

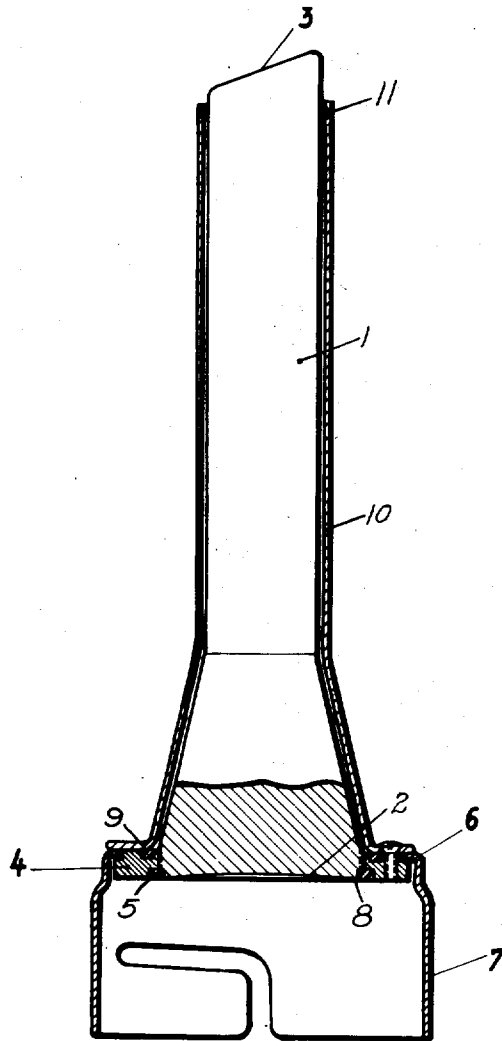
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DEVICE FOR TRANSMITTING ULTRASOUND ENERGY

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DEVICE FOR TRANSMITTING ULTRASOUND ENERGY

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This invention is concerned with an applicator comprising an elongated, e. g., a generally cylindrical rod-shaped solid member, for conducting energy in ultrasonic diagnosis and therapy to a loading medium represented by living tissue, for example, to body parts such as body cavities, which are not readily accessible.

Considerable difficulties have been encountered in providing such ultrasonic applicators. These difficulties are believed to be essentially due to the fact that in a rod-shaped solid of a diameter which corresponds to the ultrasonic wave length the ultrasonic velocity varies considerably with the frequency of ultrasonic radiation (dispersional phenomena).

The invention is based on investigations covering ultrasonic propagation in the frequency range between 300 and 1200 kc./s. within cylindrical rods of diameters of from 5 to 25 mm. One basic result of these investigations is the discovery that dispersional phenomena prevail particularly if the ratio of rod diameter to ultrasonic wave length (d/λ) is between 0.5 and 2.5. Below the ratio 0.5 the effective ultrasonic velocity within the rod approaches the value of transverse waves; above the ratio $d/\lambda=2.5$, energy is conducted in the rod in a different mode of propagation which is characterized by the longitudinal velocity

$$c = \sqrt{\frac{E(1-\sigma)}{\rho(1+\sigma)(1-2\sigma)}}$$

where E is Young's modulus, ρ the density, and σ is Poisson's ratio. In accordance with the invention, the results of these investigations are used to provide longitudinal resonance of the vibrating system which is desirable for a high efficiency of transmission of ultrasonic energy through the rodlike conductor of the applicator.

Accordingly, an object of this invention is to provide an applicator comprising a rodlike member having a diameter within the order of magnitude of ultrasonic wave length at a ratio d/λ equal to or larger than 2.5.

However, even if the condition noted above is met and the length of the rod is carefully dimensioned according to the longitudinal resonance ($l=n\lambda/2$, $n=1, 2, 3, \dots$), difficulties arise with increasing length of the rod. At a ratio of rod length to the ultrasonic wave length, e. g., of $l/\lambda=10$, the transmitted ultrasonic energy decreases to $1/4$; at a ratio of $l/\lambda=20$ it decreases down to $1/7$ of the energy transmitted to an acoustical load at the free face of the rod for the ratio $l/\lambda=2$. It appears that with increasing length of the cylindrical applicator, due to side contraction, an increasing part of energy is converted into nonlongitudinal vibrations, which have for the respective frequencies a phase angle different from the one for the desired longitudinal

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nal waves and thus add a considerable reactive component on the load impedance of the transmitter crystal.

