Applied Acoustics 103 (2016) 102–109

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

A method for testing phased array acoustic Doppler velocity log on land

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A R T I C L E I N F O

Article history:
Received 20 October 2014
Received in revised form 14 June 2015
Accepted 15 October 2015
Available online 30 October 2015

Keywords:
Phased Array acoustic Doppler Velocity Log
Phased Coupling Array Method
Misalignment angles
Eccentric error

A B S T R A C T

As Phased Array acoustic Doppler Velocity Log (PADVL) is widely used on oceanographic vessels and other platforms, it is necessary to provide a systematic examination on land. A Phased Coupling Array Method (PCAM) is proposed in this paper. When one Phased Array (defined as PA I) is placed face to face with array of PADVL (defined as PA II), simulating echo signals can be coupled from PA I into PA II. By the comparison between the predetermined parameters of the simulating echo signals and the measuring results from PADVL, the status of PADVL can be confirmed and a more reliable, comprehensive and convenient examination on land can be realized. Model of the signal interaction between the two arrays is established. And two main sources of error, i.e. misalignment angles and eccentric error are examined. The results show that: misalignment angles have small influence on the coupling performance; ideal coupling performance can be received when misalignment angle $|\beta| \leqslant 3^\circ$, $|\gamma| \leqslant 3^\circ$, $|\alpha| \leqslant 6^\circ$, and eccentric error Δx, $\Delta y \leqslant 2\lambda$. The measured results from the prototype are consistent with the simulation, which further verifies the proposed method.

1. Introduction

Acoustic Doppler Velocity Log (DVL) can measure the velocities relative to the bottom or water layers on the basis of the Doppler effect. As a high-precision speeding instrument, DVL is widely used in ocean observations, surface and underwater navigation et al. [1–7]. With the marine being explored further, a more reliable, extensive and convenient detection method is needed for DVL, especially when DVL is applied in AUV, UUV. For example, the status of DVL cannot be confirmed when the platform is debugged or maintained on land, especially when its assemblage and airtight detection have been done, which will lead to some uncontrollable risks. In addition, DVL also needs to be tested at the factory. Up to date, three general approaches are available for the test. The first one is the test in tanks, which can only test limited aspects of the system. The second one is the test during voyaging, which can provide much information, realizing a systematic test, but it is expensive and DVL must be taken off from the applied platforms. The third one is the test using an analog signal module linked directly with the signal processing unit of DVL. Since the third method ignores the influence of the array, it will reduce the reliability of the measuring results. Therefore, we are dedicated to search a more convenient and reliable method on land.

For DVL with Janus configuration, people have realized the test on land by placing four individual transducers face to face with transducers of DVL. In this way, the simulating echo signals can be fed back to DVL [8–10]. For PADVL, similar method can also be used for its test on land [11,12]. They use one receive piston transducer (dark color) to receive the radiating signals from PADVL for synchronization; and 16 transmit piston transducers (light color) to feed simulating echo signals back to PADVL. As shown in Fig. 1. The array of PADVL is composed of lots of elements arranged in a certain pattern. When each element in the array is driven with the same signal except for a phase shift, which is constant for a given frequency and element spacing, four beams can be obtained in receiving or radiation modes simultaneously. Therefore, simulating echo signals generated by limited transducers cannot be in agreement with the working mechanism of PADVL exactly [13,14].

In this paper, a new method using one phased array to simulate the working environment of PADVL is introduced (named as Phased Coupling Array Method (PCAM)). With the PA I and PA II placed face to face, the generated programmable electrical waveforms which correspond to the echo signals of the acoustic backscattered field of PADVL are fed back from PA I to PA II. By the comparison between the predetermined parameters of the electrical waveforms and the measuring results from PADVL, the status of PADVL can be confirmed, realizing the test on land under controlled velocity, depth and other backscattering conditions, which is more reliable, comprehensive and convenient. Comparing with the conventional

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http://dx.doi.org/10.1016/j.apacoust.2015.10.014

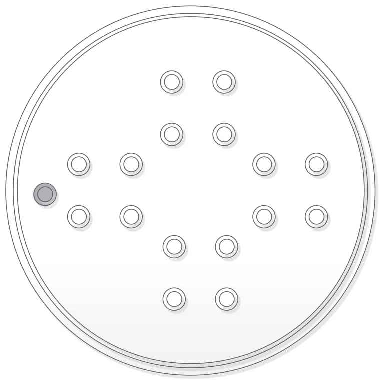

Fig. 1. The front view of PA I in Ref.

method, the PCAM technique has several merits. Firstly, PA I can receive the individual signals along four specific beam directions radiated from PA II and radiate the simulating echo signals in phased mode, which can verify the beam-forming function in transmit and receive units of PADVL respectively. The beam-forming functions are one of the most important parts for PADVL. It is necessary to provide these kinds of test for a systematic examination on land. Secondly, the simulated echo signals from PA I are radiated along the specific off-vertical directions, which can decrease the cross talk attenuation to the neighbor and opposite beam. Thirdly, the method can simultaneously forms four beams, each of which can radiate signals with different delays and Doppler shifts, to meet the actual working environments. Fourthly, since the two coupling arrays are identical with each other, it needs not to re-design a new one (array of other PADVLs can meet the requirements). In this paper, the front view of the array generating the echo signals is shown in Fig. 2. 1256 individual piston transducers arranged in the array are analyzed as an example. The transducers in the array are arranged in a 40 element diameter circular pattern and spaced at a distance about 1/2 wavelength.

