Sept. 21, 1971 L. P. FLATLAND 3,606,684

DISPLACEMENT ENGINE ESPECIALLY FOR DENTAL USE

Filed Oct. 17, 1969 5 Sheets-Sheet 1

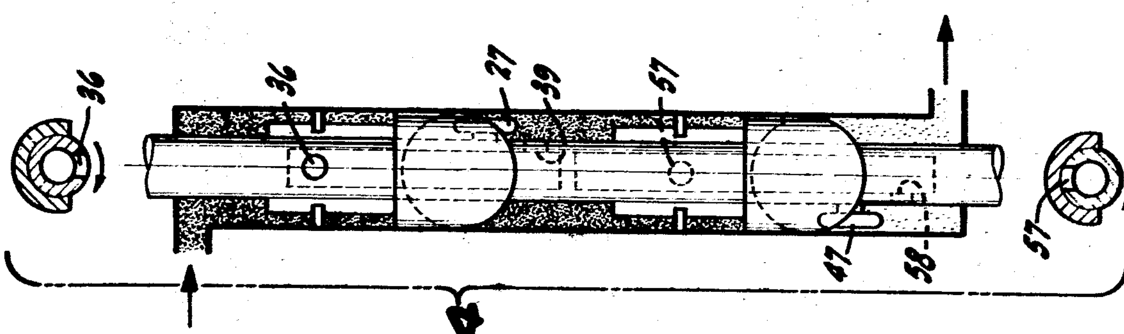

FIG. 4

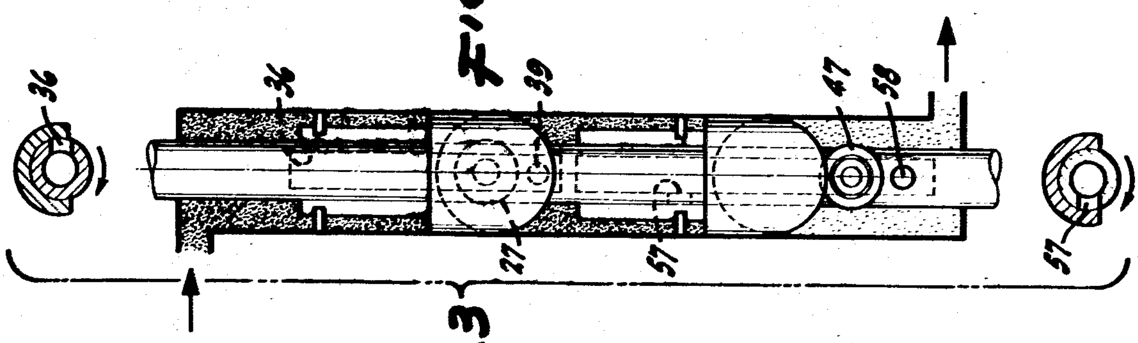

FIG. 3

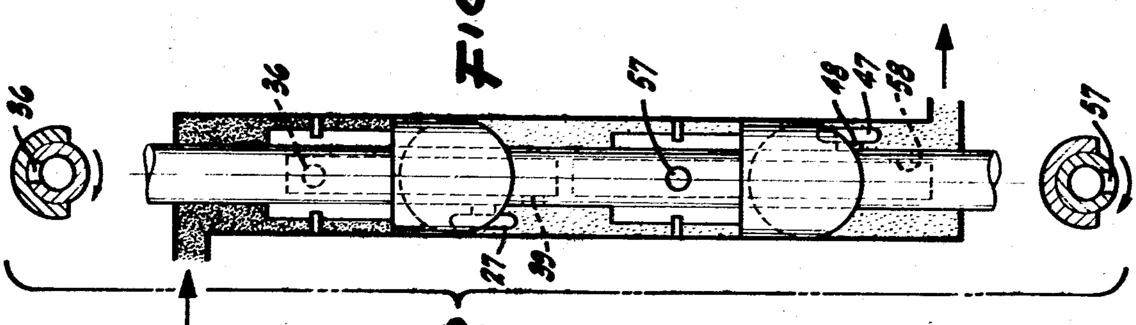

FIG. 2

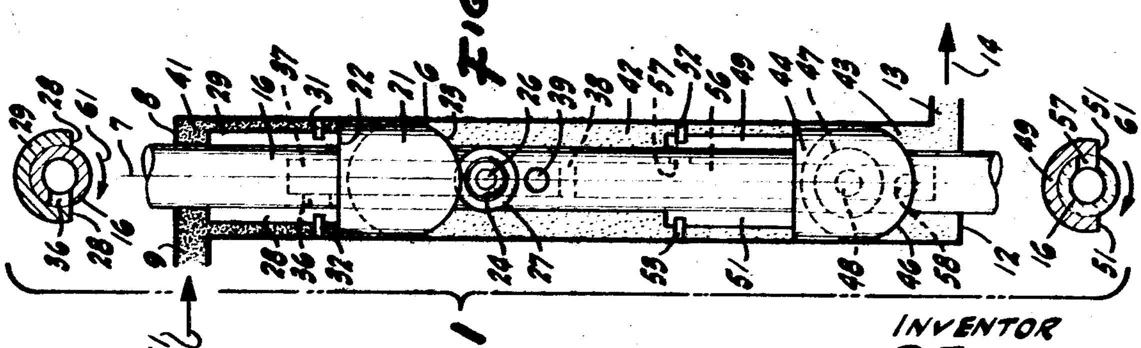

FIG. 1

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DISPLACEMENT ENGINE ESPECIALLY FOR DENTAL USE

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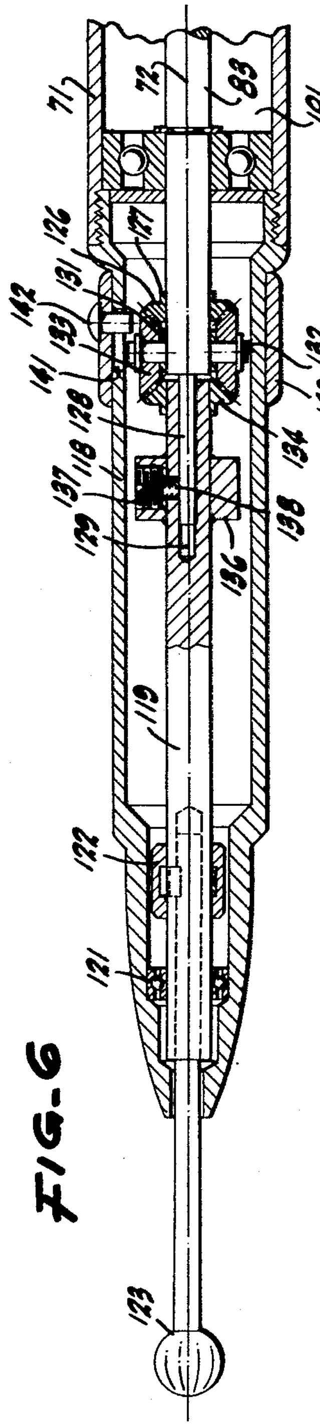

