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by

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Technical Report

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TABLE OF CONTENTS

ABSTRACT

A compact electromagnetic monopole source, requiring pressure equalization, was evaluated at the Naval Underwater Systems Center at Lake Seneca during July 1992 by scientists from the Institute of Applied Physics of the Russian Academy of Sciences (IAP RAS) and from the Woods Hole Oceanographic Institution and other American organizations. The titanium source was developed at the IAP RAS. The source has a mass of 123 kg and a diameter of 0.54 m. The source cannot be thought of as a single unit; rather the characteristics of the transmitted signal depend on a transmission system consisting of the source, the power amplifier, and a computer. The computer and the amplifier send specially adapted signals to the source to produce the desired acoustic signals. Measurements indicate the acoustic system has a center frequency of 225 Hz, a bandwidth of about 50 Hz, an associated pulse resolution of about 0.02 s, a source level of about 198 dB re 1 μPa @ 1 m, with an efficiency of about 50%. The system has an efficiency of about 67% near 225 Hz, the resonant frequency. The source is suitable for mounting on autonomous ocean moorings for several years as part of a system of monitoring climatic temperature changes over basin scales.

1. INTRODUCTION

It has been suggested that new acoustic technology will make it less expensive to monitor temperatures in the interior of the global oceans than to monitor temperatures in the global atmospheres at scales important for climate change; that is at the largely unexplored scales between the meso and basin scales (Spiesberger, 1992,1993; Spiesberger and Bowlin, 1993; Spiesberger and Metzger, 1992; Spiesberger et al., 1992). The new technology is based on sources attached to autonomous moorings and receivers dangled below freely drifting surface units. An important piece of this new technology is an acoustic source developed in 1991 at the Institute of Applied Physics of the Russian Academy of Sciences (IAP RAS). This report documents the testing of one of these sources at Lake Seneca during July 1992 by IAP RAS and WHOI. Similar sources have been used for more than ten years in scientific work in Russia (Bogolubov et al., 1986; Slavinsky et al., 1992).

We found the sources to be suitable for monitoring climatic temperature changes over basin scales in the ocean. In particular, they had a source level of about 198 dB re 1 μPa @ 1 m, a bandwidth of about 50 Hz, a corresponding temporal resolution of about 1/(50 Hz) = 0.02 s, and efficiencies of about 50%. These sources could be adapted for autonomous operation on moorings for periods of two years with modest sized battery packs.

According to the Agreement on Scientific and Technical Cooperation in the Field of Investigating Global Climate Change using acoustic tomography between the IAP RAS, Nizhny Novgorod, Russia, and WHOI, Woods Hole, MA, USA, joint tests of the low - frequency hydroacoustic sources and driving equipment developed at the IAP RAS were made in July, 1992. During the first stage, from 12 to 24 July, 1992, these groups measured the characteristics of five sources in water of about 16 m depth from the WHOI dock. During the second stage, from 26 to 30 July, 1992, the sources were evaluated on the barge at Lake Seneca operated by the Naval Underwater System Center (NUSC).

The participants at both stages were

1. From the IAP RAS:
   (a) M. Slavinsky, Deputy Director of the Hydrophysics and Hydroacoustics Department, Head of the Ocean Acoustics Division
   (b) B. Bogolubov, Head of the Applied Hydroacoustics Laboratory of the Ocean Acoustics Division
   (c) I. Alelekov, Research Associate of the Applied Hydroacoustics Laboratory
   (d) K. Pigalov, Research Associate of the Applied Hydroacoustics Laboratory
   (e) G. Maslakov, Leading production-process engineer of the Design and Technology Section of the Ocean Acoustics Division
2. From WHOI:
   (a) J. Spiesberger, Associate Scientist
   (b) P. Boutin, Research Specialist
3. Other participants during the second stage were:
   (a) K. Metzger, U. of Michigan
   (b) B. McTaggart, Naval Underwater Warfare Center (NUWC)
   (c) J. Lindberg, Naval Underwater System Center (NUSC)
   (d) D. Webb, Webb Research Corporation
   (e) L. Carlton, Director of NUSC Lake Seneca Facility

We thank the director of IAP, A. Gaponov-Grekhov, for facilitating the IAP team's time in the United States.

