April 23, 1968 A. G. BODINE, JR 3,379,263

SONIC METHOD AND APPARATUS FOR INSTALLING PILE MEMBER, CASING MEMBERS OR THE LIKE, IN EARTHEN FORMATIONS

Filed Feb. 1, 1966 4 Sheets-Sheet 1

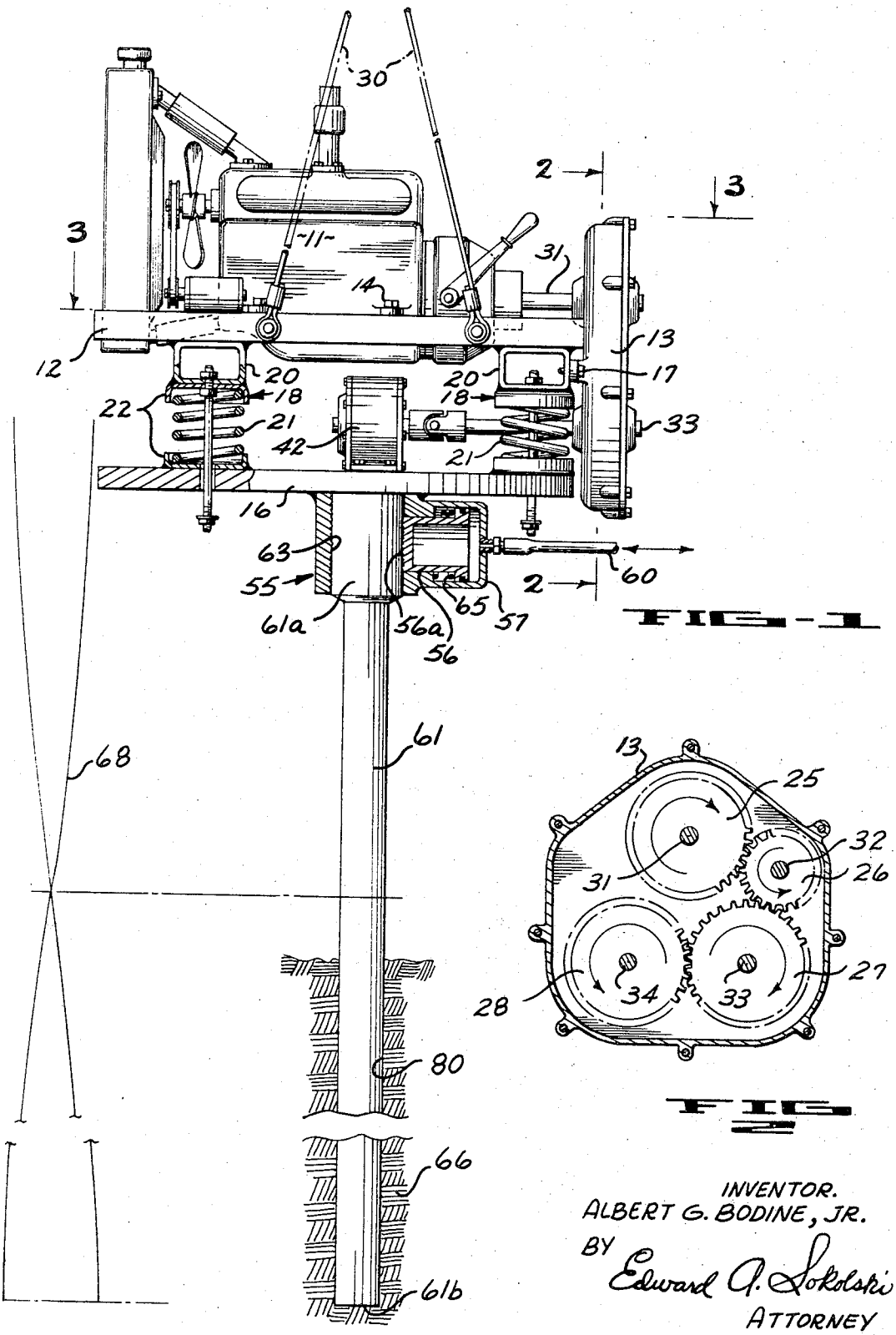


FIG. 1

FIG. 2

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Filed Feb. 1, 1966 4 Sheets-Sheet 2

