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ROTARY PUMP APPARATUS

2,965,041

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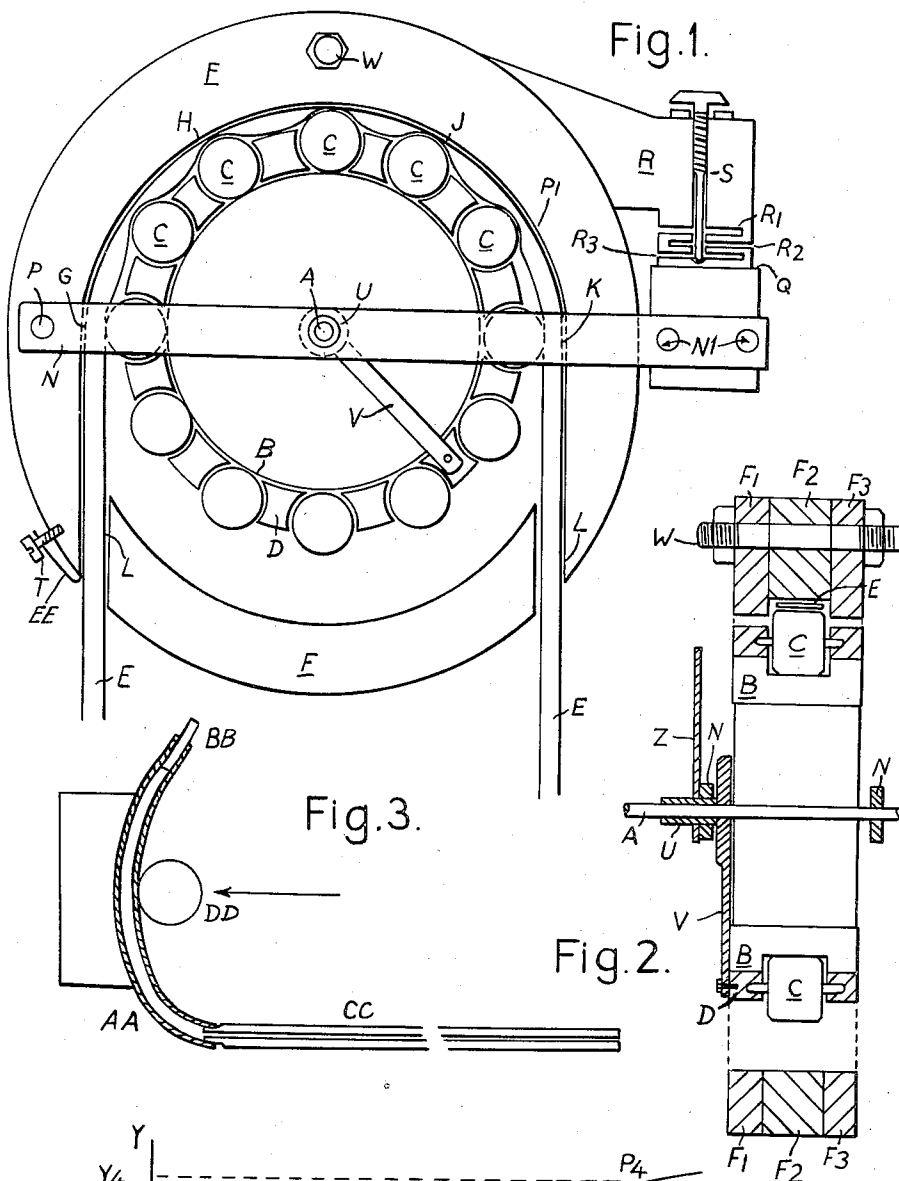


Fig. 1.

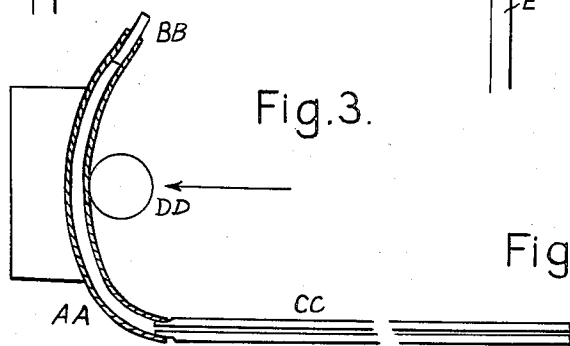


Fig. 3.

