Acoustics'08 Paris
June 29-July 4, 2008
www.acoustics08-paris.org

Low frequency hydrophone calibration with using tensometric pressure sensor

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Usually when calibrating hydrophone in acoustic coupler the piezoelectric hydrophones use as auxiliary transducer. Widely applicable reciprocity calibration is high-accuracy, but difficult in realization and laborious. The method of comparison with reference transducer is more simple and quick, but less accuracy. In the paper the method of low frequency hydrophone calibration with using the auxiliary transducer with flat frequency response up to 3 kHz is considered. The auxiliary transducer is calibrated high-accurately by change water column in acoustic coupler. It finally allows calibrate measuring hydrophones more accurately too. The measuring equipment on the basis of tensometric pressure sensor type MPX 5010 is considered.

1 The method of comparison in acoustic coupler

Now in Russia and in the world for graduation hydrophones on frequencies up to several kilohertz the measuring installations realizing a method of comparison in acoustic coupler are wide spread. The operating principle of such installations consists of transfer of the sound pressure unit size in a working frequency range to a graduated hydrophone by means of the special transducer built in the rigid chamber - a reference transducer with known sensitivity. By present time the method of comparison in acoustic coupler is well researched. Designs of acoustic couplers enough technically worked and their metrological properties are known, easily predicted and available for mathematical modelling.

The basic requirement for a traditional design of the acoustic coupler is its absolute rigidity. But it is difficult to provide rigidity and tightness of the acoustic coupler in a place of a hydrophone fastening. Sets of special gaskets are applied for this purpose. Different types of hydrophones have a rubber-like surface with the certain allowance of form and geometrical sizes that complicates their mounting into the acoustic coupler. The designs of hydrophones are individual and have no uniform standard. The nomenclature of graduated hydrophone is wide. It is necessary to apply many different and compound gaskets for each dimension-type of graduated hydrophones therefore. Work with the acoustic coupler requires high qualification operator. Mounting of each hydrophone into the acoustic coupler has specific features and is enough labour-consuming procedure. Often it is not possible to achieve satisfactory result from the first attempt. At the same time the acoustic coupler in a place of a graduated hydrophone mounting does not appear absolutely rigid. Infringement of rigidity of the acoustic coupler especially affects at low frequencies calibration. Elements of gaskets can keep in themselves air bubbles. All this leads to distribution of sound pressure in the acoustic couple which essentially differs from theoretical. There is a necessity of multiple remounting of a hydrophone into the acoustic couple. The accuracy of calibration decreases.

Now in practice piezoelectric hydrophones are very wide spread as reference transducers. However shortcomings of the piezoelectric hydrophones, for example such as high impedance, cause the certain difficulties at their use in measuring systems at low frequencies. The high input impedance of measuring devices causes their heightened sensibility to electric breakthroughs, toughens requirements to quality of insulating materials and requires application special measures for moisture protection input circuits for minimization leakage currents [1]. The reference transducers of piezoelectric type have considerable sensitivity nonuniformity of frequency dependence. So it is necessary to calibrate reference transducers in all operating frequency band. Laboriousness of measurements increases and the accuracy of calibration decreases. Therefore when creating the acoustic couples a problem of reference transducers improvement is very important. Application of the transducers on the basis of new technologies which will be without piezoelectric hydrophones shortcomings is very perspective.

2 Possibility of use a pressure sensor as a reference transducer

The recently achieved progress in creating tensometric pressure sensor allows to use hydrophones on their basis for measurement both static pressure and the pressure changing in a frequency range up to several kilohertz. A basis of a sensitive element in such hydrophones is tensometric pressure sensor at which a membrane thickness 5-15 microns located on an elastic substrate from silicon. Tensometric sensors usually have the built in amplifier to transform output signal to the industrial analog standard, the scheme of processing and the correction scheme of temperature drift of the converter parameters and also can use a supply voltage in wide enough range. The electronic scheme of processing in such sensor is integrated into a sensitive element and made simultaneously with it. Such technology allows making tiny sensors and gives ample opportunities at creation of measuring transducers [2]. All it enables to use tensometric pressure sensors for creation measuring hydrophones, particularly reference transducers.

3 The design of a reference transducer on the basis of the pressure sensor

As a basis for a reference transducer in a frequency range up to 4 kHz the pressure sensor Motorola type MPX 50-10 has been chosen. Highly linear dependence of output voltage on the pressure both static and variable up to several kilohertz is feature of the sensor. The sensor measures the constant pressure up to 400 kP and pulse pressure up to 1000 kP. Sensitivity of its converter changes no more than on 1,8 % in a range of temperatures from 0 up to 85 °C. Operating temperature range is from -40 up to 125 °C. The sensor has the protective plate to save a sensitive membrane from mechanical damages. There is a special hole in the protective plate for connecting membrane cavity with an environment in such sensor. The size of a hole which is no more than 1 mm in diameter, defines the top border of a sensor frequency range (several Hz). During designing the model of reference transducer for expansion the operating frequency range the protective plate was removed then the sensitive membrane was tightened by silicon hermetic.