During the first stage, the work was financed through discretionary funds by the director of WHOI, Craig Dorman, including the travel expenses from Russia to USA and back, as well as the living expenses for the Russian participants. During the second stage, the project was funded through the ONR contract N00014-92-J-1222.

We express our profound thanks to the Director of WHOI, Dr. Craig Dorman, whose support made this work possible, and to our WHOI collaborators, Lee E. Freitag, Marguerite K. McElroy and many others who provided aid and devoted time and effort to make the stay of the Russian scientists in the USA both pleasant and productive. We thank Capt. Ed Pope (ONR) and the NUSC collaborators, without whose help this work could have never been done.

2. OBJECTIVES AND TASKS OF THE TEST

We refer to the acoustic source, the amplifiers, and the computer controller as the system. Optimum source level, bandwidth, efficiency, and acoustic waveform depends on proper coordination and adaptation of the different system components. The source cannot be evaluated without full consideration of the interactions in the system.

The main objectives of the tests are as follows:

(a) Development of consistent methods that can be used in the future for testing low-frequency hydroacoustic systems by the Russian and American specialists.

(b) Calibration measurements of the characteristics of the system. Measurements include source level, phase and frequency characteristics, efficiency, etc.

(c) Investigation of the characteristics of the system by generation of M-sequence codes that are used for studying global climate changes of temperature using acoustic tomography. Cross-correlation techniques are used to estimate the time resolution and bandwidth characteristics of the system.

(d) Investigation of the influence of the source's hydrostatic pressure compensation system on the source's output characteristics.

(e) Investigation of the effects of pressure imbalances between interior and exterior pressure of the source.

(f) Investigation of starting the system at ambient water temperature; or the so called "cold start" test.

Knowledge of these characteristics is important for evaluating the potential of these systems for use in tomographic monitoring of global ocean temperatures.

3. DESCRIPTION OF THE TRANSMISSION SYSTEM

The transmission system includes:

(a) An electromagnetic hydroacoustic source.

(b) A thyristor power amplifier that produces current in the source electromagnet coil. This amplifier is called an inverter in what follows.

(c) A computer with a input and output modules that provides the acquisition of input signals and the formation of signals that are output to the inverter.

(d) Measuring instruments for electric and acoustic signals.

(e) A hydrostatic pressure compensation system that keeps the gas pressure in the internal source cavity equal to the hydrostatic pressure at the source location depth.

(f) Underwater and surface electric cables.

The transmission system is shown in Figure 1. The subwater part of this system contains the source (1), measuring hydrophone (2) and compensator (3). The field coil of the source is connected to the power output of inverter (4) by a multiple-conductor cable (5) of CWD type with longitudinal hermetization. All conductors in the cable are combined into two ones in order to decrease the ohmic resistance. D.C. voltage is fed to the inverter from the power rectifier (8), which is switched to the three-phase line. The IAP RAS hydrophone is connected through the cable (6) to the input module built into the computer (7), to which a signal proportional to the source coil current (source current) is also supplied. The signal formed by the output module of the computer is fed to the inverter input. All electric signals are measured by the computer and, independently, by the measuring instruments listed below.

3.1 Source

A low-frequency hydroacoustic source of electromagnetic type was tested. A sketch of this source is shown in Figure 2. The source has two round emitting membranes (1) with a special profile to minimize the mechanical loads due to bending, a case which supports the fixed part of the electromagnet core (3); each of the two moving parts of the electromagnet core (4) are rigidly fixed to the

