DIESEL PILEHAMMER

Filed Dec. 2, 1966

FIG. 1.

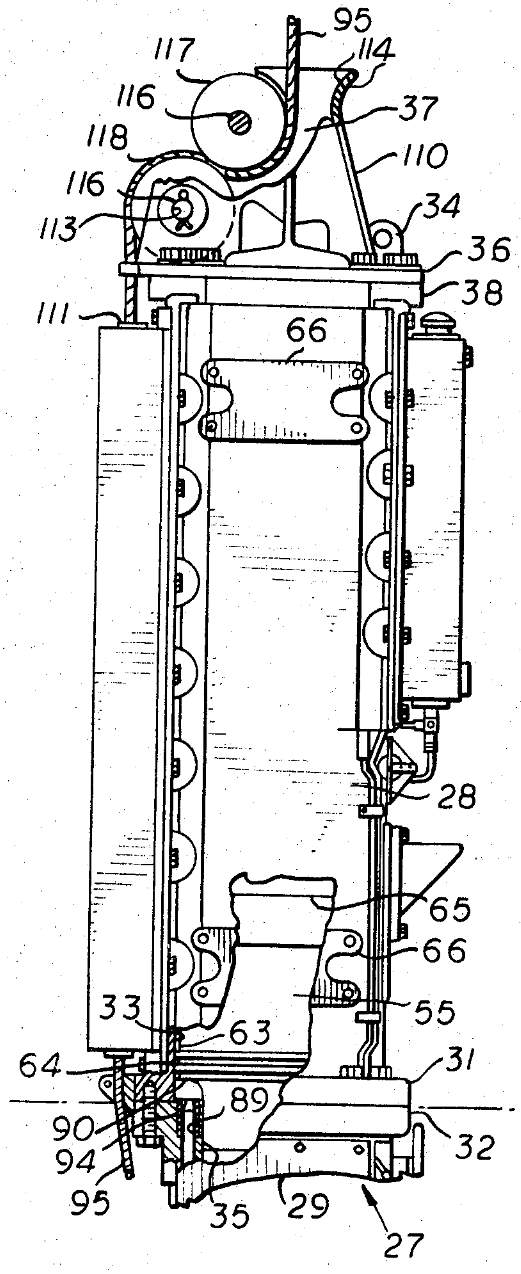

FIG. 1A.

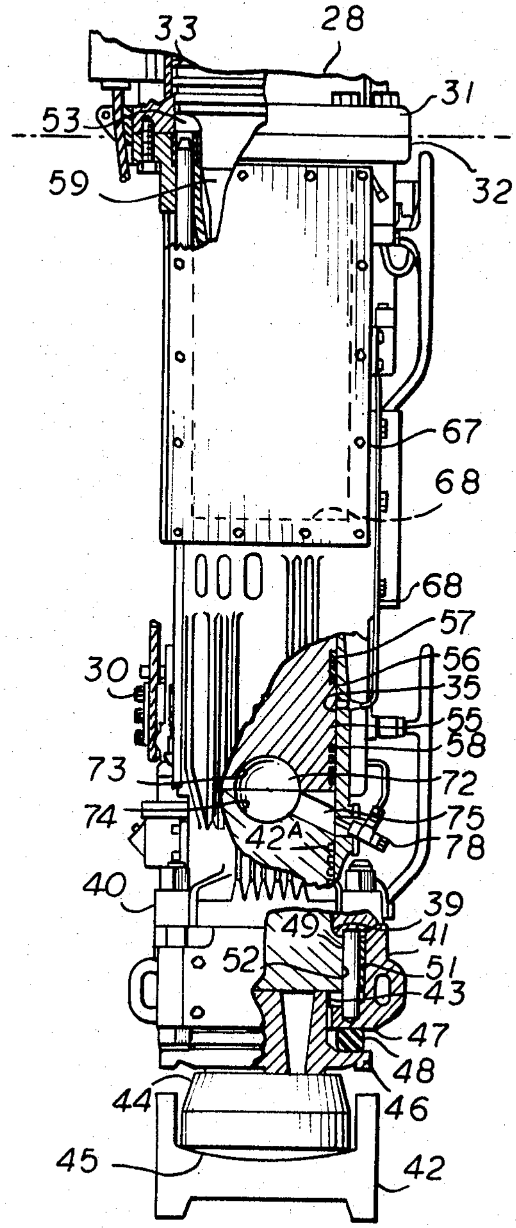

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FIG. 2.

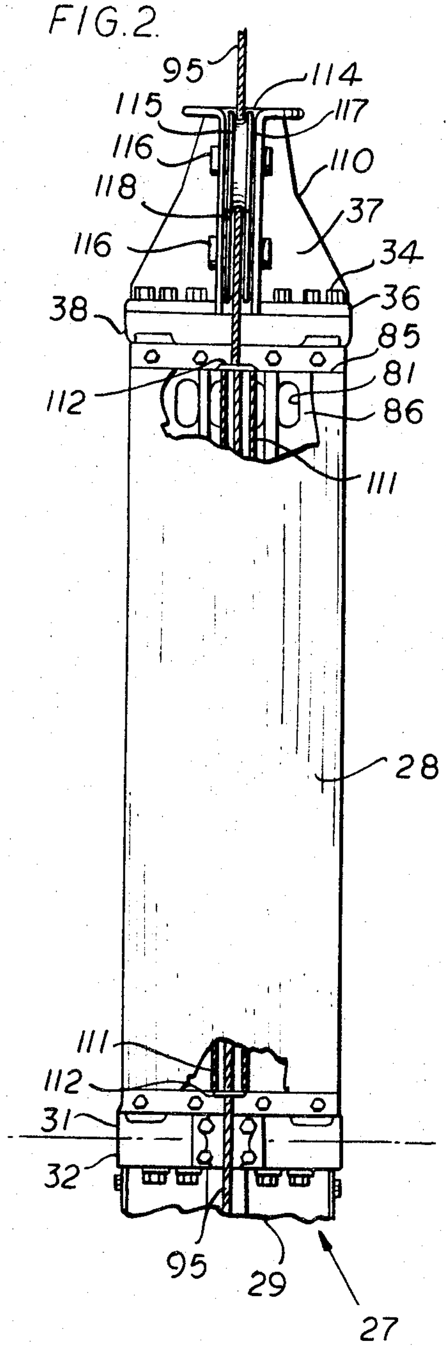

FIG. 2A

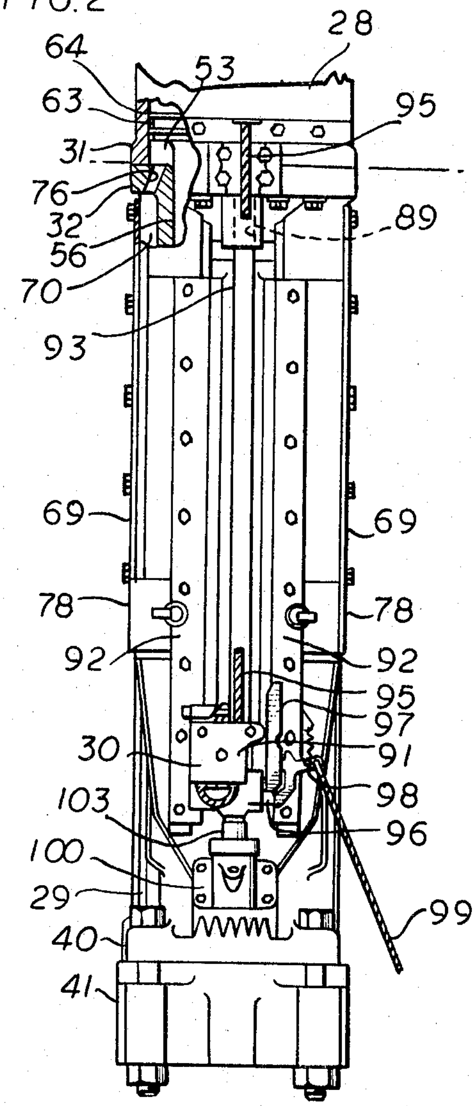

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FIG. 3.