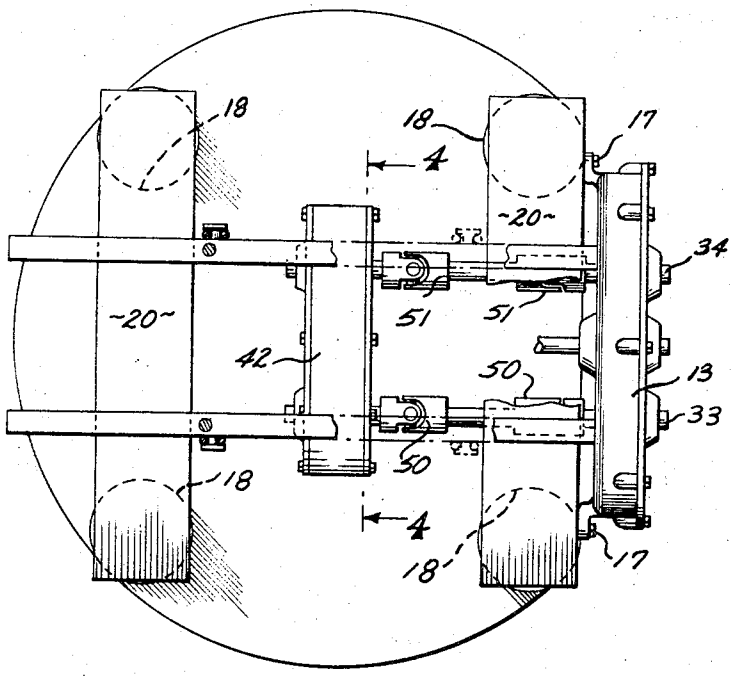


FIG. 3

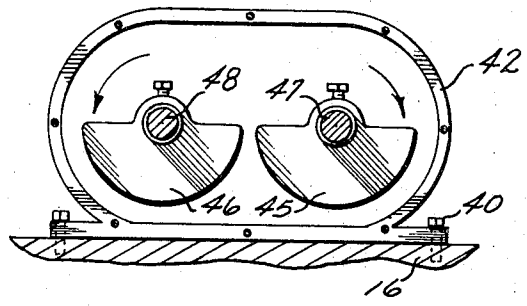


FIG. 4

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Filed Feb. 1, 1966 4 Sheets-Sheet 3

