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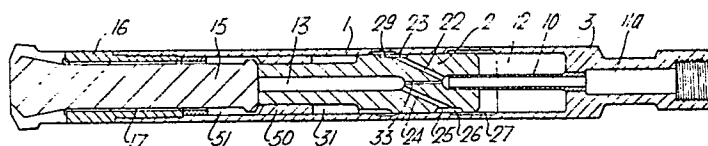
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54 **Free piston machines.**

57 A free piston machine of the valveless type using piston wall ports and cooperative flow passages in the cylinder wall for supplying live pressure fluid to the piston working chamber and for exhausting the power working chamber is characterised by an axial pressure fluid supply line (10) that enters and has open termination within a pressure recess (11, 11a) to cooperate therewith in accordance with the motion of the piston to control the flow of pressure fluid to the power working chamber of the machine. The supply line (10) may be fixed to the body of the machine and cooperate with a pressure recess (11) in the piston, or the supply line may be carried by the piston to move therewith and to cooperate with a pressure recess (11a) in the machine body.

Fig. 9.



FREE PISTON MACHINES

THIS INVENTION concerns free piston machines and in particular pressure fluid-powered free piston machines in which a piston is caused to reciprocate by the admission of pressure fluid, e.g. compressed air, alternately to working chambers at opposite ends of a cylinder within which the piston is reciprocable. Many pneumatic drills, such as hammer drills, utilise this principle.

The efficient conversion of the energy content of the pressure fluid into motion of the piston depends critically upon the manner in which the pressure fluid is directed to the working chambers and exhausted therefrom in relation to the motion of the piston. The arrangements adopted for controlling the pressure fluid flows fall, broadly, into two classes: the "valveless" arrangements in which the motion of the piston serves to cover and uncover various static ports and passages to accomplish the required control; and the "valved" arrangements in which a valve mechanism responds to the motion of the piston to switch the pressure fluid supply from one working chamber to the other at appropriate instants in the cycle of reciprocation of the piston. The present invention is concerned with the "valveless" class of machine and has as its objective the provision of improved arrangements for directing the pressure fluid to, and exhausting the spent fluid from, the working chambers of the machine.

In general, in the prior art valveless machines, for instance the machines respectively disclosed in U.S. Patents 4084647 and 4146097, the porting arrangements and pressure fluid passages are relatively complex and lead both to difficulties in manufacture of the machine and to less than optimum utilisation of the energy of the pressure fluid. The latter disadvantage mainly arises from restrictions and directional changes in the flow path of the pressure fluid to the working chambers and/or to the effort of the pressure fluid being restricted to only a proportion of the available cross-sectional area of the piston.

An object of the present invention is to provide a valveless pressure fluid-powered free piston machine that avoids these disadvantages of the prior art constructions.

5 In its broadest aspect the present invention provides a valveless pressure fluid-powered free piston machine comprising a piston reciprocable in a cylinder providing power and return working chambers respectively at opposite ends thereof, axially spaced apart pressure and exhaust piston wall ports and associated pressure and exhaust passages in the piston, and
10 cooperative flow passages formed at least partly in the cylinder wall for connecting said pressure and exhaust piston wall ports with the power and return working chambers respectively, in accordance with the position of the piston in the cylinder, and a pressure fluid supply line extending axially within the power working chamber, characterised in that the supply line
15 enters and has an open termination within a mating axial pressure recess, said supply line and said pressure recess being responsive to movement of the piston in the cylinder and cooperating to provide a flow path from the recess to the power working chamber during part of the cycle of reciprocation of the piston.

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 The pressure and exhaust passages in the piston are preferably rectilinear and inclined with respect to the axis of the piston so as to be formable by a simple drilling or like operation followed by surface finishing so as to minimise regions of stress concentration and to enable the available
25 strength of the piston material to be fully realised, while providing flow paths of suitable cross-sectional area for efficient transmission of pressure fluid to the return working chamber, and for the efficient exhaust of spent fluid from the power working chamber. These passages are also preferably disposed within the same portion of the length of the piston to provide a
30 strong and compact piston configuration.

 As in the usual case of a free piston machine, such as a hammer drill, movement of the piston in one direction constitutes the "power stroke" while movement of the piston in the opposite direction constitutes a "return
35 stroke". In a machine in accordance with the invention, the said pressure fluid supply line is arranged within the power working chamber, i.e. the chamber to which pressure fluid is admitted to effect the power stroke of

the piston, and admission of pressure fluid to this power working chamber is controlled by the position of the piston as it affects the position of the pressure recess relative to the said supply line. This arrangement enables the full cross-sectional area of the piston to be exposed to the pressure fluid at the commencement of the power stroke so that the maximum thrust is developed to displace the piston in the power stroke.

In some embodiments of the invention, the pressure recess is formed in the piston and the pressure fluid supply line is fixed to the cylinder or to a component associated therewith, the pressure recess in this case being connected to the said pressure passage in the piston.

In other embodiments, however, the pressure recess is formed in the cylinder, e.g. in a headpiece thereof, or in a component associated therewith, and the pressure fluid supply line is fixed to the piston to move therewith, being connected to the said pressure passage in the piston.

