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(54) **Positive displacement pumps.**

(57) A positive displacement pump having single or twin crews (2) is disclosed in which the screw flights (34,36,38,40) are formed in the outer surfaces thereof with balancing holes (82) which can be filled with material less dense than that of the screw flights which can each be closed by a cap (84) having an outer surface which is flush with the outer surface of the adjoining flight. Also disclosed for the or each screw flight is a wear measuring port (86) in which a measuring device can be inserted to measure relative wear between the corresponding screw flight and the pump casing. Alternatively a proximity sensor (98) can be located in the measuring port so that wear of the corresponding flight can be dynamically sensed during pump operation. Additionally, the provision of wear strips (122) on the outer surface of and of less than half the width of the screw flight are disclosed as is a fluid pressure feedback control system (119) for the or each screw flight which reduces the pressure differential over a part of the discharge end of each flight.

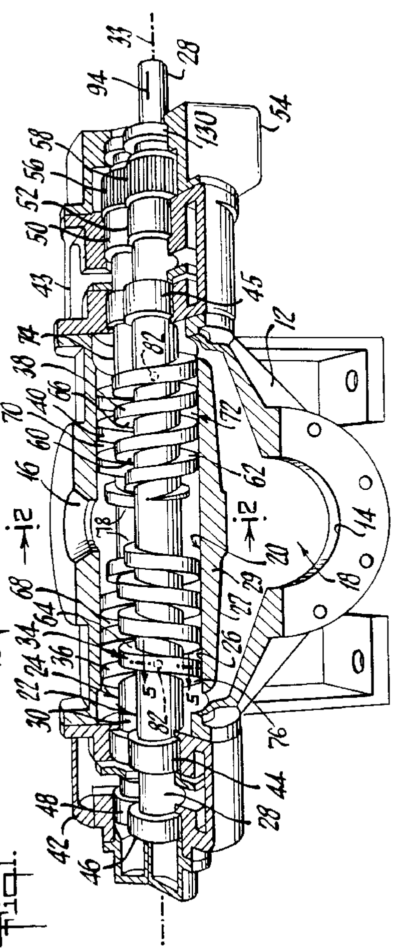

Fig.1.

EP 0 496 170 A2

BACKGROUND OF THE INVENTION

This invention relates to pumps and pumping methods. It especially relates to pumps which are operated at high pump speeds in pumping low viscosity liquids, especially in large volumes.

As used herein, high speed operation of a pump means operation at speeds of at least 500 revolutions per minute (rpm), preferably at least 900 rpm, and most preferably at least 1200 rpm. It is anticipated that pumps disclosed herein can be operated at sustained speeds between about 1500 rpm and about 1900 rpm.

It is known to use positive displacement pumps, having counter-rotating twin screws, for pumping higher viscosity products, such as pastes, creams, oils and the like.

It is known to use pumps which are not generally considered to be positive displacement pumps for pumping low viscosity fluids, such as water at high speed and in large volumes.

In the papermaking art, it is known to use fan pumps for pumping two and three phase media which are part liquid and part gas, for example foamed liquid containing 50 to 80 percent air by volume, which optionally include some solid material. Foamed fiber furnishes containing solid cellulosic fibers for use in papermaking processes are well known as disclosed, for example, in United States Patent 4,443,297 to Cheshire et al, herein incorporated by reference. Pumping of such multi-phase foam media has presented a plurality of problems as the pump speed, the volume of flow, and outlet pressure have been increased. Using conventional fan pumps, the increase in flow volume has not corresponded well with increase in speed of the pump because of the compressibility of the foamed media.

Accordingly, in order to achieve efficient pumping at higher volumes and higher pump speeds, applicants have found it expedient to use a positive displacement pump for pumping such foamed media. Such pumps have conventionally been used for pumping higher viscosity products, generally products which provide some fluid lubricity between the stationary pump casing and the moving impeller (e.g. screw).

An advantage of such positive displacement pumps is that they generally create isolated batches of the media being pumped, isolating the batches essentially at, or near, the inlet pressure, whereby batches of foamed media are susceptible to being pumped from the inlet to the outlet in essentially predictable volume, wherein the volume pumped, as measured at the pump inlet, is essentially linearly related to the speed of operation of the pump.

Applicants have found that, when pumping the above mentioned foamed media at e.g. 900 rpm, the pumping operation creates pressure pulses which are transmitted through the outlet of the pump. Essentially, the fluid in a isolated pumping cell is at a pressure below the outlet pressure of the pump. Upon reaching the outlet, the pressure in the fluid at the outlet suddenly rushes into the open cell and compresses the fluid in the cell. The sudden rushing of the fluid into the newly opened cell causes a rapid, temporary, pressure change at the pump outlet. This pressure change is transmitted out of the pump, through the pump outlet, as a pressure pulse in the fluid in the enclosed pressurized system downstream of the pump.

While such pressure pulses are of little consequence in operations which comprise only transfer of the media, where the output of the pump is intimately connected with the formation of the web in a papermaking process, such pressure pulses directly affect the uniformity of flow of furnish onto the paper-making fabric, and accordingly, the uniformity, in the machine direction, of the paper so made.

Applicants have also found that some conventionally-produced screw type positive displacement pumps experience excessive rates of wear when operated for sustained periods at their rated speed of 900 rpm for pumping the above recited three phase media, containing about 1% to about 4% by weight cellulose fiber. For example, a typical such pump, having a designed clearance of 0.020 inch (0.5 mm.) between the rotating pumping screw and the stationary bore, had a measured clearance of 0.040 inches (1.0 mm.) after sustained operation for only three hours.

It is an object of this invention to provide improved screw pumps which can withstand high speed operation over extended periods of time with substantially reduced wear between the stationary and the rotating members.

It is another object to provide means to measure the wear of the pump parts without disassembling the moving member from the stationary member.

It is a further object to provide means to monitor the wear of the pump parts over time without disassembling the moving member from the stationary member.

It is another object to provide a method of monitoring the wear of the pump parts without disassembling the moving member from the stationary member.

It is still another object to provide pumps which can pump low viscosity fluids at high speed operation with lower amplitude pressure pulses.

It is yet another object to provide pumps which can pump low viscosity fluids at high speed operation with lower rates of change of pressure.

It is still another object to provide a method of pumping low viscosity fluids at high speed operation with lower amplitude pressure pulses.

It is a further object to provide a method of pumping low viscosity fluids at high speed operation with lower rates of changes of pressure.

It is yet another object to provide a method of balancing a screw for a screw pump without increasing the leakage between the higher pressure outlet end of the screw and the lower pressure inlet end of the screw, at the loci of removing material for achievement of balance, or otherwise reducing the pumping capacity of the screw over a typical 360 degree rotation of the screw; and without significantly weakening the screw.

SUMMARY OF THE DISCLOSURE

The present invention consists in a positive displacement pump, comprising an outer casing (12) provided with an inlet (14), an outlet (16) and an internal passage (18) connecting said inlet and said outlet and formed with a bore (20); a pumping screw (22) comprising a shaft (28) and a screw flight (34) secured to and extending along and radially outwardly from said shaft and having an outer surface (32) formed between front and rear surfaces (60, 62) of said flight; and bearings (46,52) supported in said casing and in which said shaft is rotatably mounted so as to extend axially within said bore, said outer surface of said flight being disposed in relation to said bore so that clearance therebetween is sufficiently small to promote efficient pumping of material through said bore by said screw, characterised in that said screw flight is formed with one or more holes (82) therein to reduce any tendency of said screw towards imbalance during operation of the pump.

