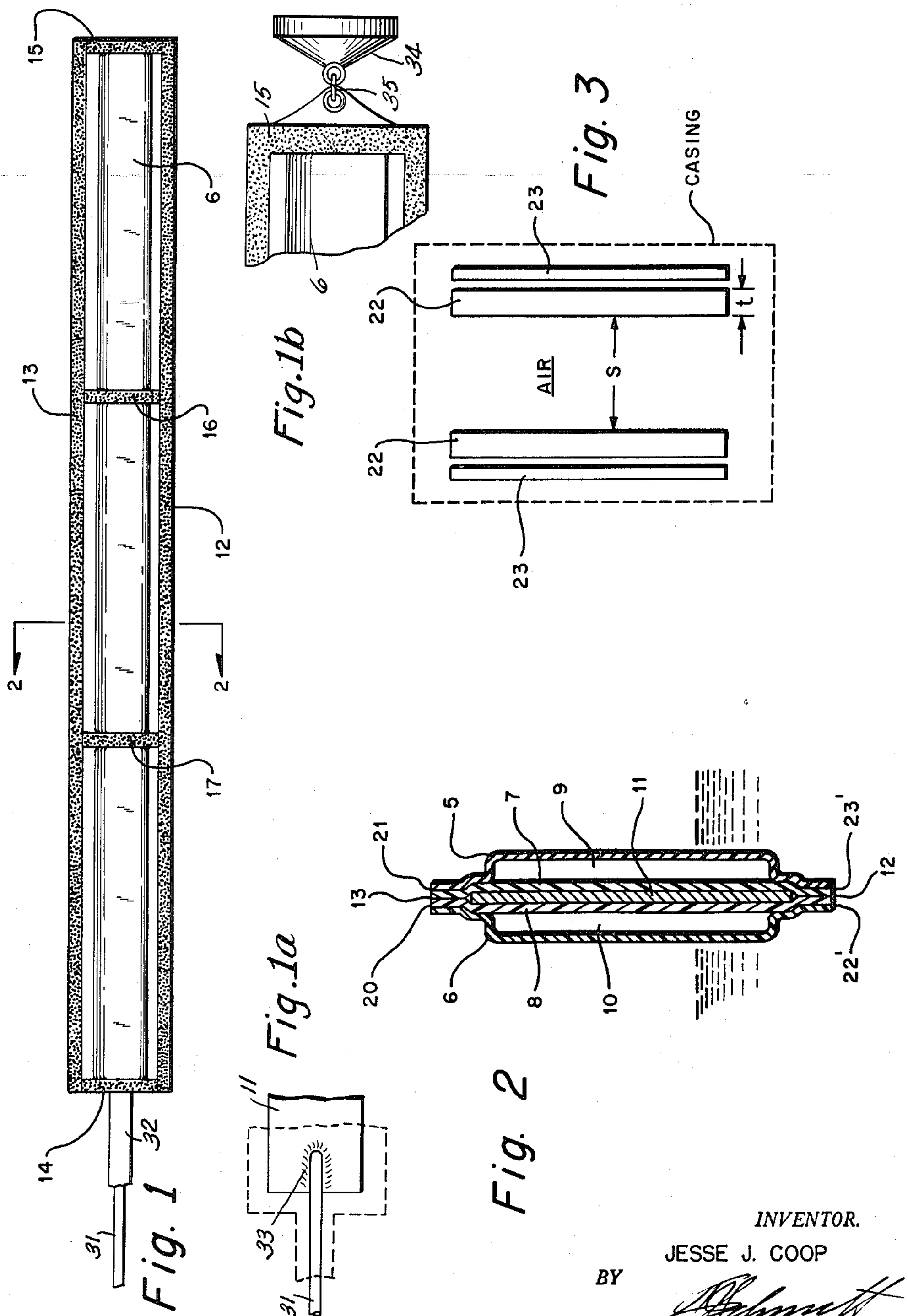
Dec. 13, 1960 J. J. COOP 2,964,731

LONG LINE CONDENSER HYDROPHONE WITH GASEOUS POCKETS

Filed June 18, 1954



INVENTOR.
JESSE J. COOP

BY [signature]
ATTORNEYS

United States Patent Office

2,964,731

Patented Dec. 13, 1960

2,964,731

LONG LINE CONDENSER HYDROPHONE WITH GASEOUS POCKETS

Jesse J. Coop, 427 E. Moreland Road, Willow Grove, Pa.