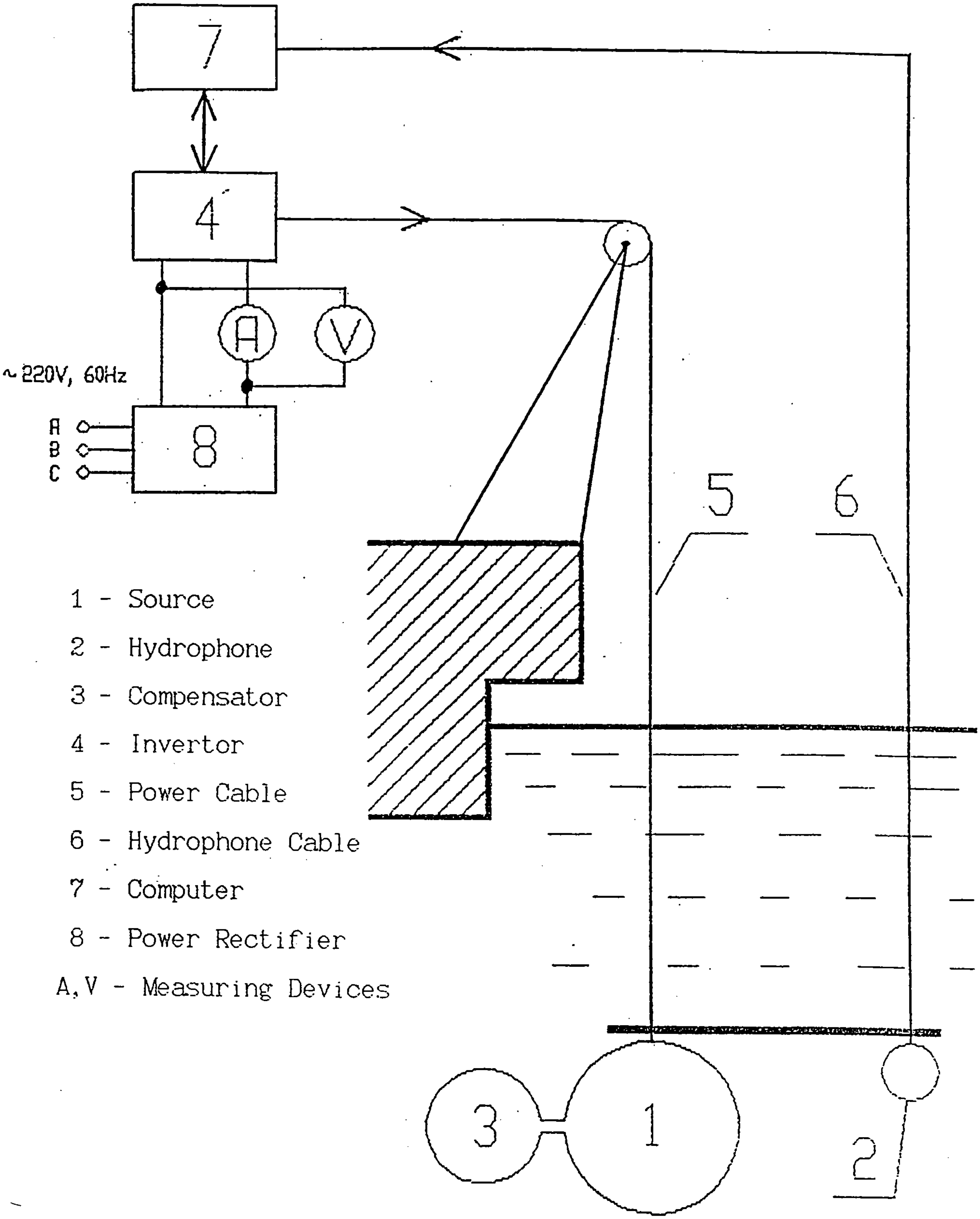
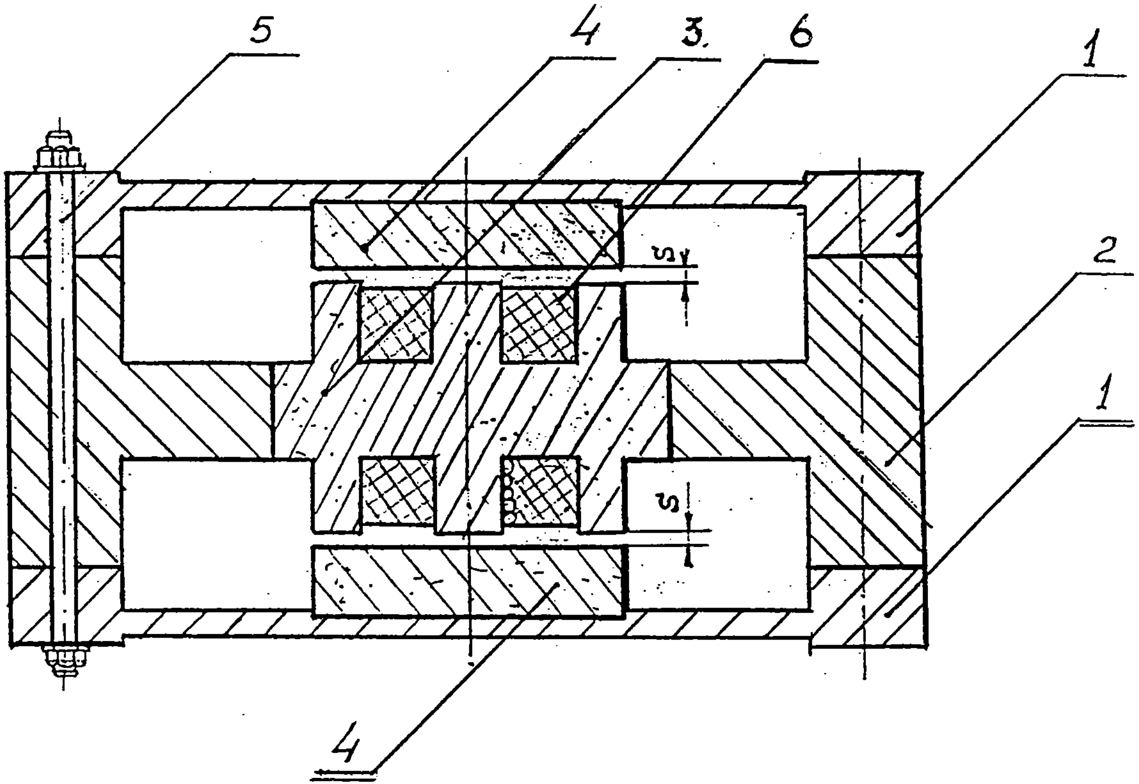


