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Hrdina

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[54] **CONTROLLED PERISTALTIC PUMP**

[75] Inventor: **Jiří Hrdina,** Praha, Czechoslovakia

[73] Assignee: **Cskoslovenska akademie ved,** Praha, Czechoslovakia

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[52] **U.S. Cl.** **417/477**

[51] **Int. Cl.** .. **F04b 43/08,** F04b 43/12, F04b 45/06

[58] **Field of Search**.................... 417/474, 475, 476, 417/477

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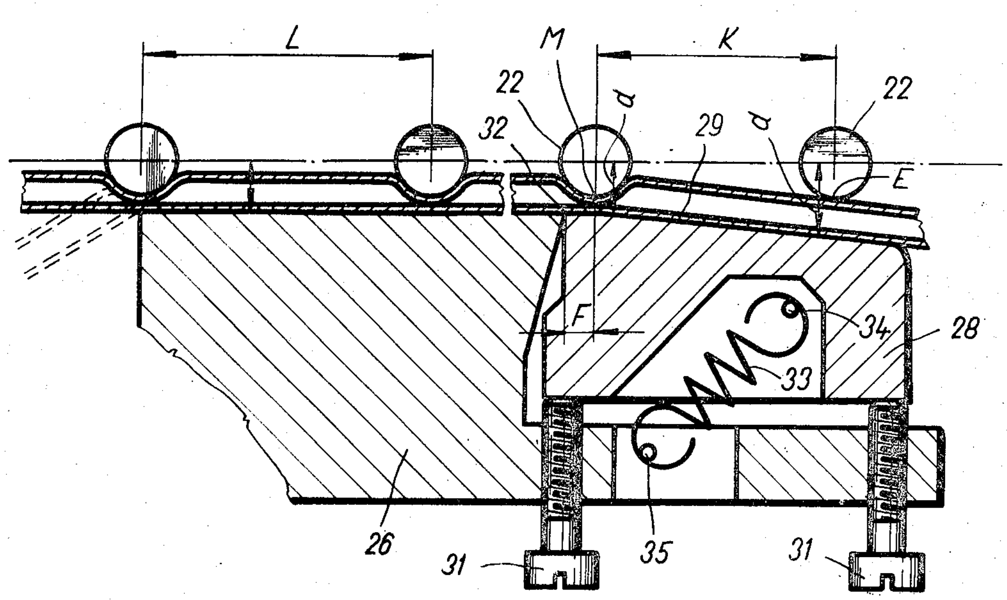
Primary Examiner—Al Lawrence Smith
Assistant Examiner—Richard E. Gluck
Attorney—Richard Low and Murray Schaffer

[57] **ABSTRACT**

In peristaltic pumps, using a number of mobile occluding organs which press a resilient hose against a support and which cause the advance of a medium within this hose, an additional support is provided from the limit point of occlusion up to the last contact point with the hose. The distance of the support from the track of the occluding organs being in inverse proportion to the required speed of advance of the medium in this hose.

