April 12, 1966 R. H. MELLEN 3,246,289

RESONANT UNDERWATER HYDRODYNAMIC ACOUSTIC PROJECTOR

Filed April 13, 1962

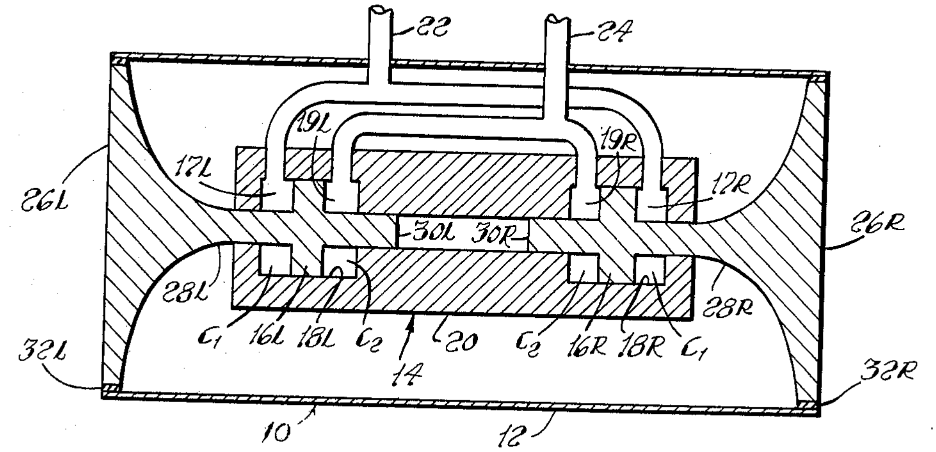

Fig. 1

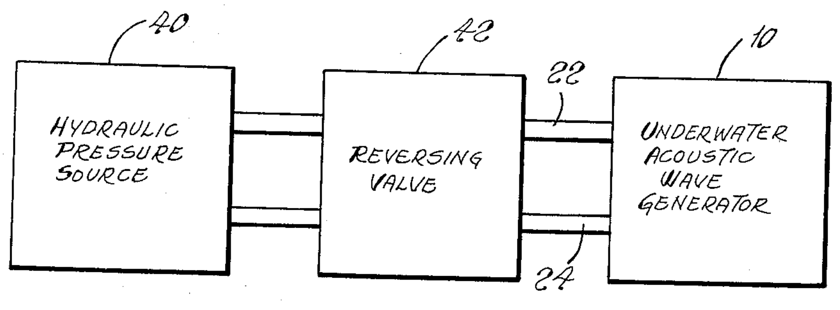

Fig. 2

INVENTOR.
ROBERT H. MELLEN

BY Arthur L Bowers
AGENT

United States Patent Office

3,246,289

Patented Apr. 12, 1966

3,246,289

RESONANT UNDERWATER HYDRODYNAMIC ACOUSTIC PROJECTOR

Robert H. Mellen, Old Lyme, Conn., assignor to the United States of America as represented by the Secretary of the Navy

Filed Apr. 13, 1962, Ser. No. 187,444
8 Claims. (Cl. 340—12)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to hydrodynamic generation and projection of acoustic wave energy.

Underwater acoustic wave projectors in use heretofore have utilized electrostrictive, magneto-strictive, or electrodynamic components. However, these types of projectors have usually been found unsuitable for generating high power at the low audio frequencies, 200 cycles or less per second. They are expensive, bulky, and require complex electronic circuitry. In addition, the elements are usually fragile, complex and expensive to fabricate. For low frequency operation at high power the elements must be large and are consequently expensive.

An object of this invention is to provide an underwater acoustic wave projector characterized by any or all of the following: resonant, efficient, omnidirectional, narrow band, capable of radiating high power at low audio frequencies, capable of continuous wave or pulse operation, structurally simple, rugged, economical to fabricate and operate, and comparatively small relative to its power capacity.

Other objects and advantages will appear from the following description of an example of the invention, and the novel features will be particularly pointed out in the appended claims.

