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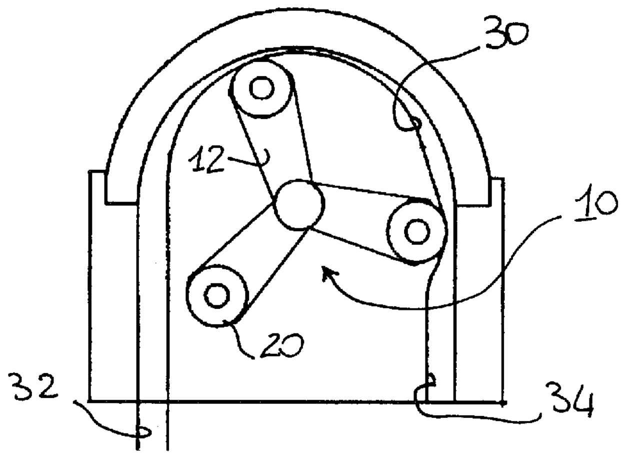
(54) A peristaltic pump for supplying fluid products and a method for controlling said pump

(57) A method for controlling a peristaltic pump for the supply of fluid products comprises the following stages in combination with one another: calibration of the peristaltic pump by calculating a series of pairs of values each formed by the volume of product supplied (V_i) and the number of strokes of the rotor (X_i) needed to obtain this volume, calculation, by an interpolation operation, of the intermediate values with respect to each pair of values (V_i, X_i) obtained at the calibration stage, calculation of a predetermined volume to be supplied (V), searching for the closest interpolated value ($V_{dispensed}$) and calculation of the number of corresponding strokes ($X_{dispensed}$), and actuation of the actuator means to carry out the supply of the required volume of fluid product.

FIG. 1



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Description

[0001] The present invention relates to a peristaltic pump for supplying fluid products, and a method for controlling said pump. The invention has been developed with particular, although not exclusive, reference to a pump adapted to be used within machines supplying dyes for the production of paints, varnishes, inks and the like.

[0002] Rotary peristaltic pumps are known and are able to supply predetermined volumes of liquid, semi-liquid, fluid and pasty products. These pumps generally comprise a rotor to which one or a plurality of rollers are attached, which, when they rotate, compress a tube and then release it causing the fluid to move forward within the tube. Known peristaltic pumps may be actuated by variable-speed electric motors, servo-motors, or step-by-step motors and the quantity of product supplied is conventionally calculated as a predetermined volume for each rotation of the rotor. However, known peristaltic pumps have some drawbacks; it is difficult, for instance, to obtain precise and reproducible fluid quantity supplies if the quantity of fluid to be supplied comprises or corresponds to fractions of the predetermined volume per rotation of the rotor.

[0003] In order to remedy this kind of drawback, many solutions have been put forward in recent years, including, for instance, an optical analysis of the flow of fluid in order to control in real time the accuracy of supply, as disclosed in US Patent Application 2007/0059184, the use of angular position transducers to monitor the position of the rotor at every instant, as disclosed in Patent Application WO/10934, and the use of devices for measuring the flow of fluid supplied, as disclosed in US Patent Specification 5 733 257.

[0004] Although operation is generally satisfactory, none of the proposed solutions seems fully to remedy the above-mentioned problem, as the quantities of product supplied in successive supply stages continue to be inaccurate. Moreover, all of the proposed solutions have further drawbacks, for instance by making the supply pump mechanically more complex and entailing higher production costs and/or a frequent need for maintenance and inspection of the device.

[0005] In order to remedy the above-mentioned drawbacks, with no substantial impact on production and operating costs and, at the same time, to provide a reliable pump, the present invention relates to a peristaltic pump and an accurate method for controlling the pump having the features set out in the accompanying claims.

[0006] Other features and advantages will become clear from the following detailed description of a preferred embodiment which is given with reference to the appended drawings which are provided purely by way of non-limiting example, and in which:

Fig. 1 is a diagrammatic front view of a peristaltic pump of the present invention;
Fig. 2 is a diagram of the supply curve obtained with the calibration stage of the method of the present invention;
Fig. 3 is a diagram of the supply curve obtained with the interpolation stage of the method of the present invention.

