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BONE CONDUCTION HEARING AID

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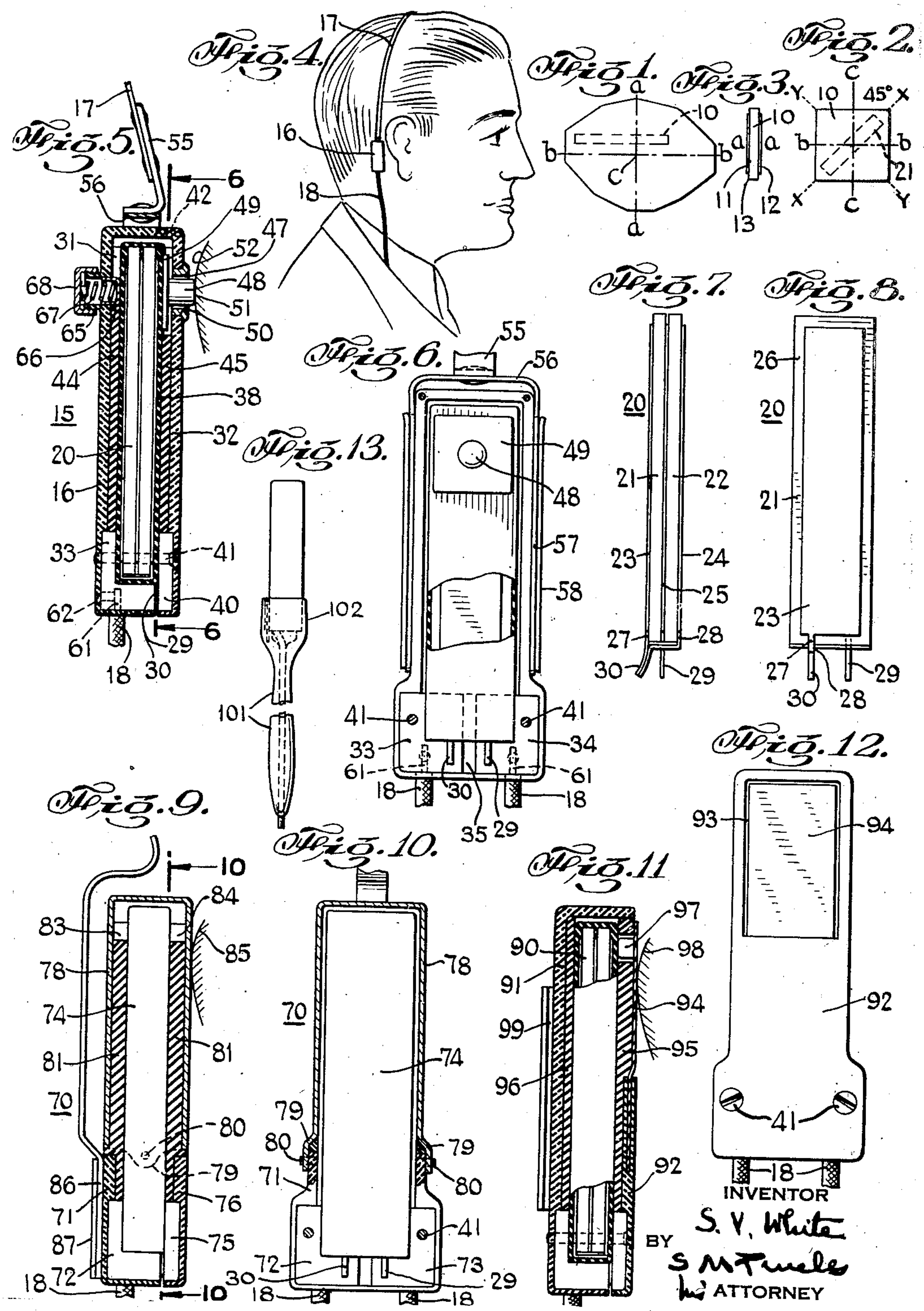

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BONE-CONDUCTION HEARING-AID

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4 Claims. (Cl. 179—107)

This invention relates to bone-conduction hearing-aids and it has among its objects an improved hearing-aid of this type in which mechanical vibrations of the sound range are imparted to the bone structure of a person by a piezo-electric vibrator unit actuated by electric sound frequency oscillations applied thereto.

