United States Patent

[11] 3,624,760

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[54] **SONIC APPARATUS FOR INSTALLING A PILE JACKET, CASING MEMBER OR THE LIKE IN AN EARTHEN FORMATION**
6 Claims, 6 Drawing Figs.

[52] **U.S. Cl.** **175/56,** 175/171
[51] **Int. Cl.** **B06b 1/10,** E21b 5/00
[50] **Field of Search** 175/19, 22, 23, 56, 171

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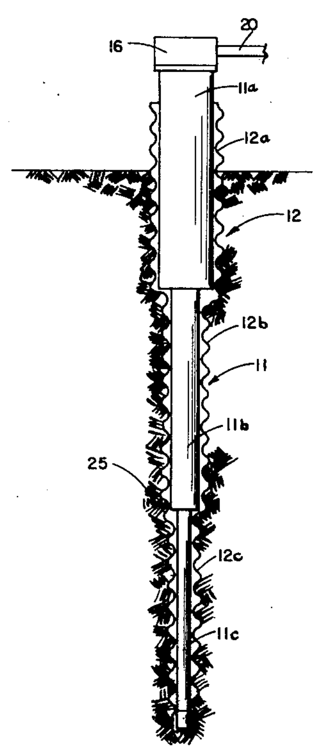
ABSTRACT: A jacket member is placed over a bar which forms a mandrel and is acoustically coupled thereto by means of adjustable couplers at a plurality of points therealong. A sonic oscillator of the orbiting mass type is coupled to the mandrel and driven at a frequency such as to set up resonant standing-wave vibration of the mandrel. Sonic energy is thus coupled to the jacket and in turn into the earthen formation into which the jacket is to be installed, thereby fluidizing the earthen material and causing the jacket to be driven into the ground.