[0007] In Fig. 1, the peristaltic pump of the present invention includes a rotor member 10 comprising a plurality of arms 12, preferably, but not limited to, three arms, each of which is connected to pressure means, for instance a roller 20. A duct, for instance a tube 30, is disposed about the rotor and comprises an inlet zone 32 and an outlet zone 34 for the fluid to be supplied. The tube 30 is normally made from resilient material, preferably silicone, PVC or other polymers which enable a resilient deformation of the tube and a high level of chemical compatibility with solvents, acids and varnishes. In operation, the rollers 20 rotate, pressing on predetermined portions of the tube, causing its compression and successive release, thus causing the fluid to move forward in the tube from the inlet zone 32 to the outlet zone 34.

[0008] The rotor is generally connected to actuator means, preferably to an electric motor, more preferably a step-by-step electric motor which enables the angular displacement and speed of rotation of the rotor to be highly accurate, without using speed sensors. The pump further comprises control means such as, for instance, a microprocessor and means for storing data, both used to supplement the control method of the present invention.

[0009] In operation, depending on the diameter of the tube 30 used and on the diameter of the rotor 10, the peristaltic pump supplies, for each revolution of the rotor 10, a predetermined quantity X of fluid. A number Y of rotations of the step-by-step motor are needed to complete a revolution of the rotor 10, with the result that, for each rotation of the step-by-step motor, a fraction of the overall quantity X is supplied. The supply curve of a peristaltic pump is, however, a highly non-linear curve as the peristaltic pump is by its nature a "pulsing" pump, as a result of which the flow rate is not constant for the single revolution. Tests conducted by the applicant have shown that calculating the number of rotations of the step-by-step motor needed to obtain the supply of any fraction of the overall quantity X by means of a linear equation does not enable accurate quantities of product to be supplied, since errors in absolute values are from time to time recorded in the successive supplies.

[0010] The method of the present invention therefore comprises a first stage of calibration of the pump during which the supply curve of the pump is reconstructed through successive checks on the volume of fluid supplied following a predetermined number of steps of the motor. More particularly, once an initial position is set, the motor is actuated for a predetermined number of steps and the corresponding quantity of product supplied is measured.

[0011] According to one of the preferred embodiments, the overall quantity of fluid supplied by the peristaltic pump for each revolution of the rotor is equal to 2 ml. A basic division of the step-by-step motor, 200 divisions per rotation, makes it possible for each division to dispense 0.01 ml. Experimental tests conducted by the applicant have shown that the transition between a quantity of fluid supplied and the following quantity of fluid supplied is too high with this division and, as a result of the non-linear nature of the supply curve, is insufficiently accurate. For greater accuracy, it is advisable to increase the divisions to 1/8 (1600 steps) and more preferably to 1/16 (3200 steps).

[0012] Calibrating such a large number of steps is nevertheless an extremely complex and time-consuming operation. According to the method of the present invention, the calibration stage comprises the calibration of a predetermined number of steps, preferably approximately 500, more preferably between 100 and 300 steps, and even more preferably between 200 and 250 steps distributed homogeneously along the whole curve. Each predetermined number of steps (X_i) corresponds to a respective volume of fluid supplied (V_i).

[0013] As shown in Fig. 2, the calibration curve, constructed from the calibration of the above-mentioned steps of the step-by-step motor, comprises a minimum number of steps X_{min}, different from zero, and corresponding to the minimum volume V_{min} that can be dispensed from the peristaltic pump on the basis of its mechanical characteristics. The curve then ends at a predetermined number of steps X_{stroke} which corresponds to a complete revolution of the rotor 10 and, therefore, to the maximum volume V_{stroke} that can be supplied with a complete rotation of the rotor 10. As can be seen, the curve comprises an inflection in its central portion corresponding to the passage of the roller 20 onto the tube 30.

[0014] According to a preferred embodiment of the present invention, the above-mentioned calibration of the steps is repeated at least three times.