The piston may have an axial exhaust recess connected to the exhaust passage or passages in the piston. This exhaust recess may be arranged to cooperate with an axial exhaust line, such as a foot valve tube, to control the flow of spent pressure fluid from the return working chamber, or this recess may serve solely for passing spent pressure fluid from the power working chamber to an exhaust outlet, the movement of the piston providing, by other means, control of the flow of spent pressure fluid from the return working chamber.

The length and location of the pressure fluid flow path-defining component constituted by the supply line, relative to the piston stroke, will determine the proportion of the power stroke over which pressure fluid may continue to flow from the supply line to the power working chamber. This flow path-defining component may comprise one or more grooves extending along the exterior of the supply line to provide one or more discrete flow paths between the pressure recess in the piston and the power working chamber when the piston is appropriately positioned in the cylinder, but in preferred embodiments the flow path-defining component comprises a suitable length of circumferential relieving of the supply line to provide greatest freedom for symmetrical pressure fluid flow from the pressure

recess to the power working chamber.

5 The said cooperative flow passages in the piston and cylinder wall may take various configurations. For instance flats or longitudinal grooves in the piston may cooperate with circumferential relieving of the cylinder wall in appropriate locations therein, or circumferential relieving of discrete areas of the piston may cooperate with suitably positioned longitudinal recesses or grooves formed in the cylinder wall. Other arrangements will be apparent to those skilled in the art.

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Exemplary embodiments of the invention, as applied to a down-the-hole hammer drill, are illustrated in the accompanying drawings in which:

15 FIGURES 1 and 1A together constitute a longitudinal section of part of a hammer drill constituting one embodiment of the invention;

FIGURE 2 is a section on line II-II of Figure 1;

FIGURE 3 is a section on line III-III of Figure 1;

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FIGURE 4 is a section on line IV-IV of Figure 1A;

FIGURES 5 and 5A correspond with Figures 1 and 1A but show a second embodiment of the invention;

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FIGURE 6 is a cross-section on the line VI-VI of Figure 5;

FIGURE 7 is a cross-section on the line VII-VII of Figure 5A;

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FIGURE 8 is a cross section on the line VIII-VIII of Figure 5B; and

FIGURE 9 is a longitudinal section of another embodiment.

35 Referring first to Figures 1 to 4, the hammer drill partly illustrated therein comprises a body defining a cylinder 1 within which a piston 2 is reciprocable. The upper end of the body has a tubular spigot 3 adapted for attachment to a drill tube (not shown) by means of which the body may be

rotated during a drilling operation and through which compressed air as pressure fluid is supplied to the drill. The pressure fluid flows into the drill by way of a passage 4 in the spigot 3, past a spring-loaded non-return valve 5 to a passage 6 communicating via ports 7 with the bore 8 of a cylinder headpiece 9 carrying an axial pressure fluid supply line 10 that extends into a pressure recess 11 in the adjacent end of the piston 2. The region within the cylinder 1 between the piston 2 and the headpiece 9 constitutes a working chamber 12 to which pressure fluid is admitted to effect the downward or "power" stroke of the piston 2 and for this reason is termed the "power" working chamber herein.

The lower end of the piston 2 is formed with an exhaust recess 13 that in the illustrated stroke-end position shown in Figure 1A receives a foot valve tube 14 that defines an exhaust line for the outflow of spent pressure fluid and that is secured in the upper end of the shank 15 of a drill bit the head of which is not shown in the drawing. The drill bit shank 15 is secured in a chuck 16 so as to have limited freedom for axial movement relatively to the drill body. Thus the bit shank 15 and the chuck 16 have cooperating splines 17 for the transmission of torque from the drill body to the bit, the splines being relieved as at 18 over a length of the bit shank to provide shoulders 19, 20 disposed to engage with a diametrically split combined sealing and retaining ring 21 to limit the axial movement of the bit.

In Figure 1A the bit is shown in a position near the uppermost extent of its free motion and the piston 2 is shown at the end of a power stroke, with its bottom end in engagement with an anvil surface at the upper end of the bit shank 15.

The pressure recess 11 in the upper end of the piston 2 is connected by pressure passages 22 to pressure ports 23 in the wall of the piston near to the lower end thereof. As shown in Figure 2, there are three passages 22 and these are preferably rectilinear so as to be readily formable by drilling and reaming techniques and to be given a high degree of surface finish to minimise stress-raising changes of section and/or direction. The passages 22 may have other configurations if desired.

The exhaust recess 13 at the lower end of the piston is connected to

exhaust passages 24 that extend obliquely upwardly to exhaust ports 25 in the wall of the piston near to its upper end. As shown in Figure 2 there are three passages 24, equiangularly spaced apart around the axis of the piston and disposed in the intervals between the passages 22. The passages 24 are
5 larger in cross-section than the passages 22 because they are required to pass air that has expanded to a lower pressure than the live compressed air to be passed by the passages 22.