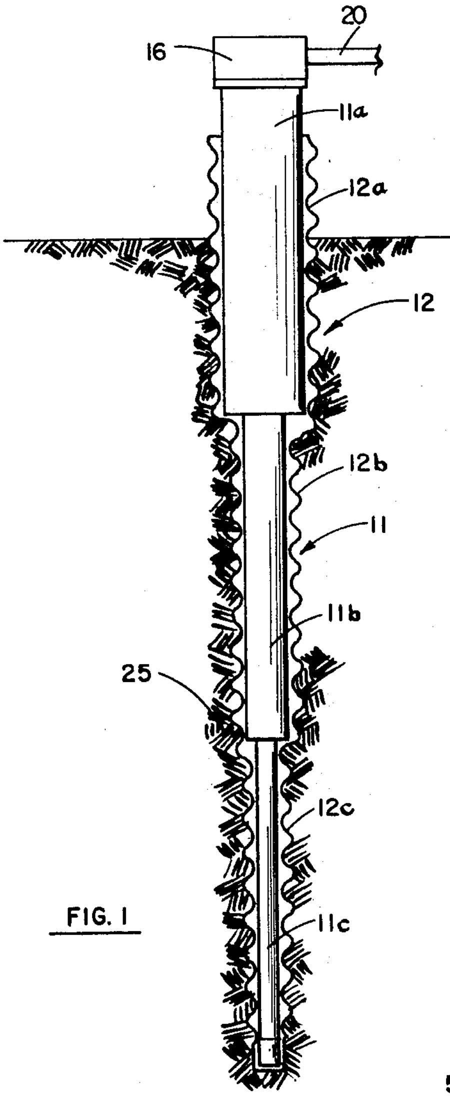


FIG. 1

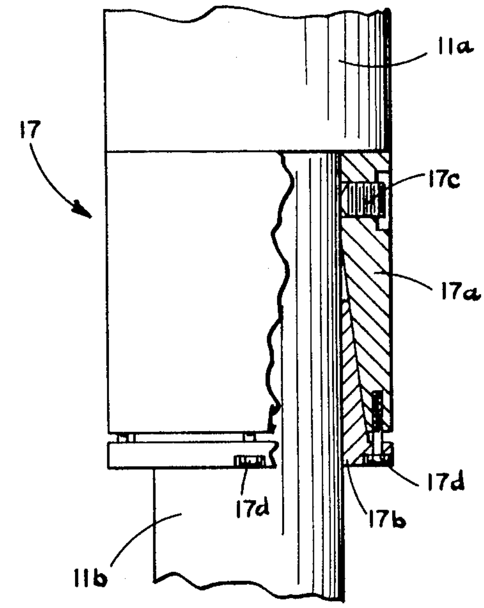


FIG. 3

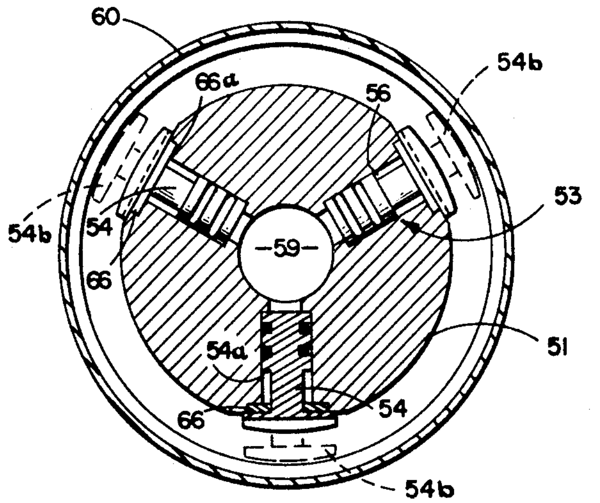


FIG. 6

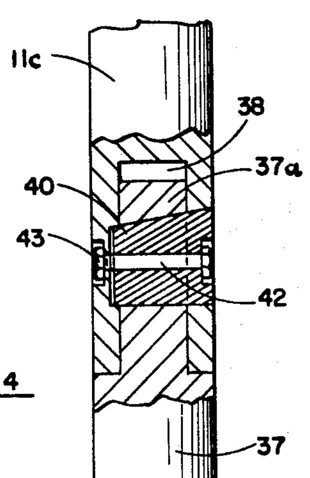


FIG. 4

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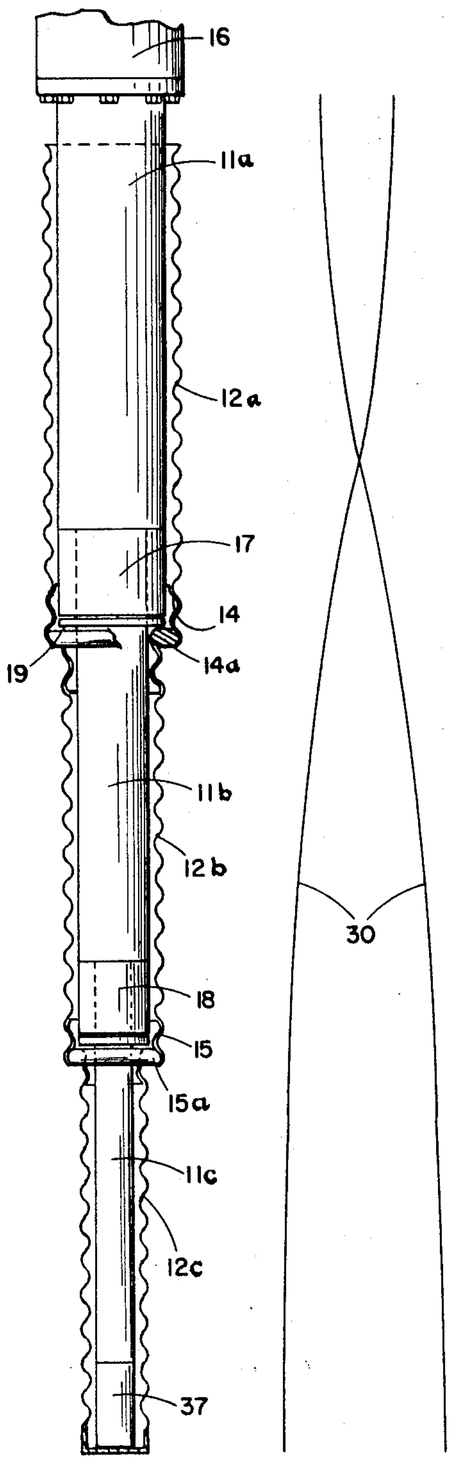