Filed June 18, 1954, Ser. No. 437,899

10 Claims. (Cl. 340—13)

(Granted under Title 35, U.S. Code (1952), sec. 266)

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

The invention of this application relates to a long line condenser hydrophone and more particularly relates to a hydrophone having high directivity at comparatively low frequencies such as sonic or supersonic frequencies. The invention presents a unit structure which is capable of being rolled up to compact sizes very suitable for sonobuoy and other applications and provides for higher sensitivity than was available with previously known devices particularly at low frequencies. These low frequencies are especially suitable for long range detection. The inventive device unlike previous devices is directional because of its large dimensions. These large dimensions are necessary to obtain the greater signal to noise ratio associated with directive arrays.

Hydrophones of the prior art provided solid backed condensers or coaxial lines using elastic solids. These proved bulky, inadaptable to sonobuoys, had a low sensitivity and were costly to produce. The inventive device overcomes these and other disadvantages and in addition presents desirable features of compactness, suitability for sonobuoy and other similar applications, higher sensitivity particularly at low frequencies, especial suitability for long range detection and greater directional characteristics.

Accordingly, an object of the invention is to provide a hydrophone having a high directivity at low frequencies, particularly in the sonic and supersonic range of frequencies.

Another aim of the invention is to present a compact hydrophone of high sensitivity which will be adaptable to sonobuoy use.

Another object of the invention is to provide a long line condenser hydrophone of compact size especially suitable for sonobuoy and other applications and wherein the device will have high sensitivity particularly at low frequencies, these low frequencies being especially suitable for long range detection.

Still another purpose of the invention is to provide a long line condenser hydrophone which will be directional because of its large dimensions necessary to obtain greater signal to noise ratio.

Another aim of the invention is to present a long line condenser hydrophone with the desirable features of great sensitivity at low frequencies and suitability for long range detection and wherein the construction will permit mass production at relatively low cost.

Another object of the invention is to present hydrophone structure which will be entirely without stiff backing members so that mass production and compact storage in a small space are facilitated.

Another aim of the instant invention is to present a foil structure of a hydrophone which will reduce the unequal trapping of air at concentrated regions along its

length and thereby provide greater accuracy in use of the device.

Still another purpose of the invention is to present a device which eliminates stiff backing members so as to permit mass production and compact storage and wherein sealing of foils at points along this length to produce air pockets distributed along the length is incorporated, wherein the device will have high directivity and high sensitivity particularly at low frequencies, the device being rugged of construction as well as economical in initial cost.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

Fig. 1 is a plan view of a representative length of an illustrative embodiment of the inventive device,

Fig. *1a* is a broken-away detailed view of the connection of the conductor to the metal foil, supplementing the showing in Fig. 1,

Fig. *1b* is a broken-away detail showing a suitable arrangement for anchoring the inventive device,

Fig. 2 is a cross-sectional view taken along the lines **2—2** of Fig. 1 and looking in the direction of the arrows, and,

Fig. 3 is a schematic representation of two dielectric materials having air entrapped therebetween, the outer surface of the dielectric materials being adjacent conducting plates in order to demonstrate theoretical effects of a change in the external pressure applied to the conducting plates.

Referring to the drawings and in particular to the representation of Fig. 3, a quantity of air as labelled in the figure is entrapped in an air space between dielectric materials **22, 22**. The outer surfaces of the dielectric materials may be in contact with adjacent conducting plates **23, 23**. The distance between the dielectric plates **22, 22** which is air space filled by air is denoted by distance S. It may readily be seen from this figure that if air is entrapped between the two dielectric materials **22, 22**, whose outer surfaces are in contact with conducting plates **23, 23**, a change in external pressure applied to the conducting plates will produce a change in volume of the air and hence a change in the distance between the condenser plates. Let:

S=distance between dielectric material (air space)
t=thickness of dielectric as indicated on the figure
A=area of dielectric sheet
K=dielectric constant of insulating sheets

The representation of Fig. 3 will thus provide a condenser or capacitor, the capacity of which is given in e.s.u. (electro-static units) by:

$$C=\frac{KA}{8\pi(KS+t)}\text{ e.s.u.} \qquad (1)$$

also

$$C=\frac{Q}{E} \qquad (2)$$

where Q is the charge and E is the potential.