As shown in Figure 3, the upper end of the piston 2 is formed with
10 external flats 26 that in the position of the piston shown cooperate with a circumferential recess 27 formed in the wall of the cylinder and that in turn communicates with the exhaust ports 25 in the piston 2. Thus in the illustrated position of the piston (and in the final part of the power stroke thereof and in the corresponding initial part of the return stroke) an exhaust
15 flow path extends from the power working chamber 12 past the flats 26 to the recess 27 and thence via exhaust ports 25 and passages 24 to the exhaust recess 13, and the foot valve tube 14, to an exhaust passage 28 leading to openings (not shown) in the head of the bit.

As best seen in Figure 4, the lower end portion of the piston 2 is
20 formed with external flats 29 that in the illustrated position of the piston overlie a circumferential recess 30 in the wall of the cylinder. The pressure ports 23 in the cylinder are positioned to overlie the recess 30 in this position of the piston so as to provide a flow path for compressed air from
25 the pressure recess 11 via the passages 22 and pressure ports 23 to the return working chamber 31 defined in the lower end of the cylinder 1 between the bottom of the piston and the anvil surface of the bit shank 15.

The piston 2 is also formed, below the exhaust ports 25 but above the
30 pressure ports 23, with a by-pass groove 32 the upper end of which breaks into one of the exhaust ports 25 and that is so positioned on the piston that if the bit shank 15 moves to its lowermost permitted position (as can happen under certain drilling conditions), the by-pass groove 32 mates with the recess 30 to provide a flow path between the return working chamber 31 and
35 the exhaust recess 13 so as to prevent live compressed air entering the chamber 31 from being effective to cause a return stroke of the piston.

The piston 2 is further formed with a small bore axial passage 33 connecting the recesses 11 and 13 for a purpose that will be explained.

5 The supply line 10 is externally relieved over that part of its length from the headpiece 9 to approximately the position of the upper end face of the piston 2 when the latter is in its normal power stroke-end position within the cylinder, that is, approximately the position illustrated. It will be noted that the pressure recess 11, except for its entrance region, is of larger diameter than the end portion of the supply line 10 and accordingly the
10 external relieving of the supply line and the enlargement of the recess 11 together provide a flow path from the recess 11 to the power working chamber 12 when the piston 2 is at or near the upper end of its permitted travel.

15 The operation of the embodiment just described in relation to Figures 1 to 4 is as follows. Assuming that the parts are in the position shown and that a supply of compressed air is available to flow past the non-return valve 5 and via the supply line 10 to the pressure recess 11, this live compressed air will flow from the recess 11 via the passage 22, pressure
20 ports 23 and recess 30, to the return working chamber 31 and thus cause upwards movement of the piston 2.

During the course of this upwards movement or "return stroke" of the piston, the pressure ports 23 will move out of register with the recess 30 and
25 thus cut off the supply of compressed air to the working chamber 31. The compressed air that has been admitted to this chamber, however, will expand to continue exerting upwards thrust upon the piston 2.

When the piston 2 has travelled by a distance sufficient to withdraw
30 the foot valve tube 14 from the recess 13, this tube 14 will be placed into communication with the working chamber 31. The spent (expanded) air in that chamber will thus be able to escape via the foot valve tube 14 to exhaust passage 28, thereby to terminate the upthrust on the piston 2.

35 During the return stroke of the piston 2, the exhaust ports 25 will move out of register with the recess 27 and thus isolate the power working chamber 12 from the exhaust passages 24 leading to the recess 13. Air thus

trapped within the working chamber 12 will therefore commence to be compressed by the continuing upward motion of the piston 2. Moreover, as the piston 2 approaches the end of its return stroke, the full section terminal portion of the supply line 10 will enter the enlarged region of the recess 11 and so establish a flow path between the latter and the power working chamber 12 for the admission of live compressed air to the working chamber 12. This admission of compressed air to the power working chamber 12 will thus arrest the upward motion of the piston and commence to drive it downwardly on its power stroke. Compressed air will continue to be admitted to the working chamber 12 until such time as the flow path from the recess 11 to the chamber 12 is interrupted by the entry of the full section portion of the supply line 10 into the matching sized entrance to the recess 11 in the piston. Thereafter the air in the chamber 12 will expand to give up energy to the piston 2 until such time as the flats 26 overlap the recess 27 to provide a path to exhaust for the spent air in the chamber 12.

At the termination of its power stroke, the piston 2 delivers a blow on the anvil surface at the upper end of the bit shank 15 and the above-described cycle then repeats.

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It will be observed that during the power stroke and until such time as the pressure ports 23 come to register with the recess 30, the full pressure of the compressed air entering the recess 11 acts effectively on the cross-section of the piston corresponding with the cross-section of the recess 11. At the same time the compressed air that is entering or has entered the power working chamber 12 from the recess 11 is exerting thrust on the annular area of the piston surrounding the supply line 10 so that, in effect, the live compressed air is active upon the total cross section of the piston to exert the maximum available thrust thereon.

