(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
5 February 2004 (05.02.2004)

PCT

(10) International Publication Number
WO 2004/012017 A2

(51) International Patent Classification[7]: G05B

(21) International Application Number: PCT/SG2002/000161

(22) International Filing Date: 17 July 2002 (17.07.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
200204078-0 8 July 2002 (08.07.2002) SG

(71) Applicant and
(72) Inventor: PAKIANATHAN, Manuel, Jesubatham [SG/SG]; Apt. Blk. 90, Bedok North, Street 4, #08-1545, Singapore 460090 (SG).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

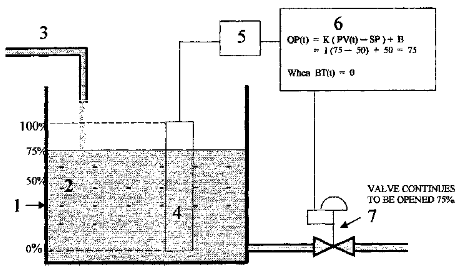
(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declaration under Rule 4.17:
— *of inventorship (Rule 4.17(iv)) for US only*

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: NOVEL BUMP-LESS TRANSFER TERM FOR CONTROL. SYSTEM



LEVEL CONTROL AFTER THE BUMP-LESS TRANSFER TERM BT(t) IS REDUCED TO ZERO AUTOMATICALLY, AFTER A TIME INTERVAL THAT DEPENDS ON THE BLEED RATE OF BT(t), CAUSING LEVEL TO SLOWLY RISE TO 75%. THUS KEEPING VALVE OPENED AT 75%.

(57) Abstract: Whenever a process control system is transferred from manual control to automatic control it is generally required to make the transfer bump-less, i.e. ensuring there is no change in output when the transfer from manual to automatic control is made. The present invention is a novel method of securing a bump-less transfer for any proportional action controller that does not have integral action. At present there is no proper way to effect bump-less transfer for such a controller. The method used calls for an additional term, which I have called as the Bump-less Transfer 'BT(t)' term, to be included in the control algorithm. This term lasts for a short period only, merely to secure the bump-less transfer. The term has two components 1) a magnitude and 2) a bleed rate. The bleed rate is the time required for 'BT(t)' to fall from its initial magnitude to zero. The initial magnitude of the 'BT(t)' term depends on the value of the manual output of the controller before transfer to automatic control, and it is set internally by the computer. The bleed rate of the term determines how long the term is active after the transfer and is determined externally by the process control engineer. Such a term, as far as I am aware, has not been used before for bump-less transfer for such controllers or for any other form of control. Because of the lack of such a term, many makers of control systems vary the bias value to effect the bump-less transfer. However, this leads to a lopsided control system that is totally unsuitable for proportional controllers without integral action. The bias value should remain fixed at 50% if we are to have a good, reliable control system. The description that follows gives, 1) an introduction that summarizes the background and prior art on the subject of control, and 2) a method description and implementation of the invention. Mathematical equations in the analogue and discrete form that define the controllers are also included in the description. These equations show the need for this novel bump-less transfer term in proportional controllers that do not have integral action. They also show why it is unnecessary to have this term for proportional controllers with integral action. To show how the system works and the pitfalls that can take place if this novel bump-less transfer term was not employed, a level control application that uses proportional only control is considered during the transfer from manual to automatic control. Three drawings, figures 1, 2 and 3 are used to illustrate the problems that arise and how they are solved when this novel Bump-less Transfer term 'BT(t)' is used in proportional only controllers during the transfer from manual to automatic control.

WO 2004/012017 A2

NOVEL BUMP-LESS TRANSFER TERM FOR CONTROL SYSTEM

DESCRIPTION :

Introduction:

In control engineering, an error signal is derived in response to a measurement of a parameter it is desired to control. An automatic control signal is then derived from the error signal by a controller and used to control some aspect of the system to compensate the error. In its simplest form, this control signal is made to be proportional to the error signal. However, quite often components of the control signal are also produced which are the first order derivative or integral of the error signal. Controllers which employ these components are usually called proportional plus derivative (P+D) or proportional plus integral (P+I) controllers. It is also possible to have a so-called three term controller, i.e. proportional plus integral plus derivative (P+I+D or PID) controller.

The derivative component is used if it is desired to reduce the lag (increase the response time of the system). Integral control is used primarily to eliminate offset, i.e. failure of the controlled parameter to return to exactly the required level (set point).

