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A Technical Discussion about COOMET Pilot Comparison Resulsts of Sound Pressure Sensitivity and Sound Pressure Gradient Sensitivity in Frequency Range 5 Hz to 400Hz

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ABSTRACT

A COOMET Pilot Comparison (COOMET/RU/646) of particle velocity receiver was performed between Hangzhou Applied Acoustics Research Institute (HAARI) and Russian National Research Institute for Physicotechnical and Radio Engineering Measurements (VNIIFTRI). In frequency range 5 Hz to 400 Hz, the reference particle velocity receiver of VHS90 manufactured by HAARI was calibrated using comparison method in the calibration facilities of participants. The reference particle velocity receiver, the calibration method and the calibration facilities used by participants are introduced. The sound pressure sensitivity and sound pressure gradient sensitivity of VHS90 were measured by participants, and the key comparison reference value (KCRV) were calculated and the degree of equivalence of participants showed that there were no significant discrepancies detected in the 60 1/3 octave frequency points of sound pressure sensitivity and sound pressure gradient sensitivity. Besides, the deviation of sound pressure gradient sensitivity between participants would be less than the deviation of sound pressure sensitivity in most frequency points, which are caused by the different sound waveguide in standing wave tube of participants.

Keywords: COOMET Pilot Comparison, Particle velocity receiver, Calibration
I-INCE Classification of Subject Number: 72

1. INTRODUCTION

Particle velocity receiver is a new kind of underwater sound receiver born in the 20th century, and it can measure the underwater vector parameter (oscillation velocity, oscillation acceleration and sound pressure gradient) and scalar parameter (sound pressure) in the sound field at the same time. Before using of it, particle velocity receiver needs to be calibrated in laboratories, which will make sure it can measure the sound parameter accurately in practice.

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To avoid disagreement between particle velocity receiver measurements performed in different countries, a COOMET Pilot Comparison (COOMET/RU/646) between Russian National Research Institute for Physicotechnical and Radio Engineering Measurements (VNIIFTRI, DI, CIPM MRA, Russia) and Hangzhou Applied Acoustics Research Institute (HAARI, DI for Underwater Acoustics, China) was performed in the frequency range from 5 Hz to 10 kHz, which is the first international metrology comparison of vector quantities in sound field of water between the national standards.

As well known, the particle velocity receiver is generally based on the principle of sound wave transmission in the water, and the parameters, such as oscillation velocity, oscillation acceleration, sound pressure and sound pressure gradient could be calculated according to the relationship between them through the sound wave equation. In this COOMET Polit Comparison, the reference particle velocity receivers have been calibrated by calibration facilities of participants using traditional comparison method in standing wave tube in frequency range 5 Hz to 400 Hz and the primary three-transducers reciprocity calibration method in free-field in frequency range 500 Hz to 10 kHz [1~4]. The reason of using two calibration methods is that single method couldn't cover the calibration frequency range from 5 Hz to 10 kHz.

The comparison method in standing wave tube is a traditional calibration method of particle velocity receiver in low frequency range. The calibration method and the calibration facilities of participants are introduced in this paper, which are used to calibrate the VHS 90 reference particle velocity receiver. The calibration results are analysed in the end of the paper. However, the sound waveguide distribution would be different in participants' calibration facilities, and the same sound pressure will have different sound pressure gradient, which will have a little influence on the calibration results. The results show that the sensitivities of sound pressure gradient of participants are more agreeable than sensitivities of sound pressure in most frequency points.

2. CALIBRATION METHOD AND FACILITIES

2.1 Calibration Method

The particle velocity receivers are calibrated in standing wave tube which is an open chamber and filled with water. The calibration facility is driven by an electrodynamic transducer or a vibration generator at the bottom of the it [5~6].

