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IMPACT-ENERGIZED SOUND SOURCE

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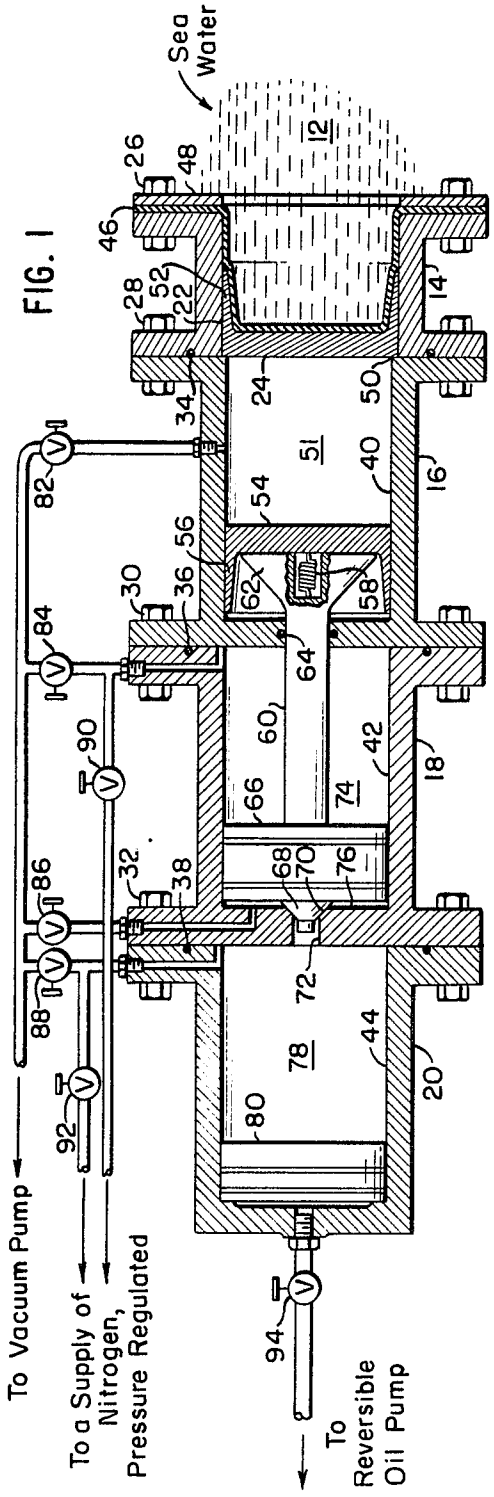


FIG. 1

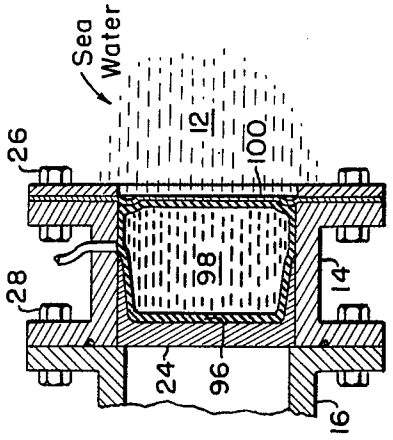


FIG. 2

INVENTORS

ARNOLD G. SHARP
WILLIAM S. SCHULTZ
JAMES R. SULLIVAN

BY Kenway, Jenney & Hildreth

ATTORNEYS

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IMPACT-ENERGIZED SOUND SOURCE

Arnold G. Sharp, Woods Hole, and William S. Shultz, Cataumet, Mass., and James R. Sullivan, Newport, R.I., assignors to Woods Hole Oceanographic Institution, Woods Hole, Mass., a corporation of Massachusetts

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This invention relates generally to sound sources, and more particularly to sound pulse sources useful for radiating acoustic energy in or through sea water or other fluid media for oceanographic, seismographic or related applications.

A principal object of this invention is to improve pulse transmitters of the impact type, comprising an anvil member in the form of a rod or plate, referred to herein as the radiating member, and an impact member or hammer which may comprise a similar rod or plate, and which is referred to herein as the striker. Sound pulses can be produced by a variety of other types of devices including explosives and spark sources, but these inherently produce undesired cavitation effects, that is, they produce pressure waves having negative portions of rather substantial amplitude that tend to confuse the measurements or records of the pulses.