In one form of the pump of the invention, said casing passage (18) connects with said bore adjacent opposite ends thereof and said outlet connects with said bore at a location substantially midway between said ends thereof and said shaft is provided with two mutually spaced screw flights which extend from respective locations adjacent the ends of said bore towards said location thereof which connects with said outlet and which are adapted in operation to pump fluid from said inlet to said outlet of the casing, said screw flights each being formed with one or more holes (82) therein to reduce any tendency of said screws towards imbalance during operation of the pump.

In another form of the pump of the invention there are provided first and second like pumping screws (22,24) disposed in parallel and rotatably mounted within said bore with the screw flights thereof mutually interleaved, each screw flight having an outer surface (32) formed between front and rear surfaces (60,62) thereof, said outer surface of said flights being disposed in relation to said bore so that clearance therebetweeen is sufficiently small to promote efficient pumping of material through said bore by said screws, and each screw flight is formed with one or more holes (82) therein to reduce any tendency thereof towards imbalance.

The invention further consists in an outer casing provided with an inlet (14), an outlet (16) and an internal passage (18) connecting said inlet andsaid outlet, and formed with a bore (20); a pumping screw (22) comprising a shaft (28) and a screw flight (34) secured to and extending along and radially outwardly from said shaft and having an outer surface (32) formed between front and rear surfaces (60,62) of said flight; and bearings (46,52) supported in said casing and in which said shaft is rotatably mounted so as to extend axially within said bore, said outer surface of said flight being disposed in relation to said bore so that clearance therebetween is sufficiently small to promote efficient pumping of material through said bore by said screw, characterised in that at least one measurement port (86) extends through the casing into the bore and is positioned so that the outer surface (32) of said flight can be disposed opposite said port whereby a measuring device can be manipulated through said port to measure the relative wear of said screw and said bore. Where the pumping screw has respective flights at opposite ends thereof at least one measurement port (86) extends through the casing (12) into the bore adjacent each flight of said pumping screw and is positioned so that the outer surface (32) of each flight can be disposed opposite said port whereby a measuring device can be manipulated through said port to measure the relative wear of said screw and said bore. Further, where the pump is a twin screw pump, at least one measurement port (86) extends through the casing (12) into the bore adjacent each flight of each pumping screw and is positioned so that the outer surface (32) of the corresponding flight can be located opposite thereto, whereby a measuring device can be manipulated through said port to measure the relative wear of said screw and said bore. Instead of a wear measuring device being manipulated through the or each wear measuring port, a proximity sensor is located in the or each wear measurement port to sense wear of the corresponding pumping screw flight, the wear measurement port being closed and sealed sufficiently to allow normal operation of said pump.

The invention further consists in a single or twin screw positive displacement pump in which the outer surface of each screw flight includes an elongated hardened wear strip having a width less than half the width of said outer surface. Advantageously, the width of the or each wear strip increases from the end of the corresponding flight adjacent the inlet of the bore to the opposite end thereof, the width at any given locus being related to the potential amount of wearing contact between the corresponding pumping screw flight and the bore.

The invention also consists in a positive displacement pump comprising an outer casing (12) provided with an inlet (14), an outlet (16) and an internal passage (18) connecting said inlet and said outlet and formed with a bore (20); a pumping screw (22) comprising a shaft (28) and a screw flight (34) secured to and extending along and radially outwardly from said shaft and having an outer surface (32) formed between front and rear surfaces (60, 62) of said flight; and bearings (46,52) supported in said casing and in which said shaft is rotatably mounted so as,to extend axially within said bore, said outer surface of said flight being disposed in relation to said bore so that clearance therebetween is sufficiently small to promote efficient pumping of material through said bore by said screw. Where the pump screw has flights at opposite ends thereof or where twin screws are present, there is provided for each pumping screw flight, a fluid pressure feedback control system (119) comprising a fluid pressure sending port (116) disposed in said casing at the higher pumping fluid pressure end of said pumping screw flight, a fluid pressure receiving port (104) disposed in said casing between opposite ends of said pumping screw flight and a conduit (112) connecting said fluid sending port to said fluid receiving port.

In any of the forms of the invention, the bore of the casing may be progressively increased in cross-sectional area in the direction towards the pump outlet (16) in a portion thereof facing a portion of the discharge end of the or each flight.

The invention further consists in the method of monitoring wear in a positive displacement pump in which a wear measurement port or ports are provided characterised by locating the outer surface of the or each screw flight opposite the corresponding measuring port, inserting a measuring device into said corresponding measuring port and employing said measuring device to measure the wear on the flight surface (32) facing said corresponding measuring port.

The invention also consists in the method of monitoring wear in a positive displacement pump in which a wear measurement port or ports are provided characterised by locating a proximity sensor in the or each measurement port, closing and sealing the or each wear measurement port to allow normal pump operation with said sensor located in the or each measurement port, and monitoring by means of said sensor the wear of the screw flight outer surface opposite said sensor during pump operation by sensing change in the distance between said sensor and the corresponding screw flight outer surface.

The invention further consists in the method of balancing a pumping screw of a positive displacement pump by locating the angular locus of imbalance of the screw about the circumference thereof and removing material at said locus to reduce said imbalance. Preferably, removal of said material is effected by forming a hole or holes (82) in the or each screw at said locus of imbalance which extend inwardly from the outer screw surface (32). Suitably, a cap is formed over the or each hole having an outer surface disposed flush with the adjoining outer screw surface. If desired, the or each hole is filled with material less dense than that of the adjoining screw flight.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 shows a front view of a pump of the invention with portions cut away.

FIGURE 2 shows a transverse cross-section of a portion of the pump, and is taken at 2-2 of FIGURE 1.

FIGURE 3 is a fragmentary cross-section showing an alternative combination of bore and screw, to achieve reduced pressure pulsation effect.

FIGURE 4 shows a fragmentary cross-section including a dynamic control system adapted to reducing pressure pulsation by providing control apparatus for controlling the amount of pressure leakage, from the screw outlet area back toward the screw inlet ends.

FIGURE 5 shows a cross-section of a balancing hole and is taken at 5-5 of FIGURE 1.

FIGURES 6 and 7 show fragmentary cross-sections of the screw and illustrate the wear strips on the screw.

FIGURE 8 is a view of the right side of the pump of FIGURE 1, showing wear strip variation with respect to position on the screw.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

Turning now to FIGURES 1 to 4,: a pump 10 has an outer casing 12, including an inlet 14, an outlet 16, and internal passages generally designated 18, traversing the casing 12 between inlet 14 and outlet 16. Internal passages 18 include a bore 20 adapted to receive therein a pair of pumping screws 22 and 24. The cross-section of bore 20, and thus the space defined therein, is defined at any given point along its length by an inner surface 26. The bore 20 further comprises an outer surface 27, and a wall 29 between inner and outer surfaces 26 and 27.

Pumping screws 22 and 24 comprise minor circumferences defined by shafts 28 and 30 respectively. Each shaft has a longitudinal axis 33 extending along the length thereof. Screws 22, 24, further comprise major circumferences 31 defined by the outer surfaces 32, see Figure 6, of helical screw flights 34, 36, 38, and 40, at the maximum circumferences of those flights. In the embodiments illustrated, each shaft has an attached pair of flights disposed toward opposing ends thereof.

Stuffing boxes 42 and 43 are attached to opposing ends of outer casing 12 and contain stuffing seals 44 and 45. The stuffing boxes 42 and 43 support screws 22 and 24 on bearings 46, 48, 50, and 52, the seals 44 and 45 being disposed between the bearings and the pumping chamber which is generally defined by internal passages 18. The bearings and seals can, of course, be reversed in position for use in pumping material which is adapted to lubricate the bearings.