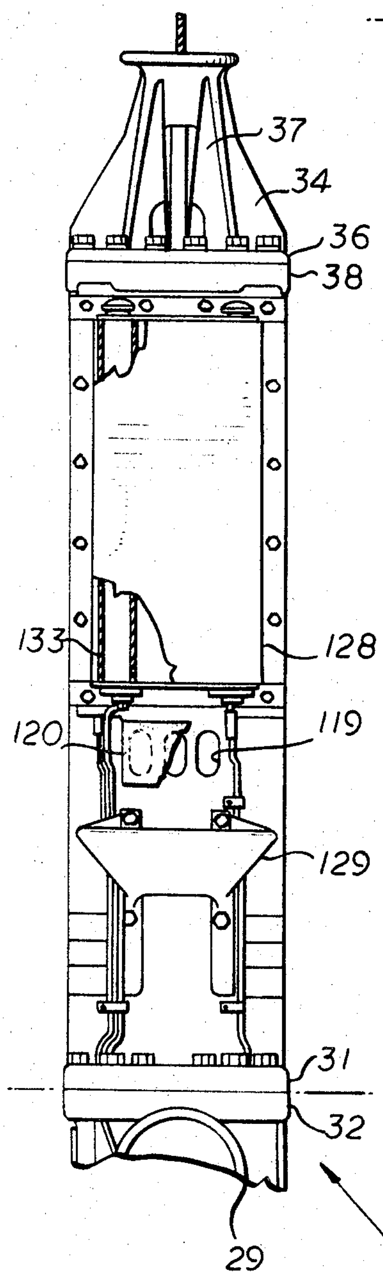

FIG. 3A

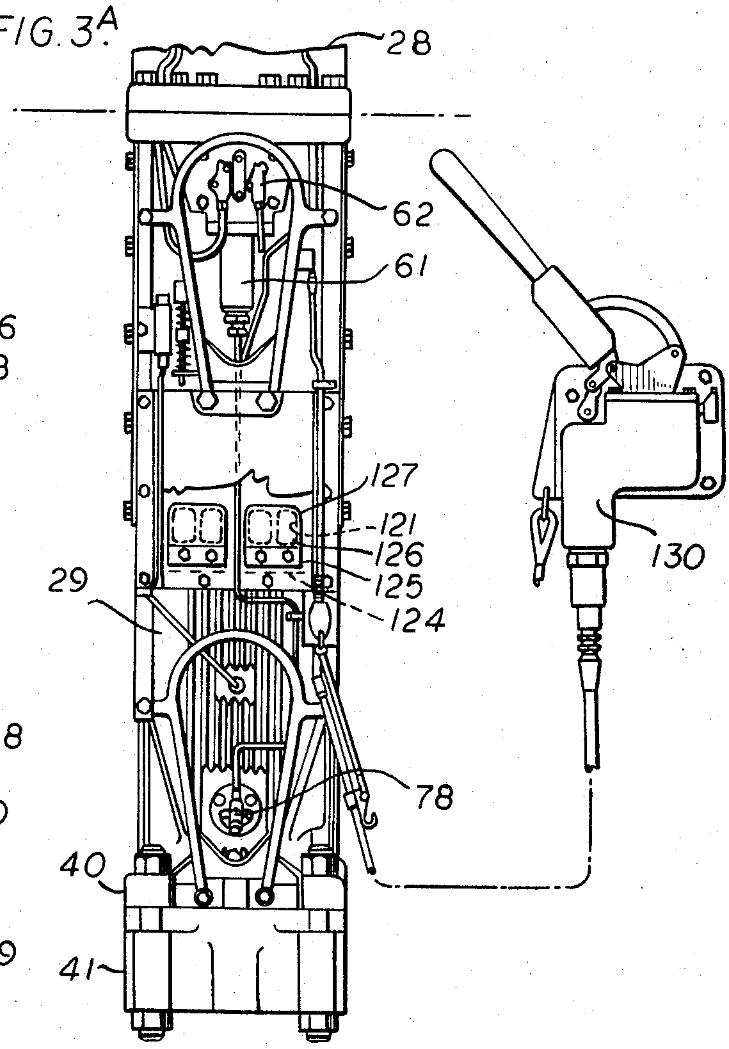

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FIG. 4.

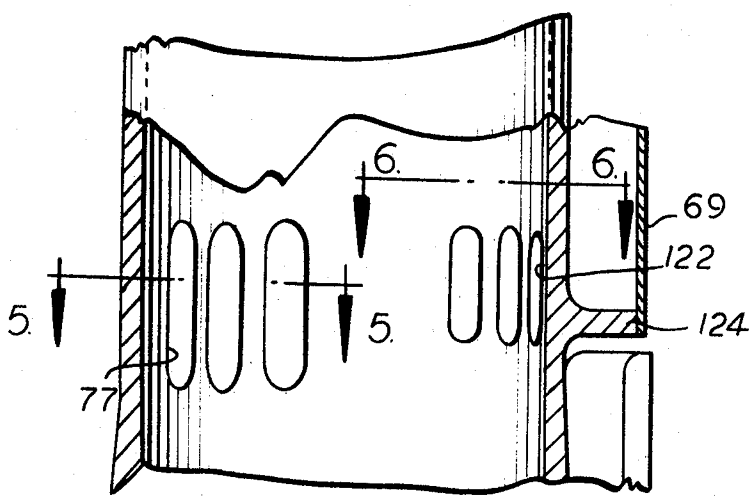

FIG. 5.

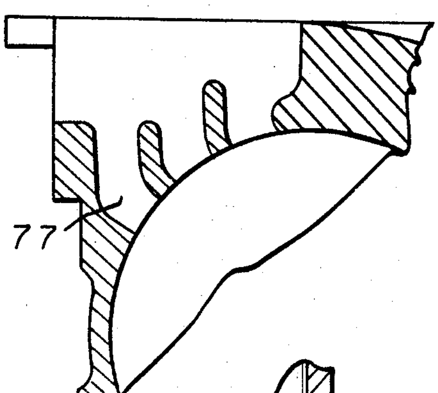

FIG. 6

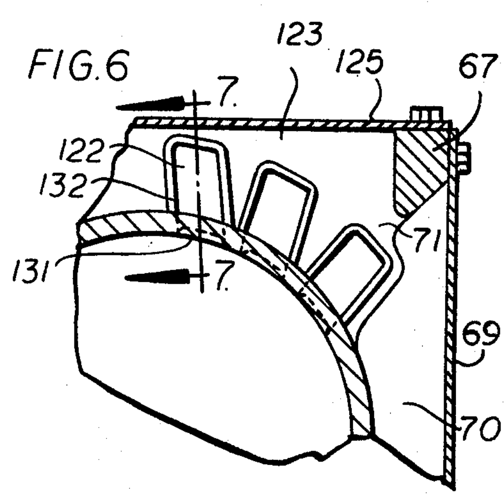

FIG. 7.

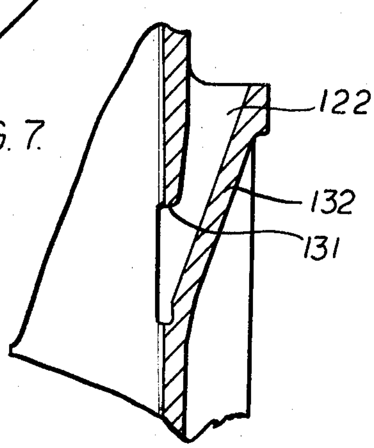

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FIG. 8.

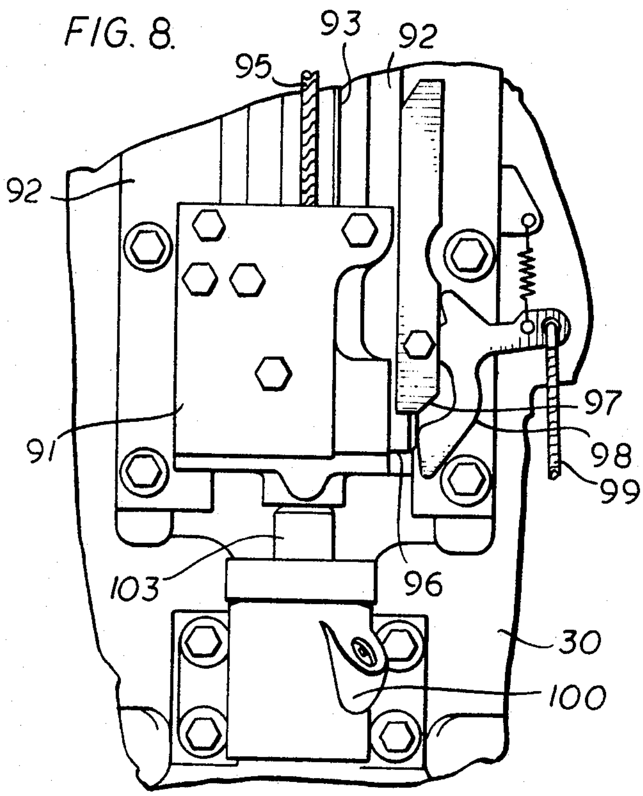


FIG. 22.

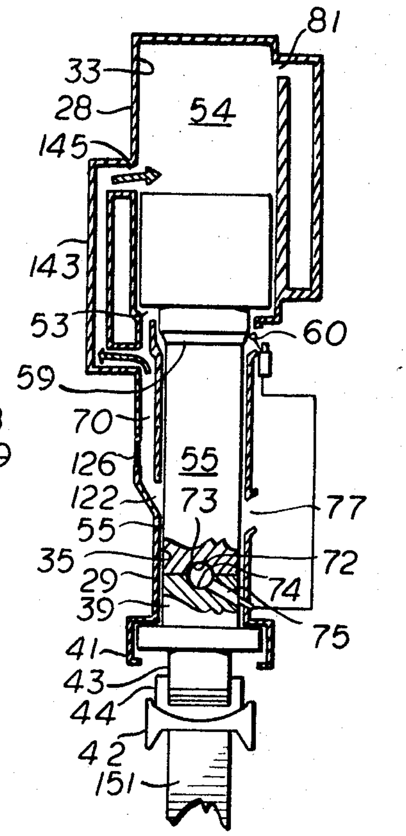
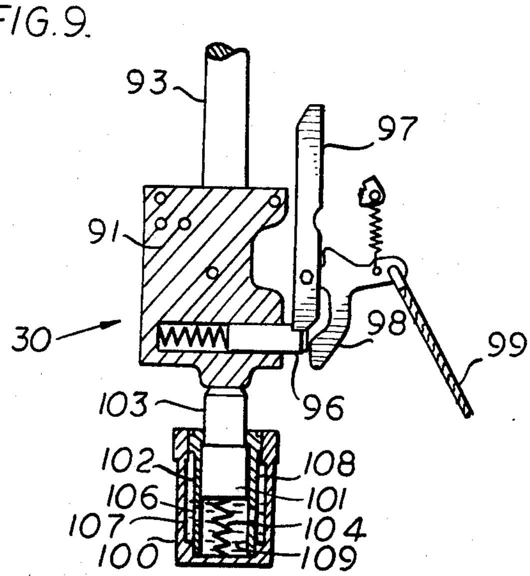


FIG. 9.