The patent to Sawyer No. 3,053,220 illustrates a device that includes springs to propel a striker against a radiating plate to produce a sudden, high-intensity acoustic pulse. This device accomplishes the general purposes of an impact sound source but has certain disadvantages and limitations. These result largely from the structure of the radiating member and the means for its support. Hydrostatic pressure and striker impact forces acting in opposite directions on the radiating plate tend to cause it to bend or dish so that the energy of the striker is not transferred through a relatively large, flat surface area of contact, and the direction of propagated strain waves is not the same at all points as would be the case for simple compression along the direction of impact. As a result, the device fails to attain the desired object, which is a large maximum amplitude pulse sustained for an appreciable interval, followed by a clean, repeatable decay characteristic. The achievement of this object is regarded as dependent upon the closest possible approximation to conditions described in classical impact theory, sometimes called stereomechanics, considered in the light of wave propagation effects. Theoretical studies lead to the prediction that an ideal pulse characteristic would arise from a longitudinal impact between two geometrically similar prismatic bars, the driven or radiating bar being backed up by a resisting fluid medium. On reaching the bar-fluid interface, a stress wave travelling along the radiating bar will be partially transmitted and partially reflected. The reflected portion will travel back along the bar to the now free impact end, and be reflected there and return to the interface where again partial transmission and partial reflection will take place. At each interface reaction, the level of stress transmitted to the fluid will be lower than that of the preceding reaction. Thus a total pressure pulse will be transmitted to the fluid, in which there will be a sudden rise to peak pressure and a decay pattern in the form of a succession of finite steps of decreasing pressure. The pressure amplitudes so produced will depend upon the velocity of impact and the elastic properties of the bar and of the fluid. The duration of each pressure step will be equal to twice the acoustic travel time through the driven bar. The stress in the fluid will ultimately return to zero, and the complete pulse characteristic will be formed when all of the kinetic and strain energy imparted to the driven bar at impact will have been dissipated.

The applications for a sound source of this type ordinarily require a relatively short pulse length, with great amplitude and a fast, clean decay, the pulse to be radiated over a relatively large area. This requires that the impacting members shall be in the form of relatively thin, flat plates. Ideally, the plates would have a plane impact which produces a single mode of wave propagation, namely axial compression, in the radiating plate. Therefore the radiating plate should ideally move as a free piston and the plates should be and remain perfectly flat so that the impact force is delivered over the entire area of the radiating plate.

In practice it has not been possible to maintain the flatness of the plates and also the degree of parallelism of one plate relative to the other that is desired for a true plane impact. The difficulty arises in part because of the necessity of evacuating the space between the striker and the radiating plate. This in turn necessitates a seal around the radiating plate, which Sawyer discloses in the form of a ring spring. The spring is designed to be flexible enough to permit motion of the radiating plate on impact, but it is also the cause of undesired bending of the plate under those conditions in which the plate is under stress with the ring at or near the limit of its flexibility. Thus, as previously mentioned, a sufficiently heavy impact by the striker can cause bending or dishing of the radiating plate in one direction, while a sufficiently large hydrostatic pressure can produce an opposite bending.

To maintain the radiating plate flat and in alignment with the striker under all conditions, elaborate forms of the Sawyer transmitter have been devised using a system of spring supports distributed over the radiating face of the plate. These springs are designed to act in compression at the time of impact by the striker and in tension against the hydrostatic pressure. Such arrangements generally interfere with the efficient transmission of energy to the medium, and it is accordingly a further object of this invention to provide alternatives to such complex arrangements.

Other objects of this invention include the provision of a self-contained and portable impact sound source, the provision of means to couple the source reliably to sea water and other fluid media, and means to provide for adjustment of the amplitude of acoustic impulses produced by the source.

Having in view the foregoing and other objects hereinafter appearing, the features of this invention include a horn having a sleeve bearing within which a radiating plate is slidably fitted. In conjunction with the horn there is provided a guide tube in which a striker is received. Before impact the radiating plate rests in a strike position within a sleeve bearing in the horn. Means are provided to propel the striker through an evacuated guide tube against the radiating plate, whereby the plate is stressed in compression and undergoes a sliding movement in the sleeve bearing as a free piston. This arrangement insures a plane impact, with the striker and radiating plate being maintained in closely parallel relationship. A seal is provided to pervent the propagating medium such as sea water from passing between the radiating plate and the sleeve bearing in the horn.

This improved sound source may be suspended from the side of a ship or submarine, or attached to its hull. It may also be attached to a float or buoy and towed behind a ship.