The foregoing and other objects of the invention will be best understood from the following description of embodiments thereof, reference being had to the accompanying drawing, wherein

Fig. 1 is an end view of a Rochelle salt crystal;

Fig. 2 is an elevation of a plate-shaped crystal member cut from the crystal in Fig. 1;

Fig. 3 is a side view of the plate of Fig. 2;

Fig. 4 is a view of the bone vibrator of the hearing-aid device as worn by a person using it;

Fig. 5 is an enlarged longitudinal sectional view of one form of the new vibrator;

Fig. 6 is a front view of the bone vibrator with the front cover removed;

Fig. 7 is a vertical sectional view through the crystal vibrator unit of Figs. 5 and 6;

Fig. 8 is an elevational view of the vibrator unit;

Figs. 9 and 10 are views similar to Figs. 5 and 6 of a modified form of the invention; and

Figs. 11 and 12 are views similar to Figs. 5 and 6 of a still further modification of the invention.

Fig. 13 is an elevational view of the vibrator unit mounted on a lorgnette handle.

It has been known for many years that a large percentage of deafened persons suffer only due to impaired middle-ear or outer-ear organs and that their interior auditory center is able to hear well sound vibrations conveyed thereto by bone-conduction. This was proven in early experiments by pressing one end of a sound conducting rod of wood against a bony part of the head, or preferably against the teeth, while the other end was placed against a musical instrument and thus imparting musical hearing sensations to an apparently deaf person. Experiments were also made in imparting hearing by fans of fibre or similar materials exposed to sound vibration and placed at one end between the teeth of the listener.

Many efforts have been made in the past to apply apparatus of the type developed in the telephone art for bone-conduction hearing-aids. More recently, there have been devised bone-conduction hearing-aids in which a microphone that converts sound waves into electrical oscillations was made to supply amplified oscillations to an electromagnetic bone vibrator and to impart therewith corresponding mechanical vibrations to the bone structure of a listener with sufficient power to induce hearing sensations in this auditory center. Such electromagnetic vibrators are relatively complicated in construction and usually require a large conspicuous structure for imparting the required mechanical vibrations to the bone structure.

I have found that vibrators made of piezo-electric substances, such as Rochelle salt crystals, are ideally suited for bone-conduction hearing-aids and enable sufficient and faithful reproduction of sound by bone-conduction in a way superior to the devices known in the past.

The principal piezo-electric substances known at present are the crystals of quartz, tourmaline and Rochelle salt, such crystals exhibiting deformation of their structure on being subject to an electric field, and generating an electric field on being subject to external pressure. Rochelle salt crystals and portions thereof give a much greater deformation under the same electrical conditions than the other substances.

A Rochelle salt crystal as shown in an end view in Fig. 1 is usually of the orthorhombic type and has a longitudinal optical axis c (perpendicular to the plane of the drawing), a major transverse axis b, usually perpendicular to two opposite prismatic surfaces of the crystal, and a minor transverse electric axis a, perpendicular to the two other axes. A rectangular plate **10**, as shown in Figs. 2 and 3, cut in longitudinal direction from such crystal, with its planes perpendicular to the electric axis a, will, upon application of a potential difference to electrode sheets **11**, **12** attached to the opposite flat crystal surfaces **13**, expand in a direction x inclined **45**° to the optical axis c, while contracting in the diametrically opposite direction which is 90° displaced against the direction x of the expansion. The directions of the expansion and contraction reverse upon reversal of the polarity of the potential difference. By cementing two such oppositely oriented crystal plates to each other into a unit and applying proper potentials to their surfaces, one pair of the diametrically opposed corners of the complete unit will bend forwardly while the other pair of corners will bend rearwardly.