Fig. 2.

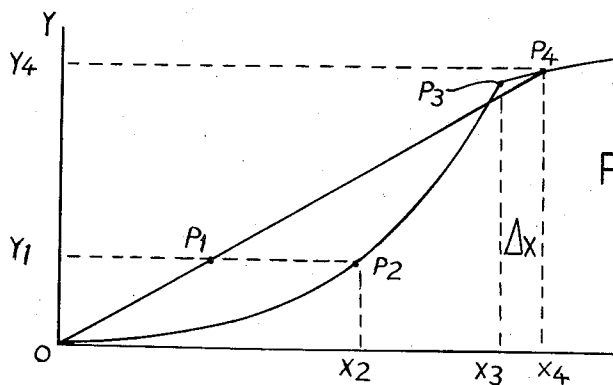


Fig. 4.

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ROTARY PUMP APPARATUS

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The present invention relates to apparatus for exerting a pumping action upon a fluid or fluids in such a manner that the quantity caused to flow may be readily ascertainable by reference to a scale, counter, or similar appliance.

The invention makes use of a well-known principle in which pressure is brought to bear upon a deformable tube which is thereby blocked, the zone of pressure being steadily moved so that fluid in the tube is caused to travel in the direction of movement of the said point or zone of pressure.

In the past, rotary pumps based upon this principle have suffered from the disadvantage that, taken over a complete revolution of the shaft, the fluid delivered by the pump cannot be made directly proportional to the angular displacement of the shaft.

The object of the present invention is to provide apparatus by which the disadvantages associated with pumps making use of the afore-mentioned principle can be substantially overcome in a simple way and so that a rotary pump employing one or more deformable tubes may readily be constructed in such a manner as to provide a continuous pumping action, the angular displacement of a pointer on a circular scale being at all times proportional to the volume of fluid pumped.

According to the invention therefore, there is provided apparatus for controlling the delivery of fluid of the kind comprising one or more flexible tubes compressible against one or more surfaces by a series of pressure members whose central longitudinal axes are disposed in the general direction of and symmetrically about a common axis, thus creating movable complete and partial constrictions in said tube or tubes, the pressure members being carried by a circular supporting member, which is adapted to be rotated to effect delivery of the fluid, in which the said surface or surfaces are curvilinear and of such shape and length that the quantity of fluid delivered is substantially linearly related to the angle through which said supporting member is rotated.

Preferably the pressure members comprise rollers whose central longitudinal axes are disposed parallel to the said common axis. The pressure members may however be conical and arranged to press the tube or tubes against a conical surface but I believe this to be less advantageous than the arrangement first referred to.

Means may be employed to protect the deformable tube or tubes from the application of longitudinal stress as a result of the movement of the pressure members, since slight stretching or even the application of such stress without appreciable stretching results in non-linearity of output or reduced life of the tube or tubes.

This may be effected in part by ensuring that there is as little friction as possible between the pressure members and the deformable tube or tubes. In a preferred form of the invention, particularly suitable when the apparatus is intended to deliver small volumes of fluid, use is accordingly made of a straight roller bearing, the outer race of which has been removed. In this form the rotation of a shaft is employed to rotate the inner race which in turn rotates the rollers in the cage of the bearing, these in turn compressing the said deformable tube or tubes in a substantially frictionless manner.

In addition, such means may take the form of bond-

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ing the deformable tube or tubes to a metallic or non-metallic tape, sleeve, ribbon or wire, or the tube may be strengthened in a longitudinal direction by the incorporation of thread, tape, ribbon or wire.

Means are preferably provided whereby, when the apparatus is not in use, the shaft can readily be shifted from its working position, thus leaving the deformable tube free and not subjected to continuous pressure.