[0015] In view of the small number of calibration points, the calibration stage described above is not sufficient to make the quantity of product supplied more accurate. The method of the present invention thus comprises a stage of interpolation of the points obtained during the calibration stage in order more accurately to determine the path of the curve. Given the non-linear nature of the curve, the use of a process of linear interpolation does not make it possible to obtain the desired results. The method of the present invention uses a process of interpolation with higher-degree polynomials. Inflections are not obtained when interpolating with a polynomial of second degree, and in the points immediately preceding and following the flat zone of the curve, cusp points are created between successive interpolation intervals. Interpolating with a polynomial of fourth degree provides two inflections which do not mirror the path of the calibration curve.

[0016] The tests conducted by the applicant have shown that an interpolation with a third-degree polynomial corrected to the first derivative makes it possible to obtain extremely surprising results. In particular, the interpolation stage comprises a stage of calculus in which the following system of linear equations has to be resolved:

$$y_1 = a_1x_1^3 + b_1x_1^2 + c_1x_1 + d_1$$

$$y_2 = a_1x_2^3 + b_1x_2^2 + c_1x_2 + d_1$$

$$y_3 = a_1x_3^3 + b_1x_3^2 + c_1x_3 + d_1$$

$$y_4 = a_1x_4^3 + b_1x_4^2 + c_1x_4 + d_1$$

[0017] The group of constants obtained, a_1, b_1, c_1, d_1, is used to interpolate the interval x_1 - x_4 at unit or greater intervals.

[0018] The stage of interpolation continues by interpolating a following group of four points which also includes the final point of the preceding group, for instance the interval x_4 - x_7, ensuring that the first derivative at the first point is equal to the first derivative obtained with the group of constants of the preceding interval. The system of linear equations to be resolved is thus as follows:

$$3a_1x_4^2 + 2b_1x_4 + c_1 = a_2x_4^3 + b_2x_4^2 + c_2x_4 + d_2$$

$$y_5 = a_2 x_5^3 + b_2 x_5^2 + c_2 x_5 + d_2$$

$$y_6 = a_2 x_6^3 + b_2 x_6^2 + c_2 x_6 + d_2$$

$$y_7 = a_2 x_7^3 + b_2 x_7^2 + c_2 x_7 + d_2$$

[0019] The group of constants obtained, a_2, b_2, c_2, d_2, is used to interpolate the interval x_4 - x_7 at unit or greater intervals. The interpolation stage continues in a recurrent manner until the whole of the calibration curve is obtained, as shown in Fig. 3.

[0020] Once the interpolation stage is completed, in order to dispense a predetermined quantity of fluid product V it is sufficient to search the closest interpolated value $V_{dispensed}$ and then to search the corresponding number of steps $X_{dispensed}$. If the required volume of fluid to be dispensed V is greater than the volume of the final calibrated point V_{stroke}, which corresponds to a complete rotation, a number N of complete rotations is subtracted from the required volume until the residual volume V' is below V_{stroke}:

$$V' = V - V_{stroke} \times N$$

where N = 1, 2, 3, etc.

[0021] If the required volume of fluid to be dispensed V is lower than the volume of the final calibrated point V_{stroke} corresponding to a complete rotation, then N = 0 and V' = V.

All the data obtained are then stored in the memory means and connected to the control means, for instance a microprocessor, so that when a request for the supply of a predetermined quantity of fluid is input, the microprocessor is able to search the corresponding number of steps in the stored data, and then actuate the motor so that it performs exactly that number of steps.

The peristaltic pump and the control method of the present invention also enable the successive supply of quantities of fluid product with a high degree of accuracy and with no limits on reproducibility. In order to achieve this result it is necessary to know the position of the rotor on the interpolated supply curve before starting a new supply cycle, and then to calculate in a highly accurate manner the number of steps of the step-by-step motor needed for each supply. If the first volume supplied V is equal to V_{stroke}, the new volume to be supplied V'' is calculated by means of the interpolated curve using the above-described stages. However, if the first volume supplied V is smaller than V_{stroke} and the subsequent volume to be supplied V'' is greater than V_{stroke} - V, the interpolated curve is not sufficient to calculate the exact number of rotations of the motor.

[0022] The method of the present invention therefore includes a stage of repositioning of the interpolated curve which returns $V_{dispensed}$ and $X_{dispensed}$ to the start of the axes and reconstructs the curve up to V_{stroke} and X_{stroke}. In other words, the point $X_{dispensed} + X_{min}$ becomes the new X_{min} and all the points of the new X_{min} up to X_{stroke} are moved. The remaining points are moved to the upper end of the curve.