In the implementation of such an automatic control system, the process is normally put on manual control before it is transferred to automatic control.

Method Description and Implementation:

When a process control system is transferred from manual control to automatic control it is generally required to make this transfer bump-less, i.e. ensuring there is no change in output when the transfer from manual to automatic control is made. For proportional plus integral control and proportional plus integral plus derivative (PID) Control, there is no difficulty in achieving this. But, for proportional action only (P only) controllers, and proportional plus derivative (P+D) controllers no such easy solution at present exists. Hence, makers of Distributed Control Systems (DCS) do not provide an easy, convenient way to secure bump-less transfers for such controllers, suitable for the plant operators. However, when they claim they do, they go about it in the wrong way, leading to lopsided control systems, often to the confusion and dismay of the unsuspecting user.

In order now to explain the preferred embodiment for a bump-less transfer for a proportional controller without integral action according to the present invention, it is necessary to resort to a mathematical description. In the formulae used the terms are defined as follows:-

OP(t)	Output of the controller in percent (time varying)
OP(m)	Manual value of Output in percent
K	Gain of the controller
PV(t)	Process Value in percent (time varying)
SP	Set Point in percent
BT(t)	Bump-less Transfer term in percent (time varying)
B	Bias value in percent (normally 50%)
T	Sampling interval

OP_n	Output in percent at the nth sampling interval
Td	Derivative action time
T_i	Integral action time
BT_n	Bump-less Transfer term at the nth sampling interval
e_k	error (PV –SP) at the kth sampling interval
e_n	error (PV –SP) at nth sampling interval
e_{n-1}	error (PV –SP) at (n-1) th sampling interval

The output of a direct acting proportional controller follows the equation:

$$OP(t) = K(PV(t) - SP) + B \qquad (1)$$

While the output of a reverse acting proportional controller follows the equation:

$$OP(t) = -K(PV(t) - SP) + B \qquad (2)$$

For a good control system, it is essential that the bias value 'B' must be kept at 50%, as can be seen from the several graphs shown in figure 1. However, for a bump-less transfer from manual to automatic control, where the manual output can be anywhere from 0% to 100%, keeping the bias value 'B' at a constant value of 50%, would mean that bump-less transfer cannot be achieved, using the above control equations. Hence, some makers of Distributed Control Systems have allowed the bias value to be floating, ranging from 0% to 100%, to enable bump-less transfer to take place. This means good proportional action control will not take place unless the bias value by chance happens to be around 50%. To overcome this conflicting requirement for good proportional action control and bump-less transfer, a novel method of control, using an additional term in the control equation, is introduced. This additional term may be called as the Bump-less Transfer term, 'BT(t)'.

The additional term 'BT(t)' in the control equation has a magnitude as well as what may be called as the bleed rate. This bleed rate is given in minutes or in seconds, and it should be set, like integral and derivative action rates by the process control engineer. The initial value of 'BT(t)' depends on the manual value of the output before the bump-less transfer to automatic control. Hence, the magnitude of 'BT(t)' is internally set, and is not externally set as its bleed rate.

Thus the control equation for a direct acting proportional controller becomes as follows:-

$$OP(t) = K(PV(t) - SP) + B + BT(t) \qquad (3)$$

while for a reverse acting proportional controller the equation is as follows:-

$$OP(t) = -K(PV(t) - SP) + B + BT(t) \qquad (4)$$

Where the initial magnitude of 'BT(t)' is set internally, and is dependent on the manual value of output before bump-less transfer to automatic control. Thus if PV(t) = SP, and the value of the manual output 'OP(m)' were to be 75% , the magnitude of 'BT(t)' will automatically be internally set as follows: BT(t) = OP(m) – B = 75% — 50% = 25%. However, the bleed rate of 'BT(t)' will be set externally by the process control engineer. The bleed rate determines how slowly or quickly the magnitude of 'BT(t)' falls at the same rate from its initial value to zero. Once the magnitude of 'BT(t)' is reduced to nothing, it remains zero for the rest of the time the system is on automatic control.