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The axial passage 33 in the piston provides for a constant bleed of live compressed air from the recess 11 to the recess 13 and thus to the exhaust system. In operation of the hammer drill, the pulsating flow of exhausted, spent, air from the exhaust system serves for cooling the bit and for flushing cuttings away from the bit face. The bleed of live air via passage 33 supplements this exhaust flow to enhance the action thereof, while maintaining an adequate flushing function at times when the piston is

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not reciprocating, as a result of movement of the bit to a position bringing the by-pass groove into register with the recess 30.

5 The embodiment of the invention illustrated in Figures 5 to 8 of the drawings differs significantly from that shown in Figures 1 to 4 only in regard to the manner in which the cooperative flow passages are formed in the piston and in the cylinder wall for connecting the pressure ports with the return working chamber, and the exhaust ports with the power working chamber, during the cycle of reciprocation of the piston.

10 Thus components of the embodiment of Figures 5 to 8 that correspond with components of the embodiment of Figures 1 to 4 have been given the same reference numerals as in those Figures and will not be further described.

15 As is apparent from Figures 7 and 8 in particular, the piston 2 in this embodiment has no terminal relieving corresponding with the flats 26 and 29 at the upper and lower ends, respectively of the piston of the embodiment of Figures 1 to 4. Instead, the cylinder 1 is formed with two sets of longitudinal grooves, for instance, by spark erosion techniques. Thus the cylinder 1 is
20 formed with a set of longitudinal grooves 41, preferably equiangularly spaced about the axis of the cylinder so as to provide symmetry of flow and disposed to provide communication between the working chamber 12 and the exhaust ports 25 during the relevant part of the piston reciprocation cycle, while minimising asymmetry in the stresses in the drill body. In the
25 arrangement shown there are four meniscus-section grooves 41 but it should be understood that there may be a different number of grooves and that these may have different sectional shapes to meet particular air flow and cylinder strength requirements.

30 A second set of longitudinal grooves 42 is provided lower in the cylinder 1 than the grooves 41 to provide the function of the flats 29 at the lower end of the piston in the embodiment of Figures 1 to 4. As shown in Figure 8, these grooves 42 are similar in configuration and arrangement to
35 the grooves 41 but other configurations and arrangements are possible to meet particular requirements as to air flow and cylinder strength.

To provide for uninterrupted communication between the grooves 41 and the exhaust ports 25 during the relevant portion of the operating cycle and regardless of the rotational orientation of the piston within the cylinder, the piston is formed with a circumferential relieving 43 with which the exhaust ports 25 communicate. Likewise the piston is formed with a circumferential relieving 44 with which the pressure ports 23 communicate so as to provide for uninterrupted communication between those pressure ports and the grooves 42 during the relevant portion of the operating cycle.

It will be noted that the circumferential relieving 43 communicates with a groove 32 to provide the same function as the similar groove in the embodiment of Figures 1 to 4.

The embodiment illustrated in Figure 9 differs from the previously described embodiments of Figures 1 to 8 in two respects: the pressure fluid supply line 10 is fixed to the piston to reciprocate therewith and to cooperate with a pressure recess 11a that is formed in the cylinder headpiece 9; and secondly in that the lower end of the piston 2 is stemmed and extends through a seal ring 50 in the cylinder and from which it is withdrawn at and near the upper stroke-end position to provide for venting of the return working exhaust chamber 31 to an annular exhaust space 51 that communicates with lateral exhaust ports (not shown).

Thus in this embodiment the exhaust recess 13 in the piston serves solely for venting the power working chamber 12 to the exhaust port of the machine.

It will be apparent that this second modification is unrelated to the first: that is to say, the rearrangement of the supply line 10 and pressure recess can be applied to the machines with foot valves and axial exhaust lines and likewise the stemmed piston and seal ring arrangement may be applied to control return working chamber venting in a machine in which the supply line and pressure recess arrangement is as in the embodiments of Figures 1 to 8.

It has been pointed out that in machines in accordance with the invention, the full cross-sectional area of the piston is available for

exposure to the pressure fluid to generate the thrust to propel the piston on its power stroke so that conversion of pressure fluid energy into usable piston energy is maximised. It is accordingly possible to design the machine to operate with short strokes and higher than usual operating frequencies to achieve higher overall power outputs than, or conversely to utilise a heavier piston operating at lower impact velocities than usual to obtain the same power output as, conventional machines of corresponding dimensions and subject to the same pressure fluid supply. It has also been mentioned that the passages formed in the piston are susceptible to simple formation techniques that enable an optimum compromise to be obtained between passage cross-section and freedom of flow path, on the one hand, and piston strength on the other hand. As noted, the passages in the piston are preferably arranged within the same portion of the length of the piston to provide a compact configuration. This also enables the passages to be located in a piston region of full cross section not weakened by the presence of recesses such as the recesses 11 and 13.

Further advantages of the machine of the invention are that the cylinder is not complicated by the need to provide therein ports and blind passages as in many prior art constructions, the only required cylinder passages in the machine of the invention being open to the bore of the cylinder throughout their length and thus being capable of being manufactured by simple machining or other forming techniques and with minimisation of the cylinder strength reduction as the result of the provision of such passages. Complicated cylinder liner systems are not required.

Moreover, because of their internal simplicity, machines in accordance with the invention may be constructed with integral or non-detachable headpieces 9 such as illustrated in Figure 9, and/or with non-detachable chucks.