A gear box 54 is mounted to the right end of the right stuffing box 43 and houses gears 56 and 58 which are preferably integral parts of the respective screws 22, 24 as illustrated. Gears 56, 58 are arranged with the teeth of gear 56 meshed with those of gear 58 such that the rotation of shaft 28, by a motor or other prime mover(not shown), causes counter-rotation of the screws 22, 24 whereby one of screws 22, 24 rotates clockwise and the other screw rotates counter-clockwise.

Each of the screw flights extends radially and longitudinally about the respective shaft, and extends outwardly from the shaft to the outer surface 32 of the respective shaft. Each flight comprises a front surface 60 disposed toward outlet 16 and a rear surface 62 disposed away from outlet 16, front and rear surfaces 60 and 62 defining the thickness of the respective flight therebetween at any point along the length of the respective flight. At any point along a given flight, the flight has a height "H" as measured between the respective shaft 28 or 30 and the respective outer surface 32.

Pumping cell spaces 64 and 66 are defined between facing portions of the front and rear surfaces of respective flights 34 and 38, between the shaft 28 and the outer surfaces 32 of the flights 34 and 38. Pumping cell spaces 68 and 70 are defined between facing front and rear surfaces of respective flights 36 and 40, between the shaft 30 and the outer surfaces 32 of flights 36 and 40.

As seen by the combined teachings of FIGURES 1, 2 and 4, the flights 34, 36, 38, and 40 of the screws 22, 24 are meshed between shafts 28, 30, by the design and positioning of the screws, such that the flights 34, 38 on screw 22 reach into the pumping cell spaces 68, 70 on screw 24, essentially closing off the cell spaces 68, 70 between the shafts 28 and 30. Similarly flights 36, 40 on screw 24 reach into the pumping cell spaces 64, 66 on screw 22, essentially closing off the cell spaces 64, 66 between shafts 28 and 30. The thicknesses of the flights and the spacing of the corresponding front and rear surfaces (the width "W" of the cell spaces) on the adjacent flights cooperate such that the clearances between the flights at the meshed screws are small enough that the flight of one screw serves as an effective closure of the cell spaces of the opposing screw at the loci where the screws are meshed between their shafts.

The clearances between the outer surfaces 32 of the respective flights and the bore 20 are small enough, and comprise enough length of bore 20, to promote efficient pumping of a low viscosity material, such as water, a foamed liquid containing, (e.g. 50% to 80% air by volume,) and the same media when including papermaking fibers dispersed therein. Typical clearances are between about 0.02 and about 0.04 inch (about 0.5 to about 1.0 mm.). The typical seat clearance is normally effective over at least one turn of each flight, thereby effectively isolating the inlet end of the flight from the outlet pressure at the outlet and of the flight.

The closure of the pumping cell spaces 64, 66, 68, and 70 by the meshing of the screws between shafts 28 and 30 creates at least one, and preferably a plurality of isolated and distinct pumping cells 72 at each flight on each screw. Each pumping cell 72 is defined within a pumping cell space, (e.g. 64) between facing front and rear surface portions 60, 62 between the respective shaft (e.g. 28) and the adjacent inner surface 26 of the bore 20, about generally one turn of the pumping cell space (e.g. 64) between consecutive extensions of the opposing flight (e.g. 36) into the pumping cell at the locus of meshing of the screws. Accordingly, each pumping cell extends approximately one turn (a bit less) about the shaft between adjacent turns of the corresponding flight. The cell has a beginning and an end where the screws are meshed. Accordingly, the pumping cell is isolated from the inlet, from the outlet, and from the other cells. Upon turning of the screw (e.g. 22) in the pumping direction, the pumping cells are advanced along the screw toward the outlet 16 at the center of screw 22.

The portions 74 of the screws which are in internal passages 18 comprise the portions between the seals 44 and 45. The portions 74 include first lengths over which the screws and the bore are coextensive (inside bore 20) and second lengths between bore 20 and the respective seals 44, 45.

Each screw flight 34, 36, 38, 40 begins at an inlet end 76 disposed toward the respective stuffing seal 44 or 45 and ends at an outlet end 78 disposed toward outlet 16. Inlet end 76 of the flights may, and preferably does, extend at least part of the distance between bore 20 and seals 44, 45. Outlet end 78 is preferably configured as in FIGURES 1 and 2, to reduce the pressure pulses in the pumped fluid. The clearance between the outer surface 32 of the flight and the inner surface 26 of the bore may be increased to the outlet end 78 of the flight over a portion of the coexistent length of the bore and the screw along the longitudinal axis of the shaft of the respective screw.

The embodiment illustrated in FIGURES 1 and 2 shows an increase in the clearance between the outer surface of the flight, at outlet end 78, and the inner surface 26 of the bore, over a full turn of 360 degrees of the flight on the shaft (FIGURE 2).

The progressive increase in the clearance between the outer surface 32 of the flight and the inner surface 26 of the bore represents a progressive (gradual) opening of the pumping cell to the operating pressure at the outlet 16 of the pump, whereby the pulsating effect of the opening of the cell is spread over a longer period of time than if the height of the flight came to an end, from its full height at the major circumference, over a shorter distance during high speed operation of the pump, which can develop about 50 psi pressure difference between the pump outlet and the pump inlet even at the lower speed of 900 rpm when pumping paper making furnishes based on water or foamed liquid as herein disclosed.

The provision of the progressive increase in clearance is illustrated in FIGURES 1 and 2 as a progressive decrease in height "H" of the screw flights at the outlet ends 78 of the flights, the size of the bore 20 being kept constant. FIGURE 3 illustrates another method of achieving the increase in clearance, namely an increase in the cross-section of bore 20 adjacent the outlet end of the flight, while the height "H" of the flight is maintained constant to outlet end 78, in accordance with the respective major circumference 31, or is tapered in height over a relatively shorter distance.

Both changes may, of course, be made, whereby the height of the flight is progressively reduced and the cross-section of the bore is changed (increase or decrease) to accommodate the desired rate of change in the clearance.

At the higher speeds of operation contemplated for the pumps of this invention, any imbalance in the screws will be evidenced by vibration and wear in the screws and bores of the pump. Accordingly the screws are preferably balanced. The balancing is accomplished by defining the angle of imbalance (the radial angle about the shaft whereat the screw is heavy) and removing an appropriate amount of material from the flights, to reduce that imbalance, at the appropriate radial angle, at locations, and in such ways, that the instantaneous efficiency of the ongoing pumping operation will not be reduced.

Preferred locations for removing material are shown in FIGURE 1. Hidden holes 82 are located at distances approximately 25% (and respectively 75%) of the distance between the bearings 46, 52, whereby they reduce the tendency of the screw to set up a standing one-cycle sine wave vibration. Holes 82 are generally made by removing the calculated amount of material with a drill. As illustrated in FIGURE 5, the holes 82 are preferably capped with a cap 84 which is welded in place over the hole, after which the cap 84 is machined or ground flush so that it becomes an integral part of the outer surface 32 of the flight. Accordingly, the balancing holes 82 do not penetrate outer surface 32, and thus have no effect on the ability of the outer surface 32 to create isolated pumping cells with appropriate control of fluid leakage between outer surface 32 and inner surface 26 of bore 20. The balancing holes can be plugged with material of lower density than that of the flight in which they are made.