If desired, means may be provided whereby small changes in the delivery rate of the fluid can be readily effected at any time by suitable means. This may be achieved by threading the deformable tube or tubes with fine wire, plastic tape, thread or similar material, which may if desired be bonded to the tube, the object being to decrease the internal cross-sectional area of the tube. In one form of the apparatus which does not incorporate the protection means afore-mentioned, the delivery rate is adjusted by stretching the tube to a controlled extent. It may also be achieved by employing a deformable tube of greater internal diameter at one end than at the other, arrangement being made so that different parts of the tube may be used at will, thus changing the delivery rate. It may also be achieved by making a small alteration in the distance between the cylinders and the central shaft. In a preferred form of the apparatus embodying the invention, the delivery rate is controlled by adjustment of the compression of the walls of the flexible tube in a manner to be described hereinafter. Or other means may be employed with the same end in view. Thus it becomes possible to ensure that a single complete turn of the shaft results in the delivery of a definite and convenient volume of fluid.

The apparatus may be so constructed as to pump more than one fluid at the same time, so that fluids may be delivered, ready mixed if so desired, in definite ratios by volume. For this purpose the said rollers, which may be of any desired length are caused to constrict two deformable tubes lying side-by-side, each being pressed against an appropriate curved surface, or against different parts of the same curved surface.

Advantageously, the apparatus is constructed so that the reading of the scale which measures the volume of fluid delivered, may easily be reset to zero, thus saving much time when it is desired to deliver large numbers of small measured volumes of a liquid. This may conveniently be achieved by the use of a scale or pointer mounted on a sleeve which is frictionally mounted on another sleeve or shaft and can readily be caused to rotate with respect to the latter when so desired.

The apparatus according to the invention is particularly useful in laboratories when it is required to deliver small but accurately measured volumes of fluids. It may be used with advantage to replace the traditional burette, over which it has a number of advantages. It may be constructed in such a way as to be readily mounted on laboratory stands or by means of an attachment to fit directly into bottles or fluids receptacles, while delivery of fluid is effected by a simple turn of a knob or handle, a circular scale being employed to register the volume of fluid delivered. The apparatus may readily be operated from a distance by means of a long shaft, or motor repeater or in other ways, this being of great advantage in measuring radio-active fluids. It requires no refilling after use, and it is readily cleaned by the passage of a cleansing fluid. Moreover since it will generate considerable pressure, and may even be used in reverse, small particles tending to block the fine end of a delivery tube are easily dislodged. The apparatus may also be operated at great speed, especially since the readings can be instantly reset to zero.

Apparatus according to the invention is also of particular value in glueing and similar operations, where

two fluids must be mixed in definite proportions shortly before use, and also when it is desired to measure gases or to transfer them in measured volumes.

Apparatus may also be constructed employing some or all of the above features but on a larger scale. For this purpose a deformable tube of wide bore may conveniently be used, cylindrical rollers being caused to press inwards upon it, so that it is forced against a designed curve. In order to prevent the formation of air bubbles, a longer arc, preferable more than one revolution, is employed, and the axis of the resulting coil which is spiral-shaped, is preferably arranged vertically. The apparatus may thus be used for pumping fluids in industrial operations.

In order that the nature of the invention may be better understood it will now be more particularly described by way of example with reference to the accompanying drawings, in which:

Figures 1 and 2 show two views at right angles through a preferred form of an apparatus embodying the invention, Fig. 2 being partly in section,

Figure 3 represents an arrangement of apparatus employed when it is desired to determine the form of the curve which must be utilised in order that the pump shall operate linearly,

Figure 4 represents the form of a graph, not drawn to scale, which is obtained by the use of the arrangement shown in Figure 3, and which enables the form of the said curve to be computed.

Referring to Figures 1 and 2, A represents the axle or shaft used for driving the apparatus, hereinafter referred to as the pump. The shaft is rigidly fixed to the inner race B of a straight roller bearing constituting a circular supporting member, the outer race of which has been removed. Around the inner race of the bearing are arranged, conveniently, twelve cylindrical rollers, C forming a part of the said bearing, which are employed to deform a deformable tube E.

The main body F of the pump, which may conveniently be made in three parts, F1, F2, F3, suitably bolted together at W, is constructed of plastic, metal, wood or other suitable material, the central part F2 being recessed in such a manner as to admit the rollers C over the range, along the curve GHJK in which it is desired to deform the tube E.