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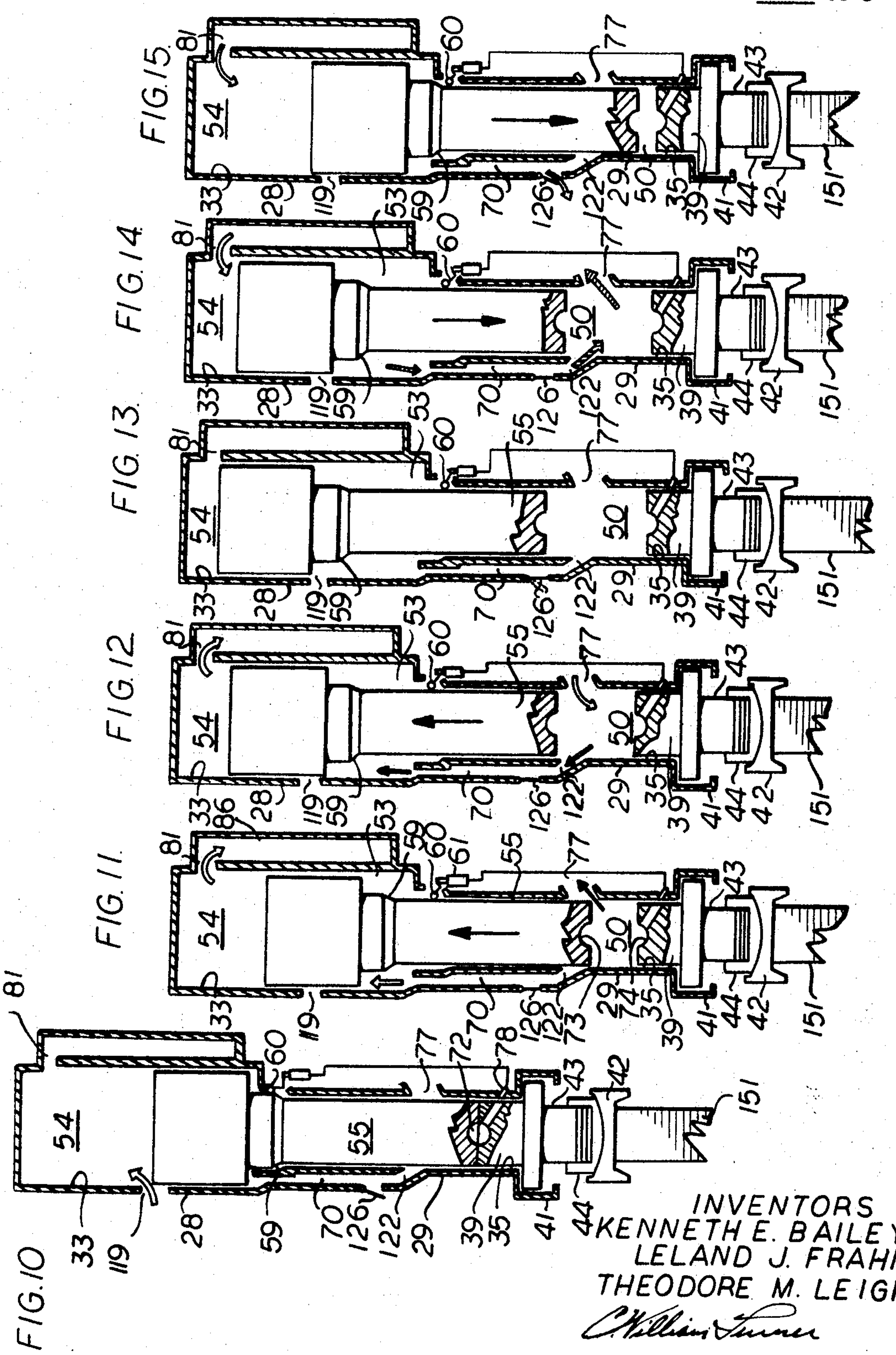

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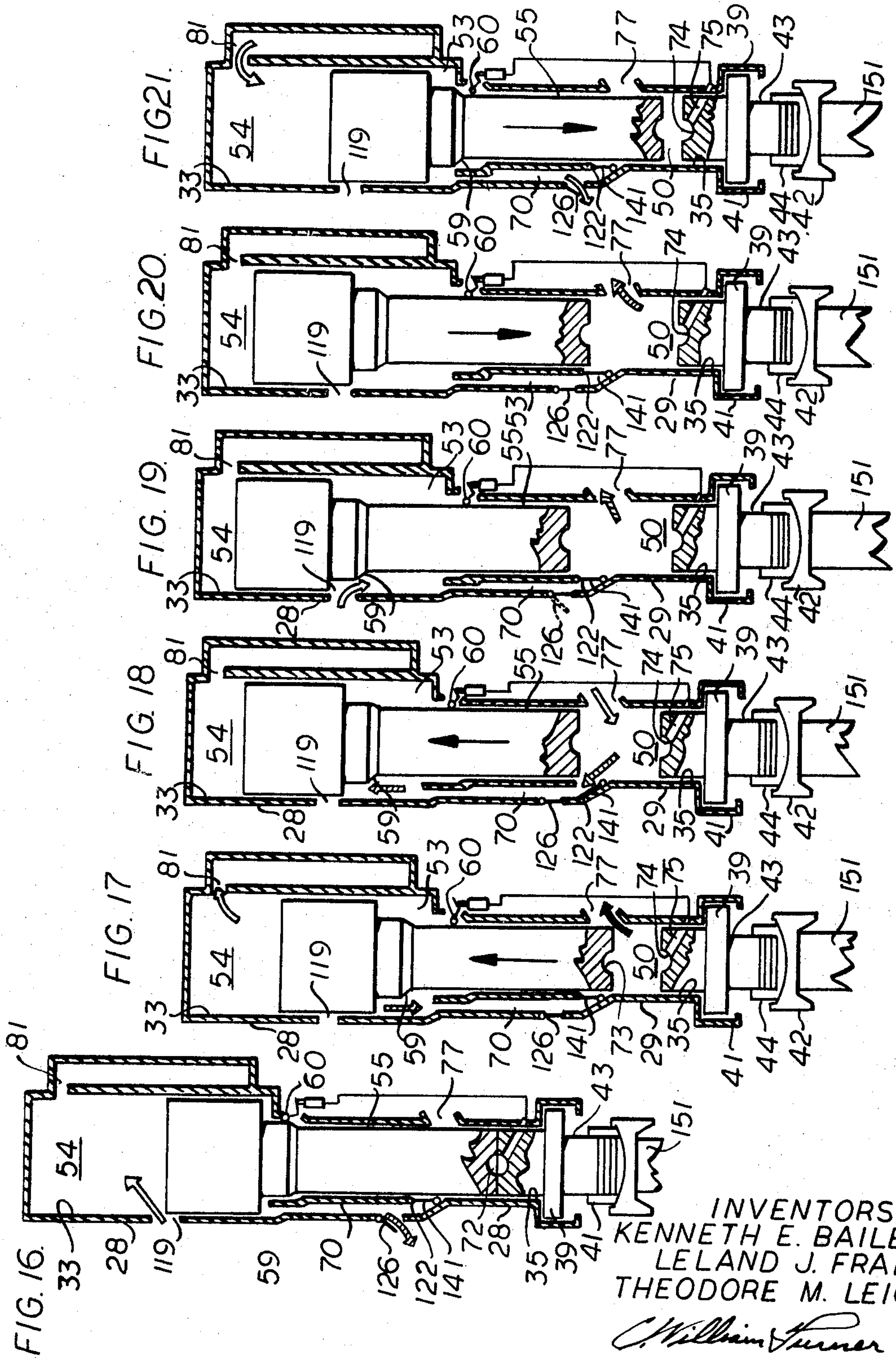

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FIG. 23.