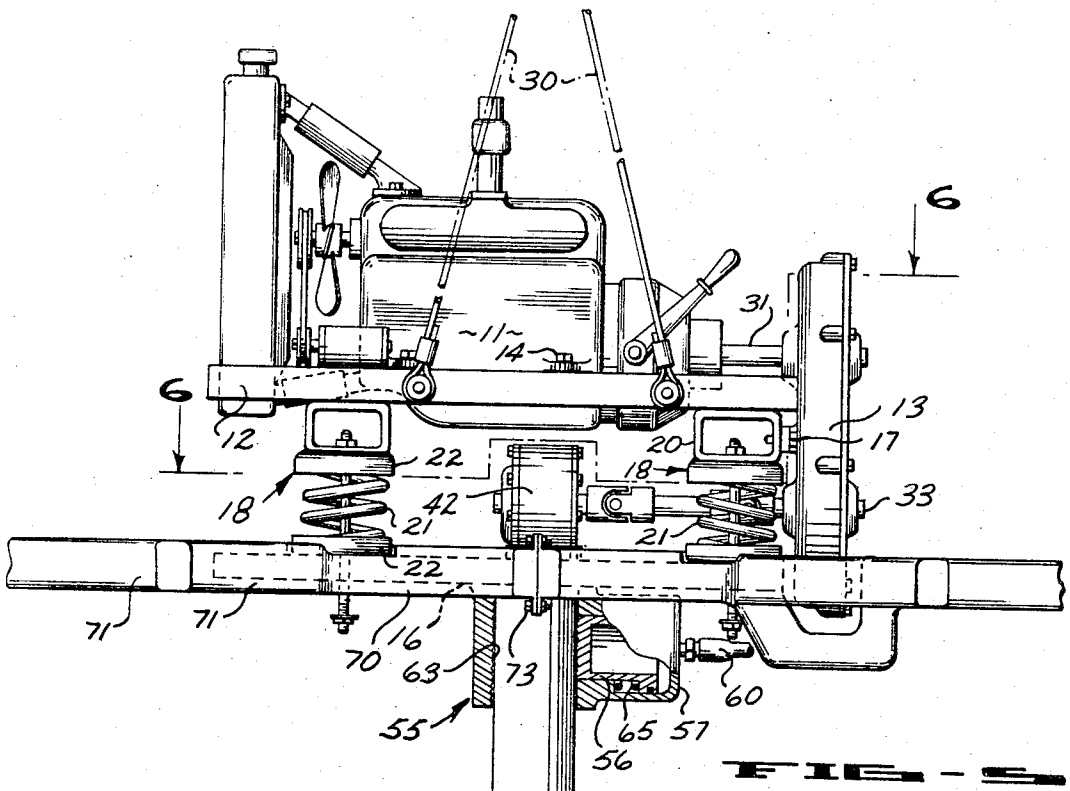
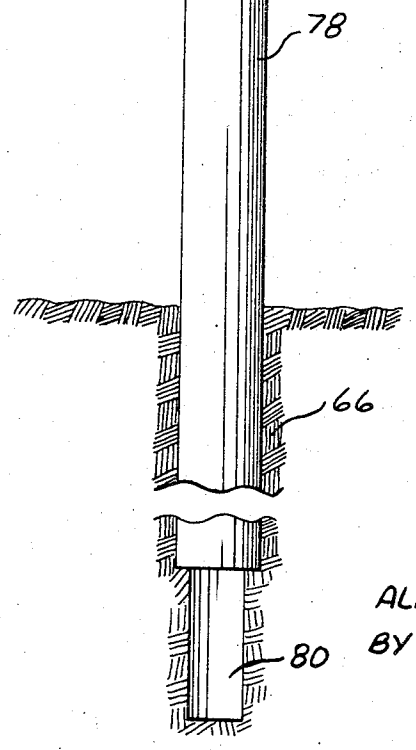


FIG. 5



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Filed Feb. 1, 1966 4 Sheets-Sheet 4