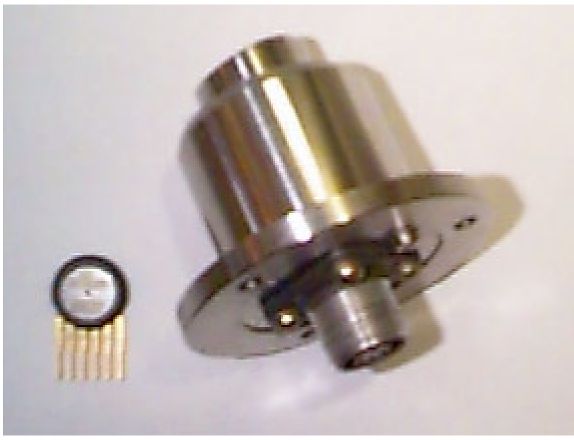


Fig.1 The pressure sensor Motorola type MPX 50-10 and the reference transducer.

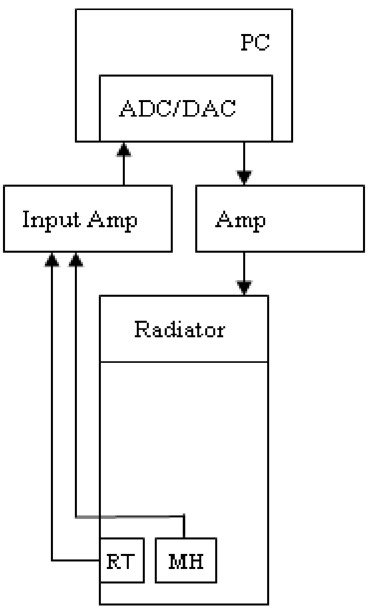
Structurally reference transducer is a metal cylinder in which the sensor is mounted. There is the connector for connecting with external devices at an opposite side of a cylinder.

4 The design of the installation with a reference transducer on the basis of the pressure sensor

The installation realizes a method of comparison with reference transducer in which sensitivity of measuring hydrophone Mmh defines under condition of influence on measuring hydrophone and reference transducer identical acoustic pressure by equation:

$$M_{mh} = M_r * U_{mh} / U_r \quad (1)$$

M_r - sensitivity of reference transducer,
U_{mh} - voltage of measuring hydrophone,
U_r - voltage of reference transducer.



.Fig.2 The block diagram of installation.

During calibrating measuring hydrophone by method of comparison for creating the variable pressure in the acoustic couple the electrodynamic radiator is used. The sine wave signal from DAC comes to the amplifier and then to the electrodynamic radiator of the acoustic couple. Variable pressure influences on water surface in cavity of the acoustic couple and creates a standing sound wave in water. This pressure is perceived by located in immediate proximity from each other measuring and reference transducer on the basis of the tensometric pressure sensor. The signals from outputs of the measuring hydrophone and reference transducer come to the input amplifier which switches and amplifies measured signals. Then signals come to ADC and transform to the digital form. Discrete signals from ADC come to PC for final processing and amplitudes determination of signals Umh and Ur. Sensitivity Mmh of a measuring hydrophone defines by equation (1).

The case of the acoustic couple is a stainless steel cylinder with the thick walls. The internal cavity of the acoustic couple has diameter of 73 mm, at external diameter of the case of 175 mm and its height is 670 mm. The cavity of the acoustic couple is filled approximately on ¾ with water. A measuring hydrophone is mounting in the special holder which represents a latticework, and aligned in it by special clamps. It provides a positioning of measuring hydrophone in a cavity of the acoustic couple relative to walls and a reference transducer. Then the holder with a measuring hydrophone plunges into a cavity of the acoustic couple. After that the quantity of water in the cavity is necessary to increase so that its level did not reach the top edge of the acoustic couple approximately on 1 cm. The cable of a measuring hydrophone is passed through the mouth of the acoustic couple where gaskets from the porous rubber are imposed for tightness and prevention of cable pressing. Through these gaskets to the mouth of the acoustic couple the electrodynamic radiator of acoustic signal fixes. The electrodynamic radiator fixes by screws to the special cover closing the acoustic couple for sound insulation of a laboratory room. The electrodynamic radiator with a cover through gaskets fixes by brads to the case of the acoustic couple. The reference transducer on the basis of the tensometric pressure sensor is screwed in a lateral wall of the acoustic couple. The acoustic couple is placed on a floor of a laboratory room by special adjustable on height supports.

5 The experimental researches of the reference transducer on the basis of the tensometric pressure sensor

Experimental researches in VNIIFTRI (the All-Russian Research Institute of Physical-technical and Radio-technical Measurements) on the state standard of sound pressure unit in the aquatic environment of the reference transducer in which the element on the basis of the pressure sensor Motorola type MPX 50-10 was used as the converter from acoustic pressure to electric signal have shown, that sensitivity of such hydrophone practically does not depend on frequency. Changes of the amplitude-frequency characteristic of sensitivity of such hydrophone in a range of frequencies from 0,1 Hz up to 3,15 kHz have not exceeded a measurement error of the standard operating in this frequency range. On the other hand, tensometric sensor unlike piezoelectric hydrophone has not significant dependence of resistance on frequency at the frequencies below 4 kHz. It is caused by the characteristic size of tensometric sensor membranes of 1 mm and 5 micrometer thickness. Theoretical calculations give value for resonance frequency Fr for such membranes of the order of 40 kHz. In addition, piezoelectric hydrophone can have the dispersion of capacity and conversion ratio - leakage impedance. So there are all reasons to suppose, that in frequency range below Fr/10 tensometric sensor has no frequency dependence of sensitivity.