FIG. 6

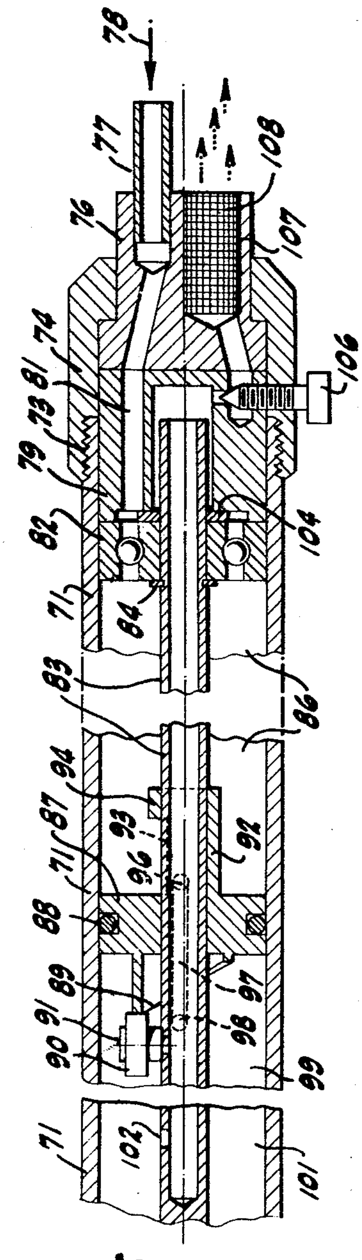

FIG. 5

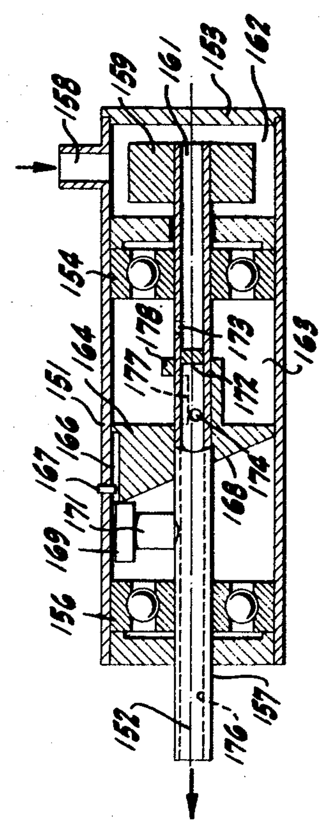

FIG. 7

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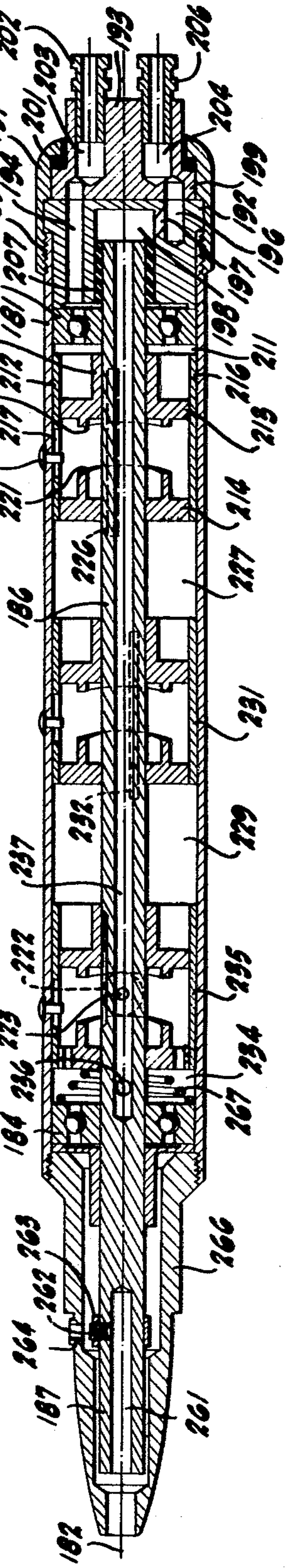