As seen in FIGURE 2, wear measurement ports 86 extend through outer casing 12, from inner ends 88 thereof at inner surface 26 to outer ends 90 thereof at the outside surface of the pump. Ports 86 have longitudinal axes 87, and are closed by removable plugs 92 which maintain the seal of the pump during normal pump operation. The simplest plug 92 (left side in FIGURE 2) is typically threaded, and is removed when the pump is out of service, whereupon a measuring tool is manipulated through the port 86 and against the outer surface 32 of the respective flight. For such use, it is necessary that the screw be positioned such that the outer surface 32 is aligned with the hole 86, between hole 86 and the shaft of the screw. Preferably the shaft 28 and the outside of the gear box, or other appropriate stationary surface, are marked at matching locations thereof, as at 94 on shaft 28, such that alignment of mark 94 on shaft 28 with the matching mark on the outside surface of the gear box brings the outer surfaces 32 of the flights into alignment with the wear measurement ports 86 which are so used.

The port 86 indicated on the right side of FIGURE 2 is closed by a plug 96 which includes a dynamic proximity sensor 98, connected by signal carrier 100 (e.g. wire cable) to a monitoring device 102. Plug 96 is in place in port 86 while the pump is in operation. Upon each rotation of the respective screw, the outer surface 32 passes proximity sensor 98 whereupon a discreet signal is sent to monitor 102, which provides for monitoring of the wear of the pump while the pump is in operation. An acceptable proximity transducer system, including proximity sensor 98 and monitor 102 is the 7200 Proximitor, available from Kaman Instrumentation Corporation, Colorado Springs, Colorado.

With such constant input of information from the proximity sensor, it is now possible to record the proximity as sensed over a period of time, and thereby to detect changes in the proximity, which indicate wear or imminent failure of the pump before the event occurs, whereupon the complex papermaking process (or other process) can be shut down in an orderly manner, and indeed such maintenance, repair, or rebuild can be efficiently planned.

Referring now to FIGURE 4, there is shown therein a fluid pressure feedback control system comprising fluid pressure receiving ports 104, pipes 106, valves 108, manifold 110, pipe 112, and fluid sending port 116. Fluid pressure receiving ports 104 are similar to wear measurement ports 86 in that they extend through wall 27 of bore 20 to the inner surface 26 of the bore. Ports 104 are typically spaced such that any plurality of fluid pressure receiving ports 104 open into different pumping cells. Ports 104 are connected by pipes 106, through valves 108 and manifold 110 to pipe 112 which is in fluid communication with the high pressure portion 114 of bore 20, through fluid pressure sending port 116. By manipulating valves 108, fluid at the outlet pressure of the pump can be controllably and adjustably fed back into the pumping cells, as indicated at pressure gauges 118, whereby the pressure differential between the high pressure portion 114 and the next opening one of the cells can be reduced by building the pressure in the cell before it is fully opened to the outlet pressure at the outlet end of the flight.

Similarly, the higher pressure fluid, and thus the fluid pressure, can also be fed by way of manifold 110, and the respective valve 108, to any or each of the pressure receiving ports 104. The pressure in the respective pumping cells (e.g. 64) can thus be controlled, and increased progressively in a given cell as the fluid traverses the length of the flight, such that the pressure change experienced by the fluid in a cell when the cell opens at outlet end 78 is controlled, and the pressure change upon opening of the cell to the outlet pressure can be minimized when desired. And as the pressure change at flight outlet end 78 is reduced, the pressure pulses associated with that pressure change are also reduced, whereby the vibration and resonance caused, in the downstream piping, by such pressure pulses, is reduced. Thus, the pressure feedback control system 119 illustrated in FIGURE 4 can be effective to reduce the fluid stress, especially the vibration and resonance stress, on the pump and on the piping and other apparatus which is subjected to the output pressure of the pump downstream from the pump.

One pressure feedback system 119 is shown in FIGURE 4, for controlling the pressure along flight 34, it being understood that a similar feedback control system is used for each flight in the pump (e.g. 36, 38, and 40).

The resonance, vibration, etc., in the operating system of which the pump is a part, as set up by high speed operation of the several components thereof, can be somewhat accommodated by manipulating the valves 108 to change the intensity and duration of pressure pulses produced by pump 10 in order to provide a dynamic control capability in the dynamic vibration and resonance environment. Further, as vibration and resonance change in the operating system (e.g. in response to changes in pump speed), the control valves can be manipulated to provide the changed optimum amounts of fluid and pressure feedback.

While the pumps of this invention are designed to operate with a clearance of e.g. 0.02 inches (0.5 mm.) between the screws 22, 24 and the bore 20, wherein the screws 22, 24 are supported by bearings 46, 48, 50, 52 near opposing ends thereof, and whereby the screws should never touch the inner surface 26 of bore 20, in actual practice, such touching does occur, in part due to vibration and resonance. In addition, the pumps which applicants contemplate using in paper making processes are large, e.g. major and minor circumferences of 50 inches (127 cm.) and 25 inches (63. 5 cm.) respectively, and unsupported distances between bearings 46, 48 and bearings 50, 52, of over 10 feet (3.05m). A variety of forces apply bending moments on screws 22, 24. For example, the mass of the material in screws 22, 24 encourages a certain amount of sag, in response to gravity, in the middles of the screws, midway between the supporting bearings, centering around the locus of outlet 16. This sag contributes to eccentric rotation of the screw. As the screws rotate, they set up resonance vibrations that contribute to eccentricity of the rotation. Also, as taught in United States Patent 2,463,460, the screws tend to shift toward the discharge opening, in a direction transverse to the lengths of the shafts 28, 30, when the pump is operated.

With such forces being applied to the screws 22, 24, the screws do experience some contact between the outer surfaces 32 of the flights and the inner surface 26 of bore 20. The momentum of the impacting contact is, of course, related to the mass of the respective screw and the velocity of the respective movement. Accordingly, outer surface 32 is effectively hardened to reduce the wear of the screw. The hardenings preferred for screws 22, 24 are illustrated in FIGURES 6-8.

In FIGURE 6, a groove 120 is cut along the middle of outer surface 32 of the flight, and is filled with a wear hard material 122 such as tungsten carbide or stellite. The wear hard material 122 is mechanically locked in place, against movement in a direction transverse to the longitudinal axis of the shaft 22, by the overlying material at wedge 128. Hard material 122 can be applied, as conventional, with a plasma arc. However, inserting a pre-formed strand of material 122 into a groove 120 is preferred, followed by locking the hard material in place by modest deformation of the surrounding material to secure the lock at wedge 128.

Since substantially less than half of the thickness, overall, of the outer surface 32 of the- flight is occupied by the hard material 122, the cost and difficultly of finish grinding outer surface 32, to form a unitary and uniform surface as shown, is commensurately reduced as compared to finish grinding the surface after applying hardening material over the entire width of outer surface 32. The mechanical locking at wedge 128 enables the use of a less expensive preformed strip of hard material rather than the conventional more expensive hot melted spray application of hard material as at 43 in United States Patent 3,841,805.

Alternative loci and orientations of attachment are shown in FIGURE 7, wherein the hard material 122 is shown at the leading and trailing edges 126 and 124 respectively of the outer surface 32, and can be at either or both edges, leading edge preferred. At leading edge 126, the wear hard material 122 is mechanically locked in place, against movement in directions both transverse to the longitudinal axis of the shaft 22 and parallel to the longitudinal axis of the shaft, by the overlying material at wedge 128, similar to the mechanical locking illustrated in FIGURE 6. In FIGURE 6, approximately half of the hard material 122 will be worn away by the time the mechanical locks of the corresponding wedges 128 are worn away. Similarly, a significant amount of material 122 will be worn away at leading edge 126 before the mechanical locks of the respective wedges 128 are worn away there.