6 Claims, 6 Drawing Figures



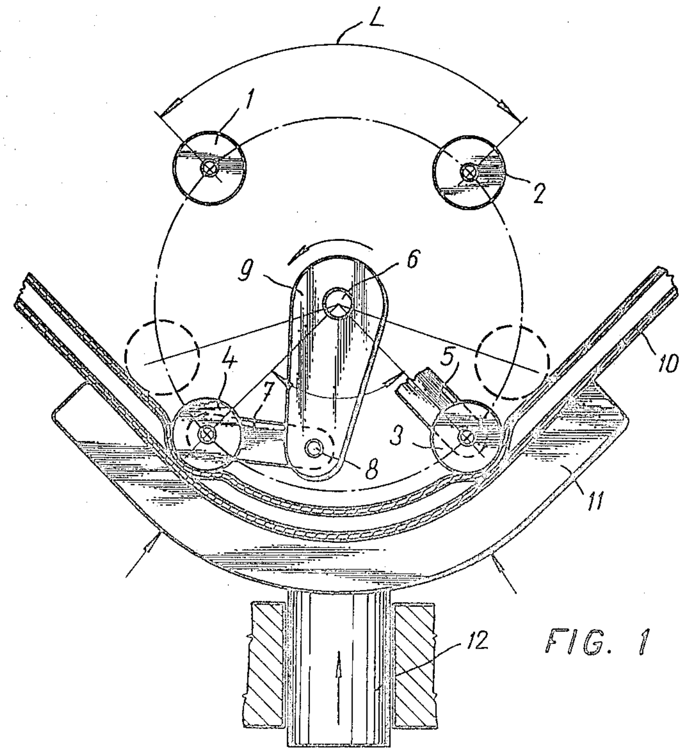


FIG. 1

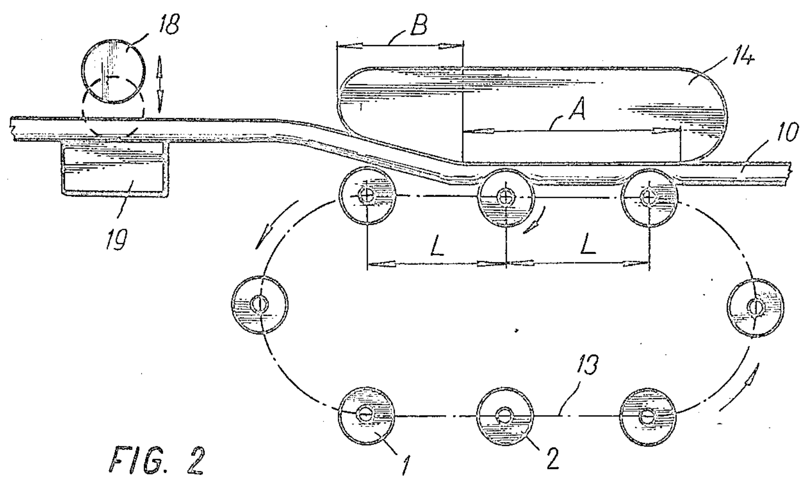


FIG. 2

INVENTOR
JIŘÍ HRDINA
BY [signature]
ATTORNEY

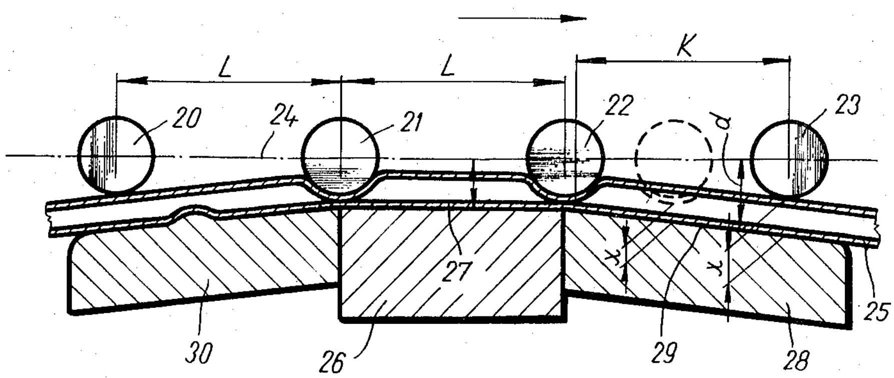


FIG. 3

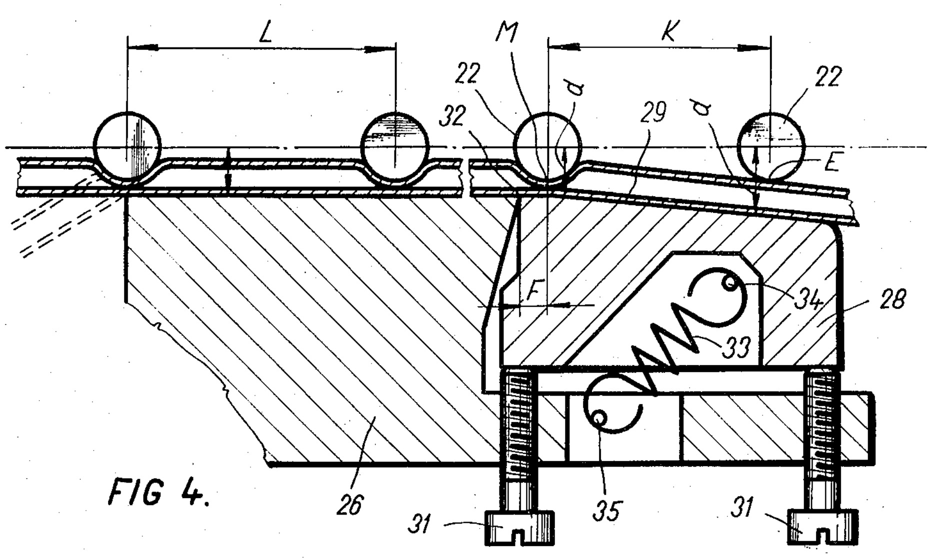


FIG 4.

