An Implosion Sound Source for Undersea Exploration Applications

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Abstract

Since light and other electromagnetic waves are highly attenuated in sea water, the sound projector for generating a controllable acoustic wave in the ocean for inner space exploration is still a challenging endeavor in oceanographic research. Devices which uses underwater explosives or air guns for oceanographic tomography measurements and undersea oil explorations not only require heavy logistical support, but also involve tasks of tedious data processing, due to the needed deconvoluting of the complex acoustic signature. This paper addresses the utilization of a highly concentrated pressure pulse caused by an implosion mechanism as an underwater sound source. The operational principle of implosion sound is simply based on the conversion of hydrodynamic energy to acoustic energy from the collapse of a cavity. However, the controllability of implosion can be manipulated by shaping the collapsible cavity to convert the induced plane shock wave into a form of spherical convergence. The reflection of a self focused wave can create a delta-function like pulse. The parameters of such a phenomenon can be formulated analytically following the cavitation process model. Test data derived from a prototype implosion sound generator conducted in the laboratory indicated that a peak acoustic pulse of ~190 dB//1 μPcal has been reached with a 40 in^3 cup shape cavity. Because no air was trapped in the vessel initially, the acoustic signature is a simple pressure pulse without any interference of bubbles generally observed in explosive or air gun operations. The simple structure of the implosion mechanism can be adapted for various engineering designs to meet the practical applications in oceanographic and underwater research activities. Future effort for implosion acoustics study will be discussed after presenting some preliminary design schemes for disposable, reusable, and array of implosion sound projectors.

1. Introduction

Ocean covers two thirds of the earth's surface and has an important effect on the world climate. Research on its effect on the weather has made great progress with the remote sensing observation from space satellites. However, the effort of studying the impact beneath the ocean surface is very limited as light and other electromagnetic waves are highly attenuated in sea water. The technology for remote sensing for the inner space is not well developed and most undersea oceanographic data are very much localized, obtained only from the on site measurement. A recent ATOC (Acoustic Thermometry of Ocean Climate) project [1] which attempted to use the acoustic sound source for the long range and wide area coverage oceanographic survey has expanded the role of underwater acoustics in inner space exploration. With the proper design of sound radiation device, the acoustic signal can be detected many thousand miles away. However, unlike the radar transmitter, the generation of acoustic waves in water is very complicated, Equipments associated with it are usually bulky, heavy, not easy and safe to operate, and costly in construction and logistics. As ocean occupies a large volume of water bounded by the dynamic sea surface and irregular ocean bottom profile, the sound projector to generate a controllable acoustic wave in the ocean for inner space exploration is still a challenging endeavor in the oceanographic research. Devices using underwater explosives or air guns for oceanographic tomography, topography measurements and undersea oil explorations not only require heavy logistical support but also involve tasks of tedious data processing, due to the needed deconvoluting of the complex acoustic signature.

Current technology for generating impulsive sound wave employs the detonation mechanism. The acoustic signal obtained in this way is not controllable: it consists of interference caused by bubbles' resonances and its sensitive to the variation of charges and operational depth. Other methods use various types of frequency synthesis approaches to form a broad band signal. However, such a sound source is not temporally and spatially localized, and its efficiency is low due to the compensation of frequency response during the electro-mechanical transduction. A highly concentrated pressure pulse caused by an implosion mechanism appears to alleviate those problems. A brief review on some of the implosion underwater sound sources is given in reference 2. The discussion covered in this short paper is focused on the control of the implosion sound generation so the implementation of the device based on such a mechanism can be made simple, safe, and low cost. Proposals of how such a device can be integrated into the ocean exploration system are discussed regarding the formation of a directional array to minimize the damage in marine life and the undersea environment.

2. Physics of Implosion

Implosion is formed by directing waves toward a focal center. Because of the energy concentration, an extremely strong pressure and high temperature can be built up in a very small region, thereby generating a sharp shock wave propagating outwards. Such a mechanism has even been employed to ignite the nuclear fission in the atomic bomb. A simple mathematical model of this phenomenon can be formulated by the collapse of a spherical void such as the Rayleigh-Plesset's equation used in analyzing the cavitation. The phenomenological interpretation of the implosion process sequence shown in Fig. 1 are: (a) the collapse of a bubble generates a spherical shock wave, (b) the implosion shock wave converges to the cavity center, (c) a high pressure pulse is created by energy concentration, (d) the intensity of a shock front is enhanced by reflection, (e) tremendous temperature at the center causes dissociation, (f) light emits from black body radiation or ionization, (g) the reflected implosion propagates out as a sound pulse. Based on the fundamental conservation laws (mass, momentum, and energy), simulation with a high speed computer can estimate the magnitude of pressure waves and the high localized temperature. However, it is not an easy task to create a particularly large void physically. Generally, an explosive source is used to build up the void and then the inward shock wave of the explosion after effect forms the implosion. In the underwater application, the gas bubbles from the residue of the explosive will interfere with the implosion pressure pulse and make the sound pulse signature complicated. Besides, the use of explosives is not safe to the operational personal, not even to mention the damage done to the ocean environment and marine life.