FIG. 2

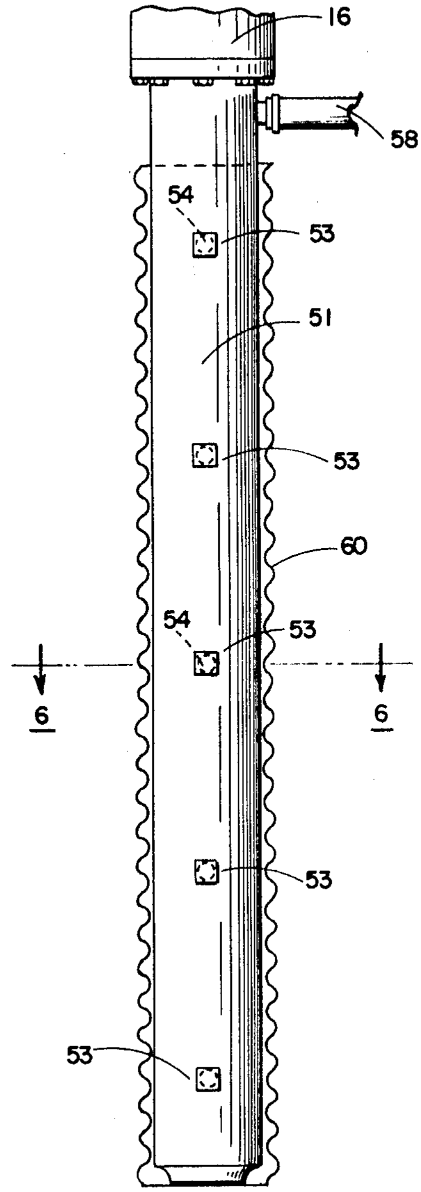

FIG. 5

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SONIC APPARATUS FOR INSTALLING A PILE JACKET, CASING MEMBER OR THE LIKE IN AN EARTHEN FORMATION

This invention relates to the driving of jacket or casing members into the ground and more particularly to the use of sonic energy for implementing such driving action.

In the prior art, apparatus is utilized for forming piles in which a mandrel, which may be tapered or stepped, has a thin steel jacket placed thereover, the two members then being driven into the ground together by means of a hammer drive. When the mandrel and jacket are in position, the mandrel is then removed, leaving the steel jacket in the ground, this jacket then being filled with concrete to form a "cast-in-place" pile. The use of a tapered or stepped construction has an advantage in this type of prior art device in that is provides an optimum use of the steel in that the smaller diameter lower sections of the jacket are held in the solider, lower-down portions of the earthen formation, while a larger diameter portion is provided closer to the surface where the earthen formation is generally not quite as dense.

A considerable improvement in the efficiency of the driving action of this type of device can be achieved by utilizing sonic energy to fluidize the earthen formation and thus implement the driving action. This type of sonic driving is described, for example, in my U.S. Pat. Nos. 2,975,846 and 3,379,263.

The device of this invention is concerned with an improved technique for coupling the sonic energy to the earthen formation by transferring such energy from the mandrel to the jacket at a plurality of optimum coupling points therealong, and in an optimum manner, so as to provide higher efficiency in the utilization of the sonic energy in driving the jacket member into position. Further, in one embodiment of my invention, a stepped mandrel and a correspondingly stepped jacket is utilized, the mandrel providing heavy mass at one end for good impedance coupling to a relatively large orbiting mass oscillator and a much lower mass at the opposite driving end which thus has a high vibrational output for optimum driving action. The device of the invention further utilizes sonic rectification of the energy at its coupling between the mandrel and the jacket to increase the efficiency of the driving operation to assure its maximum utilization.

It is therefore the principal object of this invention to improve the efficiency of the driving of a jacket or casing member into an earthen formation.

Other objects of the invention will become apparent as the description proceeds in connection with the accompanying drawings, of which:

FIG. 1 is an elevational drawing indicating the general operation of one embodiment of the device of the invention,

FIG. 2 is an elevational view in cross section illustrating the details of construction of this first embodiment,

FIG. 3 is an elevational view with partial cutaway section illustrating a coupling bushing member which may be used in the embodiment of FIG. 1,

FIG. 4 is an elevational view with partial cutaway section illustrating a removable tip portion which may be used in the embodiment of FIG. 1

FIG. 5 is an elevational view in cross section of a second embodiment of the device of the invention, and

FIG. 6 is a cross-sectional view taken along the plane indicated by 6—6 in FIG. 5.