INVENTOR
JIŘÍ HRDINA
BY Murray Schaffer
ATTORNEY

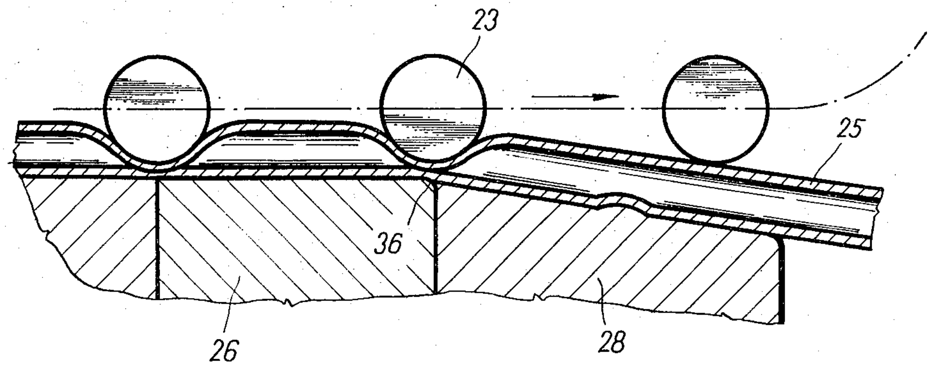


FIG. 5

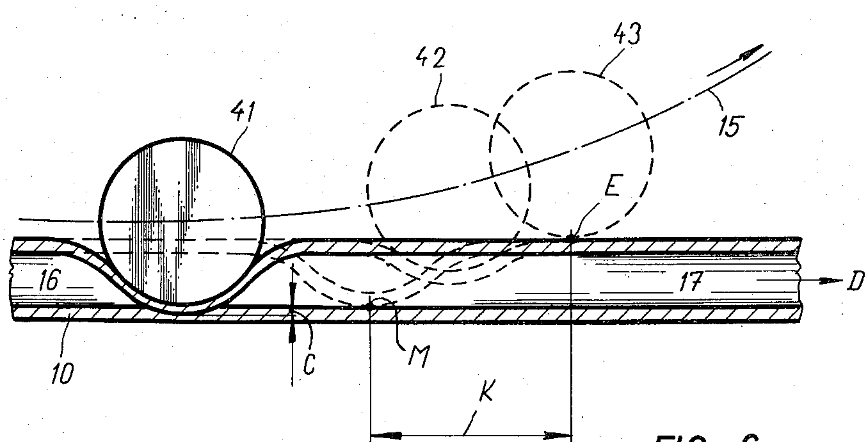


FIG. 6

INVENTOR
JIŘÍ HRDINA
BY [signature]
ATTORNEY

CONTROLLED PERISTALTIC PUMP

BACKGROUND OF THE INVENTION

This invention relates to a method and to an arrangement for regulating and programming of the discharge and suction of periodically operating pumps, particularly peristaltic pumps.

Peristaltic pumps are particularly useful in laboratories, as they enable a relatively simple mechanism to simultaneously generate a stream of a medium in a large number of resilient hoses situated side by side. Similar pumps are very suitable for operation with a segmented stream, that is with a stream of a medium subdivided by pistons (for instance gas pistons) into individual segments. Peristaltic pumps have however a number of drawbacks which are at present considered irremovable. Primarily they have a certain lack of uniformity of the stream delivery within the so called critical range of the pump. The critical range being defined as the area where the occluding organ in its compression track starts to withdraw from the hose and to release it, whereby the occlusion ceases and the hose starts to regain, by its elasticity, its normal shape. This condition generates irregularities of the delivered stream which reduce the otherwise high accuracy of peristaltic pumps.