The tube E which passes through the holes or spaces L in the central part F2 of the body of the pump, lies in contact with the curve GHJK. This curve forms a portion of the inner surface of the central part, F2, of the body of the pump. The central region of the curve HJ, forms the arc of a circle centred at or near the centre of the shaft A, at which point it may conveniently subtend an angle of 60 degrees.

The distances HA and JA which are substantially equal, are so chosen that that part of the deformable tube E, which lies between HJ and the rollers C, is completely blocked by each roller in turn as it travels in the direction H to J. Over the two ranges GH and JK, however, the curve GHJK is such that the deformable tube is only partly compressed by the rollers and compression ceases altogether at the two ends G and K, of the said curve. The total curve GHJK may conveniently subtend an angle of 180 degrees at A.

The shaft A is held in position on either side of the said bearing, by two strips N, conveniently constructed of metal, which are held rigidly together at N1, the shaft being free to rotate. The two strips N are pivoted at P about which point they are free to rotate to a limited extent, so that the rollers may easily be caused to leave the vicinity of the curve GHJK when the pump is not in use, thus ensuring that the deformable tube E is not left in a permanently deformed state and that it can, moreover, be easily removed and replaced by causing it to slip through the holes L.

A solid block of suitable material with a plane surface at Q is held rigidly between the strips at N1. When the pump is in use, the surface Q is caused to press tightly against a similar surface of a block of elastic material R which is in turn rigidly affixed to the main body F of the pump or of the outer parts F1 and F3 thereof. The two blocks of material are held firmly together by means of a spring or springs (not shown) and suitable means (not shown) are provided in order that the spring or springs may be instantly relaxed or brought into operation once more as may be desired.

The block R is slitted at R1, R2 etc. and the end of a screw S enters the lower end of the block between R3 and Q, thus ensuring that the strips N will rotate to a limited degree about the pivot P in either direction when the screw S is turned. A scale and pointer are conveniently attached near the upper end of the screw S so that adjustments may be made as desired.

The deformable tube E, which may conveniently consist of a well-vulcanized relatively thick-walled rubber tube, is bonded on one side to a thin readily flexible metallic tape EE, the metal lying flat against the curve GHJK, and being turned back and anchored by screw T so shown. In this way the stretching of the tube which is found to occur despite the frictionless nature of the roller bearing employed, is prevented from taking place. (Such stretching causes a small suck-back at the delivery end of the pump whenever a pocket of liquid is released as it enters the deformable tube in the region JK.) In order to prevent the slow movement of the tube in the direction of pumping, the said tube is anchored by means of the metallic tape EE, this being conveniently effected by means of a screw T near the inlet end of the tube.

In order that the volume of liquid may be accurately measured or registered, a scale or pointer Z which is shown on Figure 2 but omitted from Figure 1 for clarity, is frictionally mounted on a sleeve U, free to turn about the shaft A. By means of a strip V, the sleeve U is caused to rotate with the cage of the said bearing and therefore reproduces accurately the movement of the rollers which compress the deformable tube. As a result of its frictional mounting on the sleeve U the said scale or pointer may instantly be reset to zero reading when so desired.

The pump may be mounted in any convenient way. The rod W for example may be firmly fixed in the body F of the pump and held at its other end in the boss of an ordinary laboratory stand. Alternatively, a conical attachment (not shown) may be fixed to the inlet side of the pump, the said attachment being of such dimensions that it may readily be inserted into the neck of a bottle or other fluid reservoir.