If the condenser is subjected to a pressure such as produced by immersion in water the air will be compressed resulting in a decrease in volume thus producing an increase in capacity. The decrease in volume may be computed from the gas laws. If isothermal

$$PV=K \qquad (3)$$

and

$$dV=-\frac{V}{P}dP \qquad (4)$$

where P is the absolute pressure and dP is the change in pressure.

If adiabatic expansion is involved

$$PV^{\gamma}=K \tag{5}$$

and

$$dV=-\frac{V}{\gamma P}dP \tag{6}$$

where γ is the ratio of specific heat for air.

For a displacement dS the change in capacity can be computed as follows:

$$C=\frac{KA}{8\pi(KS+t)}$$

$$dC=-\frac{KA\cdot 8\pi KdS}{[8\pi(KS+t)]^2} \tag{7}$$

since

$$AdS=dV$$

$$dC=\frac{-8\pi K^2dV}{[8\pi(KS+t)]^2}=-\frac{K^2dV-}{8\pi(KS+t)^2} \tag{8}$$

from Equation 2 by differentiation

$$dE=-\frac{Q}{C^2}dC \tag{9}$$

If the charge remains constant by substituting the value of

$$\frac{Q}{C}$$

from 2

$$dE=-\frac{E}{C}dC \tag{10}$$

from Equations 8 and 10

$$dE=+\frac{E}{C}\cdot\frac{K^2dV}{8\pi(KS+t)^2} \tag{11}$$

The value of dV is obtained from Equation 6

$$dE=\frac{E}{C}\cdot\frac{K^2}{8\pi(KS+t)^2}\cdot\frac{-V}{\gamma P}dP \tag{12}$$

since

$$V=AS$$

$$dE=-\frac{EK\cdot KASdP}{\gamma C8\pi(KS+t)^2P} \tag{13}$$

from Equation 1

$$C=\frac{KA}{8\pi(KS+t)}$$

$$dE=-\frac{EKSdP}{\gamma(KS+t)P} \tag{14}$$

For a long line condenser vertically disposed the air thickness S may be expressed in terms of the static pressure P by the approximate relation

$$PS=k'$$

$$\frac{dE}{dP}=\frac{-EKk'}{\gamma P(Kk'+Pt)} \tag{15}$$

$$=\frac{-E}{\gamma P(1+Pb)}$$

where

$$b=\frac{t}{Kk'}$$

The results indicate a decrease in sensitivity with increasing depth. Also, since the displacement of the condenser plates for a given value of the signal pressure dP is expected to be proportional to the particle displacement the sensitivity should be inversely proportional to the signal frequency.

It should be understood that the condenser unit hereinafter referred to and comprising the laminated polythene layers and metal plate member represents an incomplete condenser. As best shown in Fig. 2 the second condenser plate consists of the boundary surface of the conducting medium into which the element or unit of Fig. 1 is placed. Thus, in this embodiment, the foils **5** and **7** or **6** and **8** constitute the dielectric plates **22, 22** of Fig. 3 and the metal foil **11** constitutes one of the conductive plates **23**, while the liquid in which the unit is immersed constitutes the other conductive plate.