According to another feature, we preferably provide an improved energy source for the pulse transmitter, in the form of compressed gas, for suddenly propelling the striker against the radiating plate. Preferably, such means include a self-opening valve of improved design which permits a steadily increasing gas pressure to be withheld from moving the striker until a predetermined moment at

which it is suddenly applied against the face of a piston which has a portion extending into the guide tube to propel the striker.

According to still another feature the striker has spring means which permit it to move independently of the gas driving means during the final movement ending at the instant of impact with the radiating plate.

Other features of the invention reside in certain details of construction, arrangements of the parts and modes of operation which will be more readily understood from the following description, when considered with reference to the appended drawings, in which:

FIG. 1 illustrates a preferred embodiment in the form of a gas driven impact energized sound source; and

FIG. 2 is a fragmentary illustration of an alternative embodiment utilizing a fluid bag between the radiating plate and the propagating medium.

FIG. 1 shows a preferred form of pressure pulse transmitter having its radiating end immersed in sea water **12**. The principal parts comprise a horn **14**, a guide tube **16**, a drive cylinder **18** and an accumulator **20**. Suitable connections are made to a vacuum pump and a supply of dry nitrogen under regulated pressure (not shown). This assembly may be suspended from the side of a ship or submarine, attached to its hull or towed behind it on a suitable float or buoy.

By the means described below, the desired pulses are radiated through a cylindrical bore **22** in the horn, and result from a sudden piston-like movement of a metal radiating plate **24** slidably received in the bore.

The principal parts described above are preferably constructed of metal and are of generally cylindrical configuration. They are bolted together by annularly distributed bolts **26**, **28**, **30** and **32**, the connections being sealed with the aid of O-rings **34**, **36** and **38**. Preferably, the guide tube **16**, drive cylinder **18** and accumulator **20** have cylindrical bores **40**, **42** and **44** of an identical diameter which is slightly less than that of the bore **22**.

A thin, stretchable diaphragm seal **46** is clamped over the radiating end of the horn **14** by means of a metal clamping ring **48** retained by the bolts **26**. When the unit is immersed in sea water the hydrostatic pressure acts through the seal **46** to push the plate **24** to a "strike position" defined by a shoulder **50** on the guide tube **16**, slightly stretching the seal **46** and holding it against the walls of the bore **22** and the surface of the plate. The plate **24** preferably has a rim **52** which serves to ensure straight axial translation of the plate as it slides in the bore. The operation of the transmitter, as hereinafter described in more detail, consists in causing a rapidly moving metal striker **54** to slide through an evacuated space **51** and strike the plate **24** while the latter is in the illustrated strike position. This causes the plate **24** to slide a short distance along the bore **22**, for example one-quarter inch, after which the plate **24** is allowed to return to the strike position under the force of the hydrostatic pressure. The pulse-producing movement reduces the degree of stretch in the seal **46** but is insufficient to produce folds or wrinkles in it. The striker **54** impinges on the plate **24** at considerable speed, for example 80 feet or more per second. The resulting acoustic pulse is a discrete pulse, although the unit is so constructed that pulses may be repeated in this manner at a regular rate such as once in five seconds, or at even shorter intervals.

The striker **54** and plate **24** are substantially identical in size and shape, although the striker has a slightly smaller diameter. The striker **54** has a guide rim **56**. In a typical embodiment these members may have a diameter of about five inches and a thickness of about one inch. The shapes of these members are such as to present a relatively large area to the sea water or other acoustic medium, but their thickness is relatively small so as to product a pressure characteristic with a high peak intensity and rapid decay as predicted from considerations of wave propagation within the plate **24**. The geometrical similarity of the striker and plate is generally recognized to be desirable in transmitters of this type.

We next turn to a description of the means, largely contained within the accumulator **20** and drive cylinder **18**, for propelling the strike **54** along the guide tube **16**. Although various alternate means will occur to one skilled in this art, the illustrated device is preferred because of its safe and dependable action.

A coil spring **58** is attached at one end to the striker **54** and at the other end to the bottom of a bore in a drive piston extension **60** having a force spreader portion **62**. The portion **62** fits against a face of the striker **54** without any attachment thereto except the spring **58**. The piston extension **60** passes through a sealing O-ring **64** and an end wall of the guide tube **16**. A drive piston **66** is integral with the extension **60** and slides within the bore **42**. A valve **68** is fitted on the piston **66** and cooperates with a seat **70** in an end wall of the cylinder **18**. The seat **70** is formed at the end of a passage **72** connecting the accumulator **20** with the cylinder **18**. For convenience of description the space between the piston **66** and the O-ring **64** is designated **74**, and the space on the other side of the piston **66** is designated **76**. The communicating space within the accumulator is designated **78**. A floating piston **80** is fitted within the accumulator **20**.

