 1 dB (I2, E2, C2, D2) and for no one this value exceeds 1,5 dB.

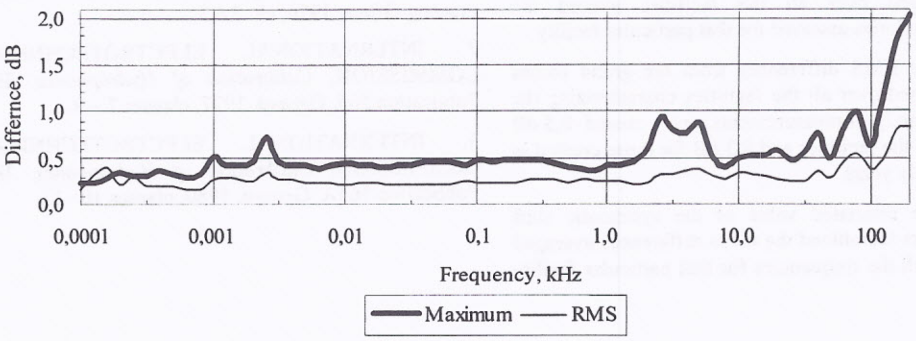

Fig. 1. Maximum and RMS differences from the grand mean averaged over all the facilities vs frequency for all the facilities.

Among all the facilities there are about fifteen created in recently years. They use more perfect techniques, computers, mathematics processing of signal and so on. Fig. 2 gives the data for these facilities.

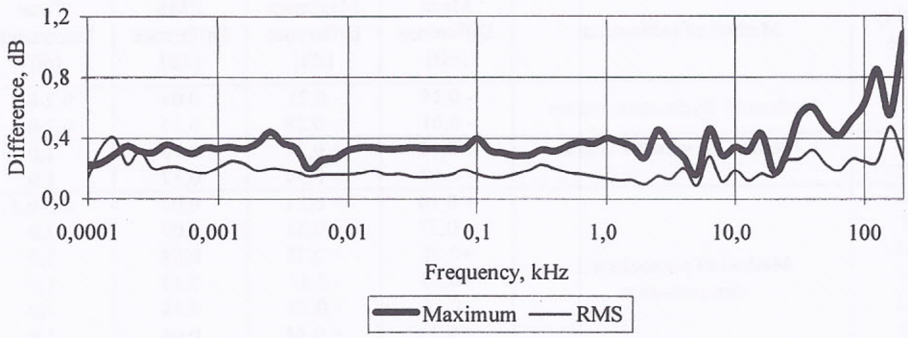

Fig. 2. Maximum and RMS differences from the grand mean averaged over all the newest facilities vs frequency for the newest facilities.

In Fig. 2. only in one case at one frequency – 200 kHz - the maximum difference slightly exceed 1 dB.

As far as the RMS differences is concerned they rarely exceed 0,5 dB for all the facilities and 0,3 dB for the newest facilities.

5. Conclusion

The first national round-robin intercomparison of hydrophone calibration undertaken in Russia in 1994 – 1997 revealed the state of the art in the underwater acoustic measurements.

Here is the main conclusions of the intercomparison:

- only in two from about thirty cases the maximum differences from the grand means averaged over all the facilities exceed the uncertainties assessed for that particular facility
- the RMS differences from the grand means averaged over all the facilities characterizing the uniformity of measurements rarely exceed 0,5 dB for all the facilities and 0,3 dB for those created in recently years
- the estimated value of the systematic shift borders (combined the mean differences averaged over all the frequencies for that particular facility and RMS differences from this mean) only for four facilities exceed 1 dB in several frequencies and was not more than 1,5 dB
- maximum differences from the grand means averaged over all the facilities only for five facilities exceed 1 dB and only for frequencies above 100 kHz
- the main difficulties is revealed when the free-field reciprocity method for hydrophone calibration is being used and it is the matter for further investigation
- in general the intercomparison confirmed the uniformity and trueness of hydrophone calibration in Russia.

References

1. R. Bobber, *Underwater Electroacoustic Measurements,* Washington (D.C.), USA, Goverment Printing Office, 1970, ch. 2.6.3.

2. INTERNATIONAL ELECTROTECHNICAL COMMISSION, *Calibration of Hydrophones,* IEC Publication 565, Geneva, 1977, clauses 7 – 9.

3. INTERNATIONAL ELECTROTECHNICAL COMMISSION, *Calibration of Hydrophones,* IEC Publication 565A, Geneva, 1980, clauses 10 –11.