Briefly described, the device of the invention comprises a mandrel member over which is placed a relatively thin-wall elastic jacket member. The jacket member is coupled to the mandrel member at several spaced points therealong. An orbiting mass oscillator is coupled to one end of the mandrel member and driven at a frequency such as to set up standing-wave resonant vibration therein, the coupler points between the mandrel and the jacket preferably being spaced to provide optimum overall energy utilization. The jacket and mandrel are placed in the ground, the sonic energy causing these members to be driven therein. In one embodiment of the device of the invention, the mandrel and jacket have a stepped configuration, the driving end having a much smaller diameter than the end being driven by the oscillator, thus providing optimum coupling between the oscillator and the mandrel with an impedance transformation being provided at the driving end to provide optimum coupling of the sonic energy from the driving tip to the ground. The coupler members for coupling the sonic energy from the mandrel to the jacket are adjustable so that they can be positioned for optimum transfer of energy from the jacket to such mandrel. A special tip attachment is provided to adapt the mandrel to various lengths of jacket in the field. In addition, the couplers are arranged so that they provide sonic rectification in the transfer of the sonic energy from the mandrel to the jacket for optimum utilization of this energy.

It has been found most helpful in analyzing the device of this invention to analogize the acoustically vibrating circuit utilized to an equivalent electrical circuit. This sort of approach to analysis is well known to those skilled in the art and is described, for example, in Chapter 2 of "Sonics" by Hueter and Bolt, published in 1955 by John Wiley and Sons. In making such an analogy, force F is equated with electrical voltage E, velocity of vibration u is equated with electrical current i, mechanical compliance C_m is equated with electrical capacitance C_e, mass M is equated with electrical inductance L, mechanical resistance (friction) R_m is equated with electrical resistance R and mechanical impedance Z_m is equated with electrical impedance Z_e.

Thus, it can be shown that if a member is elastically vibrated by means of an acoustical sinusoidal force $F_o \sin\omega t$ (ω being equal to 2π times the frequency of vibration), that

$$Z_m=R_m+j(M-(1/C_m))=F_o \sin\omega t/u \qquad (1)$$

Where ωM is equal to $1/\omega C_m$, a resonant condition exists, and the effective mechanical impedance Z_m is equal to the mechanical resistance R_m, the reactive impedance components ω(M and $1/\omega C_m$ cancelling each other out. Under such a resonant condition, velocity of vibration u is at a maximum, power factor is unity, and energy is more efficiently delivered to a load to which the resonant system may be coupled.

It is important to note the significance of the attainment of high acoustical Q in the resonant system being driven, to increase the efficiency of the vibration thereof and to provide a maximum amount of power. As for an equivalent electrical circuit, the Q of an acoustically vibrating circuit is defined as the sharpness of resonance thereof and is indicative of the ratio of the energy stored in each vibration cycle to the energy used in each such cycle. Q is mathematically equated to the ratio between ωM and R_m. Thus, the effective Q of the vibrating circuit can be maximized to make for highly efficient, high-amplitude vibration by minimizing the effect of friction in the circuit and/or maximizing the effect of mass in such circuit. The heavy, tapered pile gives good Q. Moreover, the rectifier action also increases the energy retention in the mandrel.

In considering the significance of the parameters described in connection with equation 1, it should be kept in mind that the *total* effective resistance, mass, and compliance in the acoustically vibrating circuit are represented in the equation and that these parameters may be distributed throughout the system rather than being lumped in any one component or portion thereof.

It is also to be noted that orbiting mass oscillators are utilized in the implementation of the invention that automatically adjust their output frequency and phase to maintain resonance with changes in the characteristics of the load. Thus, in the face of changes in the effective mass and compliance presented by the load with changes in the conditions of the work material as it is sonically excited, the system automatically is maintained in optimum resonant operation by virtue of the "lock-in" characteristic of applicant's unique orbiting mass oscillators. Furthermore in this connection the orbiting mass oscillator automatically changes not only its frequency but its phase angle and therefore its power factor with changes in the resistive impedance load, to assure optimum efficiency of operation at all times. This automatic adjustment to load impedance works particularly well with the rectifier feature of this invention. The vibrational output from such orbiting mass oscillators also tends to be constrained by the resonator to be generated along a controlled predetermined coherent path to provide maximum output along a desired axis.