For a better understanding, the sampled data discrete DCS form of the equations using the Bump-less Transfer term 'BT(t)' is now compared with controllers having the integral action term, as controllers with integral action do not require the 'BT(t)' term. The equations for these are given below for the direct acting controllers:-

$$OP_n = Ke_n + KT/Ti \sum_{k=1}^{n} e_k + B \text{ (for P+I control)} \qquad (5)$$

$$OP_n = Ke_n + B + BT_n \quad \text{(for P only control)} \qquad (6)$$

From the equation of the P+I controller it can be seen how the output can be easily varied to match the manual output by varying the error value summation in the integral action term without varying 'B' the bias value. Hence, the bias value of 50% need not be compromised. However, for P only control this facility is not available for bump-less transfer from manual to automatic control. Thus the need for the additional 'BT(t)' term to facilitate the transfer. However, some DCS makers vary the bias value because of the unavailability of the integral action term in P only control. This brings about a totally unacceptable lopsided control system. In some DCS makes the bias value 'B' is varied even in P+I controllers to match the manual value of output 'OP(m)'. Perhaps this is because it may be easier to program the control system for bump-less transfer by varying the bias value rather than the summation of errors. These programmers are apparently not fully conversant with control theory and do not quite realize that they have brought on a lopsided control system, as they often go unnoticed in P+I controllers. However, for P only controllers the effect is unacceptable. See fig.1 and the explanations on page 5.

P+D controllers are rarely used, as whenever derivative action is used the integral term is invariably used. Further, the transfer from manual to automatic control is usually done in the steady state. Hence, there will be no difference in the error at the nth sampling interval and the (n-1)th sampling interval, and so the derivative action term will be zero. If this is not so, it is still advisable to neglect the term as it is small, and at this stage it can be quite unreliable. However, if it is not ignored, the initial value of 'BTn' for a direct acting controller is as follows:

$$BTn = OP(m) - B - Ke_n - KTd/T\,(e_n - e_{n-1}) \quad \text{(with B=50\%)} \qquad (7)$$

Some may be of the view that because of the difficulty in effecting bump-less transfer for proportional control without integral action, why not always have proportional plus integral action, or at least whenever it required to have bump-less transfer from manual to automatic control. However, integral action has a serious side effect, which makes it not always desirable. Let us therefore examine what this is. The primary reason for having integral action is to eliminate offset. Hence, it was originally known as reset action. The side effect is, that when there is a process change, because of the memory of previous control actions it is unable to respond quickly to the process change. This can lead to wide oscillations about the set point while trying to arrive at the set point, or to even a process upset. Thus, proportional control without integral action is often necessary to bring about stability to the system. So, unless precise control at the set-point is absolutely necessary, integral action is generally avoided.

Since in the control of level, precise control at a particular level is very rarely needed, proportional control without integral action is almost always used for greater stability. Hence, for a further understanding of this novel method of control using the additional term 'BT(t)' for bump-less transfer, a level control application will now be considered. Suppose, for a certain flow into a tank, the control valve has to be opened 75% so that the level in the tank neither rises or falls, then the output to the control valve has to be 75%. Thus, if the plant operator had brought the level to 50% as shown in figure 2, because the set-point of the controller was at 50%, then PV(t) — SP will be 50% — 50% = 0. If at this point the control was switched from manual to automatic, then BT(t) would have to be 25% at the time of switching from manual to auto in order to match the output value, since the bias value remains fixed at 50%. However, it may be noted that, PV(t) does not have to be equal to SP when the bump-less transfer is made, as the initial magnitude of 'BT(t)' would be adjusted according to the equation:-

$$BT(t) = OP(m) - K\,(PV(t) - SP) - B \quad \text{(for a direct acting controller)} \qquad (8)$$

Now, suppose the bleed rate of 'BT(t)' is set at 2 minutes, then as the magnitude of BT(t) falls, the value of OP(t) also falls, causing the valve to close slightly. This in turn causes the level to rise, which in turn will cause PV(t) to be greater than SP. This will increase the value of OP(t). Thus slowly after 2 minutes the magnitude of 'BT(t)' would be reduced to zero from its initial value set internally at 25%. However, since the value of PV(t) would have risen to 75%, by the time BT(t) had fallen to zero, for a direct acting proportional controller with a gain of 1, the output remains at 75% as can be seen in the following equation:

$$OP(t) = K\,(PV(t) - SP) + B = 1(75 - 50) + 50 = 75. \qquad (9)$$

The equation also shows there will be an offset from the Set Point. However, this offset of 25% from the set point is perfectly acceptable for a proportional only controller that has a gain of one. Figure 3 shows the level in the tank when BT(t) = 0 after transfer from manual to automatic control. Without the 'BT(t)' term, a plant operator has to know the gain of the controller and calculate the required process value for a bump-less transfer that will be suitable for the manual output. This is difficult for the plant operators and so it is not preferred. Hence, some DCS makers have resorted to a floating bias to match the manual output of the controller, instead of the fixed bias of 50%. This, as mentioned earlier, results in a lopsided control system. Thus, to effect a bump-less transfer, it is imperative that the additional term 'BT(t)' is included in the control algorithm of all proportional controllers that do not have integral action. Since the initial magnitude of BT(t) before bump-less transfer is done internally by the computer and the bleed rate of the BT(t) term is set by the control engineer, the plant operator has nothing to calculate. For a fuller understanding of the problems involved, and how by using the new 'BT(t) term the present shortcomings are overcome, three figures are given below to illustrate.

Figure 1 shows five graphs. Graph A shows the level input versus the controller output for a direct acting controller with a gain of 1 and a bias value of 50%. Graph B shows a reverse acting controller with a gain of 1 and a bias value of 50%. Graph C shows a direct acting controller with a gain of 1 but with a bias value of 75%. From graph C it can be easily seen why when the bias value of a controller is set at other than the mid range value of 50%, it will result in a lopsided control system that is quite unacceptable. Graph D shows another lopsided control system if the bias value was set at 25%, when the level was at 50%. As mere additional information, graph E shows a proportional control with a gain of 2, and a bias of 50%. A controller with a gain of 2 is also known as having a 50% proportional band (PB), while a gain of 1 is known as 100% PB.

Figure 2 shows a level control system at the time of transfer from manual to automatic control. Figure 3 shows the same system when the value of BT(t) is zero, by which time the level in the tank has risen to 75%, assuming the flow into the tank has remained the same. The system consists of a tank (1) containing a liquid (2). It is filled from an uncontrolled liquid conduit (3), and it is desired to maintain the liquid between 0% and 100%. To this end a displacer type of level sensing element (4), a level transmitter (5), and a DCS controller (6), are connected to a current to pneumatic positioner of a control valve (7). The controller, in this case, is made to be a direct acting proportional only controller with a gain of 1 and a set-point of 50%. Such a controller will ensure that the system is controlled between the prescribed limits, in this case between 0% and 100%. The control valve chosen, is such that it opens more as the controller output 'OP(t)' increases. Suppose the level in the tank was 50%, matching the set-point, and the manual output was 75%, for a bump-less transfer to take place the output of the controller has also to be 75%. However, this value cannot be achieved unless the bias value was also set at 75%, since the other portions of equation 1 contribute to zero at the mid-range value of 50% as, PV(t) — SP = 50% — 50% = 0, at the time of transfer from manual to automatic control. But, as can be seen in graph C of Fig1, a bias value of 75% will result in a lopsided control system that is unacceptable. Thus, if the bias value was at 75% for the proportional only controller, the outlet valve will not close shut, as it should, even when the level had fallen to zero percent. This will lead to emptying the tank. On the other hand if the bias value was set at 25%, the outlet control valve will not open fully, as can be seen from graph D, even when the level in the tank has exceeded 100%. This will lead to an overflow in the tank. Hence, a system may not be controlled between the set limits, if we have a variable bias. So, if we are to avoid this, we require the new Bump-less Transfer BT(t) term, which, in this case adds another 25% to the output, but which is effective only for a very short period. Thus, for all proportional controllers that do not have integral action, with the new Bump-less Transfer term included in the control equation, the bias value 'B' setting at the mid-range value of 50% is not compromised, and proper control is maintained.

CLAIMS :

1.

This invention claim is for a novel method to secure a bump-less transfer when a system is transferred from manual control to automatic control for proportional action controllers that do not have integral action. At present there is no proper way to secure a bump-less transfer for such a controller. The method calls for the inclusion of a novel Bump-less Transfer 'BT(t)' term into the computer algorithm of any proportional action controller that does not have the integral action term. The inclusion of the novel 'BT(t)' term enables bum-less transfer to take place for these controllers while keeping the bias value 'B' fixed at 50%. This novel 'BT(t)' term has two components - 1) an initial magnitude, and 2) a bleed rate. The initial magnitude of the 'BT(t)' term is required to be set internally in the DCS computer to match the manual output of the controller during the transfer from manual control to automatic control. The initial magnitude of the 'BT(t)' term is determined automatically in the computer. The basic equation for determining the initial magnitude of 'BT(t)' for a direct acting controller is as follows:

$$BT(t) = OP(m) - K\,(PV(t) - SP) - B \qquad \text{with the value of B fixed at 50\%}$$