[0023] In particular, in the case in which $X_{dispensed} + X_{min} < X_{stroke}$, then

$$V_{reference} = V_{Xstroke-Xmin+\Delta steps} - V_{dispensed}$$

and to move all the points, we define

$$X = I - X_{dispensed}$$

$$V = V_i - V_{dispensed}$$

where I ranges from $X_{dispensed} + X_{min}$ to X_{stroke}, with an interval Δ_{steps}.

To move the remaining points, we define

$$X = I + X_{dispensed}$$

$$V = V_i + V_{reference}$$

where I ranges from X_{min} to $X_{dispensed} + X_{min}\ \Delta_{steps}$, with an interval Δ_{step}.

[0024] In the case in which $X_{dispensed} + X_{min} \geq X_{stroke}$, then

$$V_{reference} = V_{Xstroke-Xmin+\Delta steps} - V_{min}$$

and to move all the points, we define

$$X = I - X_{min} + X_{stroke} - X_{dispensed}$$
$$V = V_i - V_{min}$$

where I ranges from $2X_{min} - X_{stroke} + X_{dispensed}$ up to X_{stroke}, with an interval Δ_{steps}. To move the remaining points, we define

$$X = I - X_{dispensed} + \Delta_{steps} - 2X_{min} - X_{stroke}$$
$$V = V_i + V_{reference}$$

where I ranges from X_{min} to $2X_{min} - X_{stroke} + X_{dispensed} - \Delta_{steps}$, with an interval Δ_{steps}.

[0025] Naturally, the principle of the invention remaining the same, the forms of embodiment and details of construction may be varied widely with respect to those described and illustrated, without thereby departing from the scope of the present invention.

Claims

1. A method for controlling a peristaltic pump for the supply of fluid products of the type comprising a duct (30) for the supply of the fluid product, a rotor member (10), one or a plurality of arms (12), pressure means (20) engaged on the arms and pressing in use on predetermined portions of the duct (30), and actuator means for the rotor member, comprising the following stages in combination with one another:

a) calibration of the peristaltic pump by calculating a series of pairs of values each formed by the volume of product supplied (V_i) and the number of strokes of the rotor (X_i) needed to obtain this volume,
b) calculation, by means of an interpolation operation, of the intermediate values with respect to each pair of values (V_i, X_i) obtained at the calibration stage,
c) calculation of a predetermined volume to be supplied (V),
d) searching for the closest interpolated value ($V_{dispensed}$) and then calculation of the corresponding number of steps ($X_{dispensed}$),
e) actuation of the actuator means to carry out the supply of the required volume of fluid product.

2. A method according to claim 1, **characterised in that** the calibration stage comprising the following stages:

f) calculation of a minimum number of steps (X_{min}) corresponding to the minimum volume that can be dispensed (V_{min}) by the peristaltic pump on the basis of its mechanical characteristics,
g) calculation of a predetermined number of steps (X_{stroke}) corresponding to the maximum volume that can be supplied (V_{stroke}) by the peristaltic pump by a complete rotation of the rotor.

3. A method according to any one of the preceding claims, **characterised in that** the calibration stage comprises the calibration of a predetermined number of strokes of the rotor, preferably approximately 500, more preferably between 100 and 300 strokes, and even more preferably between 200 and 250 strokes.

4. A method according to any one of the preceding claims, **characterised in that** the calibration stage is repeated at least three times.

5. A method according to claim 2, **characterised in that** the interpolation stage further comprises the calculation of a first group of four points by means of the following stages:

h) calculation of a group of constants (a_1, b_1, c_1, d_1) by resolution of a system of linear equations

$$y_1 = a_1x_1^3 + b_1x_1^2 + c_1x_1 + d_1$$

$$y_2 = a_1x_2^3 + b_1x_2^2 + c_1x_2 + d_1$$

$$y_3 = a_1x_3^3 + b_1x_3^2 + c_1x_3 + d_1$$

$$y_4 = a_1x_4^3 + b_1x_4^2 + c_1x_4 + d_1$$

i) using the group of constants obtained, a_1, b_1, c_1, d_1, to calculate the values of fluid product supplied V_1, V_2, V_3 and V_4 corresponding to the strokes of the rotor X_1, X_2, X_3 and X_4.