Referring not to FIG. 1, a first embodiment of the device of the invention is illustrated. Mandrel **11** includes stepped sections **11*a*, 11*b*** and **11*c***, which are fixedly joined together by suitable means such as welding, or interference fit, to form a one-piece integral unit. Mandrel **11** may be formed of cylindrical, thick-walled pipe of a highly elastic material such as steel. Placed over the mandrel sections **11*a*, 11*b*** and **11*c*** are thin-wall steel corrugated tubing sections **12*a*, 12*b*** and **12*c***, which form a jacket around the mandrel. The jacket sections are coupled to each other by corrugated couplings **14** and **15**, as to be described in connection with FIG. 2. The mandrel is coupled to the jacket, with rectifier action, by means of adjustable or selected bushings **17** and **18**, as shown in FIG. 2 and later to be described in connection therewith. Suffice it to say at this point that the couplings may be adjusted to provide the rectified coupling (unidirectional portion of the elastic displacement cycle) of sonic energy in an optimum manner from the mandrel to the jacket.

An orbiting mass oscillator **16** has its casing attached to the top end of mandrel **11** and is rotatably driven by drive means (not shown) coupled to the oscillator through drive shaft **20**. Oscillator **16** may be of the type described in my U.S. Pat. No. 3,379,263, which utilizes a pair of eccentric rotors which are rotated in opposite directions so that they produce vibration of mandrel **11** along the longitudinal axis thereof. The speed of rotation of oscillator **16** is adjusted to a frequency whereat resonant standing-wave vibration of the mandrel occurs. The resonant energy is coupled from the mandrel through jacket **12** to earthen formation **25** to fluidize the formation thereby causing the mandrel and the jacket to be driven therein.

Referring now to FIGS. 2–4, the details of construction of a first embodiment of the device of the invention are illustrated. As already noted, cylindrical corrugated steel jackets **12*a*–12*c*** fit over associated mandrel sections **11*a*–11*c*** respectively. Jacket section **12*a*** is joined to jacket section **12*b*** by means of cylindrical corrugated coupler **14**, which matingly engages the ends of these sections in the manner of screw threads. Jacket section **12*b*** is similarly coupled to section **12*c*** by means of coupler **15**. Acoustical coupling is provided between mandrel section **11*a*** and jacket section **12*a*** by means of adjustable or selected bushing coupler member **17**, the details of which are illustrated in FIG. 3. Bushing **17** includes a cylindrical tapered spacer member **17*a***. The bushing may be held to the mandrel in a desired position opposite shoulder portion **14*a*** of coupler **14** by means of the wedge action provided by collet **17*b*** with the tightening of screws **17*d***. Further holding action for retaining the bushing to the mandrel is provided by setscrew **17*c***. Prior to the time that jacket section **12*a*** is placed over mandrel section **11*a***, bushing **17** is placed in the desired position for coupling energy therebetween and attached to the mandrel in this position by means of collet **17*b*** and setscrew **17*c***. This adjustment should be made to provide a small rectifier gap **19** between the jacket and the mandrel so that only unidirectional pulses of sonic energy are transferred to the jacket (i.e., the half-cycle of the sonic energy which provides a downward pulse), the mandrel being substantially uncoupled from the jacket on the upward vibratory excursion. The device thus functions as a sonic rectifier, downward driving pulses of sonic energy being provided from the mandrel to the jacket. Bushing **17** should be positioned in place or dimensioned so that gap **19** is such as to afford optimum transfer of downward pulsating energy. This gap has to be less than the longitudinal distance traversed by the mandrel in an elastic half-cycle. Coupler bushing **18** is similarly adjusted in position for optimum coupling of unidirectional sonic energy between mandrel section **11*b*** and the shoulder portion **15*a*** of jacket coupler **15**.

The frequency of oscillator **16** is adjusted to provide a standing-wave pattern in the mandrel as indicated by graph lines **30**. The resonant vibration as shown should be at a frequency whereby any two of the coupling points, i.e., in this instance those at coupler bushings **17** and **18**, are spaced within a quarter wavelength of the standing-wave pattern so that the sonic drives on the jacket at these various points are in unison, thereby minimizing the stress on jacket. A removable tip portion **37** is utilized, various lengths of these tip portions being available for installation at the end of the mandrel to match various lengths of jackets so as to provide rectifier action as the need may arise in the field. Tip portion **37**, or any of the other joints in the mandrel, may have a tongue **37*a*** thereon which fits into cavity **38** in the center portion of the adjoining portion of the mandrel, joinder between the two members being attained by means of a tapered key **40** which fits through apertures in tongue **37*a*** and mandrel **11*c*** and is held to the mandrel by means of bolt **42** and nut **43**.