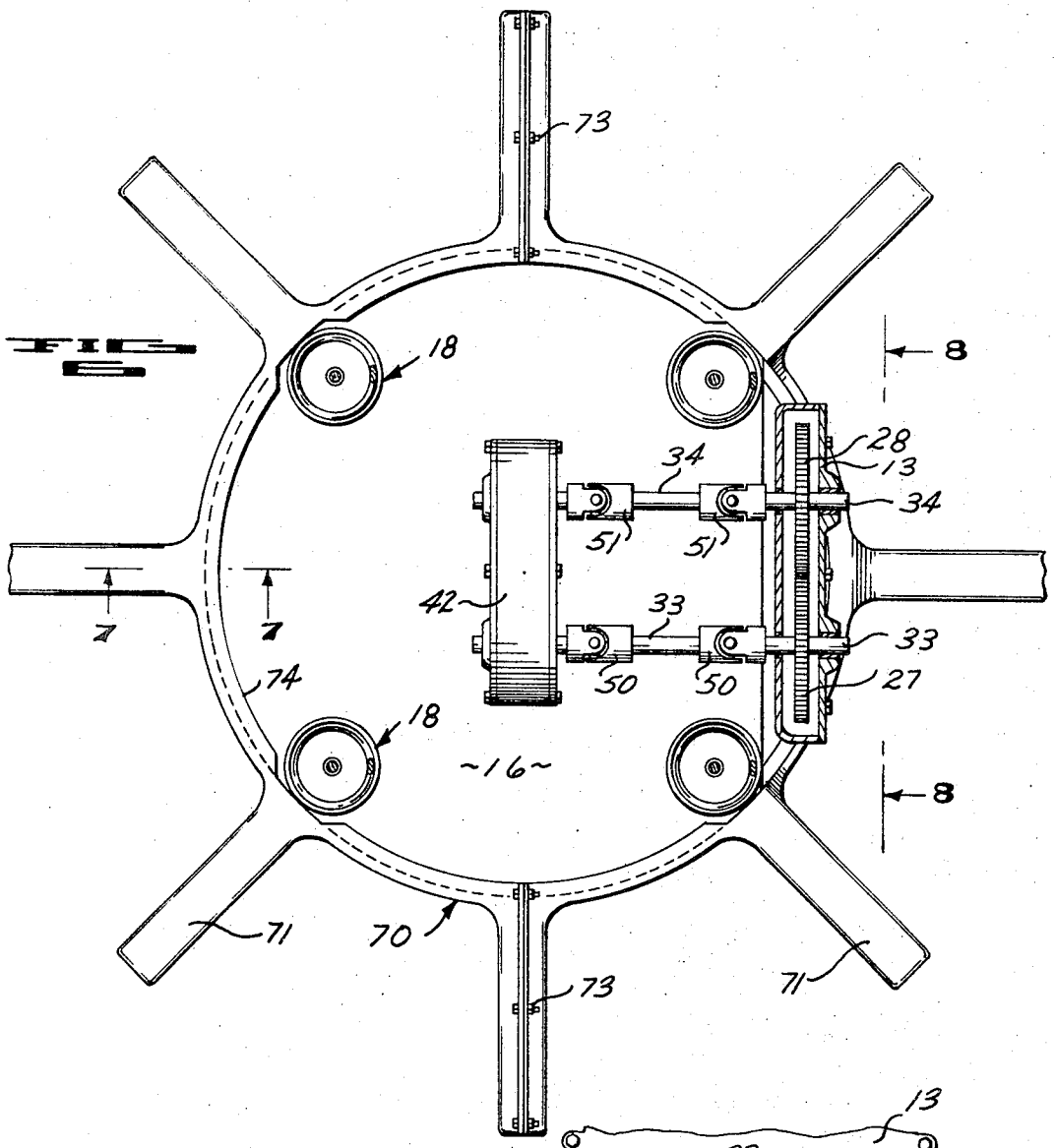


FIG 6

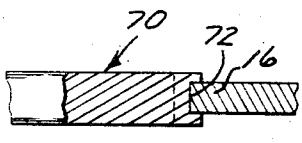


FIG 7

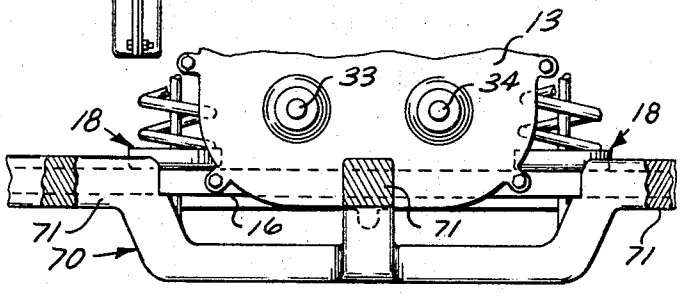


FIG 8

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United States Patent Office 3,379,263 Patented Apr. 23, 1968

3,379,263

SONIC METHOD AND APPARATUS FOR INSTALLING PILE MEMBER, CASING MEMBERS OR THE LIKE, IN EARTHEN FORMATIONS

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Continuation-in-part of application Ser. No. 340,745, Jan. 28, 1964. This application Feb. 1, 1966, Ser. No. 524,059

5 Claims. (Cl. 175—19)

This application is a continuation-in-part of my application Ser. No. 340,745, filed Jan. 28, 1964, now Patent No. 3,239,005 for "Method for Molding Well Liners or the Like."

This invention relates to a method and apparatus for installing pile members, casing members or the like, in earthen formations, and more particularly to such a method and apparatus involving a first operation in which a hole for receiving such member is punched by means of a sonically excited mandrel and a second operation in which the member to be installed is sonically lodged in the pre-punched hole.

In the aforementioned patent application, of which the instant application is a continuation in part, a method is described wherein a mandrel is sonically driven into the ground by virtue of resonant vibration thereof and then used as a mold for forming a casing by a slip form process. In this slip form process, sonic energy is coupled from the mandrel through the setting slurry to the surrounding soil. The soil is fluidized and compacted by sonic energy so as to tightly grip the molded casing member, thus assuring tight lodgement thereof in the ground. The method and device of this invention provide an adaption and improvement in this technique whereby prefabricated pile members, casing members or the like can be installed in earthen formations.