The standing wave will be produced in the chamber. At the depth h of the water, the complex pressure shall be calculated by:

$$\boldsymbol{p}_h = Ae^{jkh} + Be^{-jkh} \tag{1}$$

Where $\boldsymbol{p}_h$ is the complex sound pressure at a depth h, k is wavenumber inside the waveguide of chamber and $k = 2\pi f / c$, c is the sound phase velocity inside the waveguide, f is frequency of sound in water.

On the boundary of air and water, the magnitude of sound pressure is equal to zero, and on the bottom of the chamber, the magnitude of sound pressure is equal to p_L. The depth of water in the chamber is L. The amplitude of sound pressure at depth h could be calculated by the preface acceleration of transducer or vibration generator at the bottom of the chamber in equation (2):

$$p_h = \frac{\rho}{k} a_L \frac{sin(kh)}{cos(kL)} \tag{2}$$

Where, ρ is density of water, a_L is the preface acceleration magnitude of transducer or vibration generator at depth L.

The sound pressure reference hydrophone is used in the comparison method in standing wave tube, whose sensitivity of sound pressure was measured before, and the sound pressure at any depth x of the chamber is measured. The magnitude of sound pressure at depth of h could be expressed in equation (3).

$$p(h) = \frac{U_x}{M_x}\frac{sin(kh)}{sin(kx)} \tag{3}$$

Where, U_x is the open circuit of reference hydrophone, and M_x is the sensitivity of reference hydrophone.

The sound pressure sensitivity M_P and sound pressure gradient sensitivity M_G of particle velocity receiver at depth of h can be calculated in equation (4) and (5), where the U_G is the open circuit voltage of reference hydrophone.

$$M_p = \frac{U_G M_x}{U_x}\frac{sin(kh)}{cos(kx)} \tag{4}$$

$$M_G = \frac{U_G M_x}{k \cdot U_x}\frac{sin(kh)}{cos(kx)} \tag{5}$$

2.2 Calibration Facilities

2.2.1 Calibration Facility Used by HAARI

The sensitivity of vector channel of the VHS90 was calibrated in Particle Velocity Receiver Calibration Facility of HAARI using comparison method in standing wave tube. The schematic diagram of this facility is shown in Figure.1 [6]. During the measurement, the reference hydrophone and particle velocity receiver were positioned at the depth of 0.14m in water through calibration position system in the standing wave tube. The computer controlled the lock-in amplifier to transmit the continuous signal to drive the transducer at the bottom of the tube to transmit sound signal. The sound signal was received by particle velocity receiver and reference hydrophone at the same time, and the open circuit voltage signal of particle velocity receiver and reference hydrophone were filtered by filter and measured respectively by lock-in amplifier. The expanded uncertainty (with a coverage factor of k = 2) for calibrating particle velocity receiver in the frequency range from 5 to 400 Hz was estimated to be no greater than 1.0 dB.