The pressure fluid supply line that extends axially in the power working chamber is of simple configuration capable of being manufactured by straightforward machining or equivalent techniques that preserve the strength and avoid the formation of stress raisers in this component, such as are unavoidable in certain prior art constructions with complicated porting of a pressure fluid supply line.

The machine of the invention is mechanically simple, comprising a single moving part (the piston) and only few major functional items, viz, the cylinder, the pressure fluid supply line and the exhaust line (foot valve) or other arrangement for venting the return working chamber.

CLAIMS:

1. A valveless pressure fluid-powered free piston machine comprising a piston reciprocable in a cylinder providing power and return working chambers (12, 31) respectively at opposite ends thereof; axially spaced-apart pressure and exhaust piston wall ports (23, 25) and associated pressure and exhaust passages (22, 24) in the piston, and cooperative flow passages formed at least partly in the cylinder wall for connecting said pressure and exhaust piston wall ports with the power and return working chambers respectively, in accordance with the position of the piston in the cylinder, and a pressure fluid supply line (10) extending axially within the power working chamber (12), characterised in that the supply line (10) enters and has an open termination within a mating axial pressure recess (11, 11a), said supply line and said pressure recess being responsive to movement of the piston in the cylinder and cooperating to provide a flow path from the recess (11, 11a) to the power working chamber (12) during part of the cycle of reciprocation of the piston.
2. A machine according to claim 1, further characterised in that the pressure and exhaust passages (22, 24) in the piston are rectilinear, inclined with respect to the axis of the piston, and disposed within the same portion of the length of the piston.
3. A machine according to claim 1 or 2, further characterised in that the pressure recess is formed in the piston and is connected to the pressure passage or passages therein.
4. A machine according to claim 1, 2 or 3, further characterised in that the piston has an axial exhaust recess (13) facing the return working chamber (31) and connected to the exhaust passage or passages (24) in the piston.
5. A machine according to claim 4, further characterised in that said exhaust recess is arranged to cooperate with an axial exhaust line (14) to control the flow of spent pressure fluid from the return working chamber.
6. A machine according to any preceding claim, further characterised in that the pressure fluid flow path-defining component of the said supply line (10) comprises circumferential relieving of the supply line.

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Fig. 1.

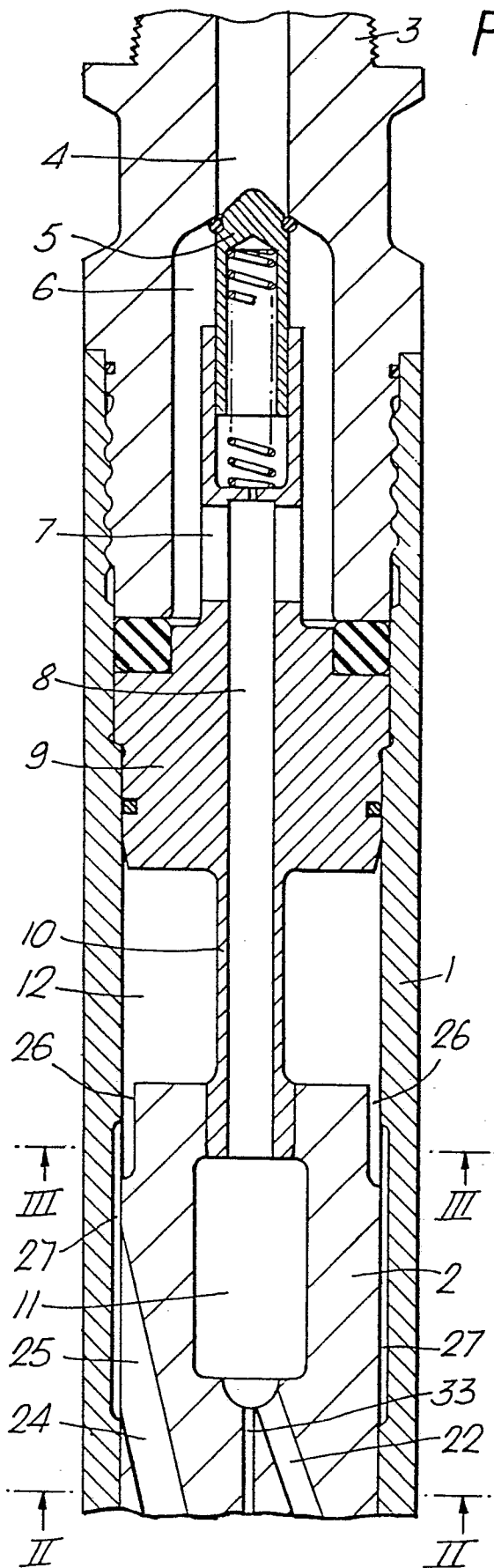


Fig. 2.