As described, for example, in my Patent No. 2,975,846, sonic energy can be utilized to efficiently drive a casing or pile member into an earthen formation. While such techniques of the prior art utilizing resonant vibrating systems in achieving sonic driving action are capable of highly efficient operation, certain difficulties are sometimes experienced where the members to be driven have any modicum of frangibility, this in view of the fairly high level of sonic energy to which such members may have to be subjected in achieving the necessary driving action.

It is highly desirable that the driven pile or casing member be firmly lodged in the earthen formation in its final position, especially where such member tends to be frangible. This is in view of the fact that with such firm retention of the casing or pile member, structural reinforcement is provided therefor by the earthen formation. This not only makes for greater structural stability but also provides greater effective durability and load and tension bearing capabilities in the casing or piling.

The method and apparatus of this invention overcomes the aforementioned difficulties by means of a two-step sonic activation of the earthen formation in which the casing or pile member is finally lodged. In the first of these steps, a mandrel member is sonically driven into the earthen formation to achieve two end results: (1) to prebore the ground and (2) to compact and effectively condition the earthen material so that it is ideally prepared for a subsequent second fluidization and final compaction. After the pre-bore has been formed, the mandrel is removed and the casing or pile member forced into the hole formed by the mandrel by sonic excitation of such casing or pile member.

It is to be noted that with the method and apparatus of this invention, that the soil itself is not made part of the resonantly vibrating system so that it does not form a reactive component of such system and therefore does not behave as a coherent vibrating mass. Rather, the earthen particles assume a random vibration relative to each other, resulting in a high degree of fluidization and eventual compaction thereof. The vibration of the mandrel thus fluidizes the earthen material surrounding the bore and sets it up in a random pattern. The second energization of such particles with the excitation of the casing or pile member causes further fluidization and compaction and when the sonic energy is finally removed from the casing or pile member when it arrives at its final position, the earthen particles settle closely against the wall of such member to provide a tight gripping action along the entire length thereof. The two-step sonic process thus enables relatively easy installment of the casing or pile member in an earthen formation and firm lodgement therein.

Apparatus is provided in one embodiment of the device of the invention for enabling a resonant system of relatively compact proportions wherein the earth penetrating member provides a lumped constant load connected to such system. In this type of system, the generation of high amplitude standing waves in the casing or pile member is avoided, this member effectively acting as a transformer to couple such energy to the soil.

It is therefore an object of this invention to provide an improved sonic method and apparatus for installing a casing or pile member in an earthen formation.

It is another object of this invention to minimize the hazard of damage to a relatively frangible casing or pile member in the installation thereof in an earthen formation.

It is still another object of this invention to provide a method and apparatus which makes for easier installation of casing or pile members in an earthen formation.

It is still a further object of this invention to enable better lodgement of casing or pile members in their installation in earthen formations.

It is still another object of this invention to improve the effective durability and weight and tension bearing characteristics of a given casing or pile member in its earth-installed position.

It is still a further object of this invention to provide a resonant sonic driving system of more compact configuration.

Other objects of this invention will become apparent from the following description taken in connection with the accompanying drawings, of which:

FIG. 1 is an elevation view partly in cross-section illustrating a first embodiment of the device of the invention operating to perform the first step of the method of the invention,

FIG. 2 is a cross sectional view taken along the plane indicated by 2—2 in FIG. 1,

FIG. 3 is a cross sectional view taken along the plane indicated by 3—3 in FIG. 1,

FIG. 4 is a cross sectional view taken along the plane indicated by 4—4 in FIG. 3,

FIG. 5 is an elevation view partly in cross section illustrating a second embodiment of the device of the invention operating to perform the second step of the method of the invention,

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

FIG. 7 is a cross sectional view taken along the plane indicated by 7—7 in FIG. 6, and

FIG. 8 is a view taken along the plane indicated by 8—8 in FIG. 7.

It has been found most helpful in analyzing the operation of the device of the invention to analogize the acoustically vibrating circuit involved 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

$$Z_m = R_m + j\left(\omega M - \frac{1}{\omega C_m}\right) = \frac{F_o \sin \omega t}{u} \quad (1)$$

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 ωM 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 most efficiently delivered to a load to which the resonant system may be coupled.