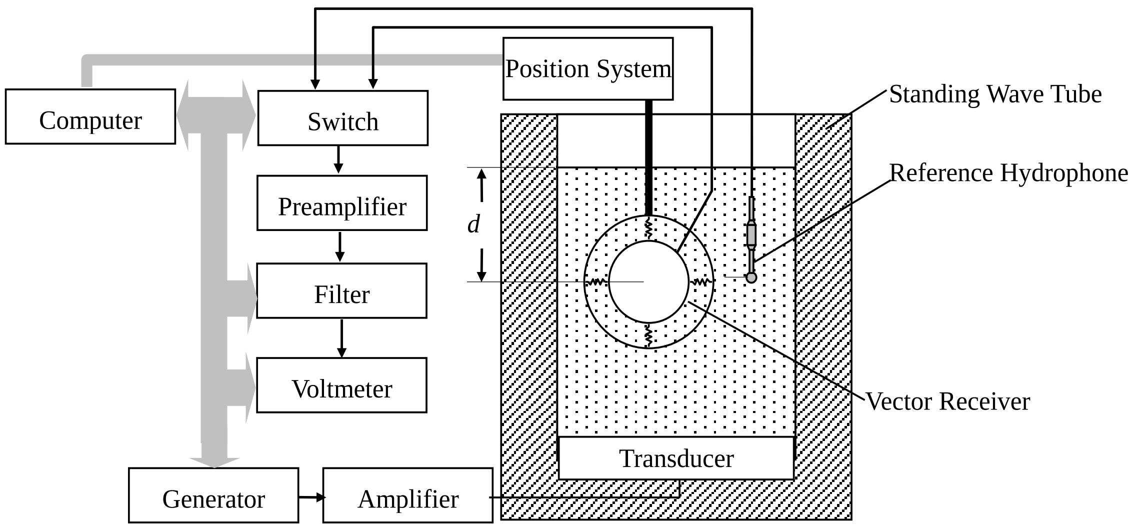


Figure.1 The schematic diagram of Particle Velocity Receiver Calibration Facility of HAARI

2.2.2 Calibration Facility Used by VNIIFTRI

Figure.2 shows a schematic diagram of calibration facilities using comparison method with a reference hydrophone in the sound field of a standing wave (vibrating water column method). Using the positioning system, the particle velocity receiver to be calibrated and the reference hydrophone were positioned at a depth of 0.15 m in the measuring chamber with a height of 0.70 m, inner and outer diameters of 0.2 m and 0.3 m respectively. The distance between the oscillating piston mounted in the bottom of the chamber and the particle velocity receiver was 0.50 m. The sound signals at a given frequencies were radiated through oscillating piston on the bottom of the chamber. The expanded uncertainty (with a coverage factor of $k = 2$) for calibrating a particle velocity receiver in the frequency range from 5 to 400 Hz was estimated to be no greater than 0.8 dB.

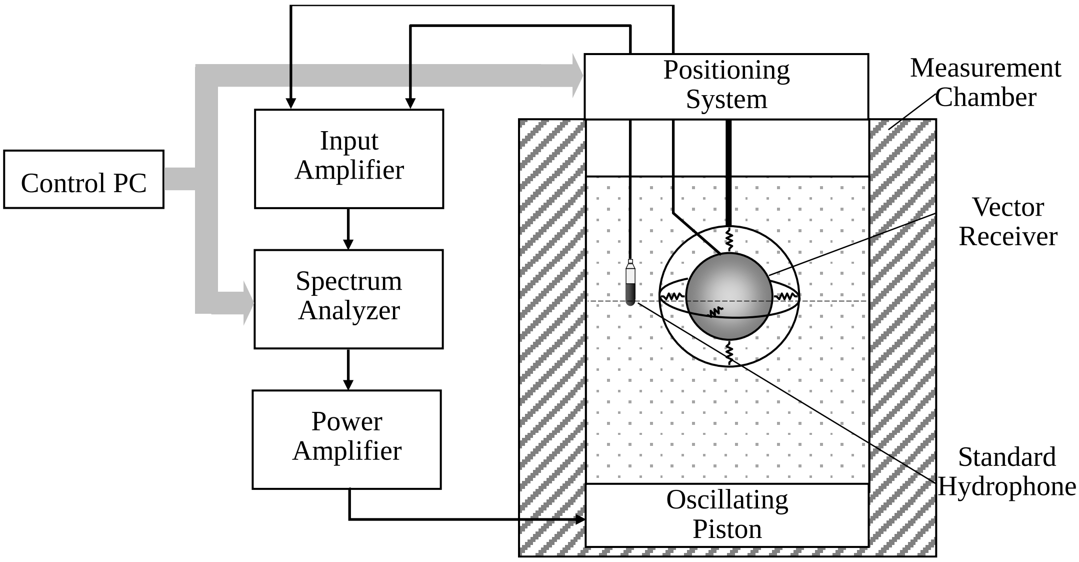
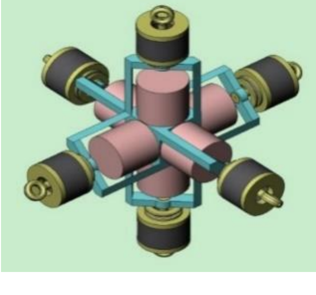