Figure 1: Configuration of the emitting complex.



1 - Membrane

2 - Case

3 - Electromagnet Core (fixed part)

4 - Electromagnet Core (moving part)

5 - Bolts

6 - Field Coil

S - Gap between field poles

Figure 2: Low-frequency hydroacoustic titanium source of electromagnetic type.

center of the corresponding membrane. The membranes and the case are rigidly integrated through the outer flange by bolts (5). The source is made of high - resistant titanium alloys for high reliability and long - term operation in sea water. The membrane oscillations are co - phased so that source behaves like a monopole. The linear dimensions of the source (0.5 m) are much less than the lengths of the acoustic waves it produces (6 - 7 m); therefore the directional pattern of the emitted acoustic field is spherical with high accuracy provided,

$$r >> 2d \quad , \tag{1}$$

where d is the maximum geometric dimension of the source, r is the distance from the geometric center of the source to the point at which the field is measured. An interesting feature of the electromagnetic emitters is that the force of attraction between the electromagnet poles is proportional to the square of the current supplied to the coil. Consequently, the frequency of forced vibrations of the source is equal to twice the frequency of the coil current and the emitted power is proportional to the coil current raised to the fourth power. On the other hand, the total power of the Joule heat losses in the electromagnet coil and the losses due to remagnetization of the core is proportional to not more than the coil current squared. The above statements imply that the electromechanical coupling coefficient and efficiency of the electromagnetic sources are not constant and increase with increasing source power. This occurs until the core is saturated. After this the efficiency decreases abruptly.

3.2 Inverter

The input impedance of an electromagnetic source of small wave dimension is mainly inductive. Typically, for matching the impedance of the source and the output resistance of the amplifier, a capacitor is switched, either in parallel or in series, to the electromagnet coil. The capacitance is chosen such that the resonance frequency of the resultant electric circuit is equal to half the resonance frequency of the source. This matching makes the narrow frequency band still narrower. The inverter ensures a better matching to the source. As the source frequency is changed, the inverter is used to keep the radiation level constant by increasing the source current. The stabilization effect is the stronger for high - efficiency emitters. Automatic stabilization of the radiation level makes it possible to generate high-quality signals with frequency and phase modulation in a frequency band much wider than the frequency band of the source. The source power is controlled by commutation of the power supply in a manner similar to pulse duration modulation. Let Ts denote the time duration that the power supply is switched to the inverter. As Ts increases, the power from the source increases. The inverter is fed from a D.C. power supply unit of voltage 250 -

300V. An electric or storage battery, or a rectifier can be used. In this case we used a three-phase rectifier with V = 220 V and f = 50 - 60Hz.