A short cut to the above calculations is obtained in using the relation

$$E=f(C, V, P) \tag{16}$$

where

$$\frac{dE}{dP}=\frac{dE}{dC}\cdot\frac{dC}{dV}\cdot\frac{dV}{dP} \tag{17}$$

$$=\frac{\partial E}{\partial C}\frac{dC}{dP}+\frac{\partial E}{\partial V}\frac{dV}{dP}+\frac{\partial E}{\partial P}$$

By carrying out these operations

$$\frac{dE}{dP}=-\frac{E}{C}\cdot\frac{K^2}{8\pi(KS+t)^2}\cdot\frac{-V}{\gamma P} \tag{18}$$

$$=-\frac{EKS}{\gamma(KS+t)P} \tag{19}$$

The value of the term

$$\frac{dC}{dP}$$

can be determined by static methods. Hence,

$$\frac{dE}{dP}=\frac{dE}{dC}\cdot\frac{dC}{dP} \tag{20}$$

in which

$$\frac{dC}{dP}=\frac{dC}{dV}\cdot\frac{dV}{dP} \tag{21}$$

is obtained experimentally by measuring the capacity as a function of the static pressure, which can be determined from the depth of submergence in the water. The apparatus described below provides a mechanism to implement these findings providing a device for underwater sound detection of targets.

Referring more particularly to Figs. 1 and 2 of the drawings wherein is shown an illustrative embodiment of the device of the invention of this application, the following steps can be taken in manufacturing the device.

Step 1.—Two outer foils of polyethylene or other appropriate insulating substance, foils **5** and **7** or foils **6** and **8** for example are sealed around their periphery as at seals **20** and **22'** or seals **21** and **23'** and across at intervals along their lengths to provide a plurality of air pockets along their major dimensions.

Step 2.—A strip of metal foil **11** of shorter and narrower dimensions than the polyethylene foils is sandwiched between two sets of the insulating foils (polyethylene, etc.), each set being sealed as described in Step 1 above.

Step 3.—The assembly formed in Step 2 above is sealed around three sides of the periphery of the metal foil (as shown in Fig. 1 at **12, 13,** and **15**) to completely enclose the metal foil. One end **14** is temporarily left open, to accommodate the conductor described below.

Step 4.—The conductor **31** is electrically joined to the metal foil **11** as by soldered joint **33** through the open end of the assembly as described in Step 3 above. See Fig. 1*a* for a detailed showing of the connection of conductor **31** to the metal foil **11**.

Step 5.—Finally, the assembly is sealed along the edge **14** around the insulating coating **32** encircling the conductor **31** to fully enclose the assembly and thereby render it air and water tight.

In large scale production this procedure could be simplified by using a continuous strip process in which the metal foil **11** and the respective foils of insulating substance **5**, **7**, **6** and **8** are fed between a pair of rollers each comprising a pair of wheels spaced to engage the longitudinal edges of the foil to form seals **12** and **13** and interconnected by spaced cross members at intervals cooperating to form lateral seals, such as **16** and **17**, at suitably spaced intervals along the assembly.

The condenser unit thus formed may then be lowered into water with a conventional anchor means such as weight **34** secured by any suitable attachment means such as link **35** to its lower end and maintained in vertical direction. The top (conductor enclosing) end may be then joined to means to charge the condenser to constant charge together with a device for detecting changes in voltage produced as a result of changes in capacity due to changes in pressure of the medium surrounding the hydrophone. If desired, changes in capacity may be detected directly without application of a fixed charge. Other means for measuring changing capacity could be utilized for detecting sound pressure.

Referring again to Figs. 1 and 2 of the drawings, by the above process a device is provided comprising a strip of metal foil **11** surrounded by two insulating foils separated by a layer of air on each side, as for example, strip of foil **5** and strip of foil **7** separated by an air pocket or layer **9** and strip of foil **6** and strip of foil **8** separated by an air layer or pocket **10**. Jointure means **12**, **13**, and **14** are provided around three edges of the unit. The outer foils are sealed across at intervals along their length as shown at **16** and **17** to provide a plurality of air pockets along the major dimensions of the polyethylene foil pair units.

The method and device thereby provides a hydrophone having high directivity at low frequencies, particularly in the sonic and supersonic ranges, which can be rolled up to very compact sizes especially suitable for sonobuoy and other applications, which has high sensitivity particularly at low frequencies suitable for long range detection and which will be directional because of the large dimensions provided so as to obtain the large signal to noise ratio associated with directive arrays.