Upon the nature of the curve GHJK, and particularly upon the length and shape of the part JK thereof, depends the proper functioning of the pump. The length of the curved portion JK must be such that when at J a roller just begins to lift away from the tube E another roller at K just ceases to touch the said tube. It will be apparent from the theory of the pump to be hereinafter described that unless this condition is satisfied the pump cannot operate linearly. It follows, therefore, that the two extremities of the part of the curve JK must subtend an angle at A which is equal to the angular pitch of the rollers or an integral multiple thereof. In Figure 1 this multiple is clearly equal to 2. The exact form of the curve GHJK that is necessary will depend upon the dimensions of the deformable tube which it is desired to employ—tubes of smaller internal diameter giving a low output and those of larger internal diameter a larger output of fluid and so on. In the said preferred form of the pump, arrangement is made so that the central part F2 of the body of the pump, or the part thereof on which the required curve is present, may conveniently be removed when so desired and replaced by a similar part constructed to give accurate linear delivery for a deform-

able tube of different cross-sectional area. Thus essentially the same apparatus may be made use of to deliver, say, 0.1, 0.5, 1.0 and 2.0 millilitres per scale revolution and the range of usefulness of the pump is greatly extended.

Having now described a preferred form of an apparatus embodying the invention, there remains the problem of the determination of the form of the curve GHJK upon which the correct functioning of the said apparatus depends.

A part of the said curve, namely HJ is, as already stated, the arc of a circle. The part GH may conveniently be a replica of JK though exact duplication is not necessary.

An approximate curve for JK may be obtained by making JK the arc of a circle with a centre at such a point that the deformable tube is fully compressed at J but is only just touched by the passing rollers at K. The resulting curve however, is not strictly accurate and gives rise to small errors, though it is of service if great accuracy is not desired.

The approximate shape of the curve JK may also be obtained mathematically. Thus it may be assumed that, when a deformable tube is compressed, the circumference of the tube will remain constant and that the shape will become, say, elliptical. The relationship between the cross-sectional area (proportional to the volume of fluid expressed) and the compression of the tube may therefore be obtained and represented in the form of a curve such as is represented in Figure 4, to be further described below. From this curve the form of the curve JK may be calculated in a manner hereinafter described. Owing to the simplifying assumptions made, however, no great accuracy is attainable in this way.

In order to determine the exact shape of the curve JK the following procedure is preferred. A portion AA (Figure 3) of a deformable tube similar to that to be used in the manufacture of the pump, with metal strip bonded to its surface, is held rigidly in contact with a portion of an arc with radius equal to JK (or better with radius midway between JA and KA) in Figure 1. The tube is filled with fluid, one end BB (Figure 3) is blocked and the other is attached to a capillary tube CC of fine uniform bore. A cylinder DD of diameter equal to the diameter of the rollers C in Figure 1 is pressed against the tube in the direction shown by the arrow. The compression of the flexible tube is now plotted against the movement of the fluid meniscus in the capillary tube CC (Figure 3) which is calibrated according to the volume of fluid expressed.

In this way a curve of the general shape shown in Figure 4 is obtained. In this curve the ordinate OY represents the position of the meniscus in the capillary tube and the abscissa OX represents the degree of compression. It will be noted that there is a sharp change in the direction of the curve at P3. This corresponds to the compression at which the opposite sides of the deformable tube come into contact. Beyond this point further compression squeezes out little more fluid.

In order that the apparatus when made shall show no tendency to leak, it must be constructed to allow for a small over-compression of the tube. This degree of over-compression (conveniently .002 to .005 inch) is first decided upon. Let it be equal to $\Delta x = OX_4 - OX_3$ in Figure 4. In the curve X_4 is seen to correspond with the point P4 which in turn corresponds with a delivery of Y4. Let the points O and P4 be joined by a straight line.

Consider now what will happen if one of the rollers C in Figure 1 situated between J and the mid-point of HJ moves forward a distance $r\theta$ where r is the mean radius and θ the angular movement. Since the tube is blocked by the roller within this range, a volume of fluid equal to $r\theta a$, where a is the cross-sectional area will be pushed forward by the roller. This is proportional to θ as is required.

Now consider a point such as P1 (Figure 4) on the straight line joining O with P4, such that OY1 is equal, say, to one third of OY4. If we imagine a deformable

tube overcompressed to the desired extent, then the fluid sucked back when the roller is partly lifted will be two-thirds of the total possible. In passing from J to K (Figure 1) a roller sucks back a volume of fluid equal to OY4 (Figure 4). If the angle JAK in Figure 1 is 60 degrees, the distance OY4—OY1 (Figure 4) will correspond to two-thirds of 60 degrees, i.e. 40 degrees if the pump is to operate in a linear manner. From Figure 4 it will be seen that the ordinate Y1 corresponds to the point P2 on the curve O, P2, P3, P4, which in turn corresponds to a compression OX2.