SUMMARY OF THE INVENTION

According to this invention the occluding organ moves within a part of its track from the marginal point of occlusion up to the last point of contact with the hose of the pump opposite to a surface having a longitudinal profile and the distances between individual points from the contact point of the occluding organ change, being reversibly proportional to the speed of advance of the stream of the medium required by the program in the individual points of said track.

The invention covers also an arrangement for regulating and programming the discharge and the suction of these pumps whereby to a fundamental supporting plate, the active surface of which has a constant distance from the track of the contact points of the occluding organs, an auxiliary support is joined, the individual points of its active surface having a distance from the contact points of the occluding organ which change being reversibly proportional to the speed of advance of the stream of the medium, required by the program in the individual points of said track.

The invention provides a peristaltic pump, where the irregularities of the stream of the medium within the critical range are eliminated and which in additon allows the adjustment of the stream at the critical area according to a predetermined program of control. Preferably the function of programming is to provide for the uniform advance of the medium, but it is also possible to achieve other conditions. For instance, it is possible to control the stream of the medium so that it comes to a stop or even to achieve within a short period of operation a negative speed value (that is a movement in the opposite direction) whereby at least a part of this negative speed together with the inlet speed of the medium produces a resultant speed in the already segmented medium behind the segmentation organ (the bubble generator) which is in fact uniform even if the segmentation medium enters the pump only within a relatively small part of a period of operation of the pump. The term "period" covers not only subsequently following periods within equal intervals but also a kinematic periodicity, where for instance equal positions of individual functional elements correspond to a certain number of revolutions of the driving mechanism (which revolutions need not be always uniform).

The term "programming" which will be used in the following covers not only a control or regulation within one period of operation, but also an extended interval of control, where for instance the mean speed of advance of the medium, corresponding to one period, changes to another value after the passage of the medium, either stepwise or continuously.

DESCRIPTION OF DRAWINGS

The attached drawings show exemplary embodiments of the prior art as well as of the present invention.

FIG. 1 is a schematic view of a peristaltic pump of known design;

FIG. 2 a schematic view of another known design of a peristaltic pump;

FIG. 3 is a schematic longitudinal sectional view of the active part of a peristaltic pump adjusted according to this invention;

FIG. 4 is a partial longitudinal sectional view of an alternative arrangement of a peristaltic pump according to this invention;

FIG. 5 is a partial sectional view of a further modification of the peristaltic pump according to this invention; and

FIG. 6 is a diagram schematically showing the occluding organ of a conventional pump at full occlusion of the hose and in the course of its subsequent release.

DESCRIPTION OF PRIOR ART

In order to enable a full understanding of the object of this invention, two peristaltic pumps of known design will be described first.

FIG. 1 shows one of the commonly used arrangements of peristaltic pumps where a number of occlusion rollers **1, 2, 3, 4** are provided either directly on arms **5** (one arm is only partly indicated in the drawing) which arms **5** are supported on a rotating shaft **6**, or according to an alternative arrangement are supported on spring loaded rocker levers **7**, connected by bolts **8** to arms **9** fixed on shafts **6**. The rollers in the course of their movement track about the shaft **6** and come into contact with an elastic hose **10** having an infeed and a discharge end. The hose **10** rests on a support **11**. The arcuate shape of the support **11** insures that the rollers, within a part of their track remain in contact with the hose **10** which is thereby compressed so that below the individual rollers a complete occlusion, that is a complete closing of the hose is caused. The support **11** is urged against the rollers by an element **12** generating pressure. In the course of rotation of the shaft **6** and thus also of the rollers **1, 2, 3, 4** the place of occlusion advances continuously along the hose at an angular speed corresponding to the angular speed of the shaft **6**.

FIG. 2 shows a pump of another type where the rollers **1, 2...** are supported by a roller chain **13** passing over sprocket wheels (not shown). The hose **10** is in this case pressed against a support **14** which is along a portion indicated by A straight and parallel with the adjacent branch of the roller chain, whereafter in part B it recedes from the rollers.