FIG. 8

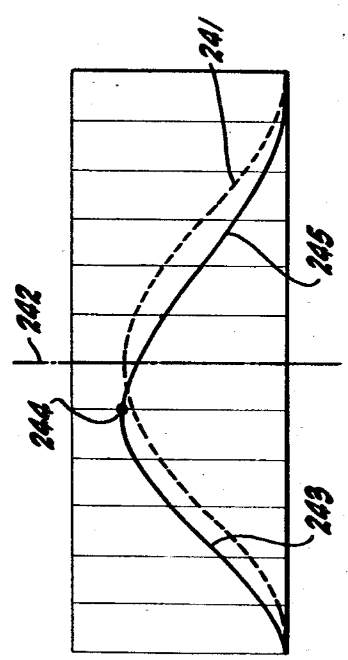

FIG. 10

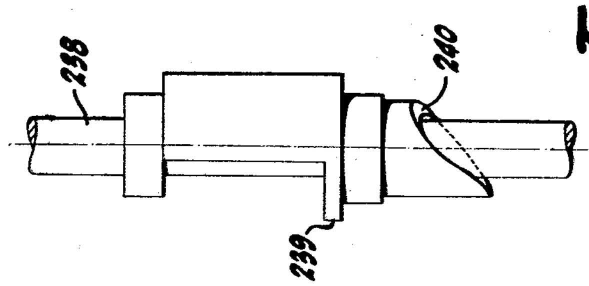

FIG. 9

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DISPLACEMENT ENGINE ESPECIALLY FOR DENTAL USE

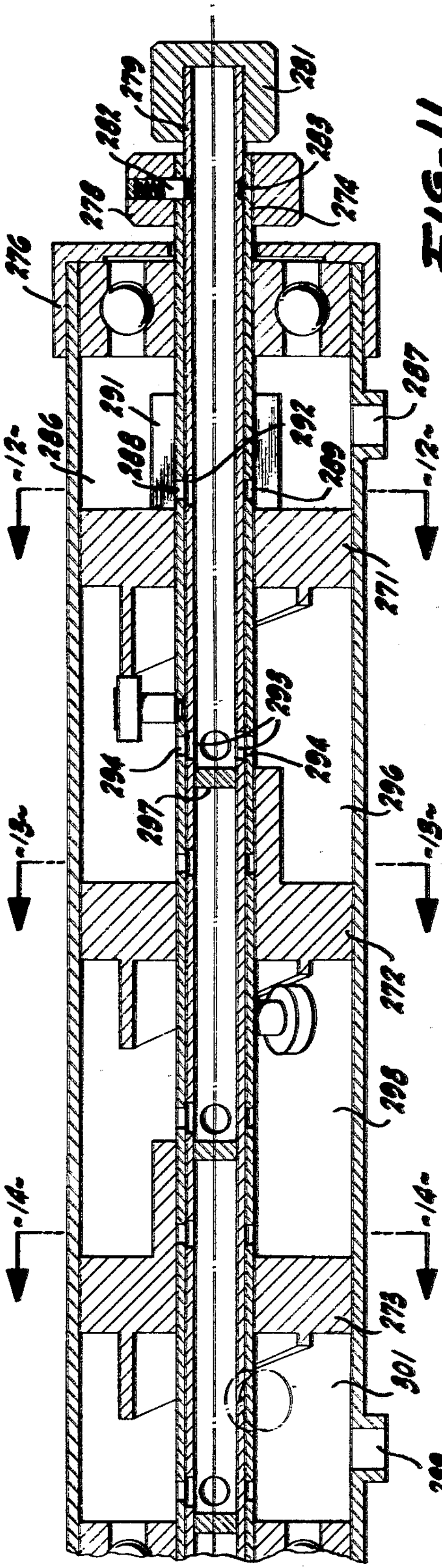

FIG. 11

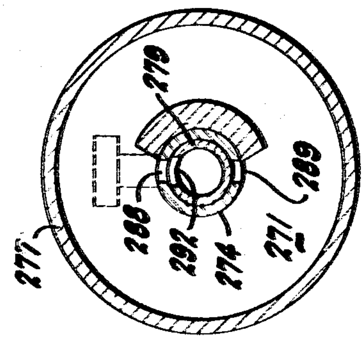

FIG. 12

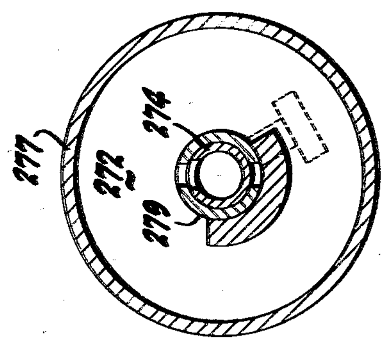

FIG. 13

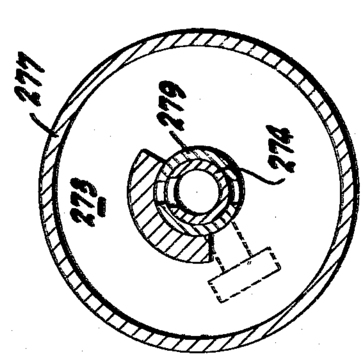

FIG. 14

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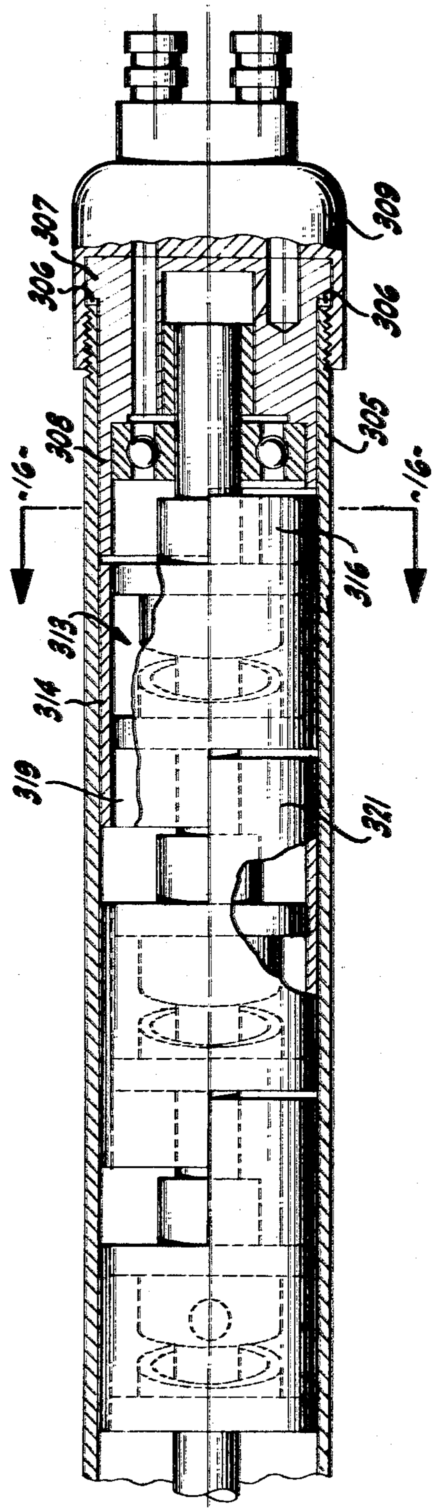

FIG. 15

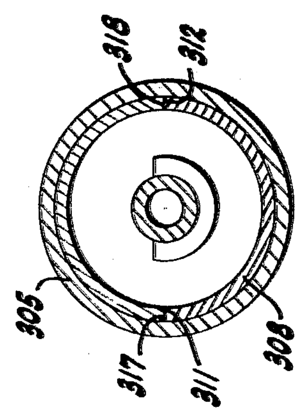

FIG. 16

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3,606,684

DISPLACEMENT ENGINE ESPECIALLY FOR DENTAL USE

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Int. Cl. A61c *1/08*
U.S. Cl. 32—26 7 Claims

ABSTRACT OF THE DISCLOSURE

A displacement engine has a cylinder with an axis. The cylinder is closed at one end and mounts a hollow shaft rotatable on the axis as a center and held against displacement along the axis. A piston is reciprocable in the cylinder and along the shaft by means of a sleeve cam surface at one end remote from the closed end of the cylinder and engaging a cam follower extending radially from the shaft. Pressure fluid is admitted to the cylinder adjacent the closed end. An exhaust port open through the shaft wall between the piston and the closed cylinder end is alternately opened and closed as the shaft rotates by means of an arcuate valve wall fast on the piston.