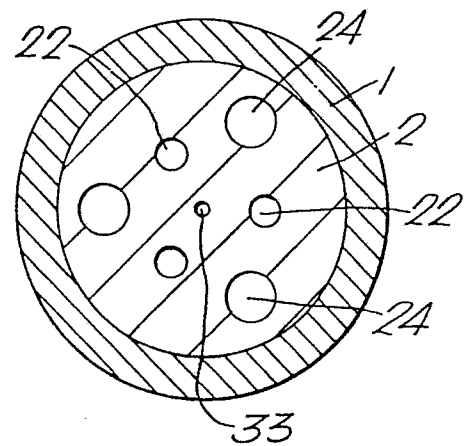
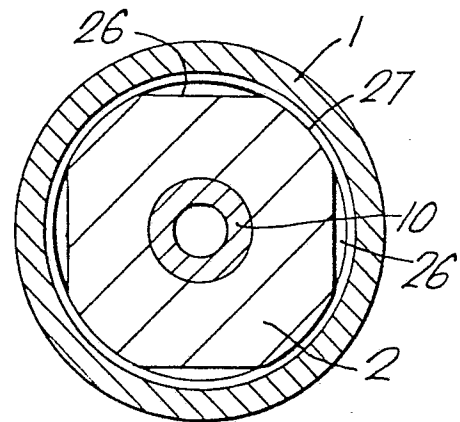


Fig. 3.



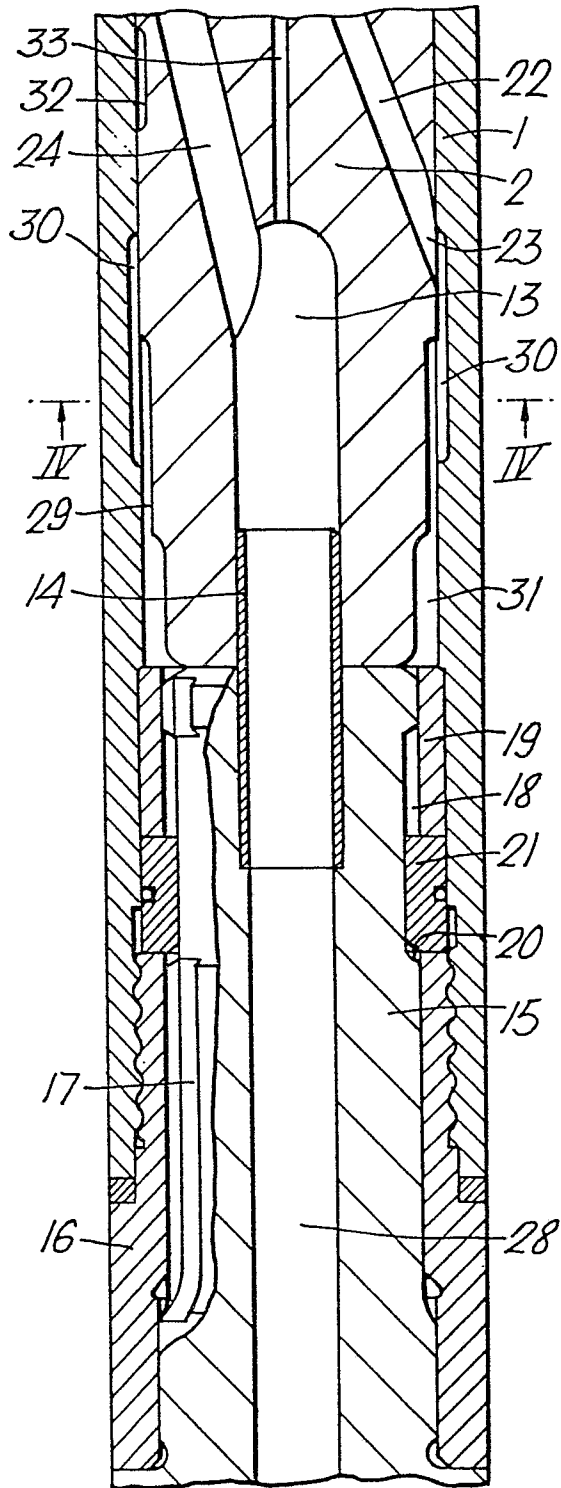


Fig. 1A.

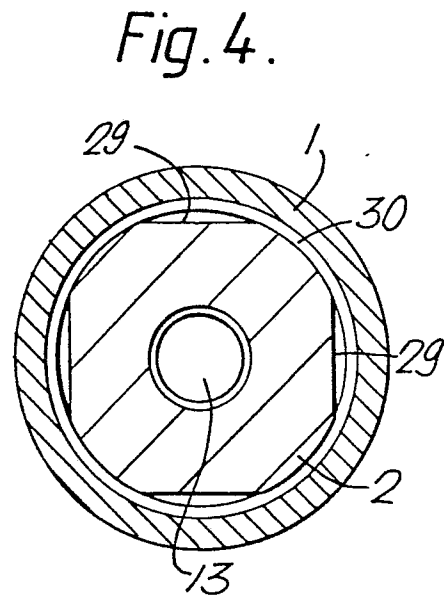


Fig. 4.