Figure.2 The schematic diagram of vibrating water column method facility of VNIIFTRI

3. REFERENCE PARTICLE VELOCITY RECEIVER

In this Pilot Comparison, the VHS90 manufactured by HAARI was used as reference particle velocity receiver in frequency range 5 Hz to 400 Hz. There are three pairs of vector sensor set in three orthogonal directions in VHS90 and these sensors and their preamplifiers are fixed onto a base metal block and sealed into a 90 mm diameter polymer ball. Figure.3 (a) and (b) show the structure diagram and photo of the VHS90 particle velocity receiver. The VHS90 particle velocity receiver is supplied by a 12V direct current (DC) power and the signals from three pairs of sensors will be output separately through a multi-core cable. To keep a particle velocity receiver in suitable orientation in application, the particle velocity receiver needs to be fixed on the rings through elastic, which make sure the particle velocity receiver is fixed and oscillating with water together and freely. The measured direction of it is vertically in standing wave tube as the Figure.3 (c) shown.



(a) Structure of VHS90

(b) Photo of VHS90

(c) The VHS90 particle velocity receiver fixed on the ring in standing wave tube

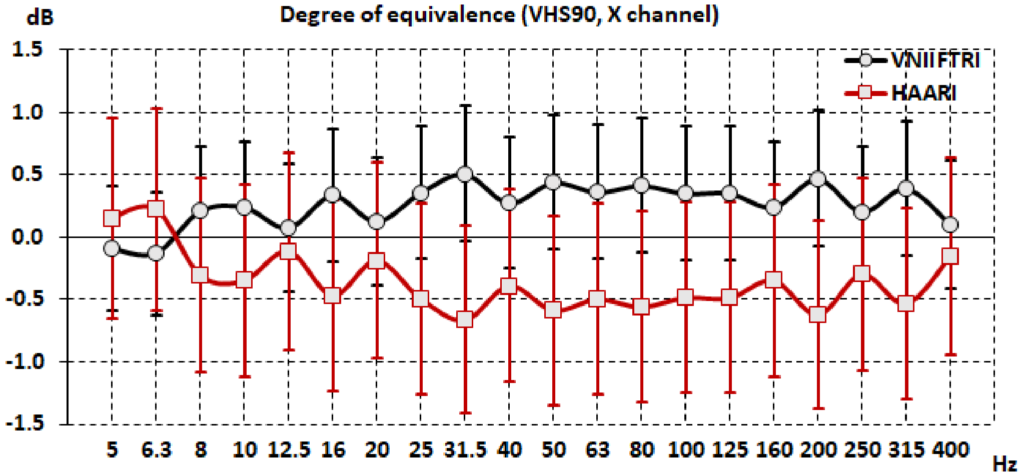
Figure.3 The structure diagram and photo of VHS90