FIGURE 8 illustrates varying the width of the hard material 122 along the length of the flight, according to the probable rate of wear at any given locus on the screw. Since the greatest moment arm in the screws is adjacent the outlet, the probabilities for wear are greatest adjacent outlet 16, and become rather progressively less when one moves in the directions toward the supporting bearings. Accordingly, at the outlet ends 78 of the flights 38, 40 the entire outer surfaces 32 thereat are surfaced with hard material 122. As one progresses along flights 38, 40 toward their inlet ends, the fractions of the surfaces 32 which are occupied by the wear hard material 122 become progressively smaller as shown in FIGURE 8.

As described above, the pumps of this invention are improved by incorporation of a variety of modifications, each of which can be used alone, or in any combination with the others. Preferably, all the improvements are incorporated into a given pump whereby the cumulative benefits thereof are obtained. Such pumps are improved by introducing some of the fluid at the outlet pressure to an isolated pumping cell prior to completely opening the cell to the outlet pressure, as illustrated in FIGURES 1-4. They are improved by balancing the screws as illustrated in FIGURES 1 and 5, by careful selection of the locus of the balancing holes as illustrated FIGURE 1, and by capping, and grinding smooth the caps on the balancing holes as seen in FIGURES 1 and 5. They are improved by providing sensors and monitors to sense and monitor screw wear. They are improved by providing pressure feedback control system 119 which allows dynamic control of the pumping pressure in the isolated pumping cells 72.

Typical materials contemplated to be pumped by pumps of this invention are low viscosity fluids such as water and compositions containing a substantial amount of water. Other materials could, of course, be pumped. A preferred material is a foamed fiber furnish for paper making as disclosed in United States Patent 4,443,297 Cheshire et al. Suitable papermaking foamed fiber furnishes contain from about 50 to about 80 percent air by volume. The overall liquid medium contains about 200 to about 300 ppm surfactant, such as the surfactant sold under the trade name A-OK by Arco Chemicals, Inc. Papermaking fiber is dispersed in the foam at a concentration up to about 2% to about 3% by weight.

In the pumping operation, a prime mover such as an electric motor, is coupled with shaft 28 of screw 22 at the right end of the pump (FIGURE 1). As the motor rotates shaft 28, the entire screw 22, including flights 34 and 38, rotates, and is supported for rotation in bearings 46, 52, as well as end bearing 130. As screw 22 rotates, engaged gears 56, 58 cause simultaneous rotation of shaft 24 in the opposite direction. Each of the flights 34, 36, 38, 40, are pitched such that the rotation of the respective screw causes material, which is entrapped in pumping cells defined by the flights of the respective screws, to be advanced, in the respective pumping cells, toward the outlet ends 78 of the respective flights, and accordingly, toward the outlet 16 of the pump 10.

Material to be pumped (e.g. three phase foamed fiber furnish) enters the pump at inlet 14 and follows divergent paths to opposing inlet ends 76 of the flights on opposing ends of bore 20. As the screws turn, the material is drawn into bore 20 by the turning screws. As the material enters bore 20, individual units of the material are entrapped in pumping cells 72, where they are isolated from the inlet, from the outlet, and from each other. The isolation is, of course, violated in small part by the ordinary leakage tolerated by the small clearances between the several respective parts of the pump. Continued turning of the screws causes advancement of the pumping cells, and accordingly the liquid entrapped therein, toward the outlet ends 78 of the flight, and ultimately out of the pump at outlet 16.

While the pumps of this invention have been described with respect to pumping water and aqueous foamed liquid dispersions at contemplated conditions, they can clearly be used with other pumpable materials and at other pumping conditions.

Whilst the improvements disclosed herein have been described with reference to a twin-screw positive displacement pump, it will be apparent to those skilled in the art that the provision of balancing holes in the pump screw flights and the method of balancing the pump screw flights would also be appreciable to single screw pumps provided either with a single screw flight or with screw flights at respective opposite ends of the screw. The provision of a wear measuring port as described herein for the or each screw flight of such single screw pumps would also be possible as would be the use in such ports of proximity sensors as described. Likewise the provision of hardened wearing strips and fluid pressure feedback control systems as described herein for the or each of screw flights of the above-mentioned single screw pumps.

Claims

1. A positive displacement pump, comprising an outer casing (12) provided with an inlet (14), an outlet (16) and an internal passage (18) connect-

ing said inlet and said outlet and formed with a bore (20); a pumping screw (22) comprising a shaft (28) and a screw flight (34) secured to and extending along and radially outwardly from said shaft and having an outer surface (32) formed between front and rear surfaces (60, 62) of said flight; and bearings (46,52) supported in said casing and in which said shaft is rotatably mounted so as to extend axially within said bore, said outer surface of said flight being disposed in relation to said bore so that clearance therebetween is sufficiently small to promote efficient pumping of material through said bore by said screw, characterised in that said screw flight is formed with one or more holes (82) therein to reduce any tendency of said screw towards imbalance during operation of the pump.

2. A pump as claimed in Claim 1 and in which said casing passage (18) connects with said bore adjacent opposite ends thereof and said outlet connects with said bore at a location substantially midway between said ends thereof and said shaft is provided with two mutually spaced screw flights which extend from respective locations adjacent the ends of said bore towards said location thereof which connects with said outlet and which are adapted in operation to pump fluid from said inlet to said outlet of the casing, characterised in that said screw flights are each formed with one or more holes (82) therein to reduce any tendency of said screws towards imbalance during operation of the pump.

3. A pump as claimed in Claim 1 or Claim 2, and having first and second like pumping screws (22,24) disposed in parallel and rotatably mounted within said bore with the screw flights thereof mutually interleaved, each screw flight having an outer surface (32) formed between front and rear surfaces (60,62) thereof, said outer surface of said flights being disposed in relation to said bore so that clearance therebetweeen is sufficiently small to promote efficient pumping of material through said bore by said screws, characterised in that each screw flight is formed with one or more holes (82) therein to reduce any tendency thereof towards imbalance.

4. A pump as claimed in any one of Claims 1 to 3, characterised in that said balancing hole or holes are disposed at locations on said flights adjacent the or each corresponding inlet to said bore.

5. A pump as claimed in any preceding claim, characterised in that the entrance to the or each balancing hole is located on said outer surfaces of said flights, and is spaced from said front and rear surfaces sufficient distances that said holes cause no significant reduction in pumping capacity of material to be pumped.

6. A positive displacement pump as claimed in any preceding claim, characterised in that balancing holes are plugged with material having a density less than the average density of the adjoining flights.

7. A pump as claimed in any preceding claim, characterised in that each balancing hole is capped with material (84) having an outer surface which is flush with the outer surface (32) of the corresponding flight.

8. A positive displacement pump comprising an outer casing (12) provided with an inlet (14), an outlet (16) and an internal passage (18) connecting said inlet and said outlet, and formed with a bore (20); a pumping screw (22) comprising a shaft (28) and a screw flight (34) secured to and extending along and radially outwardly from said shaft and having an outer surface (32) formed between front and rear surfaces (60,62) of said flight; and bearings (46,52) supported in said casing and in which said shaft is rotatably mounted so as to extend axially within said bore, said outer surface of said flight being disposed in relation to said bore so that clearance therebetween is sufficiently small to promote efficient pumping of material through said bore by said screw, characterised in that at least one measurement port (86) extends through the casing into the bore and is positioned so that the outer surface (32) of said flight can be disposed opposite said port whereby a measuring device can be manipulated through said port to measure the relative wear of said screw and said bore.