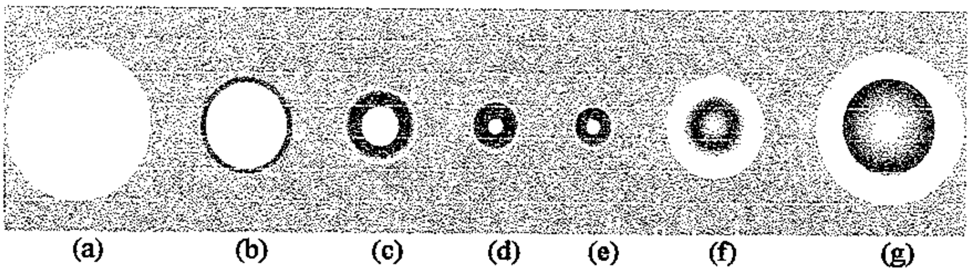


Fig. 1 Phenomenological Interpretation of Implosion

3. Controllable Shock Wave.

The practical way to generate a controlled implosion is through the manipulation of a plane shock wave [2]. According to the Chester-Chisnell-Whitam (CCW) model based on the geometrical shock wave dynamics, the nonlinear relationship at the shock wave front treats the strength of the shock wave as proportional to the area in a ray tube. This is similar to the geometrical acoustics ray theory except that the local sound speed is not constant, so the velocity of the shock wave front movement will be affected by changes in its cross section. Hence the CCW model can be used to simulate the implosion by an area change in a shock wave tube. The idea is that, by adjusting the interior boundary curvature of an open ended cavity, a plane shock wave is forced to converge to a single point. The inserted figure in Fig. 2 shows a simulated example of an open ended (half) cavity with a certain interior shape. In this example, the shock wave front is modified as it propagates from the cavity's opening towards its interior, and eventually, the plane shock wave front is forced to converge to a single point along the axis. Figure 2 shows the waveform of the implosion sound measured in the laboratory water tank from a brass open cavity with a diameter of 4" and a depth of 5". The peak value of the impulse corresponds to 188 dB/1μPcal, measured by an LC-10 hydrophone which has a flat frequency response up to 120 kHZ. The generated implosion pulse is so sharp that the recorded signal also shows the numerous interferences after the main pulse. They are contributed from the multiple reflections through the back of the cavity and the wall to the walls of the tank and have different time delays and magnitudes