It is therefore another object of this invention to reduce the large (and complex) impedance which is present in case of a rod-shaped solid applicator member having a diameter corresponding to ultrasonic wave length, and of a length $l \geq 10\lambda$, by interposing a quarter-wave coupling layer ($d=n\lambda/4$, $n=1, 3, 5, \dots$) at the input end of the solid applicator member which faces the transmitting plane of the generator. This coupling layer must be of a material having a characteristic acoustic impedance Z_1 which is smaller than the characteristic acoustic impedance of the solid applicator member Z_s , and equal to or smaller than the characteristic acoustic impedance of the loading medium, that is, of the living tissue, to be treated. The coupling layer may be a fluid, e. g., an oil layer. It may be noted for better understanding that the acoustic impedance $Z=\rho \cdot c$, where ρ is the density and c the sound velocity of the medium.

Such a coupling layer corresponds in its function to a quarter-wave section interposed in an electrical transmission line (Lescher-line). If its thickness is an uneven multiple of $\lambda/4$, it reduces the resistive component of radiation impedance at the ratio

$$\frac{Z_s^2}{Z_1^2}$$

Measurements carried out with such coupling layers on a brass rod at the ratio $l/\lambda=10$ and $l/\lambda=14$, respectively, have yielded about three-fourths to one-half of the power transmitted at the ratio $l/\lambda=2$, which means an increase of energy transmission by the factor 3.

A further object of this invention is to shape the coupling layer so as to give its thickness radially outwardly decreasing values from quarter-wave thickness in the center down to zero at the periphery. This is accomplished, e. g., by providing a concave recess on the end of the rodlike applicator member which faces and receives the fluid coupling layer.

The concave curving of the interface between the coupling layer and the rodlike applicator member is of further advantage in converting the practically parallel ultrasonic radiation of the transmitter into a convergent radiation by means of refraction. The surface areas of the applicator rod will thus be kept radiation-free. By suitably dimensioning the curvature, the position of the converging point along the rod axis can be adjusted at will, e. g., chosen so as to be situated within the plane of the free outer end of the applicator body from which irradiation into the loading medium or living tissue takes place. En-

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ergy concentration at this point will therefore be greatest.

A further object of this invention is to form the free outer irradiating end of the applicator obliquely to its axis. Such form is believed to be particularly favorable for ultrasonic application in body cavities.

Another object of the invention is to provide a solid applicator rod which has a relatively short cone-shaped base portion forming the concave recess for receiving the previously mentioned fluid coupling layer. The ultrasonic radiation concentrated by the conical base part will not be transmitted through the cylindrical part parallel to its axis, but, due to its oblique incidence, will be reflected forward on the cylindrical surface of the applicator. Investigations have shown that the efficiency of the transmission is not unduly affected by this condition.

Contact of the surface of the relatively long cylindrical applicator member with an ultrasonic conducting medium would result in undesired loss of energy. A further object of the invention therefore is to provide acoustical insulating means forming a wave-reflecting layer on the outside of the applicator member, i. e., to surround the cylindrical surface of the applicator member by a medium, the characteristic acoustic impedance of which varies from that of the solid applicator member and that of the loading medium, that is, of the tissue, into which the ultrasonic energy is to be irradiated. Most effective are means providing for a thin air layer surrounding the applicator member. A metal jacket or the like may be used for this purpose, which surrounds the member radially spaced therefrom. Since even extremely thin layers of air cause a practically one hundred per cent reflection of ultrasonic waves, it will suffice to roughen the surface of the conductor, for example, by sand-jetting, and to slide the jacket over the roughened conductor. Other solid materials may be used for the jacket, particularly materials having a high air content such as lime or cork. The jacketing of the applicator thus prevents radiation losses.