To prepare the transmitter for operation, the space **51** in the tube is evacuated by opening a valve **82**. Valves **84**, **86** and **88** are also opened to evacuate the spaces **74**, **76** and **78**. When these latter three spaces have been evacuated the valves **84**, **86** and **88** are closed and valves **90** and **92** are opened to introduce a supply of dry nitrogen to the spaces **74** and **78**. The gas pushes the piston **66** until the valve **68** is seated, and also pushes the floating piston **80** toward the inlet end of the accumulator connected through a valve **94** with a reversible oil pump. The nitrogen pressure is increased to a desired level between 10 and 100 pounds per square inch above atmosphere. The pressure is selected so as to produce the velocity of impact required to produce the desired pulse amplitude. When the parts have reached the illustrated positions and the desired pressure has been reached in the spaces **74** and **78**, the valves **90** and **92** are closed. The valve **86** is then momentarily opened to remove the small residue of gas in the space **76**. The transmitter is then ready to produce either a single discrete pulse or a sequence of pulses.

Operation of the transmitter is caused by starting the oil pump and opening the valve **94**, thereby admitting hydraulic oil to the accumulator **20** and gradually compressing the nitrogen in the space **78**. Since nitrogen is non-combustible there is no possibility of diesel explosion as a result of this compression. The pressure builds up within the space **78** until the force acting through the passage **72** upon the relatively small area of the valve **68** is sufficient to overcome the force produced by the gas in the space **74** acting upon the relatively large area of the piston **66**.

As soon as the valve **68** cracks open, the relatively large pressure within the space **78**, which greatly exceeds that in the space **74**, is applied against an entire face of the piston **66**, thereby causing it to accelerate rapidly.

The striker **54** moves with minimal resistance in the evacuated guide tube, but gas pressure builds up within the decreasing volume of the space **74**, thereby applying increasing resistance to the piston **66**. This resistance becomes great enough to arrest the movement of the piston before the striker **54** reaches the strike position. After the piston is arrested the striker continues moving at maximum velocity toward the radiating plate **24**, the spring **58** having a relatively light action to permit the plate to be struck with considerable force.

After impact by the striker, the plate **24** moves slightly within the cylindrical bore **22** as previously described. This motion causes the pressure wave or acoustic pulse which is transmitted through the seal **46** to the sea water

12. The exact character of this movement and the resulting pressure-time characteristic are of a nature predictable from the theory of longitudinal impact of prismatic bars, as briefly summarized above. After the pressure pulse has been formed, the plate **24** returns to its initial position as a result of the hydrostatic pressure of the sea water.

To reset the transmitter for another pulse, the reversible oil pump is operated with the valve **94** open. The compressed gas within the space **74** pushes the piston **66** until the valve **68** is closed, and at the same time the piston **80** is returned to its illustrated position.

A small amount of gas is trapped within the space **76** after the valve **68** has closed. This gas is removed by opening the valve **86** momentarily and then reclosing it preparatory to the generation of the next pulse. It will be observed that this constitutes the only loss of gas in the system. If required, automatic means may be provided to replenish the nitrogen in the spaces **74** and **78** by automatically opening the valves **90** and **92** when the pressure within these spaces is reduced below the desired level.

The above described apparatus is adaptable to produce output pulses having substantial frequency components as high as 3000 cycles per second and even higher. This produces a substantial frequency range suitable for many applications within the field of oceanographic studies.

The embodiment of FIG. 2 is substantially the same as that of FIG. 1, but the elastic seal **46** is replaced by a sealed elastic bag **96** which may be made of rubber, for example. Preferably, the rubber is formulated to have a velocity of sound transmission substantially equal to that of water. The bag is filled with a fluid **98** such as degassed castor oil at about 5 pounds per square inch above atmosphere, which also has the same acoustic properties as water. The bag is held in place by a thin metal plate or acoustic window **100** bolted over the end of the horn **14**. The plate **100** is preferably relatively thin so that pulses created by movement of the plate **24** are transmitted through the oil **98**, the walls of the bag **96** and the plate **100**, substantially unaltered. The bag **96** is preferred over the seal **46** in those applications where there may be a substantial risk of water penetration around the rim **52** of the plate **24** into the evacuated space **51** in the guide tube.