9. A pump as claimed in Claim 8 and in which said casing passage (18) connects with said bore adjacent opposite ends thereof and said outlet connects with said bore at a location substantially midway between said ends thereof and said shaft is provided with two mutually spaced screw flights which extend from respective locations adjacent the ends of said bore towards said location thereof which connects with said outlet and which are adapted in operation to pump fluid from said inlet to said outlet of the casing, characterised in that at least one measurement port (86) extends through the casing (12) into the bore adjacent each flight of said pumping screw and is positioned so that the outer surface (32) of each flight can be disposed opposite said port whereby a measuring device can be manipulated through said port to measure the relative wear of said

screw and said bore.

10. A pump as claimed in Claim 8 and having first and second like pumping screws (22,24) disposed in parallel and rotatably mounted within said bore with the screw flights thereof mutually interleaved, each screw flight having an outer surface (32) formed between front and rear surfaces (60,62) thereof, said outer surface of said flights being disposed in relation to said bore so that clearance therebetween is sufficiently small to promote efficient pumping of material through said bore by said screws, characterised in that at least one measurement port (86) extends through the casing (12) into the bore adjacent each flight of each pumping screw and is positioned so that the outer surface (32) of the corresponding flight can be located opposite thereto, whereby a measuring device can be manipulated through said port to measure the relative wear of said screw and said bore.

11. A pump as claimed in any one of Claims 8 to 10, characterised in that a proximity sensor (98) is located in the or each wear measurement port to sense wear of the corresponding pumping screw flight, the wear measurement port being closed and sealed sufficiently to allow normal operation of said pump.

12. A pump as claimed in Claim 11, characterised in that means (100) extend from said proximity sensor for transmitting a signal generated by said proximity sensor to monitoring device means (102) for monitoring signals transmitted from said proximity sensor through said signal transmitting means during routine operation of said pump.

13. A positive displacement pump, comprising an outer casing (12) provided with an inlet (14), an outlet (16) and an internal passage (18) connecting said inlet and said outlet and formed with a bore (20); a pumping screw (22) comprising a shaft (28) and a screw flight (34) secured to and extending along and radially outwardly from said shaft and having an outer surface (32) formed between front and rear surfaces (60, 62) of said flight; and bearings (46,52) supported in said casing and in which said shaft is rotatably mounted so as to extend axially within said bore, said outer surface of said flight being disposed in relation to said bore so that clearance therebetween is sufficiently small to promote efficient pumping of material through said bore by said screw, characterised in that said outer surface (32) of said flight includes an elongate hardened wear strip (122) having a width less than half the width of said outer surface.

14. A pump as claimed in Claim 13 and in which said casing passage (18) connects with said bore adjacent opposite ends thereof and said outlet connects with said bore at a location substantially midway between said ends thereof and said shaft is provided with two mutually spaced screw flights which extend from respective locations adjacent the ends of said bore towards said location thereof which connects with said outlet and which are adapted in operation to pump fluid from said inlet to said outlet of the casing, characterised in that said outer surface (32) of each of said flights includes an elongate hardened wear strip (122) having a width less than half the width of said outer surface.

15. A pump as claimed in Claim 13 or 14 and having first and second like pumping screws (22,24) disposed in parallel and rotatably mounted within said bore with the screw flights thereof mutually interleaved, each screw flight having an outer surface (32) formed between front and rear surfaces (60,62) thereof, said outer surface of said flights being disposed in relation to said bore so that clearance therebetween is sufficiently small to promote efficient pumping of material through said bore by said screws, characterised in that said outer surface (32) of each of said flights includes an elongate hardened wear strip (122) having a width less than half the width of said outer surface.

16. A pump as claimed in any one of Claims 13 to 15, characterised in that the width of the or each wear strip increases from the end of the corresponding flight adjacent the inlet of the bore to the opposite end thereof, the width at any given locus being related to the potential amount of wearing contact between the corresponding pumping screw flight and the bore.

17. A pump as claimed in any one of Claims 13 to 16, characterised in that portions of each of said wear strips (122) are overlain by softer material (128) comprising the main body of the corresponding pumping screw, said overlying softer material being adapted to hold said wear strip against movement out of the adjoining screw flight in a direction perpendicular to the longitudinal axis of the corresponding pumping screw both before and after initial wear of said wear strip at the surface thereof corresponding to said outer surface (32) of said screw.

18. A positive displacement pump comprising an outer casing (12) provided with an inlet (14), an outlet (16) and an internal passage (18) connecting said inlet and said outlet and formed with a bore (20); a pumping screw (22) comprising a shaft (28) and a screw flight (34) secured to and extending along and radially outwardly from said shaft and having an outer surface (32) formed between front and rear surfaces (60, 62) of said flight; and bearings (46,52) supported in said casing and in which said shaft is rotatably mounted so as to extend axially within said bore, said outer surface of said flight being disposed in relation to said bore so that clearance therebetween is sufficiently small to promote efficient pumping of material through said bore by said screw, characterised in that there is provided a fluid pressure feedback control system (119) comprising a fluid pressure sending port (116) disposed in said casing at the higher pumping fluid pressure end of said pumping screw flight, a fluid pressure receiving port (104) disposed in said casing between opposite ends of said pumping screw flight and a conduit (112) connecting said fluid sending port to said fluid receiving port.

19. A pump as claimed in Claim 18 and in which said casing passage (18) connects with said bore adjacent opposite ends thereof and said outlet connects with said bore at a location substantially midway between said ends thereof and said shaft is provided with two mutually spaced screw flights which extend from respective locations adjacent the ends of said bore towards said location thereof which connects with said outlet and which are adapted in operation to pump fluid from said inlet to said outlet of the casing, characterised in that for each pumping screw flight there is provided a fluid pressure feedback control system (119) comprising a fluid pressure sending port (116) disposed in said casing at the higher pumping fluid pressure end of said pumping screw flight, a fluid pressure receiving port (104) disposed in said casing between opposite ends of said pumping screw flight and a conduit (112) connecting said fluid sending port to said fluid receiving port.

20. A pump as claimed in Claim 18 and having first and second like pumping screws (22,24) disposed in parallel and rotatably mounted within said bore with the screw flights thereof mutually interleaved, each screw flight having an outer surface (32) formed between front and rear surfaces (60,62) thereof, said outer surface of said flights being disposed in relation to said bore so that clearance therebetweeen is sufficiently small to promote efficient pumping of material through said bore by said screws, characterised in that for each pumping screw flight there is provided a fluid pressure feedback control system (119) comprising a fluid pressure sending port (116) disposed in said casing at the higher pumping fluid pressure end of said pumping screw flight, a fluid pressure receiving port (104) disposed in said casing between opposite ends of said pumping screw flight and a conduit (112) connecting said fluid sending port to said fluid receiving port.

21. A screw pump as claimed in any one of Claims 18 to 20, characterised in that in the or each control system there are provided valve means (108) adapted to control flow of fluid through said conduit (112) between said sending port (116) and said receiving port (104).

22. A pump as claimed in Claim 21, characterised in that in the or each control system there are provided a plurality of receiving ports (104) spaced so that respective portions of the corresponding flight are disposed between successive of said receiving ports, conduits connecting said receiving ports to said sending port; and valve means (108) adapted to distribute flow of fluid from said sending port among said receiving ports, said valve means being adapted to control the pressure at each of said receiving ports whereby pressure in the fluid being pumped can be increased progressively during traverse along the length of the corresponding flight such that the pressure change experienced by the fluid upon discharge thereof from said flight is substantially less than the pressure differential between said pump outlet and said end of said screw which receives fluid being pumped from said pump inlet.