The invention is illustrated in the accompanying drawing, showing an elevational view, partly in section, of an embodiment of a rod-shaped applicator made in accordance with the invention.

Referring now to the drawings, the cylindrical rod 1 may be an aluminum rod, and is designed for an ultrasonic frequency of about 800 kc./s. It has a diameter of about 4 at the above frequency and is at its inner end provided with a conical base which terminates in the sound input plane 2. The free outer end of the applicator member 1 terminates in the irradiation face 3 which extends oblique to the longitudinal axis. The diameter of the base area of the conical part corresponds to that of the ultrasonic emitting area of the transducer. This area is inwardly curved, in the direction of wave propagation, so as to form a wall of the compartment to be filled with liquid, e. g., with oil, to form the fluid coupling layer having a thickness at its center of $\lambda/4$, and decreasing radially outwardly to zero at the periphery. The base of the applicator member 1 is screwed into a threaded brass fixture 4 carrying a gasket 5, e. g., of rubber, to make the coupling compartment fluidtight. The top side of the fixture 4 supports the base of the jacket 10 which is kept fluidtight at both ends by suitable gaskets, e. g., by rubber rings 9 and 11, one between the flange of the base of the jacket

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and the brass fixture 4 and the other at the top of the jacket. The air layer between the applicator rod and the jacket is thus protected against entrance of fluid. The bayonet cup 7, sliding with its bent-in upper edge between the jacket flange and the brass fixture 4, is shaped to envelop the casing of the associated crystal generator. The bayonet device presses the edge 8 of the base of the applicator rod tightly against the radiating plane of the generator, thus enclosing the coupling fluid between this plane and the concave base of the applicator rod.

What is claimed is:

1. In a device for transmitting ultrasonic energy from the transmitting plane of an ultrasonic generator to a loading medium into which ultrasonic energy is to be irradiated, a substantially rod-shaped solid, a tubular covering jacket surrounding said solid, and liquid-tight means for supporting said jacket at both ends with respect to said solid, the free end of said solid forming the output end protruding from said jacket.

2. In a device for transmitting ultrasonic energy from the transmitting plane of an ultrasonic generator to a loading medium into which ultrasonic energy is to be irradiated, a rod-shaped solid, the opposite ends of said solid forming input and output areas, respectively, and a tubular jacket made of an air-containing medium for covering the surface of said solid intermediate its input and output areas, the end of said solid forming said output area protruding from said jacket.

3. In apparatus for transmitting ultrasonic energy from the transmitting plane of an ultrasonic generator to a loading medium into which ultrasonic energy is to be irradiated, a generally rod-shaped solid, and a device for attaching said solid to a casing containing the ultrasonic generator, said device comprising means forming a cuplike member for enveloping part of said casing and locking thereto, said cuplike member being rotatably connected with said solid.

4. An applicator for transmitting ultrasonic energy from the transmitting plane of an ultrasonic generator to a loading medium represented by living tissue into which ultrasonic energy is to be irradiated, said applicator comprising a solid rod-shaped member, means at the inner end of said member, which is the energy input end thereof, forming a coupling layer which faces the transmitting plane of said generator, said coupling layer consisting of a medium whose characteristic acoustic impedance is smaller than the acoustic impedance of said rod-shaped member and equal to or smaller than the acoustic impedance of said loading medium which is to be irradiated.

5. An applicator for transmitting ultrasonic energy from the transmitting plane of an ultrasonic generator to a loading medium represented by living tissue into which ultrasonic energy is to be irradiated, said applicator comprising a solid rod-shaped member, a hollow concave compartment being formed at the inner end of said rod-shaped member, which is the energy input end thereof, for receiving a medium forming a coupling layer which faces the transmitting plane of the generator, the thickness of said coupling layer decreasing from a value of a quarter-wave at its center down to zero at its periphery, said coupling layer consisting of a medium whose characteristic acoustic impedance is smaller than the acoustic impedance of said rod-shaped mem-

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ber and equal to or smaller than the acoustic impedance of said loading medium.