In many fields, particularly in the field of hand-held rotating dental instruments, there is a substantial demand for an improved driving mechanism. Dental hand pieces have been rotated by mechanical means and more recently by very high speed air turbines. There are instances in which the relatively high turbine speed is not essential but substantial torque at relatively low speeds is helpful although difficult if not impossible to obtain by turbine drive.

It is therefore an object of the invention to provide a displacement engine, particularly for dental use, which will operate on a pressure fluid, for example compressed air, and will afford adequate rotational speed for most uses and will have relatively high torque at relatively low speeds.

Another object of the invention is to provide a displacement engine especially for dental use which can easily be held in the user's hand and will occupy about the same volume as hand pieces now customarily utilized.

Another object of the invention is to provide a displacement engine which will readily start and stop under the control of the operator and will assume intermediate speeds under his control.

A further object of the invention is to provide a displacement engine having a relatively long life and proreadily available for use.

An additional object of the invention is to provide a displacement engine which affords, in most embodiments, a relatively even turning moment.

A still further object of the invention is to provide a displacement engine which is quiet and vibration free.

A further object of the invention is to provide a displacement engine in which the parts, even in relatively small sizes, can be accurately and consistently manufactured.

A further object of the invention is to provide a displacement engine having a relatively long life and prolonged consistent performance.

A further object of the invention is in general to provide an improved displacement engine.

Other objects together with the foregoing are attained in the embodiments of the engine described in the accompanying description and illustrated in the accompanying drawings, in which:

FIG. 1 is inclusive of three diagrammatic views, the center one being a cross-section on an axial plane through

a form of engine pursuant to the invention in one operating position, and the end views being timing diagram illustrations in transverse cross-section through valve ports;

FIG. 2 is a view like FIG. 1 but showing the parts in a position ninety degrees after the position shown in FIG. 1;

FIG. 3 is a view comparable to the preceding figures but showing the parts in position ninety degrees after the position of FIG. 2;

FIG. 4 is a view like the preceding figures but showing the parts in a position ninety degrees after the position of FIG. 3;

FIG. 5 is a cross-section to an enlarged scale through the axis of an actual engine constructed pursuant to the invention, parts of the structure being broken away to reduce the size of the drawing;

FIG. 6 is a continuation of the structure shown in FIG. 5, the view being in cross-section on an axial plane;

FIG. 7 is a cross-section on an axial plane through a single-piston, alternate form of the displacement engine;

FIG. 8 is a cross-section on an axial plane through a further modified form of displacement engine;

FIG. 9 is a detail showing in side elevation of modified form of piston and cam construction;

FIG. 10 is a view to an enlarged scale showing in developed form the contour of the piston cam surface shown in FIG. 9;

FIG. 11 is a view similar to FIG. 8 but showing a different form of reversing arrangement;

FIG. 12 is a cross-section to an enlarged scale, the plane of section being indicated by the line **12—12** of FIG. 11;

FIG. 13 is a cross-section like FIG. 12 but indicated by the line **13—13** of FIG. 11;

FIG. 14 is a cross-section like FIG. 12 but indicated by the line **14—14** of FIG. 11;

FIG. 15 is a view similar to FIG. 8 but showing, partially diagrammatically, a different form of means for precluding piston rotation; and

FIG. 16 is a cross-section, the plane of which is indicated by the line **16—16** of FIG. 15.

The displacement engine in any of its embodiments pursuant to the invention has certain characteristics making it suitable for use in a widely different number of environments, but it is especially useful in and has been illustrated as it is embodied for use in the field of dental instruments such as a hand piece designed to drive any of various dental tools.

Furthermore, while the engine in its various modifications will operate on any appropriate fluid which can flow from a source of relatively high pressure to a sink of relatively low pressure it has conveniently been embodied to operate on compressed atmospheric air containing some finely divided lubricant therein, the air being at a pressure of, say, fifty pounds per square inch initial pressure and discharging to atmospheric pressure, as an example.

For purposes of explanation attention is first directed to FIGS. 1–4 inclusive which, although diagrammatic, illustrate the cycling of the displacement engine and for clarity omit some of the details of actual construction.

The engine includes a right, circular cylinder **6** symmetrical about a longitudinal axis **7**. The cylinder **6** is substantially closed at an inlet or head end **8** except for an inlet duct **9** leading to a source **11** of appropriate fluid under pressure. At the other end the cylinder **6** not necessarily but conveniently is substantially closed by a wall **12** except that there is provided an outlet duct **13** leading to a sink **14** at a pressure lower than the source **11**. Designed to rotate about the axis **7** and to be constrained against any axial movement with respect to the cylinder **6** is a through shaft **16**. The shaft is appropriately supported and confined and can extend from one or both ends of the cylinder. The shaft is for the most part solid in this showing.

Designed to reciprocate within the cylinder 6 is a primary piston 21 fitting the cylinder well and having a transverse, planar top or head surface 22 at its end nearest the head 8. The piston 21 has a sleeve cam surface 23 at its opposite end, remote from the head 8. The cam surface 23 is conveniently and approximately or actually defined by a plane extending obliquely to the axis 7. Arranged to abut the planar, oblique cam surface 23 is a cam follower 24 including a stub shaft 26 extending radially from and fixed on the shaft 16. In some instances the follower includes an anti-friction roller 27 directly in contact with the cam surface.

To confine the piston to rectilinear translation, that is, to preclude rotation thereof relative to the cylinder 6 and for other reasons the piston is provided with a transverse, axially extending valve wall 28 which is substantially planar and defines the margins of a partial sleeve 29 partly encompassing the shaft 16. Abutting the wall 28 on both sides of the axis are restraining pins 31 and 32 on which the sleeve margins are slidable and preclude the forbidden piston rotation.