4. CALIBRATION RESULTS AND DISCUSSION

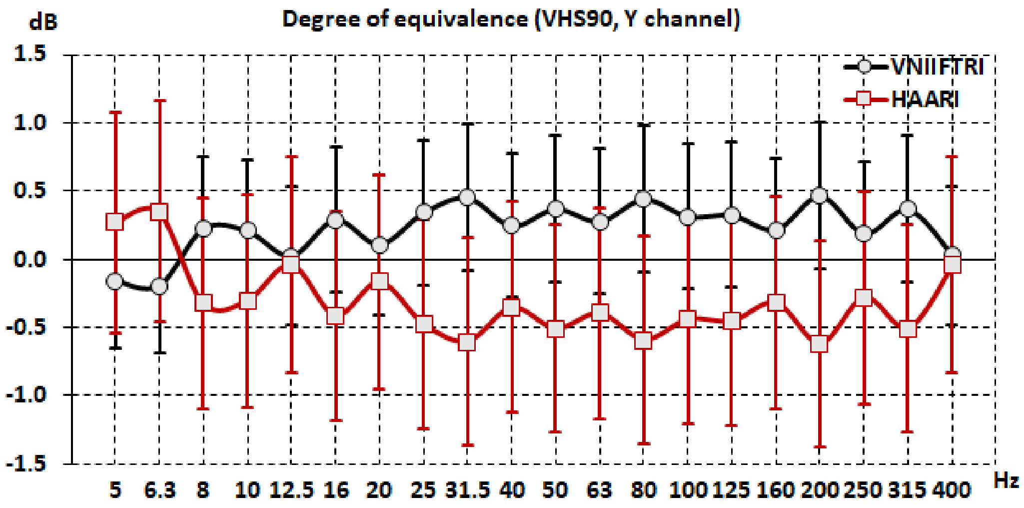
The VHS90 reference receiver was calibrated by HAARI and VNIIFTRI using their different calibration facilities separately. The calibration results are analysed in the following [8].

4.1 Sound Pressure Calibration Results

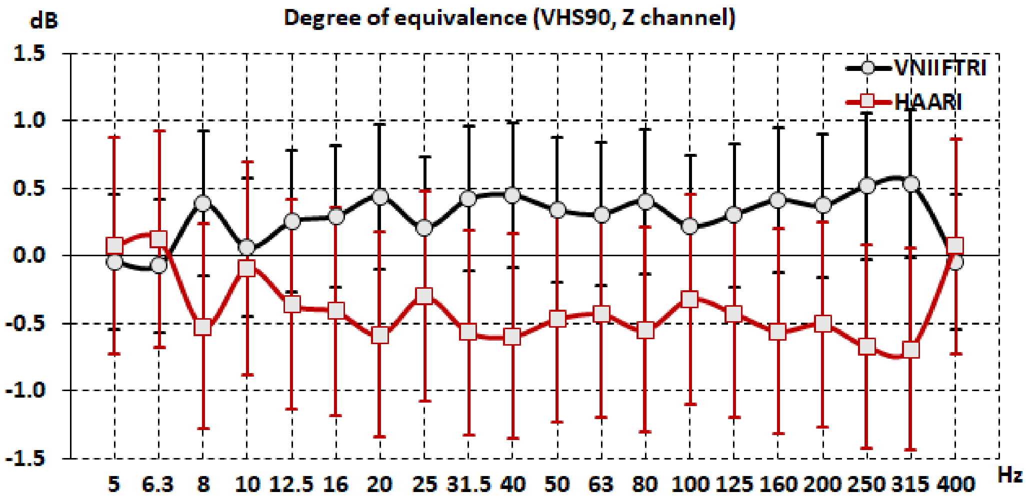
The sensitivities of sound pressure could be measured directly using equation (4). The KCRV of calibration results of participants are calculated and the degree of equivalence of VHS90 three channels of participants are shown in Figure.4. The results show that the sound pressure sensitivities of three channels of VHS 90 are congruency and the calibration results of both participants is accordant. There were no significant discrepancies detected in all 60 1/3 octave frequency points.



