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ULTRASONIC TRANSDUCER

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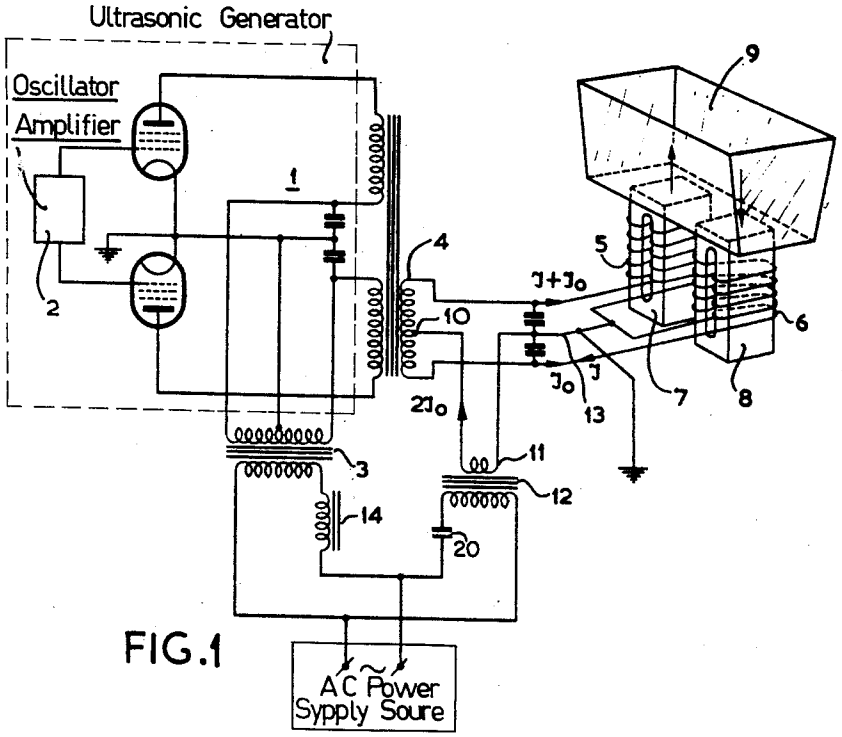

FIG.1

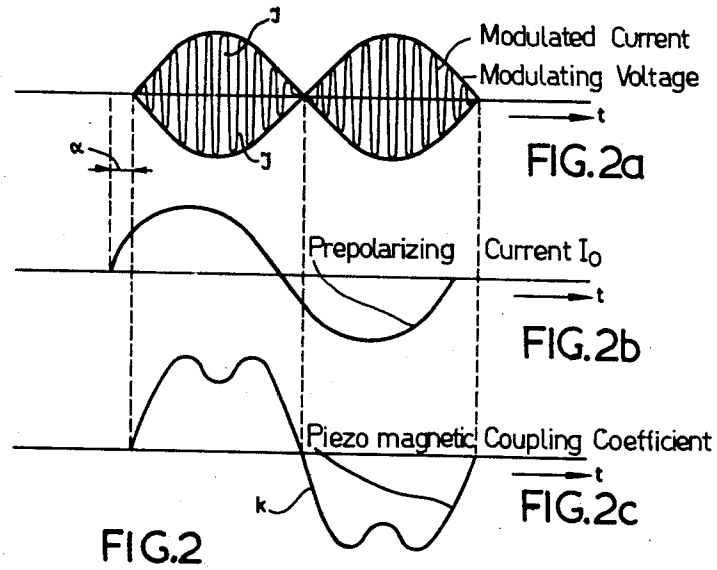

FIG.2a

FIG.2b

FIG.2c

FIG.2

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ULTRASONIC TRANSDUCER

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The present invention relates to ultrasonic transducors. More particularly, the invention relates to ultrasonic transducers for converting electrical energy to mechanical or acoustic energy by means of an ultrasonic radiator of piezomagnetic type. The radiator is powered by ultrasonic oscillations from an A.C. generator and is supplied with an A.C. pre-polarizing current. The ultrasonic oscillations produced by the generator are modulated by a modulating voltage derived from a low, 50 or 60 cycle, frequency A.C. source and the modulated ultrasonic oscillatons are supplied to the radiator, and the pre-polarizing current is preferably derived from said A.C. source.

If the pre-polarizing current is in phase with the modulating voltage the overall hysteresis losses are so low that they are beloy the permissible loss level. However, at the instant that the modulating voltage has a considerable value the piezomagnetic coupling coefficient is zero so that no oscillations of the desired frequency are produced and the transducer efficiency is adversely affected. If, a D.C. pre-polarizing current is utilized, a higher transducer efficiency results, but expensive rectifier and filter equipment is then required, maing the arrangement economically less desirable. If permanent magnees are utilized for pre-polarization, several well known disadvantages ensue due to the necessity of cementing the magnets to the transducer elements.