Unlike piezoelectric hydrophone, tensometric sensor functions at change of static pressure. It allows calibrate tensometric sensor by absolute method more accurately at change of static pressure, attaching a measure unit of pressure to the standard of static pressure.

In the acoustic couple for calibration a reference transducer on the basis of the tensometric pressure sensor the absolute method can be used, because output voltage on sensor directly proportional to static pressure on it. Change of static pressure in the acoustic couple (change the height of a water column) can be defined by the linear sizes of internal cavity of the acoustic couple. The sizes definition accuracy of internal cavity of the acoustic couple is 0,1 mm. So the accuracy of water column height measurement in the cavity of the acoustic couple is 0,1 mm too.

At practical realization of this calibration method the metal cylinder which plunged into water in the internal cavity of the acoustic couple was used. The height of water column in the internal cavity increased. So static pressure in the acoustic couple and output voltage constant component of a reference transducer increased.

It is known, that

$$\Delta P = \rho g \Delta h,$$

ΔP – increase of pressure in the acoustic couple after the cylinder plunging,
ρ – water density,
g – acceleration of gravity,
Δh – increase of water column height in the acoustic couple.

Taking into account the volume of cylinder and the area of a water surface in the internal cavity of the acoustic couple, we have

$$\Delta h = (D1 / D2)^2 \, h1,$$

D1 – cylinder diameter,
D2 – the internal cavity diameter of the acoustic couple,
h1 – cylinder height.

Sensitivity of the reference transducer is $M = \Delta U / \Delta P$. The reference transducer output voltage was measured by the voltmeter and ADC.

After the sensitivity of reference transducer has been measured, there was the calibration of measuring hydrophones with its help by the method of comparison in frequency range from 1 Hz up to 3,15 kHz. Measuring hydrophones sensitivity in all frequency range was defined on the basis of the reference transducer sensitivity, which was defined by the change of static pressure. For frequency properties research of measuring installation on the basis of tensometric pressure sensor the hydrophones have been selected with the known and well studied frequency characteristics of sensitivity. There were calibrations of hydrophones GG2 type by two installations: by installation with a reference transducer on the basis of tensometric pressure sensor (curve 2) and by the installation with a reference transducer on the basis of a piezoelectric hydrophone (curve 1).

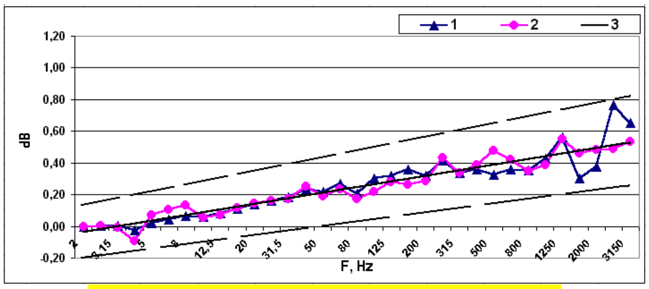


Fig.3 Calibrations of hydrophone GG2 type.

The monotonous increase of sensitivity which is characteristic for hydrophones GG2 type, can be up to 0,6 dB at frequency range from 2 Hz up to 3,15 kHz. In this frequency range dependence of hydrophone GG2 type sensitivity, which was defined by the method of comparison by the measuring installation on the basis of pressure sensor, the slanting line defined by the least-squares method (line 3) describes with a high degree of reliability. The deviation of values hydrophone GG2 type sensitivity from this line (its borders are designated by dashed lines) in all frequency range is ± 0,15 dB and does not more than the accuracy of hydrophone GG2 type calibration in acoustic couple. So fluctuations of values hydrophone GG2 type sensitivity relative to slanting line are usual for hydrophones such type because of the accuracy of measurements in the acoustic couple and not connected with possible non-uniformity of the sensitivity frequency characteristic of a reference transducer on the basis of tensometric pressure sensor. The similar results were obtained during measuring the sensitivity of other types hydrophones, for example GI20 type.

5 Conclusion

During the work the reference transducer of new type for acoustic couple was created. It has the best operating and accuracy characteristics unlike widespread now piezoelectric type hydrophones. Principles of its calibration by the absolute method directly in the acoustic couple and calibration of measuring hydrophones on the installation using as a reference transducer tensometric pressure sensor were considered. Created in VNIIFTRI on the basis of such reference transducer measuring installations are starting now to introduce in Russia actively.

References

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[2] I.A. Shumcky «Clever» sensors or physical quantities – the nearest future of measuring systems. // Checking and measuring device and system №1, 2000.