6. An applicator for transmitting ultrasonic energy from the transmitting plane of an ultrasonic generator to a loading medium represented by living tissue into which ultrasonic energy is to be irradiated, said applicator comprising a solid rod-shaped member, a concave recess being formed at the inner end of said rod-shaped member, which is the energy input end thereof, for receiving a fluid medium forming a coupling layer facing the transmitting plane of the generator, the thickness of said layer decreasing radially outwardly from a quarter-wave value at its center down to zero at its periphery, said layer consisting of a medium whose characteristic acoustic impedance is smaller than the acoustic impedance of said rod-shaped member and equal to or smaller than the acoustic impedance of said loading medium.

7. The applicator as set forth in claim 6, wherein the free outer end of said rod-shaped member is formed at an angle oblique to the longitudinal axis of the member to form the irradiation face thereof.

8. An applicator for transmitting ultrasonic energy from the transmitting plane of an ultrasonic generator to a loading medium represented by living tissue into which ultrasonic energy is to be irradiated, said applicator comprising a solid base member formed substantially in the shape of the frustum of a cone, a solid rod-shaped extension projecting from said base member axially thereof, the outer free end of said extension forming the output face for irradiation of said loading medium, a concave depression being formed in said base member at the inner end thereof, which constitutes the energy input end thereof, to form a compartment thereat for receiving a fluid coupling medium which faces the transmitting plane of said generator, said coupling medium being of quarter-wave thickness at the center and decreasing radially outwardly substantially to zero at its periphery, the characteristic acoustic impedance of said medium being smaller than the acoustic impedance of said rod-shaped extension and equal to or smaller than the characteristic impedance of said loading medium.

9. In an applicator for transmitting ultrasonic energy from the transmitting plane of an ultrasonic generator to irradiate living tissue in a body cavity, said applicator comprising a solid cylindrical member, means for coupling one end of said member to a generator, said coupled end forming the energy input end of said member and the opposite end forming the energy output end thereof, and jacket means surrounding the cylindrical surface of said member forming a wave-reflecting layer thereon for directing transmission of energy through said cylindrical member longitudinally thereof.

10. An applicator for ultrasonic therapy comprising a rodlike irradiating member forming at one end an input surface for receiving ultrasonic energy which enters said member with a normal to the wave fronts parallel to the longitudinal axis thereof and forming at its other end an irradiating output surface which extends across the width of the member at an angle to the longitudinal axis thereof, said ultrasonic energy leaving said output surface with a wave nor-

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mal at an angle to the longitudinal axis of the member.

11. An applicator for conducting ultrasonic energy from the energy-transmitting element of an ultrasonic generator to a desired loading medium which is to be irradiated, said applicator comprising a frusto-conical base member, a rodlike energy-conducting member projecting from said base member axially thereof and forming at its free outer end an energy output surface extending obliquely to the axis thereof for transmitting the ultrasonic energy to said loading medium, fastening means for removably securing said base member to said energy-transmitting element, the inner end of said base member which faces said element when secured thereto forming with the surface thereof a compartment filled with a fluid which conducts the ultrasonic energy from said transmitting element to said base member for transmission thereof to said rodlike conducting member, gasket means for maintaining the inner end of said base member in fluid-tight engagement with the surface of said transmitting element to maintain said fluid in said compartment, a tubular jacket disposed around said base member and said rodlike conducting member to form an air space along the surfaces thereof, and gasket means for maintaining the opposite ends of said jacket in fluidtight engagement with said base member and said rodlike conducting member, respectively, to prevent ingress of fluid into said air space.

12. In apparatus for the treatment of biologic media with ultrasonic energy, a solid substantially cylindrical rod-shaped applicator for transmitting ultrasonic energy longitudinally from an ultrasonic generator to a medium to be treated, the dimensions of said applicator in a direction transverse to the longitudinal direction of transmission of said energy being at all longitudinal points thereof on the order of at least

$$2.5 \frac{v}{f}$$

where v is the velocity of the ultrasonic energy of the material of which said applicator is made and where f is the frequency of the ultrasonic oscillation produced by said generator.

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