In accordance with the present invention, the pre-polarizing current is made to lead the modulating voltage in phase by an angle sufficient to cause the piezomagnetic coupling coefficient of the radiator to pass through zero at substantially the same instant that the modulating voltage has a zero value. The phase angle is preferably between 10 and 20 electrical degrees and brings the transducer efficiency to its approximately maximum value. The phase angle also depends upon the amplitude of the pre-polarizing current, but this amounts to only a fraction of a radian for the usual metallic and ceramic ultrasonic radiator materials when the efficiency and optimum amplitude value of the pre-polarizing current are considered.

In order that the invention may be readily carried into effect, it will now be described with reference to the accompanying drawing, wherein:

FIG. 1 is a schematic diagram of an embodiment of the ultrasonic transducer arrangement of the present invention; and

FIG. 2 is a graphic presentation of the oscillations present in the embodiment of FIG. 1.

In FIG. 1, circuit arrangements **1** and **2** comprise any suitable arrangement known in the art for producing ultrasonic oscillations; reference numeral **2** representing a suitable generator or oscillator-amplifier arrangement and reference numeral **1** representing the output stage of such oscillator-amplifier arrangement.

The output stage **1** produces ultrasonic oscillations and a modulating voltage is derived from an A.C. power supply source via a transformer **3**. The modulating voltage modulates the ultrasonic oscillations produced by the generator **1**, **2**. The modulated ultrasonic oscillations are supplied to windings **5** and **6** of radiator elements **7** and **8**, respectively, of the ultrasonic transducer through an output winding **4**. Transducers **7** and **8** may be of

well known form and may consist of an inductance winding on a core of a magnetostrictive metal such as nickel or a nickel-iron alloy. Alternatively, the core may consist of ceramic magnetostrictive material such as nickel-cobalt ferrite. Core materials of both of the foregoing types are discussed in the publication, "Ferroxcube Material for Piezomagnetic Vibrators" by C. M. Van Der Burgt, "Philips Technical Review" March 1957, volume 18, No. 10, pages 285–297. The modulated ultrasonic oscillations produced by the generator **1**, **2**, and supplied to the radiator windings **5** and **6**, are illustrated in FIG. 2*a*. A vessel **9** is provided with the radiator elements **7** and **8** for facilitating ultrasonic treatment of liquids.

The winding **4** is provided with a center tap **10** which is connected to one terminal of a secondary winding **11** of a second transformer **12**. The second transformer **12** derives a pre-polarizing current from the A.C. power supply source. The pre-polarizing current supplied to the radiator windings **5** and **6** is indicated in FIG. 2*b*. The center tap **10** is coupled to the radiator windings **5** and **6** through the secondary winding **11** and a lead **13**.

The modulated current is indicated in FIG. 2*a* and in the leads of FIG. 1 as "I" and the pre-polarizing current is indicated in FIG. 2*b* and in said leads as "I_0." The currents I in the lead **13** balance each other. When an odd number of radiator elements is utilized in the ultrasonic transducer, either the primary or secondary circuit of the transformer **12** should include a choke coil (not shown) for separating the high frequency (ultrasonic) circuit from the A.C. power supply source frequency circuit. In such case the pre-polarizing current will lag with respect to the modulated current.

In accordance with the invention, the pre-polarizing current is made to lead the modulating voltage in phase by an angle α, shown in FIGS. 2*a* and 2*b*, sufficient to cause the piezomagnetic coupling coefficient k of the radiator to pass through zero at substantially the same instant that the modulating voltage has a zero value. The desired phase angle, which is usually between 10 and 20 electrical degrees and brings the transducer efficiency to its approximately maximum value, is produced by any suitable means known in the art. Such suitable means may comprise, for example, a choke coil **14**, positioned in the primary circuit of the transformer **3**. Alternatively, such suitable means may comprise a capacitor **20** positioned in the primary circuit of the transformer **12**. A combination of a choke coil and a capacitor as specifically shown may be utilized to produce the desired phase angle, and, of course, the choke coil and/or the capacitor may be positioned in the secondary circuits of transformers **3** and **12**.

The utilization of an even number of separate integral radiator elements of the frame type eliminates the necessity of cementing such elements together.

While the invention has been described by means of a specific example and in a specific embodiment, I do not wish to be limited thereto, for obvious modifications will occur to those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An ultrasonic transducer comprising an alternating current generator for producing ultrasonic oscillations, an ultrasonic radiator of piezomagnetic type, an alternating current power supply source, means for deriving a modulating voltage from said source, means for modulating said ultrasonic oscillations with said modulating voltage thereby to produce modulated ultrasonic oscillations, means for supplying said modulated ultrasonic oscillations to said radiator, means for deriving a pre-polarizing current from said source, means for supplying said pre-polarizing current to said radiator, and means causing

said pre-polarizing current to lead said modulating voltage in phase by an angle sufficient to cause the piezomagnetic coupling coefficient of said radiator to pass through zero at substantially the same instant that the said modulating voltage has a zero value.