23. A pump as claimed in any preceding claim, characterised in that the bore (20) in the casing of the pump is progressively increased in cross-sectional area in the direction towards the pump outlet (16) in a portion thereof facing a portion of the discharge end of the or each flight.

24. The method of monitoring wear in a positive displacement pump of the form claimed in any one of Claims 8 to 10, characterised by locating said outer surface (32) of the or each screw flight opposite the corresponding measuring port, inserting a measuring device into said corresponding measuring port and employing said measuring device to measure the wear on the flight surface (32) facing said corresponding measuring port.

25. The method of monitoring wear in a positive displacement pump as claimed in Claim 11, characterised by locating a proximity sensor in the or each measurement port, closing and sealing the or each wear measurement port to allow normal pump operation with said sensor located in the or each measurement port, and monitoring by means of said sensor the wear of the screw flight outer surface opposite said sensor during pump operation by sensing change in the distance between said sensor and the corresponding screw flight outer surface.

26. The method of balancing a pumping screw of a positive displacement pump as claimed in any of Claims 1 to 3, characterised by locating the angular locus of imbalance of the or each screw about the circumference thereof and removing material at said locus to reduce said imbalance.

27. The method claimed in Claim 26, characterised by removing said material by forming a hole or holes (82) in the or each screw at said locus of imbalance which extend inwardly from the outer screw surface (32).

28. The method claimed in Claim 27, characterised by forming a cap (84) over the or each hole having an outer surface disposed flush with the adjoining outer screw surface.

29. The method claimed in Claim 27 or 28, characterised by filling the or each hole with material less dense than that of the adjoining screw flight.

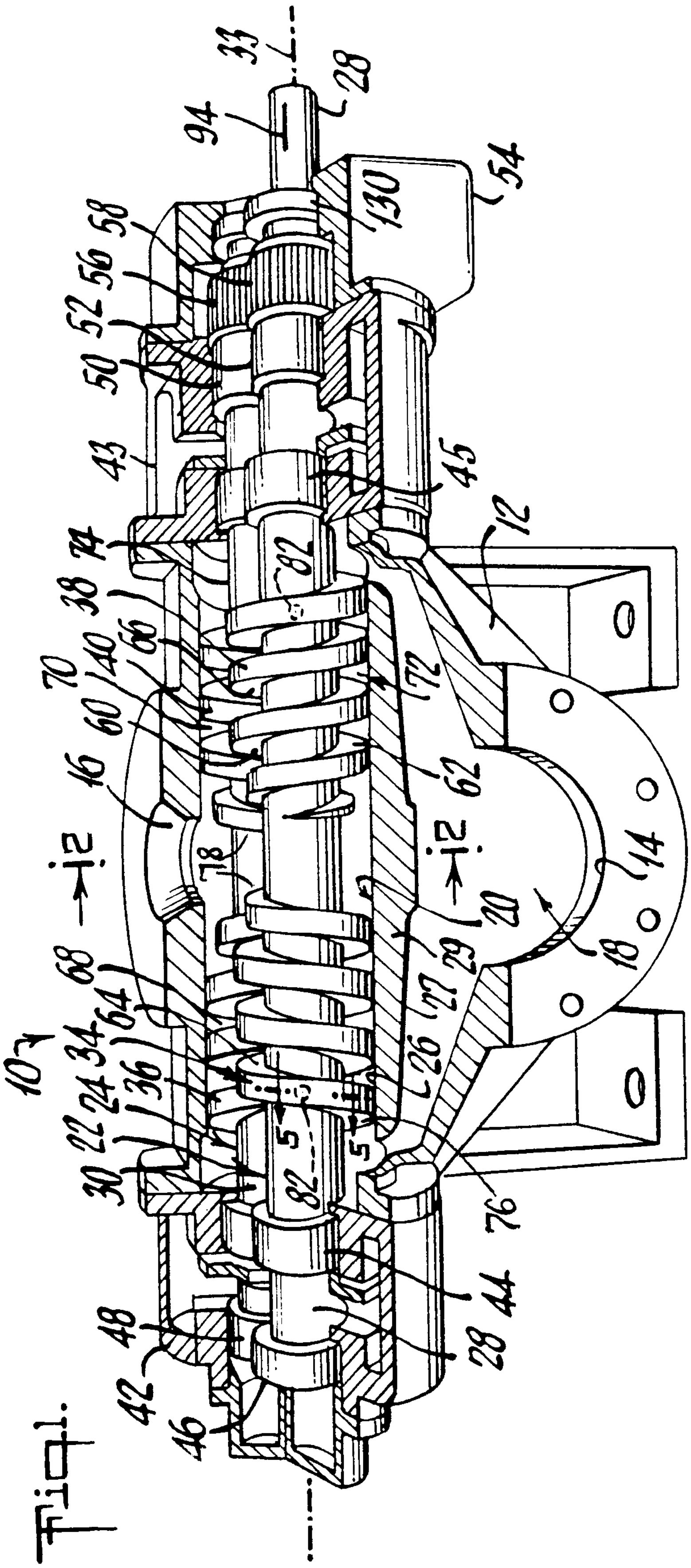
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Fig.1.

Fig.2.

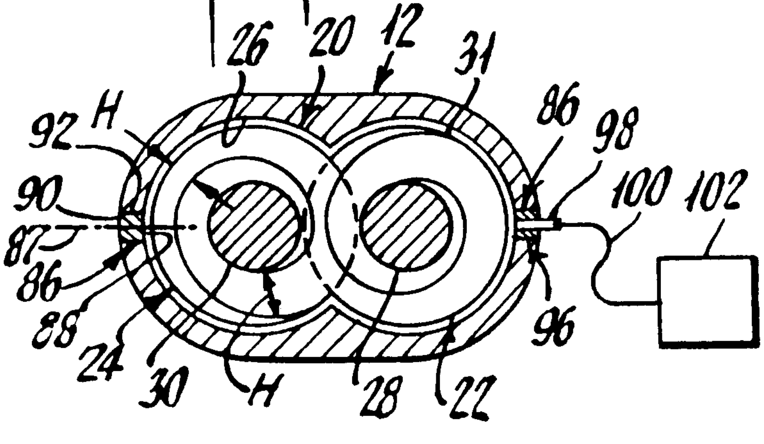


Fig.3.

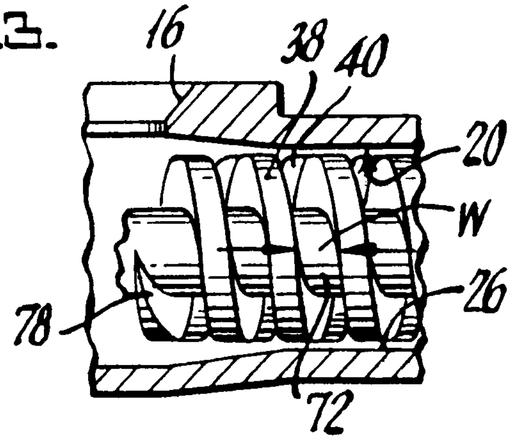
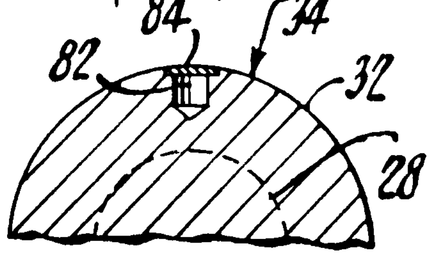


Fig.5.