(a) Degree of equivalence of channel X



(b) Degree of equivalence of channel Y



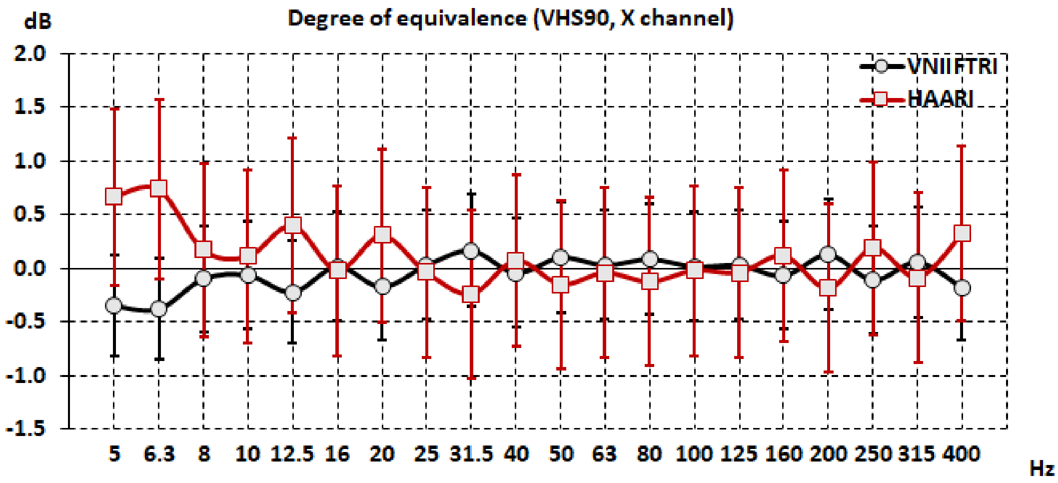
(c) Degree of equivalence of channel Z

Figure.4 Degree of equavalence of three channels of sound pressure sensitivities

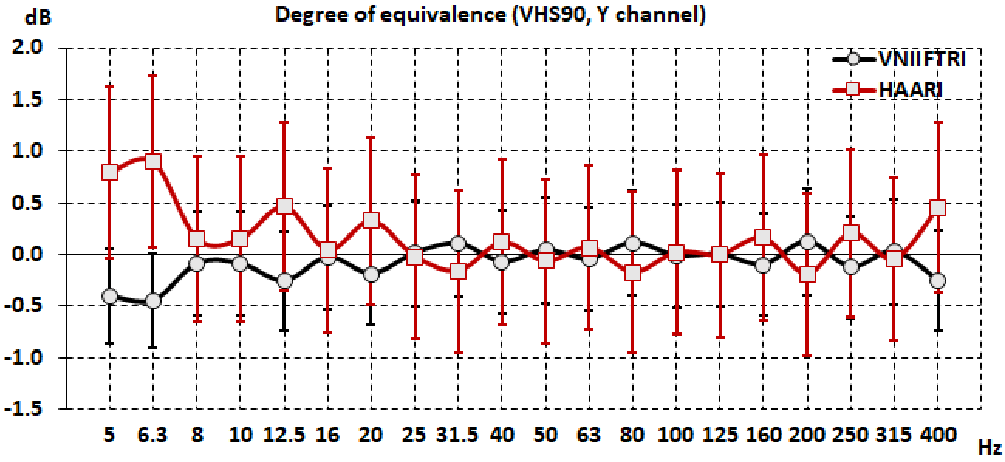
4.2 Sound Pressure Gradient Calibration Results

Because of the reference sound pressure hydrophone used in the particle velocity receiver calibration, the sensitivity of sound pressure gradient could not be measured directly. The sensitivity of sound pressure gradient could be calculated by equation $M_P = M_G \cdot k$ as the equation (4) and (5) shown. The participants used calibration facilities which has different sound pressure and sound pressure gradient distribution in waveguide of standing wave tube. All these will cause that they have different wavenumber in the waveguide of their calibration facilities. The KCVR of sound pressure gradient and the degree of equavalence of sound pressure gradient are shown in Figure.5.