Such unit, called "a twister", will twist in one or the opposite direction depending on the polarity of the potentials applied to the flat surfaces thereof and will perform twisting vibrations when the electrode sheets on its surfaces are connected to a source of alternating potential. A crystal vibrator unit of this type, 4½″ x 2½″ x ⅜″ in size will when connected to a source of sound-frequency currents, for instance, to an amplifier output circuit of a radio receiver, vibrate in accordance with the impressed electrical oscillations. Upon pressing a portion of the crystal against the mastoid bone or other portion of the bony structure of the head, such vibrating crystal unit will transmit corresponding sound vibrations over the bones of the head to the inner auditory center of the person and induce hearing sensations corresponding to the impressed vibrations. It will faithfully reproduce music and speech and will enable persons with impaired outer and middle-ear organs to hear well, and serve as an excellent bone vibrator for bone-conduction hearing-aids.

Hard of hearing persons usually seek to conceal their impairment. A hearing-aid, though satisfactory in operation, will find only very limited use if it has to be worn prominently by the user and it distorts his appearance, thus emphasizing his impairment. To be practical and find general use, a hearing-aid must not only be helpful in improving the hearing, but it must also be of a small size and form which renders it inconspicuous so that it is not prominent when worn by a person and thus eliminates the mental disturbance of the user caused by the consciousness that unlookers are noticing his impairment.

In bone-conduction hearing-aids, it is best to apply the bone vibrator to a portion of the bone structure of the head of the user, preferably to the mastoid bone back of the ear. The piezo-electric twister unit described above, though it is efficient as a sound frequency vibration transmitter, is so large that when applied to the bone structure of the head as a bone vibrator, it attracts attention to the user and is very conspicuous.

To avoid these difficulties, the bone vibrators of my invention are made of small crystal sections constructed to constitute a tiny bone-vibrator structure that may be inconspicuously applied to the head of the user, and yet able to develop sufficient vibratory power for imparting to the head-bone structure the amount of vibratory energy required to induce satisfactory hearing.

As shown in Figs. 4, 5 and 6, the bone vibrator **15** of my invention is made in the form of a small casing **16** which is held against the mastoid bone back of the ear of the user by means of a head band **17**, the head band being readily hidden under the hair of the person and the casing being so small that it is substantially fully hidden back of the ear of the person. A vibrator unit in casing **16** is supplied with electrical oscillations through a thin double conductor cord **18** which is readily hidden under the clothing of the person, the cord leading to a source of sound frequency, for instance, to the output of an amplifier which amplifies sound-frequency oscillations impressed by a microphone exposed to the sound.

Within the vibrator casing **16** is mounted a vibrator unit **20** shown in detail in Figs. 7 and 8. It comprises a pair of flat longitudinal plates or strips **21** and **22** of Rochelle salt crystal, each strip being approximately 1½″ long, ¾″ wide, and ⅛″ thick. These crystal strips are made from a Rochelle salt crystal plate, like plate **10** shown in Fig. 1, by cutting therefrom the strip along an axis inclined 45° to the optical axis, as indicated in Fig. 2 by the dotted line **21**. Such strips cut from a Rochelle salt crystal, with the plane surfaces thereof perpendicular to the electric axis, and extending longitudinally under an angle of 45° against the optical axis, will expand in longitudinal direction upon application of a potential difference to the flat surfaces on the two crystal sides, and will contract upon application of a reversed potential to said two surfaces.

By cementing two such crystal strips **21** and **22** of opposite orientation to each other so that on application of an electric field, one of them tends to expand while the other contracts, the cemented unit will be bent either in one or in opposite direction over a distance much larger than corresponding to their longitudinal expansion and contraction, in a way similar to the bending of a bimetallic thermostat having two metal strips of different linear coefficients of thermal expansion welded together. Such crystal vibrator unit is called "a bender".