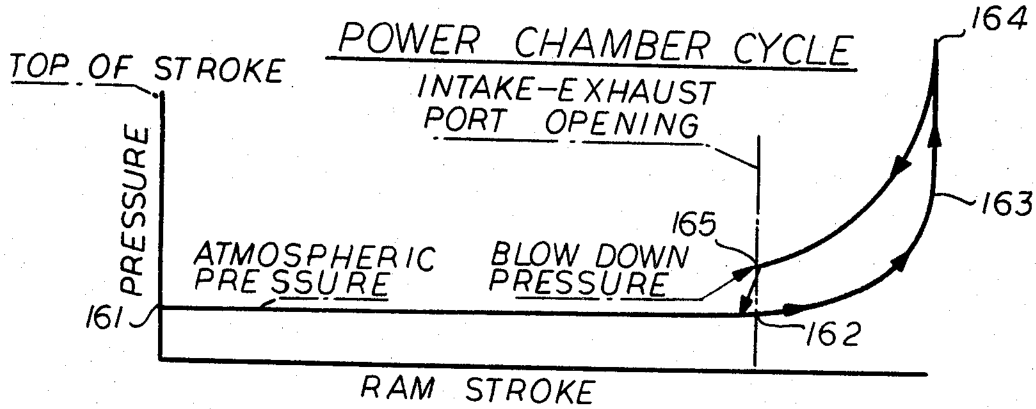


FIG. 24.

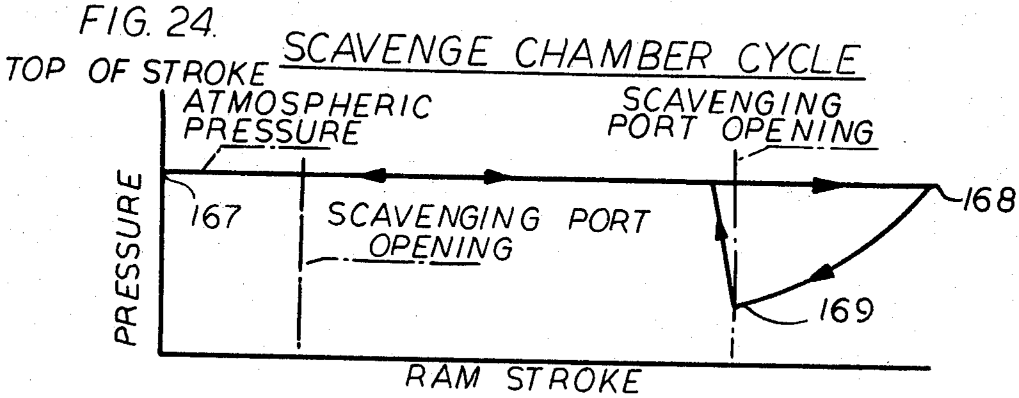
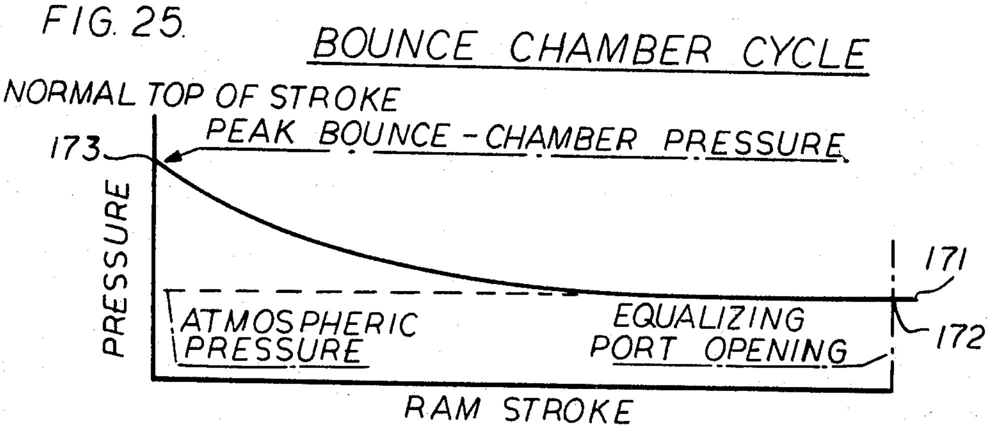


FIG. 25.



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United States Patent Office 3,437,157
Patented Apr. 8, 1969

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3,437,157
DIESEL PILEHAMMER

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Int. Cl. E21b *1/00;* E21c *3/00;* B25d *9/00*
U.S. Cl. 173—133 22 Claims

ABSTRACT OF THE DISCLOSURE

A diesel pilehammer comprising a housing having a bore formed therein for receiving a free piston in sealing engagement therewith and slidably disposed therein for reciprocating axial movement; portions of the piston being formed to cooperate with corresponding portions of the housing for defining a scavenging chamber and a power chamber interconnected by a conduit including a valve for allowing gases to pass only in one direction from the power chamber to the scavenging chamber. The housing is formed with a port having valve means to allow gases to pass in one direction from the scavenging chamber to the atmosphere as the piston moves in a direction to decrease the volume of the scavenging chamber. The housing is also formed with a port for allowing the passage of gases to and from the power chamber. The free piston and housing cooperate to define a combustion chamber within the power chamber when the free piston is in a position providing a minimum volume in the power chamber. The diesel pilehammer further comprises appropriate fuel injection means for delivering fuel to the combustion chamber to be ignited and lifting means for raising the piston to its starting position. The lifting means includes a member for engaging a downwardly facing surface formed on the piston and a latch mechanism for automatically retaining the lifting means in its lowermost position to facilitate control of the entire hammer at all stages of the hammer operation. The diesel pilehammer, as described above, is a preferred embodiment of one of several apparatus for carrying out a method of operating a diesel pilehammer including igniting a compressed fuel-air mixture in a combustion chamber underlying the piston to cause the piston to ascend; evacuating a space separate from the combustion chamber during the ascent of the piston; permitting gases to flow to said evacuated space from the chamber underlying the piston while also admitting air into the latter space for the scavenging thereof during the ascent of the piston; reversing the direction of movement of the piston due to a reversal of the imbalance of forces acting thereon; forcing the gases in the previously evacuated space to flow to the atmosphere during the descent of the piston; confining and compressing air in the combustion chamber during the descent of the piston; and injecting fuel into the compressed air to be ignited for initiating a subsequent cycle.

This invention relates to new and useful improvements in diesel pilehammers and deals more particularly with the operation and starting thereof.

A diesel pilehammer is one application of a one cylinder unbalanced free piston diesel engine, wherein the piston strikes an anvil slidable in the bore and resting on a pile. The impact of the piston on the anvil provides the principal impetus to drive the pile. The combustion of the fuel air mixture beneath the piston raises it to a position where it will have sufficient impetus to again descend driving the pile further, and simultaneously the combustion provides a driving force on the ram.

Difficulties have been encountered in the past in the use of this type hammer when driving piling into soft ground. On previous designs, once a hammer was started on a low resistance pile it sometimes ceased to continue the cycle after one or more strokes. The reason for this was that on low resistance piling, the forces of combustion acting to raise the ram were reduced by the rapid drop of the anvil. Thus the length of ram stroke was reduced and the amount of fresh air drawn in by the scavenging system was reduced. The reduced amount of oxygen trapped on the subsequent compression stroke further reduced the forces of combustion resulting in still shorter ram stroke length and thus the hammer ceased to operate after a few strokes.

A further difficulty encountered with scavenging systems on some existing diesel pilehammers is caused from their utilizing energy of the descending ram for scavenging the power chamber. The principal driving energy is supplied by the energy of the descending piston, and any utilization of this energy for other purposes subtracts from the driving force.

To start the diesel cycle the free piston is mechanically raised to a starting position and then released to compress the fuel-air mixture for ignition. Existing designs of lifting mechanisms have required a slot in the cylinder wall to provide access for the lifting lever to engage the piston and/or have been a complex over-center toggle linkage which is subject to failure. The lifting mechanisms requiring the access slot along the cylinder are mounted on or adjacent to the side of the hammer. Therefore, the lifting force is applied in a manner to cause an off-center skewing force to the hammer. This imbalance of forces tends to cock the hammer and cause the driving forces to be improperly applied.

It is the primary object of the invention to improve the operation of a diesel pilehammer on all types of piling, especially piling driven into soil offering low resistance.

Another important object of the invention is to provide a self-scavenging system that will supply sufficient oxygen for combustion when the piston stroke is shortened due to low resistance piling.

Another object of the invention is to provide a scavenging system that does not subtract energy from the descending piston that could be utilized for pile driving.

Still another object of the invention is to provide an integral scavenge pump formed by the annular chamber between stepped diameter portions of the ram and cylinder.

A further object of the invention is to provide a reliable piston lifting mechanism having few parts.

A still further object of the invention is to provide a lifting mechanism, having few parts, that will permit on-center lifting of the piston for starting.

Other objects and advantages of the invention will be apparent during the course of the following description.

While, for the sake of clearness in illustration, the hammer is shown and described in use as a pilehammer with the cylinder in a substantially upright position, but it is obvious that the hammer may be arranged to operate in a position inclined to the vertical as may be required for various types of uses to which the hammer is applicable.