2. An ultrasonic transducer comprising an alternating current generator for producing ultrasonic oscillations, an ultrasonic radiator of piezomagnetic type, an alternating current power supply source, means for deriving a modulating voltage from said source, means for modulating said ultrasonic oscillations with said modulating voltage thereby to produce modulated ultrasonic oscillations, means for supplying said modulated ultrasonic oscillations to said radiator, means for deriving a pre-polarizing current from said source, means for supplying said pre-polarizing current to said radiator, and phase shifting means interposed between said source and said generator causing said pre-polarizing current to lead said modulating voltage in phase by an angle sufficient to cause the piezomagnetic coupling coefficient of said radiator to pass through zero at substantially the same instant that the said modulating voltage has a zero value.

3. An ultrasonic transducer comprising an alternating current generator for producing ultrasonic oscillations, an ultrasonic radiator of piezomagnetic type, an alternating current power supply source, means for deriving a modulating voltage from said source, means for modulating said ultrasonic oscillations with said modulating voltage thereby to produce modulated ultrasonic oscillations, means for supplying said modulated ultrasonic oscillations to said radiatior, means for deriving a pre-polarizing current from said source, means for supplying said pre-polarizing current to said radiator, and phase shifting means interposed between said source and said radiator causing said pre-polarizing current to lead said modulating voltage in phase by an angle sufficient to cause the piezomagnetic coupling coefficient of said radiator to pass through zero at substantially the same instant that the said modulating voltage has a zero value.

4. An ultrasonic transducer comprising an alternating current generator for producing ultrasonic oscillations, an ultrasonic radiator of piezomagnetic type, an alternating current power supply source, means for deriving a modulating voltage from said source, means for modulating said ultrasonic oscillations with said modulating voltage thereby to produce modulated ultrasonic oscillations, means for supplying said modulated ultrasonic oscillations to said radiator, means for deriving a pre-polarizing current from said source, means for supplying said pre-polarizing current to said radiator, and inductive phase shifting means interposed between said source and said generator causing said pre-polarizing current to lead said modulating voltage in phase by an angle sufficient to cause the piezomagnetic coupling coefficient of said radiator to pass through zero at substantially the same instant that the said modulating voltage has a zero value.

5. An ultrasonic transducer comprising an alternating current generator for producing ultrasonic oscillations, an ultrasonic radiator of piezomagnetic type, an alternating current power supply source, means for deriving a modulating voltage from said source, means for modulating said ultrasonic oscillations with said modulating voltage thereby to produce modulated ultrasonic oscillations, means for supplying said modulated ultrasonic oscillations to said radiator, means for deriving a pre-polarizing current from said source, means for supplying said pre-polarizing current to said radiator, and capacitive phase shifting means interposed between said source and said radiator causing said pre-polarizing current to lead said modulating voltage in phase by an angle sufficient to cause the piezomagnetic coupling coefficient of said radiator to pass through zero at substantially the same instant that the said modulating voltage has a zero value.

6. An ultrasonic transducer comprising an alternating current generator for producing ultrasonic oscillations, an ultrasonic radiator of piezomagnetic type, an alternating current power supply source, means for deriving a modulating voltage from said source, means for modulating said ultrasonic oscillations with said modulating voltage thereby to produce modulated ultrasonic oscillations, means for supplying said modulated ultrasonic oscillations to said radiator, means for deriving a pre-polarizing current from said source, means for supplying said pre-polarizing current to said radiator, and means causing said pre-polarizing current to lead said modulating voltage in phase by an angle sufficient to cause the piezomagnetic coupling coefficient of said radiator to pass through zero at substantially the same instant that the said modulating voltage has a zero value, said angle having a value in the range of 10 to 20 electrical degrees.

7. An ultrasonic transducer comprising an alternating current generator for producing ultrasonic oscillations, an ultrasonic radiator of piezomagnetic type, said radiator comprising an even number of separate integral radiator elements of the frame type, an alternating current power supply source, means for deriving a modulating voltage from said source, means for modulating said ultrasonic oscillations with said modulating voltage thereby to produce modulated ultrasonic oscillations, means for supplying said modulated ultrasonic oscillations to said radiator, means for deriving a pre-polarizing current from said source, means for supplying said pre-polarizing current to said radiator, and means causing said prepolarizing current to lead said modulating voltage in phase by an angle sufficient to cause the piezomagnetic coupling coefficient of said radiator to pass through zero at substantially the same instant that the said modulating voltage has a zero value.

8. An ultrasonic transducer comprising an alternating current generator for producing ultrasonic oscillations, an ultrasonic radiator of piezomagnetic type, said radiator comprising an even number of separate integral radiator elements of the frame type, an alternating current power supply source, means for deriving a modulating voltage from said source, means for modulating said ultrasonic oscillations with said modulating voltage thereby to produce modulated ultrasonic oscillations, means for supplying said modulated ultrasonic oscillations to said radiator, means for deriving a pre-polarizing current from said source, means for supplying said pre-polarizing current to said radiator, and means causing said pre-polarizing current to lead said modulating voltage in phase by an angle sufficient to cause the piezomagnetic coupling coefficient of said radiator to pass through zero at substantially the same instant that the said modulating voltage has a zero value, said angle having a value in the range of 10 to 20 electrical degrees.

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