In Section 2, the principle and model of the signal interaction between two phased arrays placed face to face is presented. In Section 3, the performance of PCAM influenced by coupling deviations (misalignment angles and eccentric error) is analyzed. In Section 4, a prototype is built to verify the proposed method.

2. Principle and model

2.1. Principle of phased array

Before continuing, one-dimensional plane phased array as an example is analyzed to illustrate the principle of phased array.

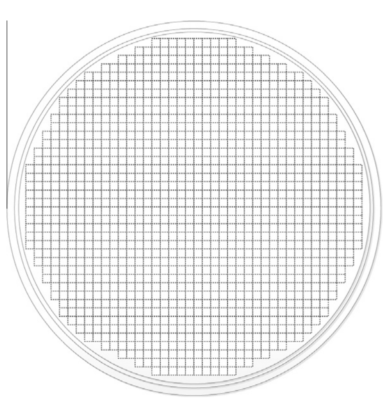

Fig. 2. The front view of PA I in this paper.

The array is viewed as an equally spaced linear array with same element sensitivities to make it easier to be understood (For circular boundary array, it can be viewed as an equally spaced linear array with different element sensitivities) [15–17].

Assuming: $N = 32$ is the element number in the linear array; d is the center spacing of adjacent element ($d = \lambda/2$, λ is the wavelength). According to the product directivity theorem, the linear array can be divided into three level sub-arrays, as shown in Fig. 3. Firstly, N elements are divided into four identical sub-arrays with $N/4$ elements. The element center spacing of the sub-array is $D_3 = 4d$. The center spacing of four equivalent sub-arrays is d. Secondly, these four sub-arrays can be equivalent to two sub-arrays with 2 elements, the element center spacing of which is $D_2 = 2d$. Finally, these two arrays can also be equivalent to an array with 2 elements, and the element center spacing is $D_1 = d$. According to the natural directivities of the three kind sub-arrays, we can obtain an independent beam pointing at $sin\theta = \lambda/4d = 0.5$ when phase compensation ψ_1 and ψ_2 are fed to the elements in level I and II respectively. As shown in Fig. 4. Phase compensation ψ_1 and ψ_2 can be described as follows:

$$\psi_1 = \frac{2\pi D_1}{\lambda}\frac{\lambda}{4d} = \frac{\pi}{2} \quad (1)$$

$$\psi_2 = \frac{2\pi D_2}{\lambda}\frac{\lambda}{4d} = \pi \quad (2)$$

On the contrary, we can also obtain another independent beam pointing at $sin\theta = -\lambda/4d = -0.5$ when phase $-\psi_1$ and $-\psi_2$ are fed to these elements respectively. According to the above analysis, the

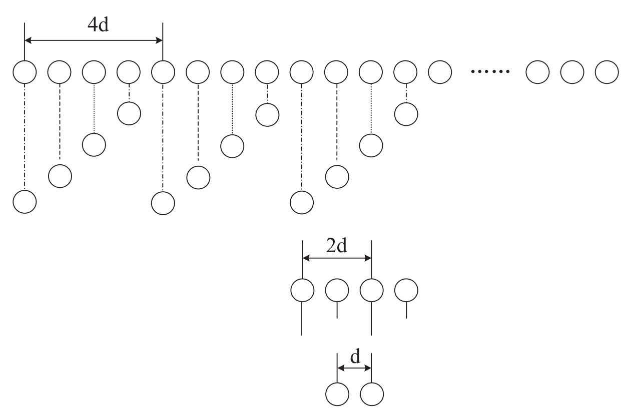

Fig. 3. Schematic diagram of three level sub-arrays.

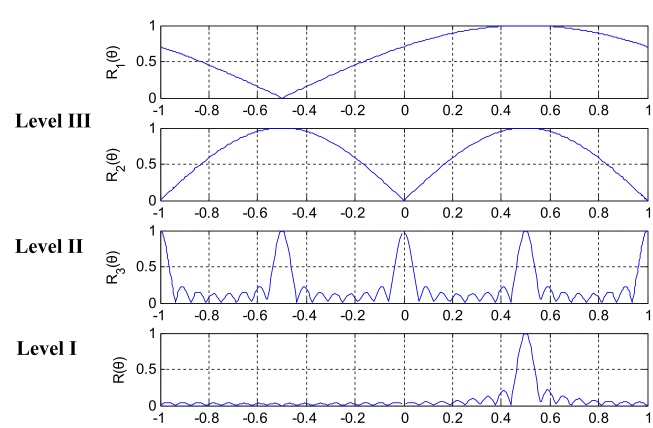

Fig. 4. Directivities of the beam phase controlled.