In order to apply the potentials to the crystal unit, an electrode layer **23** and an electrode layer **24**, in the form of tin foil, for instance, are secured to the outer flat surfaces of the two crystals, and an additional intermediate electrode layer **25** is secured to the two cemented opposite inner surfaces of the two crystals. It is important that the tin foil be placed as close as possible to the adjacent crystal surfaces to reduce to a minimum the spacing between the tin foil layer and the adjacent crystal surface and make the capacity effect between the tin foil layer and the adjacent crystal surface relatively large. In this way the larger part of the oscillatory potential is applied to the di-electric material of the crystal strips, losing only little of the available potential difference in the layers between the tin foil sheets and the crystal surfaces.

The tin foil electrodes **23, 24** and **25** are made somewhat smaller than the crystal surfaces to which they are attached to provide an insulating distance **26** around the edge of the crystal and secure a high leakage resistance between the electrode surfaces on the opposite sides of the crystal strip. Potentials are applied to the tin foil electrodes by small copper terminal strips **27, 28, 29** which are joined to the tin foil sheets and extend beyond the edges of the crystal strips, the outer terminal strips **27** and **28** being joined into a common terminal member **30** to apply the full available potential difference to each of the crystal plates **21** and **22**, the crystal plates being so oriented that one contracts while the other expands on application of such potential difference to the terminals.

The crystal unit **20** is arranged for mounting in the casing **16** which may be made of an insulating substance, such as a phenolic condensate, and is shaped to fit the contours of the crystal. At the front sides, the casing is open and its interior chamber **31** is arranged to be closed by a cover member **32**. The lower portion of the casing is slightly enlarged and has mounted therein two heavy metallic blocks **33** and **34** which are preferably rigidly secured within the casing during the molding operation. The two blocks **33, 34** are insulated from each other by an insulating rib **35** which forms a part of the body of the casing. The casing chamber **31** has at its downward end an extension formed between the blocks **33** and **34** to receive the lower end of the flat crystal unit, the height of the extension being slightly less than the thickness of the assembled crystal unit **20**. Before insertion into the chamber of the casing, the crystal unit **20** is enclosed in a thin insulating enclosure **38**, preferably of a yieldable and moisture-tight substance, such as rubber. The enclosure **38** prevents contamination of the crystal by handling and by body secretions and insulates the electrode layers against external contact. By making the enclosure 38 of a thin resilient rubber, such as dental dam rubber, there is also provided a yielding layer which distributes sudden applied forces over the surface of the crystal and prevents breaking thereof.

The lower end of the crystal unit 20 which fits into the cavity extension formed between the blocks 33 and 34 is clamped in place by an insulating clamping plate 40 of fibre, for instance, which is molded in within the lower end of the casing cover 32, and is clamped against the block by means of clamping screws 41. Additional small screws 43 serve to hold the upper portion of the casing cover 32 firmly clamped to the casing, as shown in Fig. 5. The portion of the casing chamber 31 extending above the clamping blocks 33 and 34 is somewhat wider and provides sufficient space opposite the flat outer sides of the casing for inserting two layers 44 and 45 of a soft yielding material, such as sponge rubber. These rubber bodies offer only negligible resistance against the vibratory movement of the upper portion of the vibrator unit 20 and act merely as cushions. Their use is, however, not necessary for the operation of the device.

At the upper end of the casing cover 32 near the end of the vibrator unit 20 is provided an opening 47 through which extends a contact button 48 having at its rear end a supporting flange 49 bearing against the upper end of the vibrator unit 20. The button 48 is guided in the opening 47 by means of a collar 50 seated in the opening, the collar being preferably of rubber and touching lightly the surface of the button 48 to permit its free movement therein. The outer end of the button forms a contact surface 51 which acts against the bone structure 52 of the head of the listener, for instance, against the mastoid bone as shown in Fig. 4.

The head band 17 which may, for instance, be in the form of wire or a thin strip of resilient material has at its end a flat portion 55 attached to a U-shaped member 56 having flat arms 57 fitting into a channel member 58 secured to the side walls of the casing 16, for carrying the casing and pressing the contact portion 51 of the vibrator button against the bone structure.