FIG. 1 is a longitudinal section taken generally centrally of a hydraulically operable under water sound projector embodying the principles of this invention and not including ordinary details of construction, e.g., seals, joints, fastenings, and FIG. 2 is a block diagram of a hydrodynamic system including a sound projector of the type shown in FIG. 1.

The hydraulic sound projector embodiment 10 shown in FIG. 1 includes a housing element 12 of rigid, tough material impermeable to sea water. While the housing element 12 in the drawing may be a circular cylinder, this particular shape is not significant. Centrally located and rigidly mounted in the housing element 12 with braces that are not shown on the drawing, is a hydraulic motor 14 which includes two double-acting substantially identical, driving pistons 16L and 16R reciprocable in respective in-line cylinders 18L and 18R in motor block 20. The driving pistons 16L and 16R divide the cylinders 18L and 18R into chambers 17L, 19L and 19R, 17R, respectively. A pair of separate hydraulic conduits 22 and 24 for the chambers extend through and are sealed fluid-tight in the wall of housing element 12 and are in fluid communication with the relatively remote chambers 17L and 17R, and the relatively proximate chambers 19L and 19R respectively. Identical rigid, circular, flat face radiating pistons 26L and 26R are rigidly joined by connecting rods 28L and 28R to driving pistons 16L and 16R. The areas of the opposite faces of each driving piston acted upon by the driving liquid are made equal by the addition of area compensation rods 30L and 30R that have cross sections equal to that of connecting rods 28L and 28R secured to and extending from the faces of the driving pistons opposite to the faces joined to the radiating pistons. The area compensation rods 30L and 30R are of sufficient length to extend beyond the inner ends of

the cylinders 18L and 18R toward one another and are separated by an air space in the motor block 20. The perimeters of the radiating pistons 26L and 26R and the respective ends of housing element 12 are joined in fluid-tight relationship by annuli 32L and 32R. The annuli 32L and 32R may be O-rings or other seals or they may be compliant elastomeric material bonded to the perimeters of the radiating pistons and to housing element 12. The mechanical impedance of the annuli 32L and 32R to reciprocation of the pistons are preferably as low as practical consistent with their fluid sealing function. The interior of the housing element 12 contains dry air or other gas. If intended for operation at shallow depth, air at atmospheric pressure or at the pressure corresponding to the operating depth occupies the housing element, but if the projector is intended for use at greater depths, a static pressure head compensating apparatus may be used. Pressure compensating system is well known and includes basically a differential valve subject to the pressure inside and outside the housing element for bleeding air out of the housing element when the pressure in the housing element exceeds the water pressure by a preselected differential; the apparatus also includes a compressed gas bottle and a valve responsive to pressure differential between exterior and interior of housing element, and when the exterior pressure exceeds the interior pressure by a preselected differential, the latter valve opens and admits gas from the bottle into the housing element until the differential is reduced enough for the valve to close.

The unit shown in FIG. 1 is recoilless because the reactions of the two halves are equal and opposite. However, the invention may be practised by constructing a unit having one radiating piston only, utilizing half the structure shown in FIG. 1. The latter requires reaction mass or rigid support structure.

The housing element 12 must be sufficiently stiff or rigid so that its displacement does not change when the pistons are reciprocating. In other words, the housing element must not collapse and expand in response to changing local pressure when the pistons are reciprocated. The total mass of each piston assembly is preferably no greater than necessary for stiffness or rigidity.

The projector 10 is powered by a hydraulic pressure source 40 and controlled by reversing valve 42 as shown in FIG. 2. Suitable valves for this system are the commercially available electrohydraulic servo units, such as those made by Moog Valve Co. and Cadillac Company. Also two-stage valve mechanisms that have been used in hydrodynamic shaker equipment of the type manufactured by MB Electronics of New Haven, Connecticut, and Bertea of Los Angeles, California, may be used as reversing valve 42. A solenoid operated hydraulic reversing valve for switching the hydraulic connections between the conduits 22 and 24 and the pressure and return lines of the hydraulic pressure source 40 may be used. Regardless of the type of reversing valve selected, each time the valve operates to reverse connections, the radiating pistons are displaced outwardly or inwardly.