3.3 Computer

Operation and measurement of the transmitting system is controlled by use of a PC/AT 386 computer (Fig. 3). The output module is used for conversion of the frequency , phase and time Ts codes to an electric pulsed signal which goes to the input of the inverter. The input module amplifies the source coil current signal and enhances and filters the hydrophone signal. From the input module the signals arrive at a standard module PCL 718 of containing 12-bit analog-to-digital converters (ADC). Before measurement, the amplification factors of the programmable amplifiers of the input module are chosen automatically such that the ADC ensure the maximum accuracy during the measurement.

The signal sample frequency is 1 - 2 kHz. During calibration of the source, the sample frequencies are 10 and 40 kHz. The results of the signal measurements are used to calculate various parameters such as the frequency dependence of the radiation level, the effective current of the source field coil, the phase of the emitted signal, the efficiency of the source and of the transmission system as a whole, the average current of the power rectifier, etc. The results of the measurements are shown on the computer display.

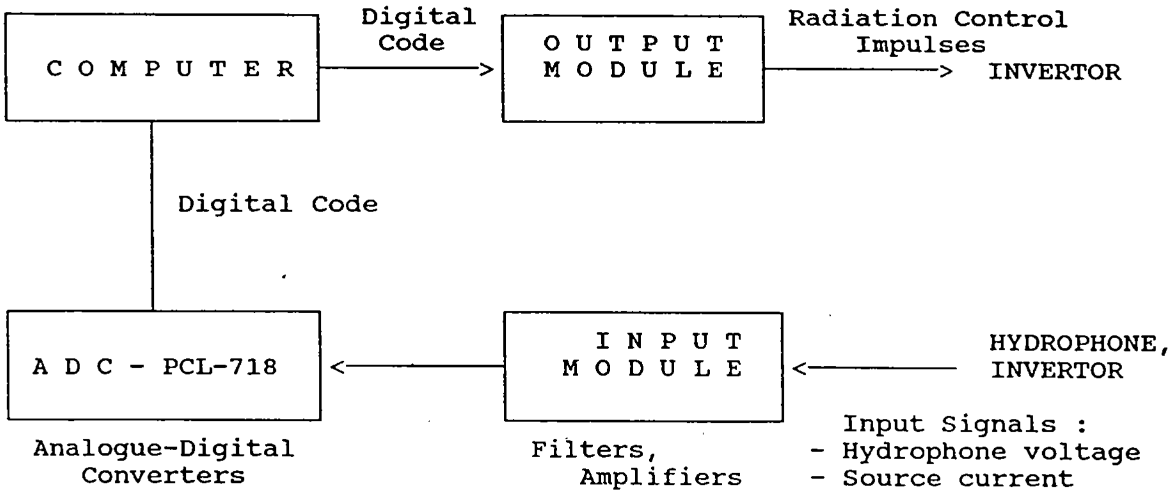


Figure 3: Structural scheme of the computer complex.

Table 1. Equipment used by the IAP.

Parameters	Measurement Unit	Type of Device	Accuracy of Measurement (%)
Power rectifier voltage	volt	M 42100	1.5
Average consumption current from rectifier	amp	M2027	0.5
Average field coil current of source	amp	M2027	0.5
A.C. voltage on hydrophone	volt	V7 - 27	0.5
Field coil inductance of source	mH	Impedance meter IMF - 600	0.1

3.4 Measuring Equipment

All electric signals are measured by the computer and, independently, by the measuring equipment. The signals being measured and the types of the devices are given in Table 1.

The American colleagues simultaneously measured electric quantities using their own devices listed in Table 2.

The acoustic pressure was measured by three piezoceramic hydrophones, the characteristics of which are given in Table 3.

3.5 Pressure Compensation System

When the source is submerged in water its membranes are bent under the action of hydrostatic pressure, which, at a certain value, can make the source inoperative. The hydrostatic pressure compensation system (PCS) is intended to keep the imbalance between the hydrostatic pressure outside the source and the gas (or air) pressure in the internal cavity of the source within admissible limits. IAP used the simplest compensator of the so- called passive type, which is a thick-walled sphere of fiber-glass reinforced plastic divided into two cavities by an elastic diaphragm (Fig. 4). One cavity is connected through holes to the environment and the other cavity is connected to the inner cavity of the source. Since the rigidity of the diaphragm is very small, the pressure in the source is essentially the same as the hydrostatic pressure outside the source