The electrical circuit connections to the electrode sheets of the crystal unit are made by soldering the ends of the contact members 29 and 30 to the two blocks 33 and 34 as indicated in Fig. 6, these strips being also held against the block by the pressure of the clamping plate 40. Downward openings 61 are provided in the rear portions of the blocks 33 and 34 into which the ends of the two lead conductors 18 are inserted and clamped by means of screws 62 threaded from the rear side of the clamping blocks.

Upon application of an electric sound frequency oscillation source to the crystal terminals 29 and 30, through the cord 18, a vibratory movement in a direction perpendicular to the plane of the crystals is imparted to the portion of the vibrator unit extending above the lower end clamped between the clamping members 33, 34 and the clamping plate 40. The members clamping the lower end of the crystals are made of large mass to have sufficient inertia to secure imparting of the required vibratory power to the bone structure. The rubber layer surrounding the lower end of the vibrator unit 20 serves as a cushioning means for permitting limited local motion of the crystal and equalizes the pressure exercised by the clamping surfaces on the crystal.

The sponge rubber cushions 44, 45 prevent excessive bending of the crystal by exterior pressure on the button or the casing, thus guarding against breakage of the crystal. The rubber sleeve 50 surrounding the button prevents rattling of the button against the casing and also serves to seal the casing and provide an additional enclosure of the interior crystal, protecting it against moisture and body excretions. The casing and enclosure 38 also isolate the user from the parts in the interior of the casing which are under potential.

The wall of the casing opposite the contact button 51 should be sufficiently spaced to permit the crystal to vibrate freely within the range imparted by the impressed electrical potentials. A definite stop should be provided about 5 to 10 mils on the rear side of the vibrator crystals to prevent excessive deformation of the crystal due to a large external force applied against the button.

In the arrangement shown in Figs. 5 and 6, special provision has been made for preventing deflection of the vibrator unit from its normal position when the vibrating casing is applied against the body and an initial pressure is exerted by the bone structure on the button tending to push the upper end of the vibrator unit in rearward direction. To this end the part of the casing wall opposite the button is provided with a circular sleeve 65 within which is slidably mounted a cup-shaped piston 66 which is held pressed inwardly against the rear surface of the vibrator unit by a helical spring 67 held within the interior of the sleeve by a cap 68 that is threadedly mounted over the opening of the sleeve 65 to permit regulation of the pressure acting on the piston 66. This pressure is so adjusted that the force exerted by the piston 66 on the rear side of the vibrator unit is equal to the force with which the button 48 is pressed against the bone structure. By this arrangement the vibrator unit is held in its normal untensioned position when the button is held pressed against the body, while no potential is applied to the crystal electrodes.

Instead of the mechanical arrangement for compensating the pressure exercised on pressing the button against the bone structure, an electrical compensation of this effect may be obtained by applying to the terminals of the crystal vibrator unit a direct current biasing potential tending to produce a bending strain equal and opposite to the force which the bone structure exercises on the button.

The vibrator device described above is characterized by a number of features which particularly adapts it for the special use as a bone-conduction instrument. By using a bender-type vibrating unit, it is possible to develop within a small inconspicuous structure sufficient vibratory power to impart to the listener enough vibratory energy for inducing satisfactory hearing sensations in his auditory center and make him hear like a normal person. By clamping the crystal unit at one end in a heavy clamp, efficient transfer of the vibrations to the bone structure is made possible. By completely enclosing the vibrating unit in a waterproof resilient enclosure, moisture and secretions are kept away from the crystal structure and the crystal electrodes are protected against contact. By using a relatively rigid casing around the vibrator unit, damage to the crystal by external forces is prevented without impairing efficient transmission of vibrations to the bone structure. The heavy clamp supplies sufficient inertia for developing vibratory power necessary for imparting the vibratory energy to the bone structure. By the special dimensioning of the interior space within the enclosing casing, there are obtained free oscillations of the crystal within the range of motion imparted to it by the impressed electrical oscillations, while excessive deflection of the vibrator unit that might cause its breakage is removed.