It is advantageous that the conduits be no longer than necessary to minimize both the mass of the slug of driving liquid moved during each cycle and the power loss due to friction between the liquid columns and the conduit walls. The diameter of the conduits is small and is selected on the basis of compromise between minimum mass of moving slug of driving liquid and minimum frictional loss between the driving liquid and conduit wall. While high pressure hoses may be used for this purpose, rigid conduits are preferable for the same reason that the housing 12 must be rigid, namely, that the housing manifest no volume change as the pressure of the driving liquid changes.

To make projector **10** resonant at a chosen frequency, narrow band, i.e. approximately 10% bandwidth and for a chosen level of radiated power, it is necessary to specify the radius or the area of the radiating piston, the mass of the movable piston assembly, the area of the driving piston acted upon by the driving liquid, the compliant element for resonating the effective mass reactance of the system at the desired frequency, and the hydraulic supply pressure at the driving piston. These parameters are substantially the same whether the unit includes one projector or two projectors back-to-back as shown in FIG. 1. The housing wall that mounts the radiating pistons is a circular cylinder in the embodiment shown in the drawing. However, the circular shape is not intended as limiting since it does not have an effect on the parameters specified above. The shape of the housing may be chosen arbitrarily provided that the housing is large enough to contain the hydraulic structure and the radiating pistons and has sufficient structural strength to meet the operating conditions.

The relationships from which these parameters are obtained are described and developed below.

Mechanical radiation impedance for a piston operating into a fluid medium is defined as the ratio of the force exerted by the piston on the medium to the velocity of the piston and is designated Z_{rm}.

Each flat circular rigid radiating piston **26** in FIG. 1 approximates a rigid flat circular piston in an infinite baffle. A plane normal to the projector half-way between the radiating surfaces is essentially an infinite baffle to the radiating pistons. The mechanical radiation impedance for the latter when radiating a sinusoidal acoustic signal is:

$$Z_{rm}=\rho c\pi a^2[R_1(2ka)+jX_1(2ka)] \quad (1)$$

where

ρ=density and is approximately unity for water
c=acoustic wave velocity
ρc=specific acoustical impedance of the medium
a=radius of the radiating piston
$k=2\pi f/c$ where f is the reciprocating frequency of the piston

$$R_1(2ka)=\frac{(2ka)^2}{2\cdot 4}-\frac{(2ka)^4}{2\cdot 4^2\cdot 6}+\frac{(2ka)^6}{2\cdot 4^2\cdot 6^2\cdot 8} \quad (2)$$

$$X_1(2ka)=\frac{4}{\pi}\left(\frac{2ka}{3}-\frac{(2ka)^3}{3^2\cdot 5}+\frac{(2ka)^5}{3^2\cdot 5^2\cdot 7}\right) \quad (3)$$

The foregoing equations are similar to those which are developed in Fundamentals of Acoustics by Kinsler and Frey, published by John Wiley 1950, pages 190 and 191. On page 190 of Kinsler and Frey, there is a graph of Equations 2 and 3.

In assigning a numerical value to ka, the factors that need to be considered are the system or overall Q and the size of the radiating piston. The numerical value of ka is too low if the system Q and thus the internal losses are unacceptably high, and the numerical value of ka is too high if the size of the radiating piston is too large for the power to be radiated. Overall system Q on the order of 10–20 provides good results. Therefore, it is preferable that ka be greater than 0.1 and less than 1.0. For $2ka$ less than 1, R_1 $(2ka)$ may be replaced by the first term of its series in Equation 2, namely, $(ka)^2/2$ and X_1 $(2ka)$ may be replaced by the first term of its series in Equation 3, namely, $8ka/3\pi$.