Several significant features of this first embodiment should be noted at this point. First, the stepped mandrel structure provides a heavy mass at one end for optimum coupling to a large massive oscillator, and a much lower mass at the opposite end to provide an effective step-up transformation of the vibration resulting in high-amplitude vibration at the driving end, where it is most needed. Secondly, the adjustable or selected bushings **17** and **18** provide means for adjusting the coupling between the mandrel and the corrugated jacket to optimum rectifier advantage for each particular installation requirement. Likewise, the use of a removable driving tip enables the use of a tip member which provides optimum driving. Further, the adjustment of the coupling between the mandrel and the jacket through the adjustable bushings to provide sonic rectification, i.e., vibrational drive only in the downward direction, provides the advantages of minimizing the stress placed on the jacket and further makes for better utilization of the sonic energy in that it is not dissipated in an upward loaded excursion, which provides no useful effect in the driving action. The sonic vibrational system by virtue of the sonic rectifier action is made to have a higher effective Q in view of the fact that the ratio between the energy stored to the energy dissipated in each vibrational cycle is thereby increased.

When the jacket has been installed in the desired position, the mandrel is lifted out therefrom and the jacket filled with concrete to form the piling.

Referring now to FIGS. 5 and 6, a second embodiment of the device of the invention is illustrated. In this embodiment, the tapered mandrel and jacket of the first embodiment are not used, the mandrel being coupled to the corrugated jacket by means of a plurality of specially designed coupler devices.

Mandrel **51** has a plurality of coupler units **53** installed therein at spaced intervals therealong. Each coupler unit **53** may include three piston units **54**, slidably supported in radial cylinders **56** formed in the mandrel. Pistons **54** are hydraulically actuated by pressurized fluid fed through line **58** to channel **59** formed in the center of the mandrel. With the pistons **54** unactuated, jacket member **60** is placed over the mandrel. The pistons **54** are then hydraulically actuated to drive them to the position indicated by the dotted lines in FIG. 6, the radial travel of the pistons being arrested by the abutment of piston shoulder **54*a*** against shoulder **66*a*** of retainer plate **66**, which is fixedly retained in the mandrel. The travel of piston **54** is thereby arrested as shown by the dotted lines, in a position whereat there is a small gap between piston head **54*b*** and the inner wall of corrugated jacket **60** both radially and longitudinally. This gap provides the rectifier gap necessary to achieve the desired sonic rectification. Thus, with the excitation of oscillator **16** at a frequency such as to cause longitudinal resonant standing-wave vibration of mandrel **51**, and with pistons **54** in their extended position, unidirectional sonic pulses are coupled from the mandrel to the corrugated jacket at the longitudinal gaps formed between the piston heads and the adjacent jacket corrugations. This second embodiment thus provides another way of transferring unidirectional sonic downward driving pulses to the jacket at several points therealong.

The device of this invention thus provides improved means for acoustically driving a pile jacket in which unidirectional sonic driving pulses are applied to the jacket in the driving direction at several points therealong.

I claim:

1. In combination,

an elastic bar member,

a jacket member surrounding said bar member,

sonic oscillator means coupled to one end of said bar member, said oscillator means being driven at a frequency such as to set up resonant standing-wave vibration in said bar member, and

means for acoustically coupling said bar member to said jacket member at a plurality of predetermined spaced points therealong, so as to rectify the sonic energy such that mainly unidirectional pulses of such energy are transferred to said jacket member.

2. The device of claim 1 wherein said bar member is a mandrel having a plurality of successively stepped sections along the length thereof, running between the oscillator and the end opposite said one end thereof.

3. The device of claim 1 wherein said jacket member is corrugated, each of said coupling means being positioned with an end thereof longitudinally spaced from one of the jacket member corrugations to form a rectifier gap therebetween.

4. The device of claim 2 wherein said jacket member is corrugated, each of said coupling means comprising a bushing member removably attached to the mandrel, each of said bushing members being placed along said mandrel with one end thereof at a position where a pair of said sections join, a rectifier gap being formed between said one end of said bushing member and a corrugation of said jacket.

5. The device of claim 4 and additionally including removal tip means attached to the end of said mandrel opposite to the oscillator-coupled end thereof for providing a predetermined extension to the mandrel to adapt it to the length of the jacket.

6. The device of claim 3 wherein each of said coupling means comprises piston means mounted in said bar member for motion radially thereof and means for driving said piston means to a position spaced from an associated corrugation of said jacket member so as to form said gap.

* * * * *