Because of the requirement that the vibrator shall be inconspicuous, the crystal vibrator unit must be of very little weight of the order of 2 to 3 grams. The head structure to which it must impart the vibrations weighs several kilograms. Although a vibrator unit of such small mass will transmit sufficient vibratory energy to the head structure at frequencies above several thousand cycles, the amount of energy transmitted by the crystal at low frequencies is negligible. The additional inertia mass provided by the clamps **33** and **34** extends this range downwardly to frequencies of several hundred cycles and below. Since only a small mass, of about 15 grams, of disposable weight can be added without too much enlarging the structure of the vibrator, the mass is concentrated at the lower end of the vibrator unit opposite the point where it is coupled to the head. Because of the relatively large mass of the head coupled to the upper end of the crystal vibrator unit and the provision of the weight of the relatively heavy clamp at the lower end of the unit, effective utilization of the limited mass available is obtained.

In Figs. 9 and 10 there is shown another embodiment of the invention in which the use of a button for transmitting the vibrations is completely avoided. A bender vibrator unit like that shown in connection with Figs. 5 and 6 is mounted within a special casing **70** having a lower portion **71** like the lower portion of casing of Figs. 5 and 6 with a pair of blocks **72** and **73** to which the vibrator unit **74** is clamped by means of a vibrator plate **75** constituting a part of a cover member **76** of the lower casing portion. The vibrator unit **74** is firmly held in this lower casing portion and the unclamped upper portion of the vibrator unit is vibrated upon application of electric sound-frequency oscillations to the electrode surfaces of the vibrator unit.

Directly above, and as a continuation of the lower casing portion, is mounted an upper casing portion **78** made of metal or other light material, and completely surrounding the upper portion of the vibrator unit **74** so that the entire unit is enclosed. At its lower side walls the upper casing portion **78** has hinges **79** which overlap the upper ends of the lower casing portion and are hinged thereon by means of pins **80** to have a limited oscillatory movement on the pins **80**. The spaces within the casing opposite the flat sides of the vibrator unit **74** contain a resilient mass **81**, such as sponge rubber, which fills all the free spaces and provides a resilient filler in the spaces between the lower edges of the upper casing and the upper edges of the lower casing portions, sealing the spaces therebetween.

Near the upper end of the casing **78**, there are provided two blocks **83** and **84**, of hard rubber for instance, which provide a good vibration transmitting connection between the vibrator unit **74** and the upper casing portion **78** so that the vibrations of the vibrator unit **74** are transmitted to the walls of the casing **78**. The casing **70** is held with its front wall against the bone structure, indicated at **85**, by means of a head band **17**, as shown in Fig. 4, the end of the head band having a flat end portion **86** which fits into a flat channel **87** provided on the rear side of the lower casing portion.

The vibrator device of Figs. 9 and 10 is of simple construction and gives thorough protection to the Rochelle salt crystal vibrator unit. Damage to the crystal body by excessive bending is prevented by the relatively short gap between the edges of the upper casing portion and the lower casing portion, these edges limiting the oscillatory movement of the upper casing member to a range at which the vibrator unit **74** cannot be excessively strained.

In the vibrator device shown in Figs. 11 and 12, a bender vibrating unit **90** is mounted in a casing **91** in a way similar to the vibrator of Figs. 5 and 6. However, instead of a button for transmitting the vibrations from the vibratory unit **90** to the bone structure, the casing cover **92** has a large rectangular opening **93** in its upper part, this opening having mounted therein a rectangular reed member **94**, the lower end of which is secured, as by molding, within the lower part of the casing cover. The reed member **94** substantially completely encloses the opening in the casing wall, and the space **95** between the reed member and the front surface of the vibrator, as well as the rear space **96** of the casing, are filled with sponge rubber permitting free vibration of the reed, while sealing the interior space. A vibration transmitting block **97** extending between the reed member **94** and the vibrator unit **90** transmits the vibratory motion of the vibrator unit to the reed member which is held pressed against the bone structure **98** by a flat end portion of a head band fitting into the channel **99** provided in the rear side of the casing.