For purposes of illustration, it is assumed that a projector **10** is needed for operation at f_0=200 cycles/sec. and 12.5 kilowatts radiated per piston. Acoustic wave velocity c in the water environment in which the projector **10** is to be used is assumed to be 1.5×10^5 cm./sec. Based upon the preceding considerations, ka is made 0.32, whereby the radius of the radiating piston is 38 centimeters,

$$R_1(2ka)=0.05 \text{ and } X_1\ (2ka)=0.3 \quad (4)$$

Whence

$$Q_r\simeq\frac{X_1(2ka)}{R_1(2ka)}\simeq\frac{8(ka)}{3\pi}\cdot\frac{2}{(ka)^2}=\frac{16}{3\pi(ka)}\simeq 5.3$$

where Q_r is the radiation Q

The acoustic power W_r radiated by a piston is equal to the rate at which work is done against the radiation resistance R_r. On page 194 of Kinsler and Frey

$$W_{rav}=\tfrac{1}{2}R_r|U_0|^2 \quad (5)$$

where U_0 is the amplitude of the velocity of the piston surface. The peak pressure P_{peak} exerted by the radiating piston face against the medium can be determined from Equation 5 by stubstituting the desired numerical value for W_r. On page 191 of Kinsler and Frey

$$U_{0e}{}^{j\omega t}=-\frac{fr}{Z_{rm}} \quad (6)$$

where fr is force exerted by the radiating piston on the medium. Therefore

$$|U_0|^2=\frac{F^2}{|Z_{rm}|^2}=\frac{|P_{peak}|^2A^2}{|Z_{rm}|^2} \quad (7)$$

where F is the peak force exerted by the radiating piston on the medium
P_{peak} is the peak pressure exerted by the radiating piston on the medium
A is the area of the radiating piston
Z_{rm} is the mechanical radiation impedance of the piston. Therefore

$$|U_0|^2=\frac{|P_{peak}|^2}{(\rho c)^2[R_1^2(2ka)+X_1^2(2ka)]}$$

The radiation resistance is obtained from Equation 1

$$R_r=\rho cA[R_1(2ka)] \quad (8)$$

Substituting Equations 7 and 8 in Equation 5

$$W_{rav}=\frac{|P_{peak}|^2A}{2\rho c}\cdot\frac{R_1(2ka)}{R_1^2(2ka)+X_1^2(2ka)}\times10^{-7} \quad (9)$$

where W is in watts and the other units are in the c.g.s. system.

For radiating piston radius of 38 cm. computed previously from ka=0.32, the area A of each radiating piston is approximately equal to 4500 cm.^{2}. ρc is equal to 1.5×10^5 gm./cm.=sec.^{2}. Since W_{rav} is to be 1.25×10^4 watts per radiating piston, Equation 9 is solved for P_{peak}.

$$P_{peak}\cong 3.9\times10^6 \text{ dynes/cm.}^2\simeq 60 \text{ pounds/in.}^2$$

To prevent cavitation, the operating depth for projector **10** must be no less than that depth at which the static pressure of the water is equal to the peak signal pressure at the radiating piston.

The peak velocity $|U_0|$ of the radiating piston is obtained from Equation 6 as follows:

$$U_{0e}{}^{j\omega t}=-\frac{fr}{Z_r}$$

$$U_{0e}{}^{j\omega t}=-\frac{PA}{\rho cA[R_1(2ka)+jX_1(2ka)]}$$

$$|U_0|=\frac{P_{peak}}{\rho c|0.05+j0.3|}\simeq 90 \text{ cm./sec.}$$

Since the projector **10** will operate as a resonant device at the selected frequency and describe simple harmonic motion,

$$X=X_0\cos(\omega_0t+\phi) \quad (10)$$

Where

X=displacement at time t from center position
X_0=displacement amplitude
$\omega_0=2\pi f_0$ where f_0 is the selected frequency of the piston in cycles per second

ϕ=phase angle at $t=0$ when motion begins
t=number of seconds following initiation of the motion

$$v=\frac{dx}{dt}=-\omega_0 X_0 \sin(\omega_0 t+\phi) \quad (11)$$

where v is the velocity at time t. When v is maximum, the displacement amplitude

$$X_0=\frac{U_0}{\omega_0}$$

At 200 cycles per second and peak velocity of approximately 90 centimeters per second, the displacement is approximately 0.07 centimeter. Therefore, peak-to-peak displacement is approximately 0.14 centimeter.