While the following dimensions and materials are in nowise to be considered as limiting in the invention, a device of the following dimensions and materials has proved effective in tests. The material used for the metal foil could be .001 inch thick aluminum foil. A polythene laminate material .0015 inch thick could be used for the insulating foils. The "air cell" may contain either air, nitrogen gas, argon gas or other gases. The gas should be as dust free as possible and should be at a pressure a fraction above atmospheric pressure. A total length of twenty-five feet has proved effective for some sonobuoy applications. The end edge bonding dimension may be of the order of 3/16 and the respective longitudinal edge bonding dimensions may be of the order of 1/8 of an inch. The air pocket may be the order of 1" in lateral dimension and the metal foil may be 1¼ in width. The length of the distance between bondings to set off separate air pockets may be of the order of 1" with 3/16 of an inch of width of bonding or sealing knurls. Devices of half-width dimensions of foil and pockets of the above illustrative dimensions have also proved successful.

Although the technique of construction illustrated permits mass production at low cost, variations in such techniques are considered within the scope of the invention. For example, it should be understood that the device could be fabricated in a continuous process to any length with a foil inserted. Alterations of some of the steps outlined in accordance with design and production engineering requirements is contemplated. The metal foil could be covered on both sides and sealed directly to the insulating foils. Other gases may be used at various pressures.

A modification of the device which has also proved effective would provide a pair of polyethylene strips bonded together across top and bottom edges of the longitudinal directions and at one end prior to assembly for sonobuoy operations and bonded at intervals along its length. A strip of metal foil could be secured or disposed adjacent to one layer of a pair of polyethylene layers and the polyethylene layers could be joined to a third polyethylene layer at top and bottom edges of dimensions identical to the pair of polyethylene layers to enclose the metal foil between the pair of polyethylene layers and the third layer. The metal foil of course would be of lesser width dimensions than the polyethylene strips. In this manner a single air chamber hydrophone could be provided in place of the double air chamber hydrophone without departing from the principles of the invention. A ½-inch double air chamber or a ½-inch single air chamber may be provided or a 1" double air chamber or a 1" single air chamber in one condenser, two condenser, three condenser, or four condenser hydrophone applications are within the scope of the invention.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A long line condenser hydrophone comprising a pair of polyethylene strips, said strips being of like dimensions and being bonded together on at least three edges, said strips being bonded together at intervals throughout their length, thereby providing a plurality of pockets, a gaseous substance disposed in said pockets, a metal foil strip disposed adjacent one of said polyethylene strips, and an enclosing member disposed around said metal foil strip and secured to the bonded edges of said polyethylene strips.

2. A long line condenser hydrophone comprising a flat flexible conductor plate, a plurality of layers of insulating foils on each side and overlapping the ends of said plate, the layers of insulating foils on each side being spaced from each other at intervals, and being joined at intervals throughout their lengths, a column of gas being entrapped in each of said spaces, a conductor connected to said plate at one end of the plate and an air seal disposed between the junction of the conductor and the plate and said insulating foils.

3. A long line condenser hydrophone comprising a first pair of polyethylene foils and a second pair of polyethylene foils, a member of each of the pairs being bonded to the other member of its respective pair around the periphery and transversely of the members across the flat surfaces at intervals along the length of the pair of members, a plurality of air pockets along the major dimensions of each pair formed by said bond, a strip of metal foil of shorter and narrower dimensions than the polyethylene foils disposed between said polyethylene foil pairs, the assembly of said pairs of foil and said strip of metal being bonded around two sides and one end of the periphery of the metal strip, a conductor electrically joined to the metal strip at the unbonded end, an insulating material disposed around said conductor, and an airtight seal formed with said insulating material bonded to said pairs of foils at the unbonded end of the metal strip.

4. A long-line condenser hydrophone comprising a flat flexible conductor plate, a first layer of insulating foil disposed adjacent to one flat side of said plate and in overlapping relationship thereof, a second layer of insulating foil disposed on the other flat side of said flat plate and in overlapping relation thereto, said first insulating layer being joined to said second insulating layer

along the longitudinal edges of said plate and along at least one end of said plate, a third insulating layer disposed adjacent to in spatial relationship to said first insulating foil layer and of dimensions substantially identical to said first layer, and bonded to said first layer along the longitudinal dimensions thereof and along at least one end and being bonded to said first layer at spaced intervals transversely of its length thereby providing pockets for a gaseous substance.