In the accompanying drawings, forming a part of this specification and in which like reference characters are employed to designate like parts throughout:

FIGURE 1 and *1a* is a side elevational view, partly in section, of a diesel pilehammer embodying the invention;

FIGURE 2 and *2a* is a rear elevational view, partly broken away, of a diesel pilehammer embodying the invention;

FIGURE 3 and *3a* is a front elevational view, partly broken away, of a diesel pilehammer of the present invention;

FIGURE 4 is a fragmentary view, partly elevational and partly sectional, showing the relative position of the scavenging ports and intake-exhaust ports in the housings of the diesel pilehammer illustrated in FIGS. 1, 1*a*, 2, 2*a*, 3 and 3*a*.

FIGURE 5 is a sectional view taken on line 5—5 of FIG. 4 showing the cross-section of the intake-exhaust ports;

FIGURE 6 is a sectional view taken on line 6—6 of FIG. 4, showing a plan view of the scavenging ports;

FIGURE 7 is a sectional view taken on line 7—7 of FIG. 6;

FIGURE 8 is an enlarged fragmentary view of the lower portion of the lifting mechanism shown in FIG. 2*a*;

FIGURE 9 is a sectional view of the lifting mechanism illustrated in FIG. 8;

FIGURES 10, 11, 12, 13, 14, and 15 are schematic representations of the operating cycle of the diesel pilehammer employing the first embodiment of the present invention;

FIGURES 16, 17, 18, 19, 20 and 21 are schematic representations of the operating cycle of a diesel pilehammer employing the second embodiment of the present invention;

FIGURE 22 is a schematic representation of the third embodiment of the present invention;

FIGURE 23 is a thermodynamic digram showing the pressure-displacement relationship of the power chamber of a diesel pilehammer embodying the present invention;

FIGURE 24 is a thermodynamic diagram showing the pressure-displacement relationship of the scavenge chamber of a diesel pilehammer embodying the present invention;

FIGURE 25 is a thermodynamic diagram showing the pressure-displacement relationship of the bounce chamber of a diesel pilehammer embodying the present invention.

In the drawings, wherein are shown the preferred embodiments of this invention, and first particularly referring to FIGS. 1, 1*a*, 2, 2*a*, 3, and 3*a*, there is shown a diesel pilehammer **27** having an upper cylinder **28** and a lower cylinder **29** connected by bolting together mating flanges **31** and **32**. The bore **33** of the upper cylinder **28** is of a larger diameter than the bore **35** of the lower cylinder **29**. At the upper end of the upper cylinder **28**, an upper cylinder head **34** is secured to the upper cylinder **28** by bolting together mating flanges **36** and **38**. This upper cylinder head **34** contains a guide sheave assembly **37** to guide the starting and lifting rope from the off-center starting mechanism **30** to an on-center hoisting location.

The lower cylinder is closed at its lower end by the anvil **39** which is slidable in the lower portion of the bore **35** of the lower cylinder **29**. The anvil **39** is retained by means of the anvil retainer **41** which is bolted to the bottom flange **40** of the lower cylinder **29**. The anvil **39** is equipped with compression rings **42*a*** to seal the lower end of the bore **35** of the lower cylinder **29**.

Beneath the anvil **39** and guided by the anvil retainer **41** is a cushion adapter plug **43** which transmits the energy from the anvil **39** to the cushion **44** which fits over the lower end of the cushion adapter plug **43**, and has a spherical lower surface **45** which mates with the spherical upper surface of the driving head **42**. The cushion adapter plug **43** has a central outwardly extending flange **46** which projects a short distance below the bottom surface **47** of the anvil retainer **41**. In the space between the flange **46** and the bottom surface **47** of the anvil retainer **41** an annular ring of elastomeric material **48** is located. The elastomeric material serves as a recoil dampener and absorbs the energy of recoil from a pile being driven. It also absorbs the shock if the hammer is dropped on the pile or if the hammer bounces on the pile during operation.

The anvil retainer **41** has a further function of providing a bearing surface for the larger diameter portion **49** of the anvil **39** so that sideward thrusts that would tend to cock the anvil are adequately resisted. Such side thrusts can be caused by pile misalignment, eccentricity and whip. The anvil retainer **41** also supports an alignment pin **51** which enters a mating hole **52** in the enlarged diameter portion **49** of the anvil **39**. The purpose of this pin **51** is to prevent rotation of the anvil **39** during operation.

Within both the upper cylinder **28** and the lower cylinder **29** is the ram **55**, which is free to reciprocate vertically. The lower portion **56** of the ram **55** is in sealing engagement with the bore **35** of the lower cylinder **29** and defines a generally cylindrical power chamber **50** between the lower end of the ram and the anvil **39**. The lower portion **56** contains a wear ring **57** and compression rings **58** near its lower end to prevent leakage of gases between the wall of the cylinder bore **35** and the lower portion of the ram **56**. The wear ring has the function of acting as a bearing ring to support the ram **55** so that the cylinder bore **35** is prevented from coming in direct contact with the ram material. Near the upper end of the smaller diameter portion **56** of the ram **55** the diameter is varied to form a cam surface **59** to actuate a cam follower **60** that drives the fuel pump **61** and the lubrication pump **62**. A short distance above the cam surface **59**, the ram diameter is increased to form a larger diameter portion **63**. This larger diameter portion **63**, which operates only in the bore **33** of the upper cylinder **28** has compression ring **64** at both its upper and lower ends and a wear ring **65** therebetween. This larger diameter portion **63** of the ram **55** divides the upper cylinder in two parts; a lower annular space which forms a scavenging chamber **53** and a cylindrical upper space which is a bounce chamber **54**.

The housing is formed with outwardly extending ribs on which various plates and accessories are attached to give the housing a substantially rectangular cross-section. FIGS. 1 and 1*a* illustrate one of two similar but opposite handed sides of the diesel pilehammer **27**. Illustrated in FIGS. 2 and 2*a* is the back of the hammer, and in FIGS. 3 and 3*a* is the front of the hammer. For purposes of describing the exterior of the hammer the two sides of the hammer **27** will first be described as they are illustrated in FIGS. 1 and 1*a*.

Formed as part of the upper cylinder are two guide angle pads **66** on which guides may be mounted to fit into corresponding leads to guide the travel of the hammer in the direction that the pile is to be driven. Formed as part of the lower cylinder **29** are two radially outwardly extending ribs **67**. These ribs are also illustrated in FIG. 6. The ribs **67** in cooperation with an outwardly extending flange **68**, the flange **32**, and a cover plate **69** bolted to the ribs form a scavenging passageway **70**. The scavenging passageway **70** opens into the annular scavenging chamber **53** through openings **76** in the flange **32**. The rib **67** toward the front side of the lower cylinder **29** is formed with openings **71** allowing gases to pass to and from a space defined in the front portion of the housing, and to be described below.

Also illustrated in FIG. 1*a* is the combustion chamber **72** defined by a semi-spherical indentation **73** in the ram **55** and a corresponding semi-spherical indentation **74** in the anvil **39**. Opening from the semi-spherical indentation **74** in the anvil **39** is a cylindrical passageway **75**. Mounted in the lower cylinder **29** is an injection nozzle **78** which injects fuel for combustion through the passageway **75** into the combustion chamber when the ram **55** nears its downward most position.

Formed in each side of the lower cylinder **29** are three intake-exhaust ports **77**. Referring now to FIG. 5 wherein is shown a cross-sectional view of these ports, the intake-exhaust ports **77** open from the power chamber **50** to the atmosphere to allow the exhaust gases to "blow-down" into the atmosphere and to allow air to flow into the power chamber for scavenging. The ports **77** are shaped to direct the incoming air down into the cylinder toward the anvil to sweep burned gases out of the power chamber **50** and combustion chamber **72** during scavenging. The intake-exhaust ports **77** are located so as to be the first ports in the lower cylinder to open as the ram rises during the power stroke.

Referring now specifically to FIGS. 2 and 2*a*, wherein is illustrated the back view of the diesel pilehammer **27**, reference character **78** refers to covers for the intake-exhaust ports which prevent foreign material from entering the power chamber when the hammer **27** is not in operation. Toward the top end of the upper cylinder **28** are shown a series of four ports **81** which open from the bounce chamber **54**, in the upper cylinder **28**, into an auxiliary bounce chamber **86** defined by the exterior of the housing and a box shaped cover plate **85**. The above mentioned auxiliary bounce chamber **86** serves as an overflow for air compressed in the bounce chamber **54** in the upper cylinder head **28** during the rise of the ram. If the ram moves past its normal upward most position, it closes off the ports **81** and enters a confined safety space in which the gases are rapidly compressed increasing the pressure in the confined safety space and retarding the upward movement of the ram to prevent the ram from striking the cylinder head **34**.

Located on the lower cylinder **29** on the back side is the ram lifting mechanism **30** which is further illustrated in FIGS. 8 and 9. The ram lifting mechanism **30** includes a guide block **91** slidable vertically in ways **92**. Attached to and extending upward from the guide block **91** is a push rod **93** which passes through an opening **89** in flange **32** and engages the annular under surface **90** of the larger diameter portion **63** of the ram **55**. The push rod is guided through the upper flange **32** of lower cylinder **29** by means of a guide bushing **94** which also serves as a seal to prevent air leakage into the annular scavenging chamber **53**. The guide block **91** also serves as the attachment point of the hoist rope **95** used to position and start the hammer.