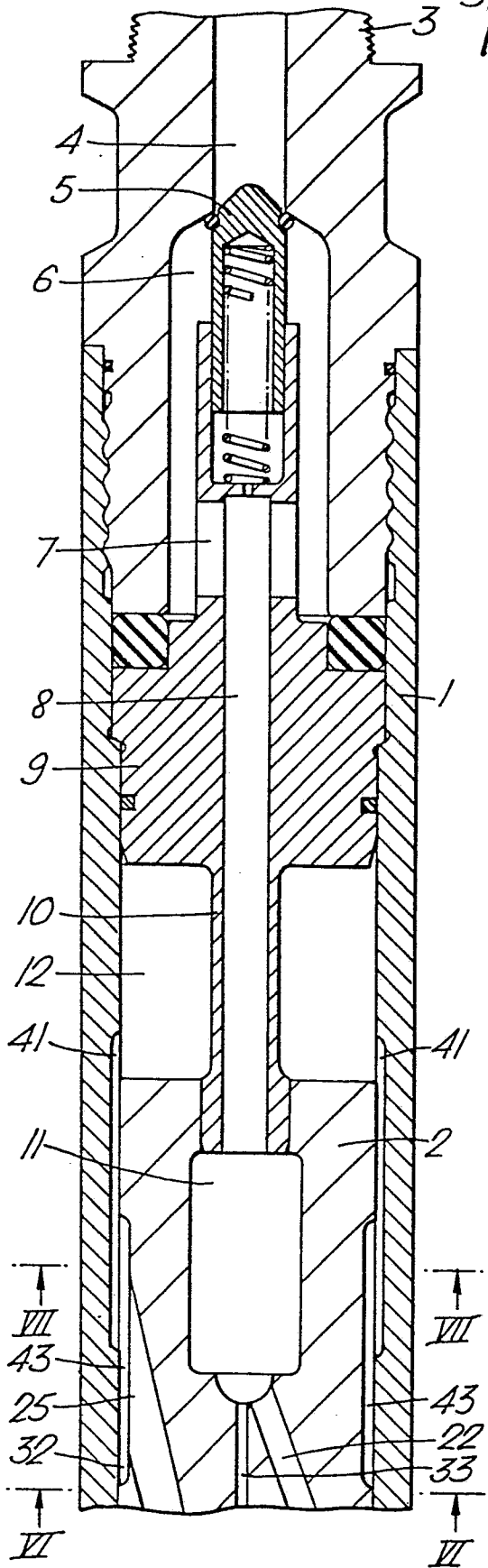
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Fig. 5.

Fig. 6.

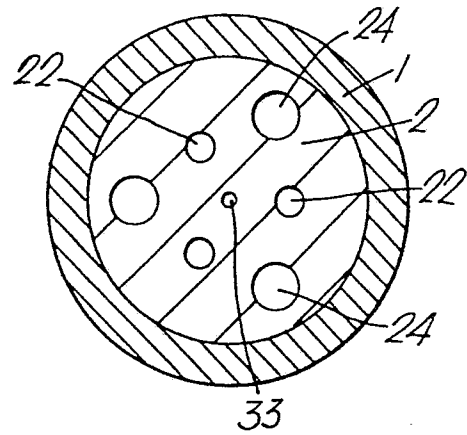
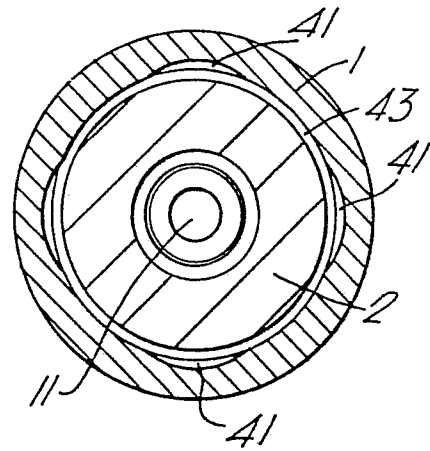


Fig. 7.