Just as in electrical circuitry, maximum acoustical energy can be transferred where a good impedance match exists. i.e., where the two elements between which the energy transfer occurs have like impedances. This fact becomes significant in the device and method of this invention in the transfer of energy from the driving end of the mandrel and the casing or piling to the earthen formation in effecting the pre-punching and final driving operations respectively. Thus, in view of the high resistive impedance characteristics of earthen formations it is desirable that the driving end of the mandrel and casing or piling exhibit corresponding high impedance characteristics to assure maximum transfer of energy in fluidizing the formation.

It is to be noted that in the device of this invention the mass and compliance for forming the resonantly vibrating system are furnished by the structural members of such system themselves such that the earthen formation is not incorporated in such system. The earth under such conditions acts as a friction load which provides no significant reactive components. This results in a random vibration of the earthen particles, rather than a lumped coherent vibration, with a considerable relative motion between the separate grains. The net result is a high degree of fluidization of the earthen structure facilitating the penetration of the driven member and the eventual compaction of such structure around such member when the sonic energization is terminated.

It is also important to note the significance of the attainment of high acoustical "Q" in the casing member being driven, to increase the efficiency of the vibration thereof and to provide a maximum amount of energy for the driving operation. 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 ωR_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.

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.

Referring now to FIGS 1–4. a first embodiment of the device of the invention is illustrated as being utilized in performing the pre-bore operation of the method of the invention.

Gasoline engine **11** is mounted on platform **12** by means of bolts **14**. Gear box **13** is supported on platform **12** by means of bolts **17**. Platform **12** is resiliently mounted on support member **16** by means of spring mounting assemblies **18**. Mounting asemblies **18** are attached to crossbars **20** which are fixedly attached to platform **12** by welding. Mounting assemblies **18** include springs **21** which are held within retainer members **22**, the top one of each of these retainer members being attached to a respective one of crossbars **20**, the bottom one of each of such retainer members being attached to support member **16**. The ends of springs **21** are effectively retained in retainer members **22** so that when the entire assembly is lifted upwardly by means of cables **30**, the springs will, under tension, support such assembly.

Contained within gear case **13** is a gear train including gears **25–28**, each of these gears being mounted on an associated shaft **31–34** respectively, for rotation on bearings contained within casing **13**. Engine **11** rotatably drives shaft **31** and gear **25** in the direction indicated by the arrow in FIG. 2. With such rotation of gear **25**, the other gears **26–28** are rotatably driven in the directions indicated by the associated arrows in FIG. 2.

Fixedly mounted on support member **16** by means of bolts **40**, is rotor housing **42**. Mounted for rotation within housing **42** are eccentric rotors **45** and **46** which are attached to shafts **47** and **48** respectively, these shafts being rotatably supported on the housing. Shafts **33** and **34** are coupled to shafts **48** and **47** respectively by means of associated U-joints **50** and **51** (see FIG. 3). Thus, rotors **45** and **46** are rotatably driven in opposite directions as indicated by the arrows in FIG. 4.

Referring now to FIG. 1, fixedly attached to support member **16** is hydraulic clamping mechanism **55**. Hydraulic clamping mechanism **55** includes a piston member **56** which is slidably supported in a cylinder member **57**. When hydraulic pressure is applied to piston **56** through hydraulic control line **60**, piston **56** is driven into tight clamping engagement with the top portion **61***a* of mandrel member **61**. Mandrel member **61** is thus tightly retained between the jaws formed by serrated wall **63** and the serrated end portion **56***a* of piston **56**. When the hydraulic pressure is released, piston **56** is urged away from the mandrel wall by spring **65**, thus releasing the mandrel.

The device of the invention is utilized to bore a hole in earthen formation **66** in the following manner: With mandrel **61** being tightly held to support member **16** by means of hydraulic clamp **55**, the entire assembly is lifted into position for boring by suitable means, such as a crane assembly which is connected to cables **30**. With mandrel **61** vertically positioned with its end portion **61***b* abutting against the earthen formation to be penetrated, engine **11** is turned on so as to cause rotation of eccentrically weighted rotor members **45** and **46**. It is to be noted that in the event that a hollow mandrel is used, the end portion **61***b* thereof should usually be capped to prevent the entry of unconsolidated earthen material therein.