At an appropriate point in the periphery of the shaft 16 there is a radial port 36, usually made circular in cross-section which communicates with a central bore 37 making this part of the shaft hollow. The bore 37 extends axially along the shaft but is blocked by a transverse barrier 38. Below the piston and above the barrier, the bore 37 opens through a second port 39 likewise circular in cross-section, into the cylinder.

With this arrangement there is a primary inlet chamber 41 defined within the cylinder above the piston and a secondary or intermediate chamber 42 defined within the cylinder below the piston. Likewise provided is a tertiary chamber 43 separated from the chamber 42 by a secondary piston 44 substantially identical with the primary piston 21. The piston 44 has a cam surface 46 comparable to the surface 23 and in the same polar orientation with respect to the cylinder 6. The secondary piston operates with a cam follower 47 having a stub arm 48 extending radially from the shaft 16 but polarly displaced one-hundred-eighty degrees from or out of phase with the stub shaft 26. The piston 44 has a valve sleeve 49 with a transverse surface 51 like the wall surface 28 engaged by a pair of pins 52 and 53 stationary in the cylinder. In this fashion the secondary piston is allowed to reciprocate but is prevented from rotation.

The interior of the shaft 16 is bored out to provide a chamber 56 below the plug 38 and a port 57 like the port 36 is provided through the shaft wall between the chamber 56 and the cylinder but the port 57 is displaced polarly one-hundred-eighty degrees from the port 36. At a convenient location an outlet port 58 opens from the chamber 56 into the tertiary chamber 43.

With the parts in position as shown in FIG. 1, the shaft 16 is intended to rotate in the direction of the arrow 61. The primary chamber 41 has just been sealed by closure of the port 36 and remains sealed except for the always open supply duct 9. The secondary chamber 42 and the tertiary chamber 43 are both open to the low pressure exhaust 14 because the port 58 is always open and the port 57 is just about to open. Thus, there is a relatively high pressure on the head of the piston 21 and a low pressure beneath the piston 21 so that the piston tends to be driven away from the head 8 by the pressure difference. The cam face 23, bearing upon the follower 27, causes further rotation of the shaft 16 after the shaft has moved slightly past the upper dead center position illustrated.

As the piston 21 is driven away from the head 8 it rotates the shaft 16 for a quarter turn into the position shown in FIG. 2. The port 36 is still blocked by the valve sleeve 29 and the other ports remain as previously described. The motion of the piston 21 continues downwardly for another ninety degrees into the lower dead center position shown in FIG. 3. In that position the port 36 has rotated with the shaft 16 until it begins to emerge from the barrier provided by the valve sleeve 29. This permits the pressure fluid within the primary chamber 41 to discharge through the port 36 into the bore 37 to flow along the axis and discharge through the always open port 39 into the secondary chamber 42. At this time the port 57 has rotated into a closed position in which flow through the port is blocked by the valve sleeve 51. Under these conditions pressure fluid from the source flows into and from the primary chamber 41 into the secondary chamber 42 now having a blocked outlet. The pressure in both chambers 41 and 42 quickly becomes substantially the inlet pressure. Since the port 57 is closed the pressure within the tertiary chamber 43 remains at a low value.

As soon as the air pressure on opposite sides of the primary piston 21, the piston becomes inert as to driving force but the unbalanced pressure then on the piston 44 drives the secondary piston away from the head 8. The piston 44 imparts rotational pressure to the shaft 16 immediately following the cessation of such rotational pressure by the piston 21. Movement of the piston 21 becomes relatively easy since pressure on opposite sides thereof is balanced but the piston 44 exerts full force on the shaft 16. As the shaft turns the piston 44 continues away from the head 8 into the position illustrated in FIG. 4. This is ninety degrees later than the FIG. 3 position. The port 57 is still closed to trap pressure fluid within the secondary chamber 42 while the low pressure continues beneath the piston 44. During this time the rotation of the shaft has caused the follower roller 27 to cam against the surface 23 on the piston 21 and to drive the piston toward the head 8 during which operation the port 36 has remained open.

During the next ninety degrees of rotation of the shaft the parts travel from the position shown in FIG. 4 and return to the position shown in FIG. 1. At that time the port 57 resumes the about to open position shown in FIG. 1 so that the pressure within the secondary chamber 42 and within the tertiary chamber 43 shortly drops to the exhaust value. At the same time the valve port 36 returns to its FIG. 1 position in which it is blanked by the valve sleeve wall 29. Pressure fluid from the source can no longer leave the primary chamber 41. The pressure therein persists at the high value whereas the pressure beneath the piston in the secondary chamber 42 resumes the low value. The force is then on the primary piston 21 to move away from the head 8, as before, during which motion of the shaft 16 the follower 47 restores the piston 44 to its former position.

With this mechanism the pressure fluid displaces the two pistons within the cylinder in cyclic paths to impart two successive driving torques to the shaft for each shaft rotation. While there are two dead center positions with this two piston mechanism and while occasionally the mechanism must be externally started, continued rotation is readily accomplished because the moving parts have sufficient momentum to act a a fly wheel. For illustration herein, the timing of the various events is presumed to take place instantaneously and exactly at the locations indicated.

The actual timing is varried considerably from the theoretical concept and the port size, both circumferentially and axially, is also varied. Sometimes the port area especially during cylinder exhaust is partially restricted to retain some pressure on the piston to hold the cam in contact with the follower when a unidirectional cam is used. The timing of the events also varies with the amount of air to be used, with the designed speed range of the shaft and to allow for tolerances in manufacture and wear of the parts.

In practice there is some slight leakage not only through the various covered ports but also past the pistons. This is a small amount and instead of being considered detrimental is advantageous in that it affords an air bearing between the relatively moving parts. The air bearings reduce and may eliminate the lubricant, such as oil, that usually is introduced with the propulsive fluid. In any event a displacement engine, as described, is effective to utilize the force of a pressure fluid to afford a satisfactory rotation of a driven shaft, the parts being quite simple and being arranged in such a fashion that the shape or envelope of the resulting structure lends itself to many uses and particularly to incorporation in a dental handpiece.