The radiation reactance X_r of a piston is always positive and its effect is therefore equivalent to adding to the actual mass of the piston an additional mass M_r where

$$M_r=\frac{X_r}{\omega_0}=\frac{\rho c A X_1(2ka)}{\omega_0}\simeq 1.6\times 10^5 \text{ grams}\simeq 350 \text{ pounds} \quad (12)$$

The piston should be stiff or rigid and lightweight; in other words the piston should be no heavier than required for stiffness. Assuming that the mass M_p of each radiating piston required for a rigid radiator is equal to M_r, then the Q_s of the overall system will be twice the radiation Q_r or $Q_s \simeq 10.6$ which is acceptable. The total driving force required for each piston is obtained as follows:

$$F=ma=(M_r+M_p)a$$

$$a=\frac{dv}{dt}=-\omega_0^2 X_0 \cos(\omega_0 t+\phi)$$

$$a_{\max.}=\omega_0^2 X_0$$

since

$$X_0=\frac{|U_0|}{\omega_0}$$

$$a_{\max.}=\omega_0|U_0|$$

Therefore

$$F=(M_r+M_p)\omega|U_0|\simeq 3\times 10_{10} \text{ dynes} \quad (13)$$

or approximately 80,000 pounds.

The projector **10** is made series resonant, One method by which one may introduce the compliance necessary for making projector **10** resonant is to use properly designed spring elements in the form of elastic rods attached to the piston assemblies. However, the most advantageous means for supplying the proper compliance is to make the driving liquid chambers or cavities on each side of each driving piston of proper volume and proportion for resonating the mass reactance.

Resonance will occur when the acoustic reactance equals zero, i.e., when

$$\omega_0 M=\frac{1}{\omega_0 C}$$

where

M is acoustic inertance
C is acoustic compliance

$$M=\frac{m}{S^2} \quad (14)$$

where

m is the effective mass of the element (M_r+M_p)
S is the area of the driving piston upon which the driving liquid acts.

Therefore

$$\omega_0\frac{(M_r+M_p)}{S^2}=\frac{1}{\omega_0 C} \quad (15)$$

The stiffness reactance is provided by two compliance elements C_1 and C_2, in series with the acoustic inertance M, namely, the driving liquid cavities on each side of each driving piston. To obtain C_{total} for the two compliances C_1 and C_2 in series in each half of the projector **10**,

$$\frac{1}{C_{total}}=\frac{1}{C_1}+\frac{1}{C_2} \quad (16)$$

whereby

$$C_{total}=\frac{C_1C_2}{C_1+C_2}$$

since C_1 and C_2 are equal,

$$C_{total}=\frac{C \text{ (for one cavity)}}{2}$$

C for an enclosed volume V is equal to

$$V/\rho c^2$$

where ρ is the density and c the speed of sound of the driving liquid. In this example it is assumed that ρ and c of the driving liquid is the same as specified above for water. Therefore

$$C_{total}=\frac{V}{2\rho c^2}$$

where V is the volume of each compliance chamber.

Substituting in Equation 15

$$\frac{\omega_0(M_r+M_p)}{S^2}=\frac{2\rho c}{\omega_0 V}$$

Therefore

$$\omega_0(M_r+M_p)=\frac{2\rho c^2 S^2}{\omega_0 V}=\frac{F}{U_0}=\frac{P_0 S}{U_0} \quad (17)$$

where P_0 is the supply pressure of the hydraulic pump. Alternating hydraulic pressure systems are commercially available for operation at several standardized pressures, i.e., 1500, 3,000, and 5,000 pounds per square inch. The system pressure is somewhat adjustable. For purposes of this example, a hydraulic system operable at 3,000 pounds/in.^{2} or approximately 2×10^8 dynes/cm.^{2} is selected. This pressure will be modulated from 0 to 6,000 pounds/in.^{2} under full drive.