The guide block **91** contains a latch mechanism used to lock the starting mechanism **30** in the downward position when using the hoist rope **95** to lift and position the hammer **27**. Located in the guide block **91** is a spring loaded pin **96** which engages a latch block **97** bolted to the lower cylinder **29**. Pivoted on the latch block **97** is a spring biased push arm **98** which engages the spring loaded pin **96**. Normally the pin is in its outward position to engage the latch block **97** and hold the lifting mechanism **30** in its downward most position so that the entire pilehammer **27** may be hoisted and positioned by means of the hoist rope **95**. Upon tensioning of the latch release rope **99**, the arm **98** slides the pin **96** into the guide block **91** to allow the hoist rope **95** to raise the push rod lifting mechanism **30** to engage and lift the ram **55** to its proper starting position. The tension on the hoist rope **95** is then released allowing the ram **55** and push rod lifting mechanism **30** to descend compressing fuel and air in the combustion chamber **72** for ignition. The push rod lifting mechanism **30** has its downward descent stopped by a recoil dampener **100** located on the lower cylinder housing **29** directly beneath the guide block **91**. The recoil dampener **100** includes a cup shaped housing **101** containing a sleeve **102** having a series of openings **106** through its lower position. The sleeve **102** has a stepped bore to retain the pin **103**, biased upward by the spring **104**, within the bore of the sleeve **102**. Hydraulic fluid is contained within the cup **101** and sleeve **102** upon downward movement of the pin **103**, due to the descent of the guide block **91**, the hydraulic fluid is compressed and forced through the openings **106** in the sleeve **102** and into the annular space **107** defined between the outer wall **108** of the sleeve and the inner wall **109** of the housing **101**. The resistance of the hydraulic fluid to flow through the openings **106** causes the lifting mechanism **58** to come to a smooth halt allowing time for the spring loaded pin **96** to engage the latch block **97**.

The hoist rope **95** extends from the sheave guide mechanism **37** through a tube **111** passing through the auxiliary bounce chamber **86**. The tube **111** is welded and sealed at both of its ends **112** so that the auxiliary bounce chamber **86** is hermetically sealed.

The hoist rope guide mechanism **37** includes a housing **110** having a flared opening **114** at its upper portion through which the hoist rope **95** enters from an independent lifting means (not shown). Also formed in the housing **110** is a radial slot **115** which opens into the flared opening and extends the entire length of the housing. Passing through the housing substantially perpendicular to and intersecting the slot **115** are two pins **116** which are fitted into appropriate holes **113** in the housing **110**. One hole **113** is located below and in back of the other hole. Pivotally mounted on the pins **116** are two sheaves **117** and **118** located within the slot **115**. Referring again specifically to FIG. 1 wherein is shown a side cross-sectional view of the hoist rope guide means **37**, the first sheave **117** is located so that the hoist rope enters axially of the diesel pilehammer **27** and passes under the sheave **117**. The second sheave **118** is located below and in back of the first mentioned sheave **117** so that the rope passes from the first sheave **117** and over the second sheave **118** and extends down the side of the housing through the tube **111**. The purpose of the guide means **37** is to cause the hoisting force to be exerted on a line axially with the center of the housing to prevent any off-center force from cocking the angle of the pile hammer **27** while it is lifted and positioned on a pile to be driven. The flared opening **114** on the housing **110** causes the hoist rope to enter the guide sheaves **117** and **118** properly regardless of the amount of off lead present.

Referring now specifically to FIG. 3, wherein is shown the front view of the diesel pilehammer **27**, reference character **119** refers to equalizing ports positioned to be open when the ram is at its upward most position allowing passage of air to the annular scavenging chamber **53** from the atmosphere to relieve any vacuum. The equalizing ports **119** are also open when the ram is in its lower most position allowing air to flow from the atmosphere into the cylindrical bounce chamber **54** to replace air lost therefrom through the compression rings during compression of the gases in the bounce chamber **54**. While the hammer is not in operation the equalizing ports **119** are sealed by the cover **120**. Referring now specifically to FIGS. 1, 1*a*, 3, 4, 6, and 7 for a description of the six scavenging ports denoted by reference character **122**. The scavenging ports **122** are located to open subsequent to the opening of the intake-exhaust ports **77** as the ram rises during the power stroke. The six scavenging ports **122** open into a chamber **123** defined by two radially extending ribs **67** and two outwardly extending flanges **124** and a cover plate **125** bolted to the ribs. The lower cylinder **28** is formed with six rectangular lateral openings **131** and six three-sided deflector plate projecting outward from the openings to form the scavenging ports so that the gases are directed up through the chamber **123** during the scavenging cycle.

During the power stroke the ram rises to create a vacuum in the scavenging chamber **53** which draws air through the power chamber **50** to facilitate the scavenging thereof. During scavenging the gases pass from the atmosphere through the intake-exhaust ports **77** and into the power chamber **50** in a swirling fashion. Thence the gases flow from the power chamber **50** through the scavenging ports **122** into the chamber **123**. The flow continues through the openings **71** in the rib **67** into the scavenging passageways **70** on either side of the pilehammer **27**. The gases then enter the annular scavenging space **53** through the openings **76** in the flange **32**. As the ram descends it closes the scavenging ports **122** and compresses the gases in the annular scavenging chamber **53** forcing the gases through the passageway into the chamber **123** and then out the scavenging valve **126**. The scavenging valve **126** includes four openings **121** in the plate **125** covered by two thin tempered metal plates **127**, bolted along one edge to plate **125**, which act as reed valves to allow passage of gases only from the chamber **123** when the pressure therein is raised a predetermined amount above atmospheric pressure. There are two sets of three scavenging ports **122**, one set located on each of the two sides of the front portion of the diesel pilehammer **27**. The arrangement of the scavenging ports **122** in relationship to the intake-exhaust ports **77** is illustrated in FIG. 4.

Also attached to the front side of the diesel pilehammer **27** is the fuel tank **128** with the lubrication tank **133** located therein. Directly beneath the fuel and lubrication tanks is a protector **129** to guard the fuel and lubrication tanks **128** and **133** and the associated hoses and fittings. Located on the lower cylinder **29** is the lubrication pump **62** which is actuated by a cam follower **60** which engages the cam surface **59** on the ram. On each stroke of the ram a predetermined amount of lubrication is dispersed to selected points within the bore of the two cylinders **28** and **29**. Also actuated by the cam follower **60** is the fuel pump mechanism **61** which is of a standard type, as illustrated in American Bosch catalog number APF–1CC 180T–3035C. The fuel pump delivers a controllable amount of fuel to the nozzle **78** which injects said fuel into the spherical combustion chamber **72**. The amount of fuel dispersed is controlled remotely by the controller **130** located generally a distance away from the diesel pilehammer. Also attached to the front side of the diesel pilehammer is a starting fluid injector which is described in Patent No. 3,161,184 which only on the starting stroke may inject a predetermined amount of starting fluid into the combustion chamber.

Method of operation

FIGS. 10, 11, 12, 13, 14, and 15 illustrate the cycle of operation of a diesel pilehammer **27** as illustrated in FIGS. 1 through 9 and show the position the ram and the condition of the various ports and valves during the cycle. For purposes of illustration, FIGS. 10 through 15 employ a solid arrow to show the movement of exhaust gases, a partially shaded arrow to show the movement of a mixture of exhaust gases and fresh air, and an open arrow to show the movement of fresh air.

Referring now specifically to FIG. 10, ram **55** is at the bottom of its stroke and impacting anvil **39** to start driving pile **151**. Scavenging port **122** and intake-exhaust ports **77** are closed, and air confined in the combustion chamber **72** is compressed. Equalizing ports **119** are open to allow any air lost through the compression rings during the compression of air in the bounce chamber to be replaced, to bring bounce chamber pressure up to atmospheric pressure. Nozzle **78** has injected fuel into combustion chamber **72** and, ignition of the fuel air mixture is taking place, raising the pressure between ram **55** and anvil **39** to start the ram moving upward and maintaining a driving force on pile **151**.

FIG. 11 illustrates the condition of the hammer subsequent to the combustion of the fuel air mixture in combustion chamber **72**. Ram **55** has risen a sufficient amount to close equalizing ports **119**. Cam follower **60** has descended down cam surface **59** on ram **55** allowing fuel injection pump **61** to recharge. The upward movement of the ram creates a sub-atmospheric pressure in annular scavenging chamber **53** and compresses the confined air in bounce chamber **54** and auxiliary bounce chamber **86**. The compression of the confined air in the bounce chambers **54** and **86** transfers some of the kinetic energy of the ram **55** into potential energy of the compressed air. Ram **55** in the position shown in FIG. 11 is still sealing scavenging ports **122** but has allowed intake-exhaust ports **77** to open, permitting burned gases in power chamber **50** to "blow-down" to atmospheric pressure.