Rotors **45** and **46** are position phased as indicated in FIG. 4 and when rotated in opposite directions produce vibrational forces that are additive longitudinally and which effectively cancel each other out insofar as transverse vibration is concerned. Mandrel **61** is thus longitudinally vibrated at a frequency determined by the speed of rotation of rotors **45** and **46**. This rotation speed is adjusted so as to produce resonant vibration of mandrel **61** with standing waves as indicated by graph lines **68** being set up therealong. As indicated by graph lines **68**, maximum vibrational activity is provided at the boring end of mandrel **61** where it is most needed to accomplish

the boring operation. It is further to be noted that once the properly dimensioned orbiting mass oscillator has been set to cause resonant vibration of the mandrel, that it tends to automatically adjust its rotation frequency such as to maintain such resonance with changes in the impedance of the resonantly vibrating system.

Mandrel **61** is preferably fabricated of a material such as steel having relatively high "Q" characteristics to make for a resonant system having optimum efficiency.

When the desired penetration depth has been achieved, the mandrel **61** is lifted out of the bored hole by means of cables **30**, sonic excitation thereof being continued as necessary to facilitate such removal.

During this first operation, the earthen particles are fluidized and compacted so that they in effect stand back from the mandrel permitting relatively easy penetration. In view of the fact that the resonant vibration system is contained fully within the mandrel and the associated components, the earthen material being penetrated tends to act as a resistive load with the particles being caused to vibrate randomly rather than as a unitary mass. It is believed that each of the individual irregular grains when energized by the sonic energy in this fashion separately vibrates in a random path with a relatively fixed radius of vibration which changes in direction but remains fixed in magnitude. Such random vibration effectively separates the irregular particles so that they do not adhere to each other and are thus kept in a highly fluid condition. This high degree of fluidity not only greatly eases the penetration of the mandrel member but also conditions the soil surrounding the pre-bore so that highly effective lodgment of the casing or pile member subsequently driven therein is possible.

With certain soil conditions it has been found to be preferable to make the pre-bore smaller in diameter than the casing member to be installed. Such a smaller diameter pre-bore is generally preferred where the soil has a relatively low consolidation such as in the case of soft loam. On the other hand, a pre-bore having a larger diameter than that of the member to be installed may be preferable with other types of soil conditions.

Referring now to FIGS. 5–8, a second embodiment of the device of the invention is shown as being utilized to drive a casing or pile member into the pre-bore. This embodiment is similar to the first embodiment described except for the addition of a resonant spoke member which provides an elastically vibrating system independent of the casing or pile member to be driven. The use of such a resonant spoke member has two advantages. First, it enables the attainment of resonance where a relatively short member to be driven is involved; and secondly, it obviates the necessity for resonantly vibrating the driven member so as to avoid subjecting such member to overly large vibrational forces, this second factor being particularly significant where relatively frangible casing or pile members are being installed.

Spoke member **70** comprises a ring portion **74** having a plurality of radial spokes **71** extending therefrom. The spoke member is formed in two sections so that it can readily be attached to and detached from support member **16**. This enables the utilization of the sonic driving mechanism alternatively either with a resonantly vibrating driven member or the resonant spoke member. The spoke member has a groove **72** formed in the ring portion **74** thereof, such grooved portion fitting over the edge of support portion **16**. Spoke member **70** is removably attached to support member **16** by means of bolts **73**.

The dimensions of spoke member **70** are such that the sonic vibrational energy generated by the orbiting mass oscillator contained within housing **42** will cause resonant vibration of the system including such spoke member and support member **16**. Engine **11** and its associated drive assembly is, as in the case of the first embodiment, isolated from platform **16** by means of spring isolator members **18**.

The casing or pile member **78** to be installed is tightly held to support member **16** by means of hydraulic clamp assembly **55**. The member **78** to be installed does not form an elastic part of the resonantly vibrating system and rather acts as a lumped constant inductive load thereon. The vibrational energy coupled to member **78** is coupled therefrom to earthen formation **66**. Casing **78** is thus driven into the pre-bore **80** previously formed by the mandrel. It is to be noted that as member **78** is sonically driven, that the soil **66** is compacted away from the wall of such member with the individual particles thereof being maintained in a highly fluid state by virtue of the random vibration instituted therein. With the earth particles standing back in this fashion, member **78** can easily penetrate into pre-bore **80**. When the sonic excitation is halted, the fluidized soil particles fall tightly against the casing walls in a highly compacted state which results in firm lodgment of such casing member in its finally installed position.