Referring again to Figure 1, we see that if the angle JAP1 is 40 degrees, then, if the pump is constructed to work in a linear manner, the relation—

$AP1$ (Figure 1) = AJ (Figure 1) + $OX4 - OX2$ (Figure 4) must be satisfied.

Proceeding in this way, the angle JAP1 in Figure 1 is related to the radial distance AP1 for all desired points on the curve JK and the form which the curve must take in order that the pump shall operate in a linear manner is determined. The curve JK and conveniently GH also is therefore constructed according to the form determined in the manner above disclosed.

In order to simplify the argument it has been assumed that only one roller is in contact with the partly compressed tube over the range JK in the curve in Figure 1. There may however, be more than one such roller. In the preferred form of the pump two rollers will be involved but each will traverse the whole of the length JK and provided they are sufficiently far apart they will function independently. The linear response of the pump will not therefore be affected.

The theory of the pump has now been given for the case in which the shaft A in Figure 1 is in its standard position at the centre of the arc HJ. If, however, adjustments are made by means of the screw S, the shaft A will be displaced slightly from its standard position. The wall compressions of the deformable tube at H and J will now be unequal. If the distance AJ is altered a new curve for JK will be required in theory and this new curve may be computed from Figure 4 by altering the position of the point P4. The change required in the curve is however, exceedingly small and the use of the original curve JK causes negligible departures from linearity over the range (3 or 4 percent) of output variation which can be achieved by adjustment of the screw S.

If it is desired that the pump shall deliver a definite volume, say 1 millilitre, per scale revolution, use is made of the law—

Delivery per revolution = K (cross sectional area of deformable tube)

and the pump is constructed for the calculated size of tube, small adjustments being made later by means of the screw S or in other ways as already described.

I claim:

1. Precision rotary pump apparatus for the linear delivery of fluid, comprising a shaft, a plurality of rollers symmetrically and circularly disposed about said shaft so as to be equally angularly pitched about said shaft, a member defining a surface spaced from said rollers, at least one deformable tube between said rollers and said surface, said rollers being movable along and pressable against said at least one deformable tube to press said deformable tube against said surface to create in said deformable tube pockets of fluid, said surface comprising three parts, a central part which is cylindrical and concentric with the axis of said shaft so as to compress the deformable tube fully to provide a pumping action, and two curved side parts on opposite sides of said central part, all said parts being continuous, said side parts being spaced at a slightly greater distance from said shaft than is said central part, and at least one of said side parts

having a length such that it subtends an angle at the centre of said shaft which is an integral multiple of the angular pitch of said rollers.

2. Precision rotary pump apparatus for the linear delivery of fluid, comprising a shaft, a plurality of rollers symmetrically and circularly disposed about said shaft, so as to be equally angularly pitched about said shaft, a member defining a surface spaced from said rollers, at least one deformable tube between said rollers and said surface, said rollers being movable along and pressable against said at least one deformable tube to press said deformable tube against said surface to create in said deformable tube pockets of fluid, said surface comprising three parts, a central part which is cylindrical so as to compress the deformable tube fully to provide a pumping action, and two side parts on opposite sides of said central part, all said parts being continuous, said side parts being spaced at a slightly greater distance from said shaft than is said central part, and at least one of said side parts having a length such that it subtends an angle at the centre of said shaft which is an integral multiple of the angular pitch of said rollers, and an indicator member mounted about said shaft to move proportionally to the angle through which said rollers as an assembly are moved about said shaft.

3. Precision rotary pump apparatus for the linear delivery of fluid, comprising a shaft, a plurality of rollers symmetrically and circularly disposed about said shaft, so as to be equally angularly pitched about said shaft, a member defining a surface spaced from said rollers, at least one deformable tube between said rollers and said surface, said rollers being movable along and pressable against said at least one deformable tube to press said deformable tube against said surface to create in said deformable tube pockets of fluid, said surface comprising three parts, a central part which is cylindrical so as to compress the deformable tube fully to provide a pumping action and two side parts on opposite sides of said central part, all said parts being continuous, said side parts being spaced at a slightly greater distance from said shaft than is said central part, and at least one of said side parts having a length such that it subtends an angle at the centre of said shaft which is an integral multiple of the angular pitch of said rollers, and a flexible but non-extensible tape attached to said deformable tube.