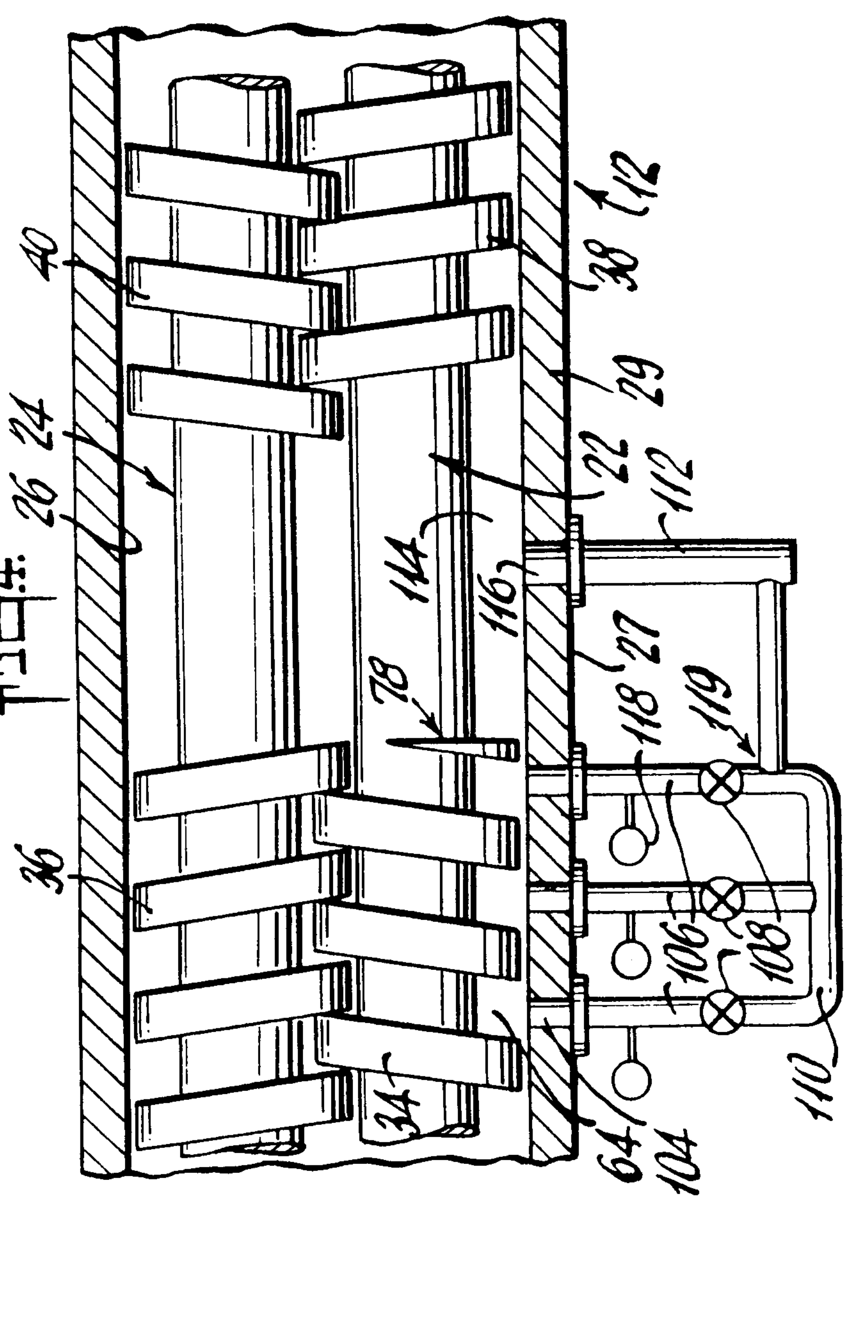

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Fig.4.

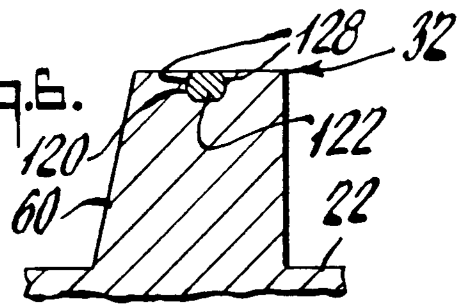

Fig.6.

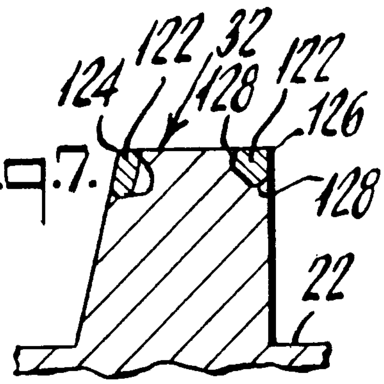

Fig.7.

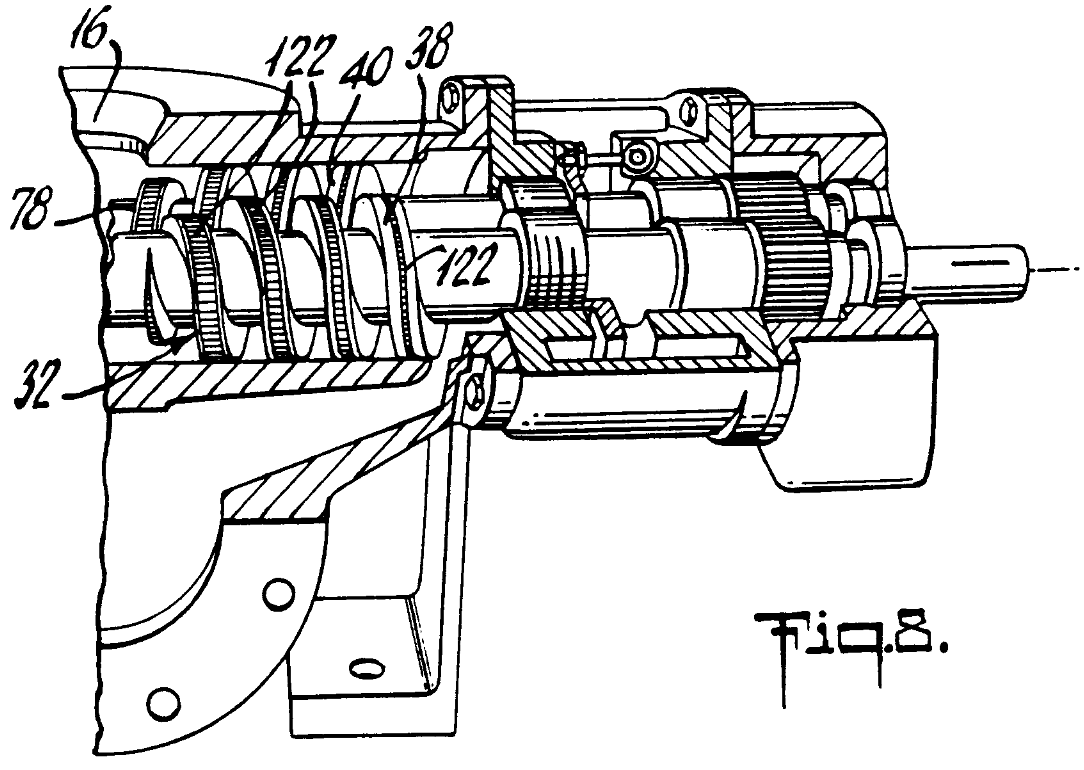

Fig.8.