FIG. 6 shows the operation of the pump schematically. As seen, each occlusion organ **1,2,3,** travels along a curved path **15** a portion of which constitutes the compression track wherein the roller compresses one portion of the wall of the hose **10** against the opposing wall portion. The depth of compression of roller (e.g. **41**) provides an occlusion reserve C since so long as the compression is maintained within this depth, occlusion of the hose is maintained. During mainteneance of the occlusion reserve C the hose is segmented by the roller forming a portion **16** behind it and a portion **17** ahead of it and by which the media is separated. This occlusion reserve is required to insure that a tight seal is made between sections **16** and **17.** Further, at the initial stage of compression, the compression of the hose reduces the volume of the hose, thus increasing the pressure of the medium in the hose between itself and the next preceeding roller. The moving occlusion organs thus push the medium conveying a stream of medium to the discharge end along the path D.

The rollers, when driven along their path **15** at a constant speed, act to impart an irregularity to the flow of medium in the conveyed stream within the pump range which is detected at the discharge end of the hose. This irregularity is caused by the action of the roller when it releases from the hose during the course of each individual compression period (a period being defined as the distance between successive rollers). Actually, at the moment when the occlusion roller **41** lifts in its track along the curve **15** from the hose **10** and the roller **41** first releases the so called occlusion reserve C, that is, as the part of one hose wall which is pressed into the opposite one begins to recede and as soon as each roller recedes so far that the reserve C is liquidated, (note roller **42**), the occlusion stops and the space **16** behind the roller becomes connected with the space **17** in front of it, and the hose is refilled with medium. The point where the occlusion stops, defined as "limit point of occlusion" is indicated in FIG. **6** by the letter M. In the course of the further movement of the particular roller (position indicated by **42**) along the curve **15,** the medium in the hose is no longer conveyed at a uniform speed in direction of the arrow D. As the hose starts to expand up to the place where the roller just leaves it (point E at position **43**) the medium rushes to fill the increasing volume reducing its forward speed. The range between the limit point M and the contact point E is referred to as the "critical range" and is indicated by the letter K. In the course of release of the hose **10** suction is generated in space **17** acting against the discharge of the medium, so that the resulting discharge is equal to the difference between the discharge movement generated by the next succeeding roller and this suction. The amount of medium delivered within this critical range K is therefore reduce in dependence on this suction. Since the speed of back flow into the tube from the discharge is directly proportional to the speed of the rollers, the suction may even rise to such a value that its surpasses the medium discharge speed, so that the stream of the medium may actually be reversed and proceeds in the opposite direction, (i.e., against the direction indicated by the arrow D). This irregularity is very inconvenient, particularly if a discharge having uniform proportionality is to be achieved. This proportionality cannot be achieved with known pumps and particularly for purposes which have hoses of different diameters. Up till now this drawback could not be removed and it was particularly this drawback, which caused peristaltic pumps to have been considered to be not quite accurate. Although it is common knowledge that their total delivery is uniform, the periodic delivery is not and so far only the mean values of discharge are considered in determining capacity.

Various steps have been taken in order to eliminate this undesirable circumstance, one of which is the use of a clamp **18,** commonly called a "bar" indicated schematically in FIG. **2.** The "bar" is located between the compression track and the discharge. The clamp **18** is adjustable with respect to a fixed support **19** and is resiliently pressed against the support **19** to cause selected deformation of the hose **10** up to a complete occlusion. The "bar" is particularly used for a stream of gas such as air segmented by pistons rather than rollers. If the bar is closed, the air or gas compressed between the closed bar and the next approaching occlusion roller is held until the moment when the bar is lifted and releases the passage of the medium through the hose **10.**

None of the arrangements attempted, not even the "bar," could remove the above irregularities in delivery of the stream within the individual periods.

It has been of course equally impossible to obtain a programmed, that is, controlled stream of the medium within the critical range of the peristaltic pump and thus also in the discharge conduit of the pump.

It is therefore an object of this invention to provide a peristaltic pump which would enable a uniform advance of the pumped medium.

It is another object of this invention to enable an arbitrary programming of the stream of the medium both in the suction and in the discharge conduit.