An actual, operating form of a displacement engine driven dental handpiece is illustrated in FIGS. 5 and 6. Therein a metal cylinder **71** is symmetrical about an axis **72** and at one end has threads **73** on which a head cap **74** is screwed. The head cap is flanged partially to confine an aperture head fitting **76** into which a flexible supply tube **77** extends. The tube **77** extends to a source **78** of fluid under pressure. The fitting **76** is not only confined by the cap **74** but is likewise axially located by a head plug **79** fixed within the cylinder **71** and formed with a through passage **81**. A bearing **82** is fixed within the cylinder **71** and rotatably supports one end of a hollow shaft **83**, a retainer **84** holding the bearing against the plug **79**. There is a sufficient opening through the bearing **82** to allow fluid from the passage **81** into a primary chamber **86** between the bearing and a piston **87** reciprocable within the cylinder **71**.

The piston **87** represents any one of two or three or more pistons identical with each other and arranged axially apart and within the cylinder. The piston **87** carries a packing ring **88** to reduced leakage and has a cam track **89** adapted to abut a roller bearing **90** on a radial stub shaft **91** fast on the shaft **83**. Also the piston **87** carries a valve wall **92** having a valve surface **93** lying in a plane parallel to the axis **72** and, in addition, has a saddle **94** to assist in forming a good bearing for the piston **87** on the shaft. A port **96** in the shaft communicates through a shallow groove **97** and a port **98** with a secondary chamber **99** whenever the port **96** is uncovered.

Successive pistons are similarly arranged but with their ports **96** or their valve surfaces **93** appropriately positioned peripherally of the shaft. That is, if a single piston is utilized then the port **96** has a location with respect to the valve wall **92** and the cam **89** substantially as shown in FIG. 5. If there are two pistons then the valve walls (or ports) are disposed one in the same polar location shown in FIG. 5 and the other at one-hundred-eighty degrees thereto. If there are three pistons then the valve walls **92** (or ports) are disposed one as shown in FIG. 5 and the other two at one-hundred-twenty degrees progressively therefrom. Similarly, if there are four pistons then the orientation of one of the valve walls is as shown in FIG. 5 with the successive valve walls at ninety degrees thereto and to each other.

In an arrangement of this sort, particularly one having three or four pistons or more, the closure of each chamber relative to the closure of the chamber next in succession following it is preferably of an angular duration of three-hundred-sixty degrees divided by the number of pistons. That is, three pistons have a closure duration of one-hundred-twenty degrees each, whereas four pistons have a closure duration of ninety degrees each and so on. The cams, when contoured as shown, have two dead center positions one-hundred-eighty degrees apart (in most instances) but the duration of the effective driving impulse of the related piston is something less than one-hundred-eightly degrees. The configuration of the valve wall **92** and the contour of the ports are consequently preferably arranged so that the pressure differential across any piston occurs centrally and symmetrically with respect to the total theoretical stroke. That is, if the theoretical power stroke of the piston extends over one hundred eighty degrees of shaft rotation, then it is preferred to arrange the piston exists at maximum for only one-hundred-twenty degrees of shaft rotation,then it is preferred to arrange the valve wall and exhaust port so that discharge from the chamber above each piston is blocked beginning thirty degrees past top dead center, continues to be blocked for the next one-hundred-twenty degrees and then resumes through the exhaust port at one-hundred-fifty degrees past top dead center. In this way the pressure difference on each piston is most effective when the cam driving mechanism is likewise most effective.

Spent pressure fluid is released to the ultimate chamber **101** and flows through a port **102** into the hollow shaft **83** toward the same end at which it entered. That is, the exhaust fluid travels from the interior of the shaft into a discharge chamber **103** segregated from the primary chamber **86** by a packing washer **104**. Efflux from the chamber **103** is controlled by a manually adjustable needle valve **106** governing communication to an outlet duct **107** carrying a fibrous muffler **108** to reduce the sound of the discharge to the atmosphere. With this arrangement the operator by adjusting the needle valve **106** can regulate the back pressure and so the volume of fluid passing through the mechanism and the speed of rotation of the shaft.

At the opposite end the cylinder **71** carries a bearing **116** supporting the other end of the shaft **83**, there being a retainer **117** to preclude any axial displacement. The bearing is also confined against a tip housing **118** screwed in position and symmetrical about the axis **72**. This body carries a tail shaft **119** supported in an auxiliary bearing **121** adjacent a dental chuck **122**. A burr **123** or comparable tool can readily be introduced into the chuck **122** for temporary retention and for rotation.

Under some conditions it is desired to reverse the rotation of the tool **123** without reversing the rotation of the engine itself. Under those conditions I provide on the shaft **83** within the housing **118** a bevel gear **126** nonrotatable on the shaft **83** and backed by a collar **127**. The shaft **83** has a pilot extension **128** within a bore **129** within the tail shaft **119**. A sleeve **131** is freely rotatable on the shaft **83** and carries a number of radial, stub shafts **132** each of which carries a central bevel gear **133** meshing on one side with the bevel gear **126** fast on the shaft **83** and on the other side with a bevel gear **134** fast on the tail shaft **119**. Extending from the shaft **119** is a radial collar **136** carrying one or more radial screws **137** urging friction blocks **138** against the shaft extension **128**. Under normal conditions of operation the friction load between the shaft **119** and the pilot shaft **128** is sufficient so that the planetary differential mechanism (the gears **126, 133** and **134**) rotates as a body and the shafts both turn together in the same direction.

Means are provided for reversing the tool direction. Movable in a slot **141** cut in the housing **118** is a stop pin **142** connected to a sleeve **143** slidable on the outside of the housing **118**. In the retracted position of the sleeve and the pin **142**, as shown in FIG. 6, the differential mechanism is not interfered with. However, when the user displaces the sleeve **143** toward the left in FIG. 6 the pin **142** gets into the rotary path of the spindles or stub shafts **132** and precludes further rotation. The shaft **83** continues to rotate the gear **126** which in turn causes the gears **133** to revolve about their stub shafts and to drive the gear **134**. This operates the shaft **119** in a sense opposite to that of is previous direction of rotation accompanied by sliding friction between the blocks **138** and the pilot extension **128**. When reverse movement is no longer required the user restores the sleeve **143** to its original condition with the stop pin **142** out of the path of the stub shafts **132**. The differential mechanism then revolves as a body due to the frictional drag of the blocks **138** and the shafts **83** and **119** resume their rotation together in the same direction.