Structural variations in the above-described apparatus will occur to those skilled in this art, particularly with regard to the vacuum and gas connections and means of replenishment, and the shapes and configurations of the various parts. These and other variations are intended to be included within the spirit and scope of this invention.

Having thus described the invention, we claim:

1. A pressure pulse transmitter having, in combination,
   - a tubular horn member, one end of said member extending within a sound propagating medium,
   - a plate member having an annular guide rim slidably fitted in said tubular member,
   - a flexible seal means attached to said one end and extending into said tubular member and against said plate member to prevent said medium from passing through the sliding fit between said plate member and said tubular member,
   - a guide tube connected with the other end of said tubular member, said guide tube and tubular member being dimensioned to provide an abutment means for said plate member in its strike position,
   - a piston-like striker member slidably mounted in said guide tube and adapted for impact with said plate member when the plate member is in its strike position, and
   - fluid actuating means operatively associated with said guide tube and striker member to propel said striker member along said guide tube and against said plate member, thereby to cause said plate member to move toward said one end and to radiate a pressure pulse to said medium.

2. The combination according to claim **1**, in which the seal means comprise a flexible bag filled with a liquid, having contact with the plate member when the plate member is in the strike position.

3. The combination according to claim **1**, in which the seal means comprise a flexible bag filled with a liquid having acoustic properties similar to those of the propagating medium, and having a portion fitted within the tubular member and against the plate member when the plate member is in the strike position.

4. The combination according to claim **1**, in which the seal means comprise a bag of elastic material filled with a liquid having acoustic properties similar to those of the propagating medium, having a stretchable portion fitted within the tubular member and a portion sealing said one end of the tubular member, whereby pressure of the propagating medium stretches the stretchable portion against the plate member when the plate member is in the strike position.

5. The combination according to claim **1**, in which the seal means comprise a flexible sheet fitted within said one end of the tubular member and against the plate member when the plate member is in the strike position.

6. The combination according to claim **1**, in which the seal means comprise a flexible and stretchable sheet fitted within said one end of the tubular member, sealing said one end and adapted to stretch against the plate member in response to the pressure of the surrounding medium when the plate member is in the strike position.

7. The combination according to claim **1** with means to evacuate the space in the guide tube between the striker member and the plate member.

8. A pressure pulse transmitter having, in combination,
   - a tubular horn member, one end of said member extending within a sound propagating medium,
   - a plate member having an annular guide rim slidably fitted in said tubular member,
   - a flexible seal means attached to said one end and extending into said tubular member and against said plate member to prevent said medium from passing through the sliding fit between said plate member and said tubular member,
   - a guide tube connected with the other end of said tubular member, said guide tube and tubular member being dimensioned to provide an abutment means for said plate member in its strike position,
   - a piston-like striker member slidably mounted in said guide tube and adapted for impact with said plate member when the plate member is in its strike position,
   - a cylinder connected to said guide tube and axially aligned therewith,
   - a piston slidably received in said cylinder and having a portion extending into said guide tube,
   - said striker member and said portion of said piston having a resilient connection therebetween,
   - and fluid means connected to said cylinder to apply a sudden pressure surge thereto.

9. The combination according to claim **8**, in which the piston and cylinder form a valve and seat of substantially smaller effective area than that of the cylinder.

10. The combination according to claim **8**, including means to evacuate the space in the guide tube between the striker member and the plate member.

11. The combination according to claim **8**, in which the portion of the piston extending into the guide tube is connected with the striker member by spring means.

12. The combination according to claim **8**, in which the piston and cylinder form a valve and seat of substantially smaller effective area than that of the cylinder, and means to apply fluid pressure to the cylinder comprising a source of steadily increasing fluid pressure to said valve.

(References on following page)

References Cited

UNITED STATES PATENTS

1,689,574	10/1928	Williams	340—12
1,753,368	4/1930	Remond et al.	340—12
2,044,820	6/1936	Turner	340—12
3,039,559	6/1962	Ellsworth	181—0.5
3,053,220	9/1962	Sawyer	116—137
3,056,104	9/1962	DeKanski et al.	340—5

3,105,460	10/1963	Bouyoucos	116—137
3,143,999	8/1964	Bouyoucos	116—137
3,349,367	10/1967	Wisotsky	340—12

LOUIS J. CAPOZI, *Primary Examiner.*

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