6. A method according to claim 5, **characterised in that** it comprises the interpolation of successive groups of four points, which also include the last point of the preceding group, until the value of the maximum volume (V_{stroke}) which may be supplied by a complete rotation of the rotor is calculated.

7. A method according to claim 2, **characterised in that** after the supply of the required volume of fluid product, if $X_{dispensed} + X_{min} < X_{stroke}$, the method further comprises the following stages of calculation of new pairs of values (V, X):

j) $$V_{reference} = V_{Xstroke-Xmin+\Delta steps} - V_{dispensed}$$

$$X = I - X_{dispensed}$$

$$V = V_i - V_{dispensed}$$

where I ranges from $X_{dispensed} + X_{min}$ to X_{stroke}, with an interval Δ_{steps},

k) $$X = I + X_{dispensed}$$

$$V = V_i + V_{reference}$$

where I ranges from X_{min} to $X_{dispensed} + X_{min} - \Delta_{steps}$, with an interval Δ_{sters}.

8. A method according to claim 2, **characterised in that** after the supply of the required volume of fluid product, if $X_{dispensed} + X_{min} \geq X_{stroker}$, the method further comprises the following stages of calculation of new pairs of values (V, X):

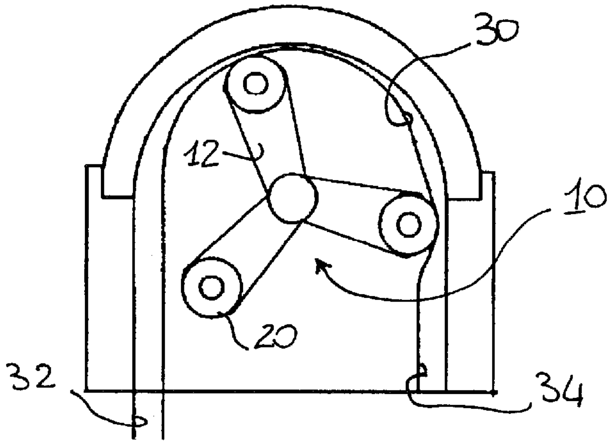
$$\text{l)}\quad V_{reference} = V_{Xstroke-Xmin+\Delta steps} - V_{min}$$
$$X = I - X_{min} + X_{stroke} - X_{dispensed}$$
$$V = V_i - V_{min}$$

where I ranges from $2X_{min} - X_{stroke} + X_{dispensed}$ up to X_{stroke}, with an interval Δ_{steps}, and

$$\text{m)}\quad X = I - X_{dispensed} + \Delta_{steps} - 2X_{min} - X_{stroke}$$
$$V = V_i + V_{reference}$$

where I ranges from X_{min} to $2X_{min} - X_{stroke} + X_{dispensed} - \Delta_{steps}$, with an interval Δ_{steps}.