DESCRIPTION OF PREFERRED EMBODIMENT

FIG. **3** shows one of the simplest arrangements which can be made according to this invention. Rollers **20, 21, 22, 23** of a peristaltic pump are arranged at mutual distances L and move along a straight path **24** which passes over a hose **25** suitably supported so that the rollers and hose engage in a track of corresponding shape. The hose **25** is subsequently deformed from the place of first contact of the individual roller with the hose which is indicated in the drawing as being below the roller **20** which has just touched the upper wall of the hose. This deformation corresponds to the consecutive change along the direction of movement of the distance between the path **24** and the support. The support consists of a base supporting plate **26,** the upper active surface **27** of which is parallel with the path **24** and at the discharge end an auxiliary support **28** having an upper surface **29.** The auxiliary support **28** is joined to the supporting plate **26,** so that its upper surface **29** is shaped so that its longitudinal profile at the place supporting the hose consists of an inclined line, the individual points of which lie at an distance *d* from the path **24.** Preferably in the direction of movement of the roller toward the discharge side of the pump (as seen by the arrow) the distance *d* increases while in the direction opposite thereto, that is toward the suction side, the distance *d* decreases inversely proportional to the speed of the stream of the medium required by the program at each of the individual points of the critical range K.

In accordance with this invention, the interval of release K of one roller is made to extend through the entire length of the discharge stroke L of next succeeding roller. Therefore uniform discharge is obtained.

In the simplest case wherein a uniform discharge of the medium is required by the program, it is desirable to shape the upper active surface **29** of the auxiliary support **28** so that the speed of the stream is slowed to correspond for instance to the time of supply of the bubble piston (e.g., "bar") at the segmentation point prior to discharge. This achieves a uniform speed of the medium behind the segmentation point. Any other shape to control speed according to the requirements of any program is of course equally possible.

What has been said about the discharge branch of the pump can be obviously equally applied in the suction branch if a desired discharge program, such as for instance a uniform suction is required. This case is indicated in FIG. **3** where an auxiliary support **30** is provided at the suction end, the upper surface of which is shaped so as the meet requirements according to the stipulated program. If no programming of suction is needed, the auxiliary support **30** may be omitted, so that the pump will have only a single auxiliary support at the discharge end. The converse holds true if only suction is programmed.

FIG. **4** shows an alternative arrangement where the auxiliary support **28** is adjustable. The auxiliary support **28** rests on set screws **31** which are screwed in into the body of a supporting plate **26** and joined at its upper active surface **29** to the corner edge **32** of the supporting plate **26.** The supporting plate **28** is pressed against the screws **31** by the force of the spring **33** suspended between a bolt **34** on the auxiliary support **28** and a bolt **35** on the supporting plate **26.** The spring **33** is preferably situated in an inclined position with respect to the active surfaces of the supporting plate **26** and of the auxiliary support **28** so that it is biased toward both the auxiliary support **28** and the supporting plate **26** as well as to the set screws **31.** In this way the corner edge **32** need not be covered.

A double arrow F (FIG. 4) indicates the length of the compression track, which each roller has to traverse in order to eliminate the occlusion reserve C (see FIG. **6**) that is from the point where the roller must begin to lift from compressive position up to the place, where the occlusion ceases. From this point on, which is the limit point M of occlusion, upt to point E, where the roller just leaves the hose **25,** the complete release of the hose is effected. This distance, indicated by the double arrow K is the aforementioned critical range of operation. The length of the distance K for the same pump must be different for different diameters of hoses, since each diameter of hose will create its own variable suction. The uniform discharge effect of the moving rollers will therefore be influenced by the chosen hose as well as the distance K.

The adjustability of the auxiliary support **28** and thus also of the length of the critical range K is rather important for modern peristaltic pumps which may be designed to pump through a larger number of hoses (for instance up to 28 hoses), the diameters of each of which may be different from the other. It was impossible in the known devices to achieve a proportionality of the discharge in each of the different hoses. For instance in the design shown in FIG. **2**, there is no possibility of adjustment and therefore no possibility to program, that is, control the combined effect of discharge and suction within the critical range. This form of control is enabled only by this invention. Thus one of the main disadvantages of prior peristaltic pumps which had been up to now considered irremovable has in fact been removed. That this improvement is important is due to the fact that differences of profiles of hoses for currently used pumps can be rather substantial. For instance, hoses range from an internal diameter 0.127 mm up to a diameter 2.80 mm or from an external diameter of 1.56 up to a diameter 4.2 mm.