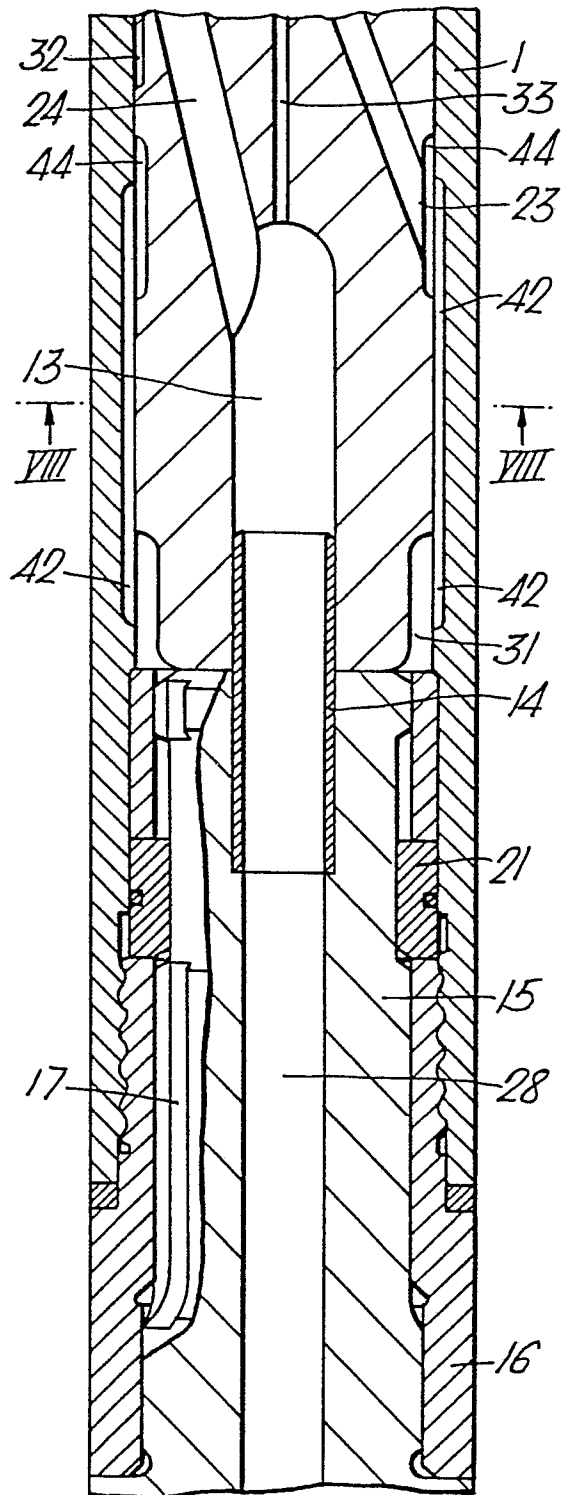


Fig. 5A.

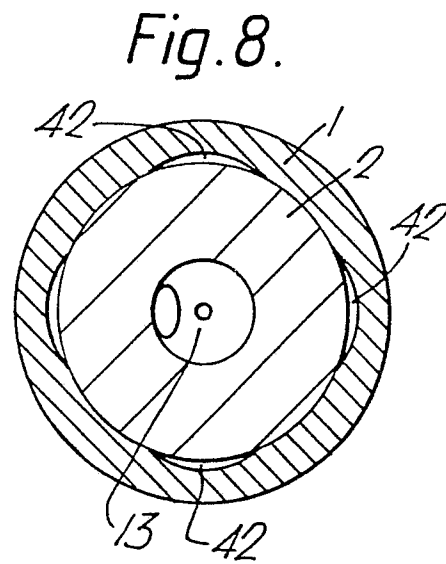
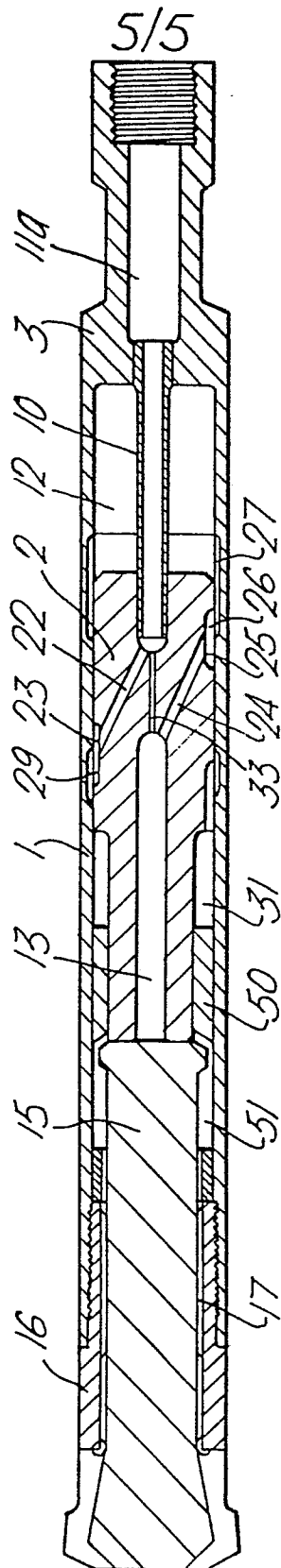


Fig. 8.

Fig. 9.





European Patent
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EUROPEAN SEARCH REPORT

0040026

Application number

EP 81 30 1919

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
	US - A - 4 030 554 (A.W. KAMMERER et al.) * Column 3, line 52 - column 4, line 42; figures 1a-5 * --	4-6	E 21 B 4/14
A	GB - A - 749 328 (HUGHES TOOL)		
A	US - A - 3 970 153 (A. GIEN et al.)		
A	US - A - 3 964 551 (G. BASSINGER)		
DA	US - A - 4 146 097 (A.R. CURINGTON)		TECHNICAL FIELDS SEARCHED (Int. Cl.)
DA	US - A - 4 084 647 (W. LISTER) ----		E 21 B E 21 C B 25 D
			CATEGORY OF CITED DOCUMENTS
			X: particularly relevant A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: conflicting application D: document cited in the application L: citation for other reasons
			&: member of the same patent family, corresponding document
The present search report has been drawn up for all claims			
Place of search	Date of completion of the search	Examiner	
The Hague	30-07-1981	JAUNEZ	