4. Precision rotary pump apparatus for the linear delivery of fluid, comprising a shaft, a plurality of rollers symmetrically and circularly disposed about said shaft, so as to be equally angularly pitched about said shaft, a member defining a surface spaced from said rollers, at least one deformable tube between said rollers and said surface, said rollers being movable along and pressable against said at least one deformable tube to press said deformable tube against said surface to create in said deformable tube pockets of fluid, said surface comprising three parts, a central part which is cylindrical so as to compress the deformable tube fully to provide a pumping action and two side parts on opposite sides of said central part, all said parts being continuous, said side parts being spaced at a slightly greater distance from said shaft than is said central part, and at least one of said side parts having a length such that it subtends an angle at the centre of said shaft which is an integral multiple of the angular pitch of said rollers, a support member mounted on said surface, said support member carrying said rollers and said shaft, and means for moving at least part of said support member away from said surface to take said rollers out of engagement with said deformable tube.

5. Precision rotary pump apparatus for the linear delivery of fluid, comprising a shaft, a plurality of rollers symmetrically and circularly disposed about said shaft, so as to be equally angularly pitched about said shaft, a member defining a surface spaced from said rollers, at least one deformable tube between said rollers and said

surface, said rollers being movable along and pressable against said at least one deformable tube to press said deformable tube against said surface to create in said deformable tube pockets of fluid, said surface comprising three parts, a central part which is cylindrical so as to compress the deformable tube fully to provide a pumping action and two side parts on opposite sides of said central part, all said parts being continuous, said side parts being spaced at a slightly greater distance from said shaft than is said central part, and at least one of said side parts having a length such that it subtends an angle at the centre of said shaft which is an integral multiple of the angular pitch of said rollers, and said shaft being slightly movable towards and away from said deformable tube.

6. Precision rotary pump apparatus for the linear delivery of fluid, comprising a roller bearing having a plurality of rollers set in a cage, a driving shaft fixed to the inner race of said bearing, said rollers being equally angularly pitched about said shaft, a member defining a surface spaced from said rollers, at least one deformable tube between said rollers and said surface, said rollers being movable along and pressable against said at least one deformable tube to press said deformable tube against said surface to create in said deformable tube pockets of fluid, said surface comprising three parts, a central part which is cylindrical so as to compress the deformable tube fully to provide a pumping action and two side parts on opposite sides of said central part, all said parts being continuous, said side parts being spaced at a slightly greater distance from said shaft than is said central part, and at least one of said side parts having a length such that it subtends an angle at the centre of said shaft which is an integral multiple of the angular pitch of said rollers.

7. Precision rotary pump apparatus for the linear delivery of fluid, comprising a roller bearing having a plurality of rollers set in a cage, a driving shaft fixed to the inner race of said bearing, said rollers being equally angularly pitched about said shaft, a member defining a surface spaced from said rollers, at least one deformable tube between said rollers and said surface, said rollers being movable along and pressable against said at least one deformable tube to press said deformable tube against said surface to create in said deformable tube pockets of fluid, said surface comprising three parts, a central part which is cylindrical so as to compress the deformable tube fully to provide a pumping action and two side parts on opposite sides of said central part, all said parts being continuous, said side parts being spaced at a slightly greater distance from said shaft than is said central part, and at least one of said side parts having a length such that it subtends an angle at the centre of said shaft which is an integral multiple of the angular pitch of said rollers, a flexible but non-extensible tape attached to said deformable tube, an indicator member mounted about said shaft to move proportionally to the angle through which said rollers in their cage are moved about said shaft, a support member mounted on said surface, said support member carrying said roller bearing and said shaft, and means for moving at least part of said support member away from said surface to take said rollers out of engagement with said deformable tube.

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