The actual development of suction within the critical range K can be empirically determined with acceptable accuracy. Actually delivered volumes created by deformations of hoses having different parameters are registered. Based on the thus determined curves, it is easy to further determine the time course of changes of distances d that is the angle and length of the surface **9** from the path **24** within the critical range K (see FIG. **3** and **4**). By establishing these determination of changes of discharge achieved by the sum of the fundamental discharge effect of the peristaltic pump in combination with the suction effect within this critical range can be made so that they would correspond to the given requirements of the pump program. So for instance if a perfect uniformity of the stream is desired, or if undesirable sudden changes of speed are to be eliminated at places both close to the limit point M of occlusion or close to the contact point E, it is necessary that the length of the critical range K is, as far as possible, selected to be equal to the distance L of the occlusion rollers. This condition is not met by any of the known peristaltic pumps. Another important condition that has not been met by the prior art is that the difference between the distance d at the limit point M and the distance d at the contact point E should be different for different profiles of hoses. It has been heretofore impossible to achieve in practical pumps a uniform stream and even less a controlled stream of the kind produced by the present invention.

FIG. **5** shows another modification of this invention. The auxiliary support **28** is in this case joined to the base supporting plate **26** so that at the place of contact of these two elements there is a sudden drop or step indicated by the reference mark **36.** In this arrangement, the roller, for instance roller **23** advances very quickly from a position, where it still fully occludes the hose **25** with the required reserve, to a closely adjacent point, where the occlusion immediately stops and the hose opens. In this case the length of the track portion F, as indicated in FIG. **4,** which the roller must traverse in order to eliminate the occlusion reserve C (FIG. **6**) is practically reduced to zero. It is obvious that this step **36** can be achieved in the arrangement according to FIG. **4** by a suitable adjustment of the left set screw **31** so that the auxiliary support **28** can not only be deviated around the edge **32,** but may be also shifted perpendiculary to the edge **32.**

The auxiliary support **28** can be provided either for each hose alone or as a common support for several hoses. Of course individual adjusting elements can be provided for an entire group of individual hoses either of equal or different profiles.

Recently arrangements of most modern multichannel peristaltic pumps are desired as automatic analysers, a part of which are just peristaltic pumps, which can perform different kinds of analysis. For this purpose wholly assembled constructional units are provided, corresponding respectively to different possible analysis conditions. This invention is particularly suitable for similar cases, as it is possible to achieve with relatively simple means the most advantageous control even if hoses of rather different diameters are used in each. In such cases the auxiliary support **28** can form a unit in combination with the hose supporting plate **26,** so that no individual adjustment is required.

In the preceding discussion a type of a pump according to FIG. **2** has been considered, where the occlusion rollers move along a track with a straight active branch. Everything that has been said about this type of pump holds true for other types of peristaltic pumps, particularly where the active part of the roller track is curved, as for instance the circular track seen according to FIG. **1.**

I claim:

1. Controlled peristaltic pump comprising at least one flexible hose having a suction end and a discharge end for suction and discharge, respectively, of a liquid medium, supporting means having an active surface for supporting said hose, compressing means disposed opposite said supporting means, movable along a predetermined path and adapted to progressively compress said hose against said supporting means and to generate a peristaltic pumping effect, said supporting means including at least a first support member substantially parallel to the path of said compressing means and a second support member disposed next to said first member, said second support member being adjustable with respect to the predetermined path to selectively vary the distance from said compressing means thereby controlling the action of said compressing means and the discharge of said liquid medium.

2. The pump as defined in claim **1** wherein the second support member is pivotable with respect to the first support member to meet changing diameter and thickness requirements of hoses supported by the supporting means.

3. The pump as defined in claim **1** wherein the second support member is pivotable around an edge through which it contacts the first support member and is perpendicularly adjustable to said edge.

4. The pump as defined in claim **1** wherein the second support member is freely supported by set screws and provided with spring means acting in an inclined direction with respect to the active surface of the supporting means and pressing said second support member simultaneously against the first support member and against said set screws.

5. The pump as defined in claim **1** wherein the active surface of the second support member of the support means forms a step at the place of contact with the first support member of said support means.

6. The pump as defined in claim **1** wherein said compressing means further comprising spaced adjacent members which occlude said hose until a last point of occlusion, and continuing to engage said hose until a last point of contact, the distance between said last point of occlusion and said last point of contact being substantially equal to the spacing between said spaced adjacent members.

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