Since $V=SL$ where L is the length of each compliance cavity

$$L=\frac{2\rho c^2 U_0}{\omega_0 P_0}\simeq 16 \text{ centimeters} \quad (18)$$

and

$$S=\frac{\omega_0^2(M_r+M_p)L}{2\rho c^2}\simeq 180 \text{ cm.}^2 \quad (19)$$

Hydraulic systems of the type marketed commercially for operating shaker tables can be utilized for practising this invention; systems with two stage valves operate at high power, one such system, taken as illustrative, is described in U.S. Patent No. 2,953,123. The teachings of this invention may be applied to the elements **20–25** shown in FIG. 1 of the patent, by designing the cavities into which feed the conduits **23** and **24** for resonance and by proper proportioning of the effective areas of driving and radiating pistons. M. B. Electronic of New Haven, Conn., and Bertea Co. of Los Angeles, California, fabricators of hydraulic shaker devices are examples of commercial sources of hydraulic systems than can be used in practising this invention. If a hydraulic system is selected from those available commercially, the characteristics that must be considered are power, frequency, and pressure, and the system is modified in accordance with the principles outlined above.

While this invention is especially advantageous for radiating acoustic power into water at high power $0<f<200$ cycles/sec. this is not to be constructed as a limitation on the frequency at which this invention may be used. If a structure as shown in FIG. 1 is used in practicing this invention, the projector is omnidirectional because it is small compared to the operating wavelength. If the Q is within the range discussed, the projector bandwidth will be on the order of ten percent. If the bandwidth is narrow the invention is inherently resonant; even if the alternating pressure applied is not sinusoidal, only the fundamental will be radiated. While the mathematics in this description relates to a flat face circular rigid piston, the same treatment may be applied to back-to-back or single pistons and of substantially different shapes, e.g. noncircular, domed, recessed, and others. While the results will be less accurate than for a flat circular rigid piston in an infinite baffle, the mathematics will provide a good approximation adequate for most practical purposes.

It will be understood that various changes in the details, materials and arrangements of parts (and steps), which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention, as expressed in the appended claims.

I claim:

1. A resonant underwater sound projector for operation at a frequency near the lower end of the audio-band comprising a rigid radiating piston, a hydraulic motor having a cylinder and a driving piston mounted for reciprocatory oscillation in said cylinder in line with and affixed to said radiating piston, said driving piston and cylinder together defining substantially identical chambers for hydraulic fluid on opposite sides of said driving piston, identical hydraulic fluid fully occupying both chambers, a housing rigidly mounting said hydraulic motor therein and having an opening in its wall for mounting the radiating piston, a water-sealing means disposed between the edge of said radiating piston and said housing, a hydraulic conduit sealed into each fluid chamber in the hydraulic motor and extending through and sealed water-tight in the housing for connection to a hydraulic pressure source of driving liquid wherein the pressure varies at said frequency, said housing and radiating piston confining a water-tight chamber, wherein the volume not occupied by motor, radiating piston, and conduits is dry and occupied by gas, the chambers having dimensions and the hydraulic fluid therein having rho and *c* characteristics whereby the mass inertance of the piston mass plus the effective radiation mass is resonated by the compliance of the fluid in the two chambers, and the effective areas of the driving and the radiating piston are relatively proportioned for matching.

2. An underwater sound projector resonant at a predetermined frequency comprising a rigid radiating piston, a hydraulic motor including a cylinder and a driving piston mounted for reciprocatory oscillation in said cylinder and rigidly joined to said radiating piston said driving piston and cylinder together defining substantially identical chambers for hydraulic fluid on opposite sides of said driving piston, identical hydraulic fluid fully occupying both chambers, a housing rigidly mounting said hydraulic motor therewithin and having an opening in its wall for mounting the radiating piston, water-sealing means disposed between the periphery of said radiating piston and said housing, a hydraulic conduit sealed into each fluid chamber in the cylinder, said housing and radiating piston confining a water-tight chamber wherein the volume not occupied by the hydraulic motor radiating piston and conduits is dry and occupied by gas, the hydraulic fluid chambers having dimensions and the hydraulic fluid having rho and *c* characteristics whereby when the projector is operated under water it is resonant at the predetermined frequency.

3. A resonant underwater sound projector as defined in claim 2 and further including structure identical thereto and joined therewith in line and back-to-back.