It is to be noted that while the utilization of spoke member **70** is described in conjunction with the driving of the member to be installed, it could also be utilized to equal advantage in conjunction with the mandrel in making the pre-bore should the situation so require.

In practicing the method of the invention, the mandrel **61** is first utilized as described in connection with FIGS. 1–4 to make a pre-bore **80** for receiving the casing or pile member to be installed. In such first operation, the soil **66** in which the pre-bore is formed is fluidized and compacted away from the mandrel, with the individual grains of the soil vibrating in random fashion relative to each other. The soil not being part of the resonantly vibrating system does not vibrate as a unitary mass, and thus the individual particles are highly fluidized. When the mandrel **61** has penetrated to the desired depth, it is withdrawn from the earth, leaving the pre-bore **80** with the soil surrounding same in optimum condition for the second step involving the installation of member **78**.

When mandrel **61** has been removed from the pre-bore it is detached from support member **16** by deactuation of hydraulic clamp member **55**. The member **78** to be installed is then joined to support member **16** by means of the hydraulic clamp, and set into position over the pre-bore **80** by means of a suitable crane mechanism (not shown) connected to platform **12** by means of cables **30**. With member **78** in position, sonic energy is applied thereto from the resonantly vibrating system including support member **16** and spoke member **70**, which is resonantly excited by the orbiting mass oscillator.

The vibrational energy passes through member **78** to the soil **66** causing it to stand back away from member **78** thus permitting penetration of such member into the pre-bore. The second activation of the soil again causes random vibration and further compaction thereof, further fluidizing the soil structure. When member **78** finally reaches the bottom of the pre-bore, or a predetermined distance beyond, resonant sonic excitation thereof is discontinued. When this occurs, the earth particles settle tightly against the wall of casing member **78** in a highly compacted condition, firmly gripping such member and holding it in firm lodgment in the earthen formation.

The method and device of this invention thus provides means for facilitating the installation of casing, pile members or the like in earthen formations, wherein a superior installation of such member is achieved. By virtue of the pre-conditioning of the soil achieved in the pre-bore operation and the following excitation of the earthen formation in a manner which provides optimum fluidization and compaction thereof, the member to be installed is firmly lodged in and supported by the penetrated soil structure. Further, means are provided in the form of a resonant spoke member for achieving resonant vibration of the over-all drive system without resonantly exciting the member being driven, thus minimizing the chances of damaging relatively frangible such members during the driving operation and enabling the driving of relatively

short members incapable of achieving self-resonance at the vibrational drive frequencies.

While the method and device of the invention have been described and illustrated in detail it is to be clearly understood that this is intended by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of this invention being limited only by the terms of the following claims.

I claim:

1. A method for installing an elongated member in an earthen formation comprising the steps of

forming a pre-bore in said earthen formation and fluidizing and compacting the earthen particles surrounding said pre-bore by sonically vibrating a mandrel member to cause such member to bore into said formation,

when said pre-bore condition has been achieved, removing said mandrel therefrom and placing said member to be installed in said pre-bore,

sonically vibrating said member to be installed so as to cause further fluidization and compaction of the soil in said pre-bore and to cause said member to be driven therein, and

when said member to be driven has penetrated into said pre-bore to the desired depth, discontinuing the sonic energization thereof whereby the earthen particles surrounding said member fall tightly against said member in tight gripping relationship therewith.

2. The method as recited in claim 1 wherein said mandrel member is resonantly vibrated as part of a resonant vibration system independent of said earthen formation.

3. The method as recited in claim 1 wherein a resonant elastic member is connected to said member to be installed during the sonic vibration theerof, said elastic member forming part of a resonant vibration system coupled to said member to be installed, whereby said member to be installed acts as a vibratory load on said resonant system.

4. The method as recited in claim 1 wherein said mandrel member and said member to be installed are vibrated by means of an orbiting mass oscillator.

5. The method as recited in claim 1 wherein the pre-bore is made to have a slightly smaller diameter than that of said member to be installed.

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