5. A condenser hydrophone comprising a first plurality of pocket members including a first flat polyethylene strip of comparatively large longitudinal dimension with respect to its lateral dimension, a second polyethylene strip of substantially the same configuration and size as said first polyethylene strip, means to bond the strips along each of the edges thereof in mating relationship, a substantial portion of the area of said strips being spaced apart, means to bond the strips of polyethylene material at intervals along their lengths and covering substantially the width of the strips to form pockets to entrap gases, a metal conductive plate of relatively flat strip-like configuration and of flexible material disposed on the face of one of said polyethylene strips and insulating means disposed around said metal strip and joined to the edges of said polyethylene strips to form an airtight seal.

6. The device of claim 5 wherein said insulating means to enclose the metal strip includes a second plurality of polyethylene strips of configuration and size substantially identical to said first plurality of polyethylene strips.

7. A long line condenser hydrophone comprising a relatively flat flexible metal conductor plate, a plurality of layers of insulating foils disposed on each side of said plate and overlapping the ends of said plate, the layers of insulating foils on each side being spaced from each other at intervals and being joined at intervals throughout their lengths to thereby trap a column of gas in each of the spaces, a conductor connected to said plate at one end, an air seal disposed at the junction of said conductor and said plate with said insulating foils, means to suspend the condenser hydrophone from a sonobuoy device and means to anchor the long line condenser in extended relationship beneath the surface of a body of water.

8. A mechanism for underwater sound detection of targets comprising first and second pairs of foils of insulating substance of comparatively large longitudinal dimensions in relation to their lateral dimensions and of relatively small thickness, each pair sealed around their periphery and transversely at intervals along their lengths to provide a plurality of air pockets along their major dimensions, a strip of metal foil of shorter and narrower dimensions than the insulating foils symmetrically enclosed between the respective pairs of insulating foils, first sealing means to seal the foils and metal strip around three sides of the periphery of the metal foil to completely enclose the metal foil, one long dimensional end being left open, conductor means electrically joined to the metal foil through the open end, insulating material disposed around and enclosing the conductor, and second sealing means to seal the open end of the foils around the insulating material enclosing said conductor so as to make an air and water tight seal completely enclosing the metal foil and its electrical conductor.

9. A device for underwater sound detection of targets comprising a pair of strips of insulating foils bonded around their periphery and across at intervals transversely of their lengths to provide a plurality of gas pockets along their major dimensions, a strip of metal foil of shorter and narrower dimensions than the insulating foils disposed adjacent the face of one of the insulating foils, insulating cover means disposed around the metal foil and secured to the edges of the insulating foils to thereby form a water and airtight seal, a conductor electrically joined to the metal foil through one end of the assembly, an insulating material disposed around the conductor and sealed by the insulating foils and the cover member so as to make an air and watertight seal completely enclosing the metal foil and its electrical conductor, thereby providing a hydrophone capable of responding to changes in pressure due to the changes in pressure in the medium surrounding the hydrophone for transmission of said changes to an indicating device.

10. A condenser-type hydrophone for immersing in an electrically conductive liquid medium wherein the boundary surface of the medium at said hydrophone constitutes an exterior electrical charge-bearing plate, comprising: only one flat flexible elongated conductor plate for bearing an electrical charge, a layer of flexible insulating foil adjacent to and entirely enveloping said elongated conductor plate, another layer of flexible insulating foil disposed on at least one side of said elongated conductor plate and sealingly joined around the entire peripheral edge and along the minor dimension of said enveloping layer at spaced intervals over its length forming thereby a plurality of enclosed pockets, and a gas entrapped within said pockets for producing changes in electrical capacitance between said plate and the boundary surface as a function of any external pressure changes present in the medium.

References Cited in the file of this patent

UNITED STATES PATENTS

1,471,547	Chilowsky et al.	Oct. 23, 1923
1,584,613	Comstock et al.	May 11, 1926
2,649,579	Alexander	Aug. 18, 1953
2,768,368	Crane et al.	Oct. 23, 1956

FOREIGN PATENTS

526,683	Germany	June 9, 1931