In all of the foregoing arrangements, the vibrator unit is completely protected, being entirely enclosed in a casing which limits excessive bending thereof, but permits its free vibrations under the applied potentials. The unit is extremely small, its height being less than 2 inches, its width being only about ½ of an inch, and its thickness slightly over ¼ of an inch.

Such vibrator devices may be made to directly expose a portion of the crystal vibrator unit and permit its direct application to the bone structure. Thus, for instance, the arrangement as shown in Fig. 5 may be modified by leaving off the front portion of the upper end of the casing **16** to expose the front part of the upper end of the crystal vibrator unit and permit its direct application to the bone structure of the head. By completely enclosing the crystal unit, the vibrations are transmitted to the bone structure to substantially the same extent as they are transmitted in arrangements where a part of the bone vibrator itself is brought in direct contact with the bone structure.

Instead of using a head band, the bone vibrator may also be mounted on the end of a lorgnette handle **101** as shown in Fig. 13, the lorgnette handle being provided at its upper end with a suitable member fitting into the channel **86** at the rear wall of the casing for receiving the flat end of the head band. The upper end of the handle may also be provided with a hollow portion **102** arranged to receive and clamp the lower end of the vibrator casing and increase the mass and the inertia thereof.

The invention is not limited to the details of construction and arrangement described in connection with the exemplifications thereof, as many modifications will suggest themselves to those skilled in the art. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of the invention.

1. In a piezo-electric hearing-aid bone-vibrator device, a piezo-electric vibrator unit of inconspicuous size, electrode means for impressing electric sound-frequency oscillations on the piezo-electric substance of said vibrator unit to produce a vibratory motion of said unit, a floating support of substantial mass holding a portion of said unit, means for coupling a portion of said vibrator unit to hearing-inducing bone structure of a person for imparting thereto hearing-inducing vibratory energy by the vibratory motion of said unit, and an enclosure extending from said support enclosing the piezo-electric substance of said unit.

2. In a piezo-electric hearing-aid bone-vibrator device, a piezo-electric vibrator unit of inconspicuous size, electrode means for impressing electric sound-frequency oscillations on the piezo-electric substance of said vibrator unit to produce a vibratory bending motion of said unit, a floating support of substantial mass holding a portion of said unit, means for coupling a portion of said vibrator unit to hearing-inducing bone structure of a person for imparting thereto hearing-inducing vibratory energy by the vibratory motion of said unit, and an enclosure extending from said support enclosing the piezo-electric substance of said unit.

3. In a hearing-inducing bone-vibrator device actuated by electric sound-frequency oscillations for imparting corresponding mechanical vibrations to a bone structure of a person and inducing by bone-conduction corresponding sounds in his auditory center, a piezo-electric vibrator unit of small size suitable for inconspicuous wear, conducting electrode layers in said unit for receiving electric sound-frequency oscillations and imparting by piezo-electric action mechanical vibrations corresponding to said oscillations to said unit, a floating support of substantial mass holding one portion of said vibrator unit, means for coupling another portion of said vibrating unit spaced from the supported portion to hearing-inducing bone structure of a person in a position at which said vibrator unit will impart to said bone structure an amount of vibratory power sufficient for imparting to said person satisfactory hearing, and a yieldable enclosing coating on said vibrator unit preventing direct contact between said electrode layers and the exterior surface of said bone structure.

4. In a piezo-electric hearing-aid bone-vibrator device, a piezo-electric vibrator unit of inconspicuous size, electrode means for impressing electric sound-frequency oscillations on the piezo-electric substance of said vibrator unit to produce a vibratory bending motion of said unit, a floating support of substantial mass holding a portion of said unit, means for coupling a portion of said vibrator unit spaced from said support to hearing-inducing bone structure of a person for imparting thereto hearing-inducing vibratory energy by the vibratory motion of said unit, and an enclosure extending from said support enclosing the piezo-electric substance of said unit.

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