FIG. 12 shows ram **55** after it has moved further upward, opening scavenging ports **122**. Since scavenging chamber **53** and the scavenging passageway **70**, prior to the opening of scavenging ports **122**, were at a sub-atmospheric pressure, air at atmospheric pressure flows in through intake-exhaust ports **77** scavenging power chamber **50** and combustion chamber **72** of burned gases. The burned gas, scavenging air mixture is drawn through scavenging ports **122** and into passageway **70** and scavenging chamber **53**. As ram **55** continues upward movement, it increases the volume of annular scavenging chamber **53** drawing additional fresh air from the atmosphere through power chamber **50** and into scavenging chamber **53**. This process continues until equalizing ports **119** are opened into scavenging chamber **53** to establish atmospheric pressure therein. The opening of equalizing ports **119** into the scavenging chamber **53** is not essential to the operation and should not occur until ram **55** has moved upward a sufficient distance to provide for adequate scavenging. Upward movement of ram **55** into bounce chamber **54** compresses the confined air therein imparting additional energy from the ram to compress air.

Referring now specifically to FIG. 13, the ram **55** is illustrated in its upward most position. As ram **55** has been moving upward, energy imparted to it by the forces of combustion undergoes conversion to potential energy of the ram, energy imparted to the air compressed in bounce chamber **54** and auxiliary bounce chamber **86**, and work performed in reducing pressure in scavenging chamber **53** plus small amounts of work overcoming friction of the ram and windage of air and gases moved at atmospheric pressure. When all the kinetic energy of the ram **55** has thus been converted, the ram ceases its upward movement and begins its downward stroke.

FIG. 14 shows ram **55** after it has been acted upon by gravity and the pressure of the air in bounce chamber **54** which begins the descent of the ram. The now highly dilute burned gases in scavenging chamber **53** and passageway **70** are driven out scavenging ports **122**, across power chamber **50** and out intake-exhaust ports **77**. Excess air beneath ram **55** and above intake-exhaust ports **77** also is blown out ports **77**. Air in bounce chamber **54** expands to transfer the potential energy stored therein back to ram **55** as kinetic energy.

Referring now particularly to FIG. 15, wherein is shown ram **55** just prior to injection of fuel and combustion. As ram **55** descends to the point shown in FIG. 15 it closes scavenging ports **122** and decreases the volume of scavenging chamber **53** raising the pressure therein. When the pressure in scavenging chamber **53** and scavenging passageway **70** rises a sufficient amount above atmospheric pressure, scavenging valve **126** opens to vent the gases drawn into the scavenging chamber during the scavenging cycle. Upon closure of intake-exhaust port **77** by ram **55**, air confined in power chamber **50** is compressed between ram **55** and anvil **39**. As ram **55** approaches anvil **39** cam follower **60** rides up cam surface **59**, causing fuel pump **61** to begin delivery of fuel to injector **78**. Bounce chamber air continues to expand imparting kinetic energy to ram **55** until equalizing ports **119** open. When ram **55** strikes anvil **39**, fuel injection is complete and ignition begins. Impact of ram **55** on anvil **39** delivers the ram's energy to anvil **39** and thence to pile **151** through cushion block **44** and driving head **42**. After impact, ram **55** rises under action of the expansion of the burning fuel-air mixture, and this expansion, acting on the now descending anvil **39** transfers additional energy to the pile **151**.

FIGS. 16, 17, 18, 19, 20, and 21 illustrate the cycle of operation of a diesel pilehammer **27** including the second embodiment of the invention. As described above the second embodiment of the invention is substantially the same as the first embodiment with the inclusion of reed valve **141** to allow flow of gases only from power chamber **50** to passageway **70**, and not in the reverse direction. Since the operation of equalizing ports **119**, scavenging ports **122**, scavenging valves **126**, and intake-exhaust ports **77**, are the same as in the description of the method of operation of the first embodiment of the invention, they will not again be described. The shading of the arrows shown in the figures illustrating the cycle of operation of the second embodiment of the invention have the same significance as in the description of the first embodiment operation.

Referring now specifically to FIG. 16, wherein ram **55** is shown at the bottom of its stroke. Reed valves **141** are closed preventing the flow of gases through scavenging ports **122**. The slight positive pressure in scavenging passageway **70** holds the valves **141** closed.

Ram **55**, as illustrated in FIG. 17, subsequent to ignition has risen a slight amount but yet still seals scavenging ports **122**. Since scavenging ports **122** have not yet opened, reed valve **141** still is in its closed position.

After ram **55** has risen a sufficient amount to open scavenging ports **122**, as illustrated in FIG. 18, the subatmospheric pressure in scavenging chamber **53** and passageway **70** causes reed valves **141** to move to their open position and remain there until the pressure in the passageway **70** becomes atmospheric. FIG. 19 shows the ram at a position opening equalizing port **119** into scavenging chamber **53** raising the pressure therein to atmospheric allowing reed valve **141** to close.

FIGS. 20 and 21 show ram **55** during its descent creating a slight positive pressure in scavenging chamber **53** and passageway **70** closing off reed valves **141** and preventing the flow of the dilute burned gases back into power chamber **50**. Excess air beneath ram **55** and above intake-exhaust ports **77** is blown out ports **77**. The ram confines air within power chamber **50** and compresses said confined air prior to injection of fuel and the combustion of the fuel air mixture to begin the next cycle.

FIG. 22 is a schematic representation of the third embodiment of the invention and corresponds to FIG. 10 and FIG. 16, respectively, of the first embodiment and second embodiment of the invention. In the other embodiments of the invention the equalizing port **119** opened to the atmosphere, as ram **55** approached the bottom of its stroke, in order to make up the air lost during compression of air in bounce chamber **54**. In the third embodiment of the invention bounce chamber **54** is connected by conduits **143** to the scavenging passageways **70**. As ram **55** descends a slight positive pressure is created in scavenging chamber **53** and scavenging passageway **70**. This embodiment of the invention allows the ram as it approaches the bottom of its stroke to open port **145** connecting the slight positive pressure in scavenging passageway **70**, by means of the conduit **143**, to bounce chamber **54** to make up any air lost from the bounce chamber during compression of the gases therein on the upstroke. Since the port **145** is connected to scavenging passageway **70** the negative pressure created during scavenging is not vented to the atmosphere, and the effective scavenging cycle is increased.

The operation subsequent to combustion of a pilehammer including the third embodiment is the same as is illustrated in FIGS. 11, 12, 13, 14, and 15 and described above.

Thermodynamic cycle

FIGS. 23, 24, and 25 show the pressure-displacement diagrams for the first embodiment of this invention. For purposes of presentation diagrams of power chamber **50**, scavenging chamber 53, and bounce chamber **54** are each shown separately. Vertical scales have been distorted so that ordinate values of pressure are not to scale and do not depict true relative values. This is done for clarity, since atmospheric pressure (14.7 p.s.i.a.) would otherwise not be apparent when compared to peak compression pressure (500 to 600 p.s.i.a.) and peak combustion pressure (1,000 to 1,200 p.s.i.a.). Pressure-displacement diagrams are used instead of pressure-volume diagrams so that the port and stroke relationship can be properly related between the different curves.

Referring now specifically to FIG. 23, wherein is shown the cycle of power chamber **50**. Starting at point **161** at the extreme left end of the curve, which represents the top of the stroke, the pressure below ram **55** in power chamber **50** is atmospheric pressure. As ram **55** descends (moving toward right along curve), the pressure remains atmospheric until intake-exhaust ports **77** are closed (represented by point **162**). After intake-exhaust ports **77** are closed the pressure beneath ram **55** rises approximately adiabatically reaching peak compression pressure at bottom of stroke (represented by point **163**). Assuming constant volume combustion, the pressure rises vertically to peak combustion pressure indicated by point **164**. Actually both anvil **39** and ram **55** move during the combustion pressure rise, but for simplicity a constant volume pressure rise is assumed. Upward movement of ram **55** (moving toward the left along the graph) causes pressure to drop approximately adiabatically to point **165** corresponding to the opening of intake-exhaust ports **77**. At this point "blow-down" of burned gases drops the pressure in power chamber **50** to atmospheric where it remains for the rest of the cycle.

Referring now specifically to FIG. 24, wherein is shown the thermodynamic cycle of scavenging chamber **53**. Starting at the extreme left end of the curve (top of the stroke indicated by point **167**), the pressure below the enlarged diameter of ram **55** in annular scavenging chamber **53** is atmospheric since equalizing ports **119**, scavenging ports **122**, and intake-exhaust ports **77** are open to the atmosphere. As ram **55** descends pressure in scavenging chamber **53** remains approximately atmospheric until the bottom of the stroke (indicated by point **168**). When scavenging ports **122** are closed, there is a slight rise in pressure which is required to open scavenging valve **126**. This pressure increase however is nominal and is here considered negligible. Upward movement of the ram (toward the left on the graph) now causes approximate adiabatic reduction of pressure below atmospheric. When the scavenging ports **122** open (represented by point **169**), gases from the power chamber **50** and air from the now opened intake-exhaust ports **77** raise the pressure quickly to atmospheric where it remains for the rest of the cycle. The closing of the equalizing port **119** on the down stroke and its opening on the up stroke has no influence on the pressure-displacement relationship. Port **119** only serves to provide some incidental aeration of scavenging cyclinder **53** which actually is a nonessential function.