FIG. 1



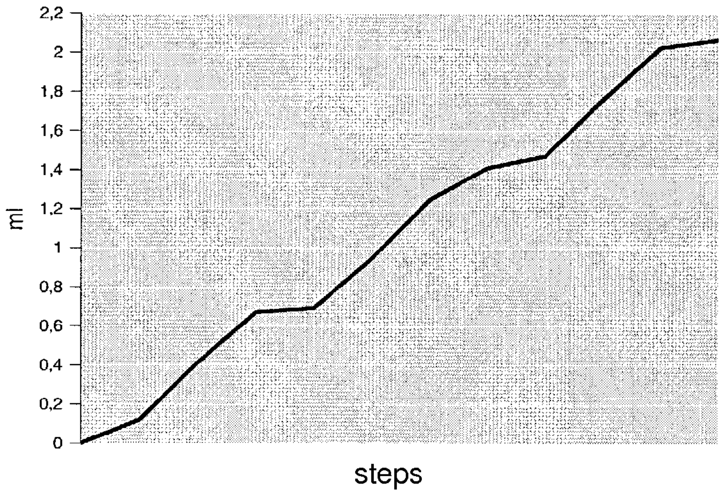


FIG. 2

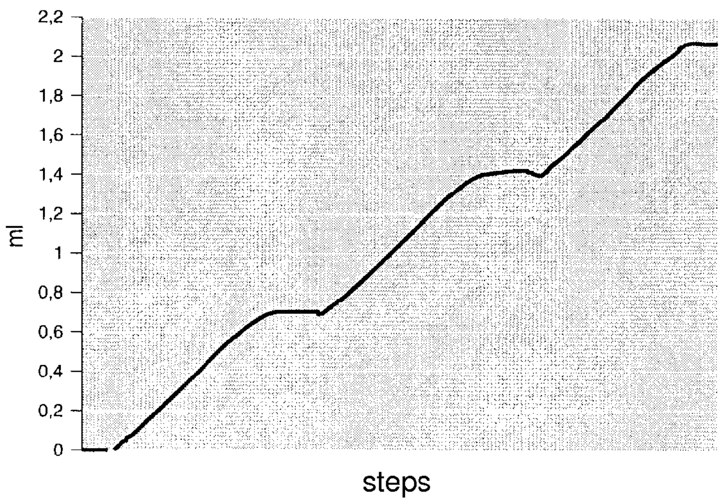


FIG. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 08 10 1184

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
D,A	US 2007/059184 A1 (BACH DAVID T [US]) 15 March 2007 (2007-03-15) * the whole document * -----	1-8	INV. F04B49/00 F04B43/12
D,A	WO 91/10934 A (BAXTER INT [US]) 25 July 1991 (1991-07-25) * the whole document * -----	1-8	
D,A	US 5 733 257 A (STERNBY JAN [SE]) 31 March 1998 (1998-03-31) * the whole document * -----	1-8	
A	US 2005/180856 A1 (BACH DAVID T [US]) 18 August 2005 (2005-08-18) * the whole document * -----	1-8	
A	GB 1 326 373 A (IVAC CORP) 8 August 1973 (1973-08-08) * the whole document * -----	1-8	
A	US 4 830 218 A (SHIRKHAN HAMID [US]) 16 May 1989 (1989-05-16) * the whole document * -----	1-8	TECHNICAL FIELDS SEARCHED (IPC) F04B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	26 June 2008	Olona Laglera, C

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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26-06-2008

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2007059184 A1	15-03-2007	NONE	
WO 9110934 A	25-07-1991	CA 2047231 A1	12-07-1991
		DE 69030254 D1	24-04-1997
		DE 69030254 T2	30-10-1997
		EP 0462238 A1	27-12-1991
		JP 2887418 B2	26-04-1999
		JP 4504298 T	30-07-1992
		US 5003239 A	26-03-1991
US 5733257 A	31-03-1998	AT 200031 T	15-04-2001
		DE 69426985 D1	03-05-2001
		DE 69426985 T2	19-07-2001
		DK 723463 T3	30-04-2001
		EP 0723463 A1	31-07-1996
		ES 2155094 T3	01-05-2001
		JP 9503415 T	08-04-1997
		JP 3615762 B2	02-02-2005
		PT 723463 T	28-09-2001
		WO 9510310 A1	20-04-1995
US 2005180856 A1	18-08-2005	NONE	
GB 1326373 A	08-08-1973	CA 943422 A1	12-03-1974
		CA 942850 A2	26-02-1974
		CA 955137 A2	24-09-1974
		CA 955138 A2	24-09-1974
		CH 587662 A5	13-05-1977
		CH 587663 A5	13-05-1977
		CH 563166 A5	30-06-1975
		CH 566788 A5	30-09-1975
		CH 587059 A5	29-04-1977
		CH 587591 A5	13-05-1977
		DE 2037946 A1	28-10-1971
		GB 1326374 A	08-08-1973
		GB 1326375 A	08-08-1973
		GB 1326376 A	08-08-1973
		GB 1326371 A	08-08-1973
		GB 1326372 A	08-08-1973
		JP 51024836 B	27-07-1976
		JP 51025672 B	02-08-1976
		JP 51025673 B	02-08-1976
		JP 51025674 B	02-08-1976
		US 3736930 A	05-06-1973
US 4830218 A	16-05-1989	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 20070059184 A **[0003]**
- WO 10934 A **[0003]**
- US 5733257 A **[0003]**