4. Apparatus for projecting acoustic waves underwater at a selected frequency and a selected level of radiated power comprising a rigid radiating piston, a hydraulic motor including a cylinder and a driving piston mounted for reciprocatory oscillation in said cylinder and rigidly joined to and in line with said radiating piston, said driving piston and cylinder together defining substantially identical chambers for hydraulic fluid on opposite sides of said driving piston, identical hydraulic fluid fully occupying both chambers, a housing rigidly mounting said hydraulic motor therewithin and having an opening in its wall for mounting the radiating piston, water-sealing means disposed between the periphery of said radiating piston and said housing and presenting negligible mechanical impedance to piston reciprocation, a hydraulic conduit sealed into each hydraulic fluid chamber in the cylinder, said housing and radiating piston confining a water-tight chamber wherein the volume not occupied by the hydraulic motor radiating piston and conduits is dry and occupied by gas, the effective area of the radiating piston being not appreciably larger than necessary to radiate said selected power at a selected operating depth without cavitation, and being large enough for the overall Q to be on the order of 10–12, the hydraulic fluid chambers having dimensions and the hydraulic fluid having rho and *c* characteristics whereby when the apparatus is operated under water it is resonant at the selected frequency.

5. A method of generating underwater sound comprising:

(a) supporting a reciprocable piston assembly underwater with a radiating force for delivering sound energy to the water,
(b) driving and resonating the effective reciprocating mass at a predetermined frequency with the same hydraulic fluid.

6. A method of generating underwater sound comprising:

(a) supporting a reciprocable piston with a radiating face for delivering sound energy to the water,
(b) driving the radiating piston with a double acting piston,
(c) confining chambers of identical hydraulic fluid and of substantially identical dimensions on opposite sides of the double acting piston for resonating the effective reciprocating mass under operating conditions at a predetermined frequency and for delivering alternating force differential across the double acting piston, and
(d) creating a pressure differential between the two chambers of fluid and alternating the pressure differential at said selected frequency.

7. Apparatus for generating underwater sound at a selected frequency comprising:

(a) a radiating piston,
(b) means reciprocably supporting said piston with a radiating face exposed for delivering sound energy to the water,
(c) a driving piston rigidly joined to said radiating piston,
(d) a cylinder in said supporting means and mounting said driving piston for oscillatory reciprocation therein and together therewith defining susbtantially identical chambers for hydraulic fluid on opposite sides of said driving piston,
(e) identical hydraulic fluid fully occupying both chambers, the fluid chambers having dimensions and the hydraulic fluid in said chambers having rho and *c* characteristics,
(f) whereby the fluid in said chambers and the effective reciprocating mass of the apparatus when under water are resonant at the selected frequency,
(g) a conduit sealed into each of the chambers for delivering fluid-borne alternating pressure differential to the chambers of hydraulic fluid at the resonant frequency of the apparatus for causing oscillatory reciprocation of said driving piston of negligible peak-to-peak amplitude compared to the length of each fluid chamber.

8. An underwater sound projector for resonant operation at a frequency near the lower end of the audio band comprising:

(a) a hydraulic motor having a cylinder and a driving piston reciprocable in the cylinder,

(b) a hydraulic fluid fully occupying the cyinder on opposite sides of the piston,

(c) two hydraulic conduits joined to said cylinder for continuous fluid communication with the fluid on respective sides of said piston, the cylinder being essentially fluid-tight except for communication with said conduits,

(d) whereby alternating pressure differential between opposite sides of said piston transmitted by the hydraulic conduits causes the piston to reciprocate in the cylinder, a rigid radiating piston having a radiating face in line with and affixed to said driving piston,

(e) means secured to the perimeter of said radiating piston and rigidly secured to said piston and confining a gas-filled chamber behind said radiating piston,

(f) the fluid on opposite sides of said driving piston delivering driving power to the driving piston and having dimensions and characteristics for resonating the effective reciprocating mass at said frequency when said projector is operating under water.

References Cited by the Examiner

UNITED STATES PATENTS

929,623	7/1909	Nuinberg	116—27
2,172,066	9/1939	Logsdon	116—27
3,056,104	9/1962	DeKanski et al.	340—5
3,059,663	10/1962	Whitenack	137—623

CHESTER L. JUSTUS, *Primary Examiner.*

LOUIS J. CAPOZI, *Examiner.*

GERALD M. FISHER, *Assistant Examiner.*