For most uses it is preferred to have the relatively smooth, uniform operation of an engine with three or more pistons but it is entirely possible for some uses to provide a displacement engine in which only one piston is employed. As particularly disclosed in FIG. 7, the arrangement includes an outer cylinder **151** symmetrical about an axis **152** and having a substantial closure **153** at one end. Anti-friction bearings **154** and **156** are situated within the cylinder **151** and support a shaft **157** for rotation about the axis **152**. Leading into the cylinder adjacent one end thereof is an inlet duct **158** for fluid under pressure. Near the inlet duct **158** within the cylinder and fast on the shaft **157** is a fly wheel **159** having sufficient mass under normal conditions to rotate the shaft **157** for several cycles once sufficient energy has been imparted thereto.

The shaft **157** preferably is substantially hollow to afford an inlet passage **161** from a head chamber **162**. Defining one end of a primary chamber **163** within the cylinder is a piston **164** having an axial slot **166** cut in one side thereof. A stationary pin **167** anchored in the cylinder **151** projects into the slot **166** and while permitting reciprocation of the piston precludes rotation thereof. The piston has an inclined cam face **168** bearing against an anti-friction bearing **169** journaled on the end of a stub shaft **171** extending radially from and fast on the shaft **157**.

A barrier or block **172** within the shaft **157** prevents communication through the shaft but pressure fluid can flow from the passage **161** through a port **173** into the primary chamber **163**. Outflow from the primary chamber **163** is governed by a port **174** covered and uncovered by the generally planar surface of a partially circular valve wall **177**. A saddle **178** affords extra bearing for the piston. Flow through the port **174** is into a shaft passage **176** leading to the atmosphere and, except for the block **172**, being a continuation of the passage **161**.

In the operation of this device when pressure fluid is made available through the duct **158** and to the head chamber **162** and the primary chamber **163** the shaft **157** is initially rotated by any suitable means, thus imparting some energy to the fly wheel **159**. At an appropriate point in the rotation of the shaft the port **174** is blocked by the valve wall **177** so that a differential pressure on the piston results. This port blocking occurs substantially when the piston is at its upper dead center position or shortly thereafter. The piston descends under pressure for substantially a half rotation of the shaft not only imparting force to the shaft but also imparting energy to the fly wheel **159**. Near bottom dead center the port **174** is opened by rotation of the valve wall **177** so that pressure fluid from the duct **158** flows through the entire device. The piston **164** is then subjected to only a small differential force. Since the shaft then has the momentum of the fly wheel **159** to keep it turning the follower **169** bears against the cam face **168** and restores the piston **164** to its inner or top dead center position or slightly beyond. The cycle then repeats since substantially at this time the port **174** is reclosed. While this form of the device is not self starting it does operate well and has the virtue of being simple.

Under some more sophisticated conditions it is desired to provide a structure which starts with high torque, can be reversed and can operate smoothly for protracted times in either direction of rotation. Under those circumstances an arrangement as shown in FIG. 8 is preferred. In this instance there is provided an outer cylinder **181** symmetrical about an axis **182**. The cylinder houses bearings **183** and **184** for a through shaft **186** carrying a dental tool chuck **187** near one end. The cylinder near the head end has threads **189** to engage a removable cap **191** which grips the flange **192** of a head plug **193**. The plug has a pressure bore **194** therethrough and a discharge bore **196** therein. The latter leads through a duct **197** to a central chamber **198**.

Adapted to abut the plug **193** is a head fitting **199** rotatable about the axis **182** relative to the cylinder **181** by means of a bearing **201**. A flexible tube, not shown, joins a fitting **202** seated within a supply passage **203** communicating with the passage **194**. Similarly, the passage **204** in the fitting communicated with the passage **196** and carries a connector **206** either left open to the atmosphere or preferably carrying a flexible discharge tube (not shown) leading to a convenient discharge point. With this arrangement, when the fitting **199** is in the position shown then the incoming pressure fluid travels through the passage **194** and the discharge fluid travels through the passage **196**, but when the fitting is rotated a half turn with respect to the cylinder **181** then the passage **196** becomes the pressure passage and the passage **194** becomes the exhaust passage. At intermediate locations of the fitting the passages **194** and **196** are variably obstructed and act as throttles.

Surrounding the shaft **186** within the chamber **198** is a seal bushing **207** effective to preclude leakage between the high pressure and low pressure sides of the shaft.

Within the cylinder **181** is a primary chamber **211** partially defined by a piston assembly **212**. This includes a pair of piston members **213** and **214** secured together by an encompassing sleeve **216** slidably bearing on the inside of the cylinder. The sleeve **216** has an axially extending slot **217** into which a pin **218** extends. The piston assembly therefore is prevented from rotating but can reciprocate. The piston member **213** has cam surface **219** thereon whereas the piston member **214** has a cam surface **221** thereon. The two surfaces **219** and **221** are complementary and define a closed cam track between them. Within the cam track a follower **222** is disposed on a radial stub shaft **223** fixed on the shaft **186**. A channel **226** cut into but not through the shaft affords communication between the primary chamber **211** and a secondary chamber **227** when a valve wall **228** on the piston uncovers the port within the chamber **211** defined by the end portion of the channel **226**.

In a comparable fashion the secondary chamber **227** is separated from a tertiary chamber **229** by a piston assembly **231** having its own channel port **233** and similarly the tertiary chamber **229** is separated from a discharge chamber **234** by a piston assembly **235** just like the piston assemblies **212** and **231**. The discharge chamber **234** is always connected through a port **236** to a central passage **237** in the shaft opening to the chamber **198** and so to the discharge connector **206**.

With this arrangement the shaft is rotated by oscillation or reciprocation of the pistons and the direction of rotation depends on which side of the piston assembly happens to be at the higher pressure depending on the location of the head fitting **199**.

With displacement engines of the present sort it is not essential that the various cam faces always be symmetrical. It is preferable in some instances to provide an asymmertical cam surface. That construction is shown in FIGS. 9 and 10. In this instance the shaft **238** is as before and so is the main piston body **239** but the cam surface **240** is not symmetrical. As shown in FIG. 10, a symmetrical development of the cam surface is represented by the broken line **241** showing the cam equally contoured on opposite sides of a center line **242**. An asymmetrical cam has a steep ramp **243** so that the maximum point **244** is displaced from the line **242**. Although the ramp **243** is considerably steeper than before, the complementary ramp **245** is less steep. This means that a "stroke" of the cam in one direction might involve more than one-hundred-eighty degrees rotation of the shaft and in the other direction might involve less than one-hundred-eighty degrees rotation of the shaft.