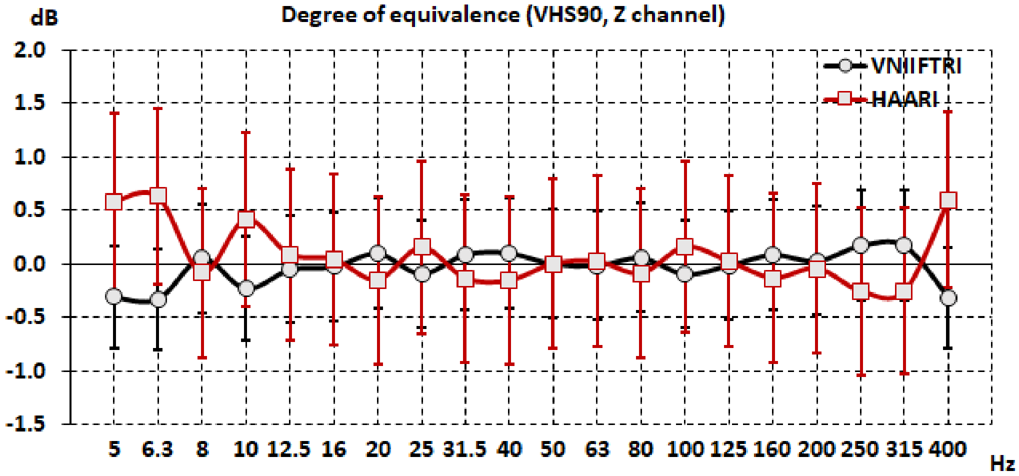
There also no significant discrepancies detected in all frequency points except 6.3 Hz in channel Y calibration and the deviation is only 0.05 dB, which will have little effect and could be ignored. Compared with the calibration results of sound pressure sensitivities, degree of equivalence of sound pressure gradient sensitivities of participants are more less than sound pressure sensitivities in most frequency points, which means that the calibration results of sound pressure gradient sensitivities are more agreeable.