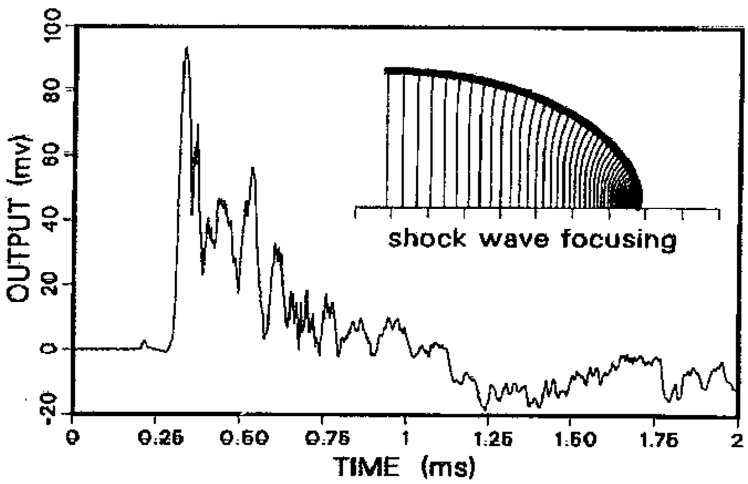


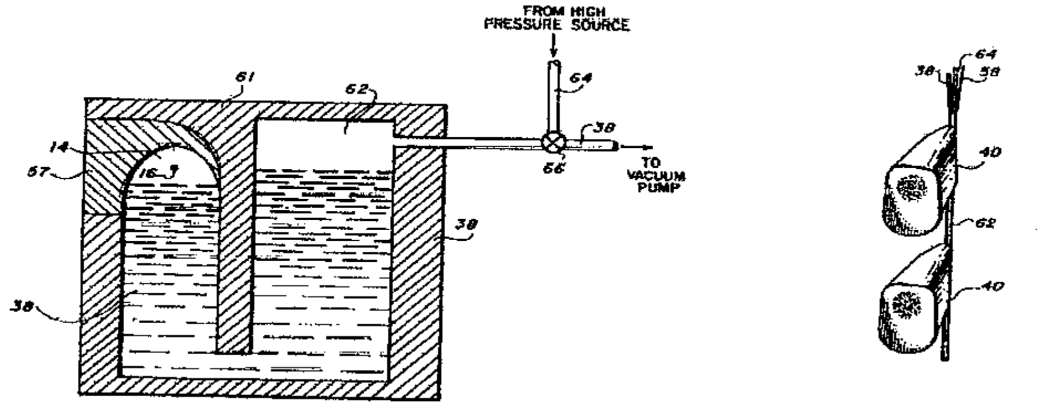
Fig. 1 Implosion Sound Measured in Water

4. Implosion Sound Projectors

Various types of implosion sound projectors [4] can be constructed based on the controllable implosion mechanism described in the previous section. Their design parameters depend on the application requirements and cost constraints. They can be made into simple, disposable, and low cost units or fabricated as a part of an acoustical survey system.

One of the designs illustrated by the sketch shown in Fig. 3 (a) has the feature which could be integrated with undersea survey system for directional scanning. This sound generated unit consists of an housing #61, the implosion chamber # 14 with its implosion center at #16. An electronic controlled valve #66 is used to create an artificial void in #14 with a vacuum pump. For the implosion operation, the valve switches the tube connection to a high-pressure tank and forces the fluid #38 inside the housing squash to the tip of the chamber #62 and causes a convergent collapse center at # 16. The cover #57 is an acoustic transparent material so the generated acoustic wave can be directed out through this window. Many of such a unit #40 can be arranged to form an array as shown in Fig. 2 (b), where #38, #64, and #58 are the vacuum hose, the high-pressure tube, and the control electrical cable respectively. With the proper placement of implosion units and timing delay opening of control valves, the radiated sharp implosion acoustic impulse can be directed to a desired direction for remote scanning search.

A prototype single unit with the design similar to Fig. 2 (a) has been constructed with the implosion chamber size of a 1" diameter and 1.5" in depth. Performance tests in the laboratory tank operated with vacuum of 0.022 ATM and a high-pressure of 1 ATM, generates an impulse of peak intensity 195 dB/1μPcal with a pulse width less than 50 μs at 3 feet away from the implosion projector.



(a) Implosion Unit (b) Array Arrangement

Fig. 2 Implosion Sound Projector for Array Application

5. Discussion

The use of implosion sound source described here has demonstrated that an underwater acoustic wave generator designed with this type of mechanism is simple and safe to operate for undersea remote surveying application. At the current stage, only a simple prototype has been constructed and laboratory tests have demonstrated its practicability for underwater application as an effective sound source. Because of the simplicity of the implosion mechanism, in comparison with the traditional acoustics radiators, this type of sound source has much better performance features in the areas of acoustic signature (a temporal and spatial concentrated wide band signal), operation handling (light weight), system integration (small size), and low cost (less logistic support). Many alternative designs other than those mentioned in this paper can be adapted for some engineering modifications to meet the needs in oceanographic and underwater research activities. Future effort for implosion acoustics study will be directed to the optimization of the design based on a specific task requirement.

Reference

1. W. H. Munk, "Acoustic Thermometry of Ocean Climate", J. Acoust. Soc. Am. 100, p. 2587, Oct. 1996
2. Nai-chyuan Yen, "Application of Implosion to Underwater Sound Generation, J. Acoust. Soc. Am. 100, p 2716, Oct. 1996.
3. Nai-chyuan Yen, "Controlled Implosion Sound Generation", Nonlinear Acoustics in Prospective 1996 (Ed. R. J. Wei), 14th International Symposium on Nonlinear Acoustics, Nanjing Unversity Press, pp. 292-297, (1996).
4. Nai-chyuan Yen, "Controllable Implosive Sound Projector", Reg. Number H1664, United States Statutory Invention Registration, July 1, 1997.