FIG. **25** illustrates the thermodynamic cycle of the compression of air in bounce chamber **54** and its associated auxiliary bounce chamber **86**. The description of this curve will start at point **171** (at the extreme right end of the diagram, bottom of the stroke) and proceed first to the left. The pressure in bounce chamber **54** and auxiliary bounce chamber **86** is atmospheric at point **171**, since equalizing ports **119** are open from the bounce chamber to the atmosphere. The pressure remains atmospheric during the short rise of the ram until equalizing ports **119** are closed by ram **55**. Continued rise of ram **55** causes an approximate adiabatic pressure increase to the normal top of the stroke (indicated by point **173**). Descent of ram **55** results in an approximate adiabatic reduction in pressure which is shown by proceeding along the same curve as the rise of pressure to point **172**. At point **172** equalizing ports **119** open into bounce chamber **54** to vent the same at which time the pressure becomes atmospheric and remains so until the equalizing ports are closed.

The thermodynamic cycle of power chamber **50**, scavenging chamber **53**, bounce chamber **54** and auxiliary bounce chamber **86** of the second and third embodiments of the invention are substantially the same as the thermodynamic cycle described above.

It is to be understood that the forms of this invention herewith shown and described are to be taken as a preferred example of the same, and that various changes in the shape, size, number, and arrangement of parts may be resorted to without departing from the spirit of the invention or the scope of the subjoined claims.

Having thus described the invention, we claim:

1. In a diesel pilehammer the combination of:

a housing having a bore,

a reciprocating free piston in sealing engagement with and slidably disposed in the bore for axial movement therein, portions of the piston cooperating with the housing to define a scavenging chamber and a power chamber each having at least one movable wall,

valve means to allow gases to pass in one direction from the scavenging chamber to the atmosphere when a movable wall of the scavenging chamber moves in a direction to decrease the volume thereof,

a conduit connecting the power chamber and the scavenging chamber to allow gases to pass from the power chamber to the scavenging chamber upon movement of a movable wall of the scavenging chamber in a direction to increase the volume thereof,

the housing having a port to allow passage of gases to and from the power chamber,

the portions of the piston and housing defining the power chamber having opposed surfaces spaced from each other to form a combustion chamber when a movable wall of the power chamber is in a position providing a minimum volume in the power chamber,

fuel injection means to deliver fuel to the combustion chamber for ignition, and

lifting means to raise the piston to its starting position.

2. A diesel pilehammer as defined in claim 1 further characterized by:

means sealing one end of the bore and cooperating with the housing and piston to form a bounce chamber having at least one movable wall moving in a direction to decrease the volume of the bounce chamber as a movable wall of the power chamber moves in a direction to increase the volume of the power chamber.

3. A diesel pilehammer as defined in claim 2 further characterized by:

a laterally disposed chamber; and

conduit means connecting the laterally disposed chamber to the bounce chamber.

4. A diesel pilehammer as defined in claim 3 further characterized by:

the conduit means being located in a position to be shut off by the movement of the piston in a direction to decrease the volume of the bounce chamber to create a cushion of gases between the sealing means and the piston for arresting the movement thereof.

5. A diesel pilehammer as defined in claim 1 further characterized by the housing including:

an anvil sealingly retained for limited axial movement in one end portion of the bore, portions of the anvil and piston having surfaces defining walls of the combustion chamber.

6. A diesel pilehammer as defined in claim 2 further characterized by:

the housing having a port to equalize the pressure of the bounce chamber with atmospheric pressure when the movable wall of the bounce chamber is at the position to provide for maximum volume in the bounce chamber.

7. A diesel pilehammer as defined in claim 6 further characterized by:

the equalizing port opening into the scavenging chamber to equalize the pressure therein with atmospheric pressure when the movable wall of the scavenging chamber is at the position to provide for the maximum volume in the scavenging chamber.

8. A diesel pilehammer as defined in claim 2 further characterized by:

the housing having a stepped cylindrical bore providing two coaxial portions, one portion having a diameter larger than the other forming a shoulder therebetween;

the piston having a portion in sealing engagement with each of the two portions of the housing and a shoulder therebetween, the sealing means in cooperation with the larger diameter portions of the housing and piston defining the bounce chamber, the shoulders of the housing and the piston cooperating to define the scavenging chamber, the smaller diameter portions of the piston and housing defining the power chamber.

9. A diesel pilehammer as defined in claim 1 further characterized by:

valve means associated with the conduit to only allow flow of gases from the power chamber to the scavenging chamber.

10. A diesel pilehammer as defined in claim 2 further characterized by:

a conduit connecting the bounce chamber to the scavenging chamber to equalize the pressure therebetween when the movable wall of the bounce chamber is at a position providing maximum volume in the bounce chamber.

11. A diesel pilehammer including a housing, a reciprocating free piston, and means for lifting the piston wherein the lifting means comprises:

a radially outwardly projecting portion on the piston;

a lifting mechanism including a rod slidably mounted on the housing for movement parallel to the reciprocation of the piston, the rod underlying and engaging the radially outwardly projecting portion of the piston to impart the lifting force thereto;

means associated with the lifting mechanism for applying a lifting force thereto to raise the piston and for releasing the lifting mechanism to allow the mechanism to descend to its original position and to permit the piston to descend to start the diesel cycle;

a cable interconnecting the rod and the force applying means;

means for fastening the cable to the rod; and

guide means associated with the housing to direct the path of movement of the cable.

12. A diesel pilehammer as defined in claim 11 wherein the guide means comprises:

a sheave mounted on the upper portion of the housing so that the cable engages the sheave substantially axially of the housing and passes under the sheave;

a second sheave mounted on the upper portion of the housing and engaging the cable to guide the cable into a path extending down the side of the housing to the fastening means.

13. A diesel pilehammer as defined in claim 11 wherein the lifting mechanism further comprises:

a latching means operatively connected to the rod;

an abutment formed on the housing for cooperation with the latching means to normally secure the rod in its down position and to cause an upward force applied by the cable to the lifting means to position the entire pilehammer.

14. A diesel pilehammer as defined in claim 11 wherein the lifting means further comprises:

a cushioning means to stop the descent of the lifting rod after the lifting mechanism is released and to prevent the rod from rebounding to a position that would interfere with the descent of the piston.

15. The method of operating a diesel pilehammer including a reciprocating free piston comprising:

igniting a compressed fuel-air mixture in a confined space underlying the piston to cause the piston to rise;

evacuating a space, separate from the space underlying the piston, during the rise of the piston;

permitting gases to flow to the evacuated space from the space underlying the piston and admitting air into the latter space for the scavenging thereof during the rise of the piston;

reversing the direction of movement of the piston due to a reversal of the imbalance of the forces acting thereon;

forcing the gases in the previously evacuated space to flow to the atmosphere during the descent of the piston;

confining and compressing air in the space underlying the piston during the descent of the piston; and

injecting fuel into the compressed air prior to igniting the mixture.

16. The method of operating a diesel pilehammer including a reciprocating free piston as defined in claim **15** further comprising:

confining and compressing gases in a space during the rise of the piston to assist the reversal of the imbalance of force and to shorten the distance the piston rises for increasing the cyclic rate.

17. The method of operating a diesel pilehammer including a reciprocating free piston as defined in claim **15** further comprising:

preventing gases from flowing to the space underlying the piston from the evacuated space during the descent of the piston to prevent the return of scavenged gases to the space underlying the piston.

18. The method of operating a diesel pilehammer including a reciprocating free piston as defined in claim **16** further comprising:

permitting air to flow into the last mentioned space when the piston approaches its downward most position to replenish any escaped gases.

19. The method of operating a diesel pilehammer including a reciprocating free piston as defined in claim **16** further comprising:

permitting fluid communication between the last mentioned space and the evacuated space when the piston approaches its downward most position to equalize the pressure therebetween.

20. A diesel pilehammer including a housing, a reciprocating free piston, and means for lifting the piston wherein the lifting means comprises:

a downwardly facing surface formed on the piston;

a lifting mechanism mounted on the housing and movable in a direction parallel to the reciprocation of the piston, the lifting mechanism having a portion for engaging the downwardly facing surface to raise the piston to its starting position;

means associated with the lifting mechanism for applying a lifting force thereto to raise the piston and for releasing the lifting mechanism to allow the mechanism to descend to its original position and to permit the piston to descend for starting the diesel cycle;

a cable interconnecting the lifting mechanism and the force applying means;

means for fastening the cable to the lifting mechanism;

means associated with the lifting mechanism and cooperating with a portion of the housing for automatically, releasably latching the lifting mechanism in its normal lowermost position to cause an upward force applied through the cable to the lifting mechanism to be imparted directly to the housing for positioning of the entire pilehammer; and

guide means associated with the housing to direct the path of movement of the cable.

21. A diesel pilehammer as defined in claim **20** wherein the guide means comprises:

a sheave mounted on the upper portion of the housing so that the cable engages the sheave substantially axially of the housing and passes under the sheave; and

a second sheave mounted on the upper portion of the housing and engaging the cable to guide the cable into a path extending down the side of the housing to the fastening means.

22. A diesel pilehammer as defined in claim **20** wherein the lifting means further comprises a cushion means for stopping the descent of the lifting mechanism after the release thereof to prevent the mechanism from rebounding to a position of interference with the descent of the piston.

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