(a) Degree of equivalence of channel X



(b) Degree of equivalence of channel Y

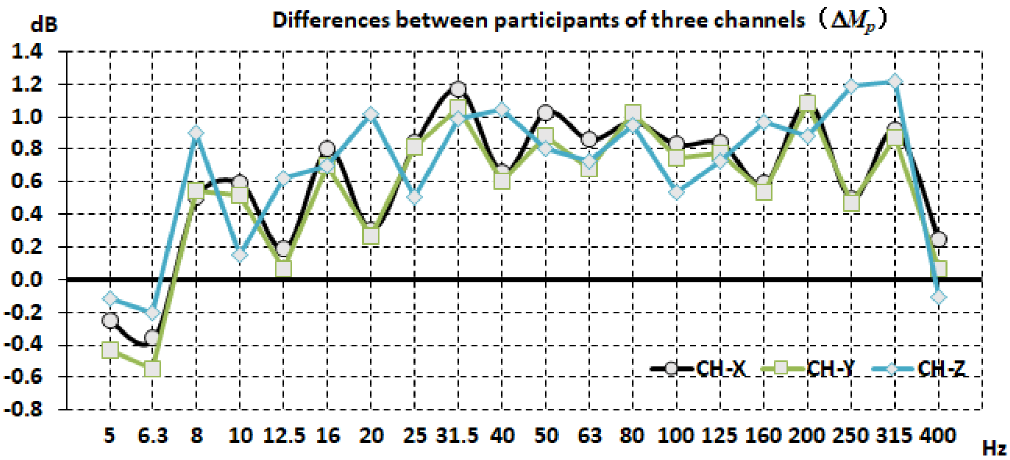


(c) Degree of equivalence of channel Z

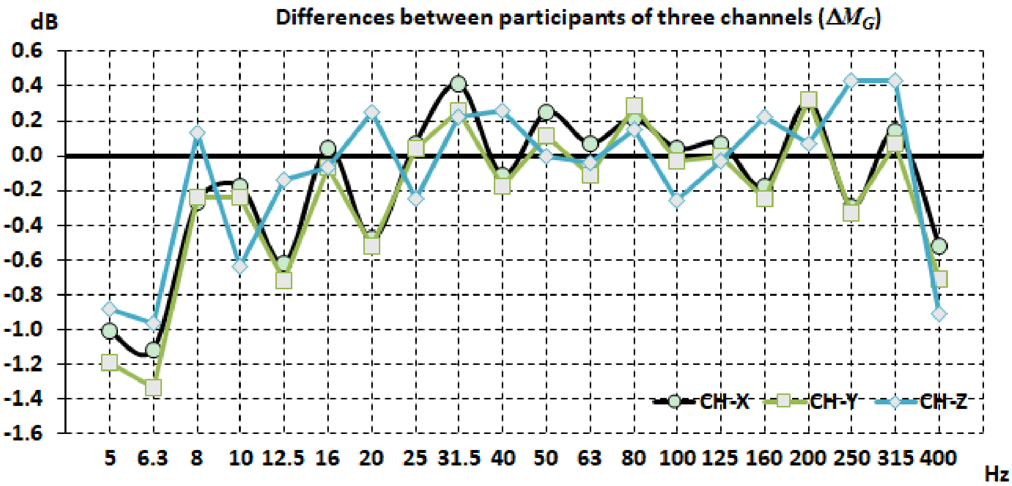
Figure.5 Degree of equavalence of three channels of sound pressure gradient sensitivities

4.3 Discussion of Calibration Results

To have an analysis about the calibration results of sound pressure sensitivity and sound pressure gradient sensitivity, the differences of sensitivity between participants are calculated in the equation: $\Delta M = M_{RU} - M_{CN}$, where M_{RU} is the calibration results of VNIIFTRI and M_{CN} is the calibration results of HAARI. ΔM_p is the difference of sound pressure sensitivity and ΔM_G is the difference of sound pressure gradient sensitivity. The differences of three channels of particle velocity receiver are shown in Figure.6.



(a) Differences of participants of sound pressure sensitivities



(b) Differences of participants of sound pressure gradient sensitivities

Figure.6 Differences of sensitivities between participants of three channels

In the Figure.6, the differences of sound pressure sensitivities is larger than the differences of sound pressure gradient sensitivities, which seems to be like a significant fixed deviation in most frequency points of sound pressure sensitivities, although there are all no significant discrepancies in all these frequency points. Here, the explains are tried to be given about the phenomenon of the deviations of calibration results between sound pressure and sound pressure gradient. The inner sensor of VHS90 particle velocity receiver is vector sensor, which is sensitive to vector parameter underwater. However, in the standing wave tube calibration, what must be done is to convert the vector parameter measured by particle velocity receiver to sound pressure and compared with reference hydrophone whose sound pressure sensitivity was measured before. Because of different calibration facilities were used in this COOMET Polit Comparison, sound pressure distribution in standing wave tube is complex and the waveguide is different in facilities of participants. The wavenumber k is equal to $2\pi f/c$ and c is the vertical phase velocity of sound in the chamber of calibration facilities. In the chamber of HAARI, the velocity of it is 1400 m/s, and in the chamber of VNIIFTRI, the phase velocity of it is 1280m/s, which would cause the calibration deviation of participants. This is the reason that the sound pressure gradient sensitivities of participants are more agreeable than sound pressure sensitivities in COOMET Pilot Comparison.

5. CONCLUSIONS

According to the calibration results and analysis above, the following conclusions can be drawn:

The calibration results of COOMET Pilot Comparison between HAARI and VNIIFTRI in frequency range 5 Hz to 400 Hz are analysed in this paper. The results show that the VHS 90 particle velocity receivers is stables and reliable, the sensitivities of three channels is congruency.

There are no significant discrepancies in all 60 frequency points of sound pressure sensitivities and sound pressure gradient sensitivities in frequency range 5 Hz to 400 Hz, which proves the calibration method is correct and calibration facilities of participants is accurate and stable.

The coherence of calibration results of sound pressure gradient sensitivities is better than sound pressure sensitivities in most frequency points. The reason of it is analysed, which is caused by the complex waveguide in the standing wave tube. In different waveguide, as for the same vector parameter, such as oscillation velocity, oscillation acceleration and sound pressure gradient, when they are converted to sound pressure, the wavenumber *k* must be considered, which would have an influence on the sensitivity of particle velocity receiver.

6. ACKNOWLEDGEMENTS

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