The arrangement of FIG. 8 is particularly adapted for use with a dental chuck adapted to be positioned in one rotational location when a tool is inserted or removed. The shaft **186** has a reentrant bore **261** adapted to receive a tool stem. A set screw **262** is threaded into the shaft and is frictionally retained by a block **263**. The screw preferably has an Allen head accessible to a wrench inserted through an open collar **264** on the tip housing **266** threaded into the cylinder **181**. So that the collar **264** and the set screw **262** will be alignment when the tool stops, a conical spring **267** is disposed between the bearing

184 and the adjacent piston assembly **235**. When no other forces are exerted, the spring **267** moves the assembly **235** and the shaft **186** to upper dead center position of the follower **222** at which the set screw is available through the hole of the collar **264**.

If the direction of tool operation must be often reversed, an arrangement as shown in FIGS. 11–14 is preferred. Some parts are omitted or are not referred to since they are as before. The construction is quite similar to that shown in FIG. 8 but the pistons **271**, **272** and **273** are single acting and the tubular drive shaft **274** extends through the head **276** of the cylinder **277** and carries a thumb wheel **278**. A reversing sleeve **279** is telescoped within the shaft **274** and has an end knob **281**. A spring pressed detent **282** in the wheel **278** engages either of two opposite depressions **283** in the sleeve **279**. The shaft **274** and the sleeve **279** can revolve together but can be put and held 180 degrees out of phase with each other.

The primary chamber **286** has a high pressure inlet **287** and has two opposite outlet ports **288** and **289** in the shaft **274**. These are opened or blocked by a valve wall **291** on the piston **271** in the usual way. Registering with either one of the ports **288** and **289** is a single exhaust port **292** opening into the sleeve **279** which also has several outlet ports **293** always open through a ring of discharge ports **294** in the shaft **274** into the secondary chamber **296**, as before. A plug **297** precludes further flow through this portion of the sleeve. The construction is repeated for the piston **272** and the piston **273** at the bottom of the tertiary chamber **298**. Exhaust to the atmosphere is through a duct **299** from the outlet chamber **301**.

With the reversing sleeve **279** in one position relative to the shaft **274**, as shown in FIG. 11, the direction of shaft rotation is in one sense, since all of the corresponding ports like port **288** are operable, whereas all of the ports like port **289** are covered and are inoperable. When the reversing sleeve **279** is rotated one-half turn relative the shaft **274**, the port **288** and others like it in the chambers **296** and **298** are covered and the opposite ports **289** and those like it in the secondary and tertiary chambers **296** and **298** become operative. The rotational sense of the shaft **274** is thus reversed.

It is necessary to keep the pistons from rotating within the cylinder and several means are shown for that purpose involving engagement with the cylinder wall. In some cases it is preferred not to involve the cylinder wall nor the piston wall in performing this function. As shown in FIGS. 15 and 16, the construction generally is as previously described but the head end **305** of the cylinder has irregularities **306** engaged by a fitting flange **307** of a retainer shell **308** held in place against rotation and translation by a cap **309**. The semi-cylindrical retainer shell **308** has diametrically opposed sliding ways **311** and **312**.

The primary piston assembly **313** is typical of all the piston assemblies and has an enclosing casing **314** substantially as shown in FIG. 8 except that at one end the casing has an extension **316** on one side to provide sliding ways **317** and **318** abutting the ways **311** and **312**. Thus, while the piston assembly **313** can reciprocate freely in the cylinder, there can be no relative rotation therebetween. Comparably, the assembly **313** has an oppositely disposed extension **319** at the other end engaging an extension **321** on the next piston assembly, and so on. The piston asembly nearest the outlet from the cylinder may or may not have an extension engaging a related extension anchored in the outlet end of the cylinder and substantially duplicating the retainer shell **308**.

In all of the forms of the invention there is provided a displacement engine particularly adapted for use in a dental handpiece and for operation on compressed air. The engines easily afford a range of speeds from 0 to about 10,000 revolutions a minute. There is afforded high torque starting in either direction and very close and ac-

curate speed control with quiet, smooth functioning in a lasting and economical manner.

What is claimed is:

1. A displacement engine especially for dental use comprising a cylinder having an axis and closed at one end, a shaft, means mounting said shaft in said cylinder for rotation about said axis and against displacement along said axis, a piston constrained to reciprocation in said cylinder and along said shaft, means forming a cam surface at the end of said piston opposite said one end, a cam follower in engagement with said surface and fast on said shaft, means for admitting actuating fluid to said cylinder adjacent said one end, means including an exhaust port opening from said shaft into said cylinder adjacent said one end for conducting said fluid from one end of said piston to the other end thereof, and a valve wall on said piston adapted during rotation of said shaft to cover said exhaust port as said piston moves away from said one end and to uncover said port as said piston moves toward said one end.

2. A device as in claim **1** including multiple pistons reciprocable in said cylinder and along said shaft, means forming multiple cam surfaces one adjacent each of said pistons at the end thereof opposite said one end, multiple cam followers each in engagement with a respective one of said cam surfaces, means including multiple exhaust ports opening from said cam surfaces, means including multiple exhaust ports opening from said shaft into said cylinder for conducting said fluid from the corresponding one end of each of said pistons to the corresponding other end thereof, a valve wall on each of said pistons adapted during rotation of said shaft to cover a respective one of said ports as said respective pistons move away from said one end and to uncover said respective one of said ports as said pistons move toward said one end, said ports, said valve walls said cam surfaces and said cam followers associated with each of said pistons being evenly spaced apart around said shaft.

3. A device as in claim **1** including means for precluding relative rotation between said piston and said cylinder.

4. A device as in claim **1** in which said cylinder is of a diameter and length to be readily held in a human hand, a tool-receiving chuck is connected to rotate with said shaft, and said means for admitting actuating fluid is flexible.

5. A device as in claim **1** including means for releasing spent actuating fluid from said cylinder adjacent the other end thereof, and means for alternatively connecting said admitting means or said releasing means to high pressure actuating fluid while simultaneously connecting said releasing means or said admitting means to atmosphere.

6. A device as in claim **1** in which said cam surface has an out-stroke portion of a predetermined length and an in-stroke portion of a different length.

7. A device as in claim **1** in which the out-stroke part of said cam surface has portions in unfavorable driving engagement with said cam follower and has an intervening portion in favorable driving engagement with said cam follower and said valve wall covers said exhaust port only when said can surface has said intervening portion in favorable driving engagement with said cam follower.

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