The basic equation for determining the initial magnitude of 'BT(t)' for a reverse acting controller is as follows:

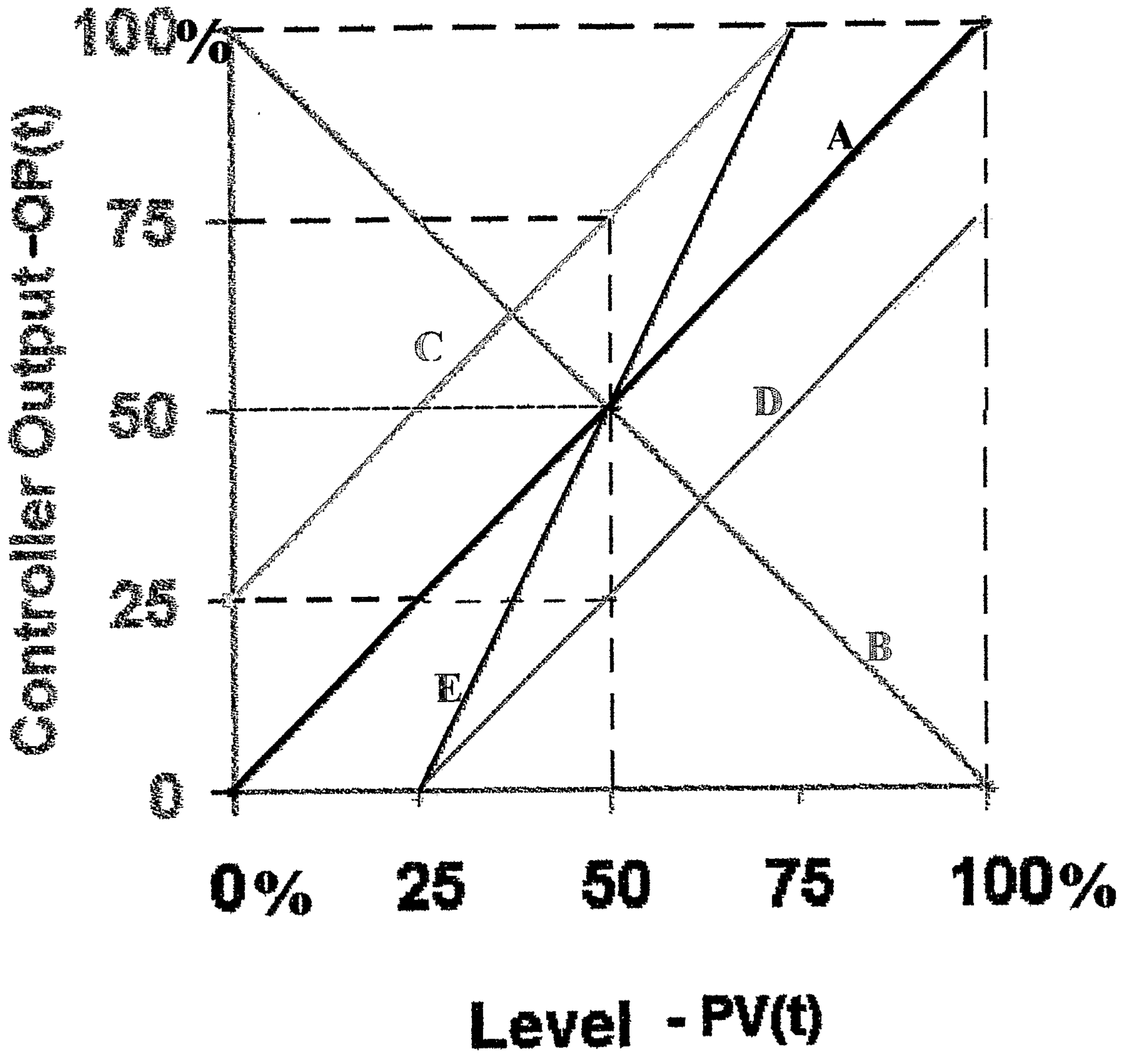
$$BT(t) = OP(m) + K\,(PV(t) - SP) - B \qquad \text{with the value of B fixed at 50\%}$$

The bleed rate is the time taken for the magnitude of BT(t) to fall gradually from its initial value to zero. The bleed rate is set externally by the process control engineer, in the same way the gain 'K' and the set-point 'SP' of the controller are set.

2.

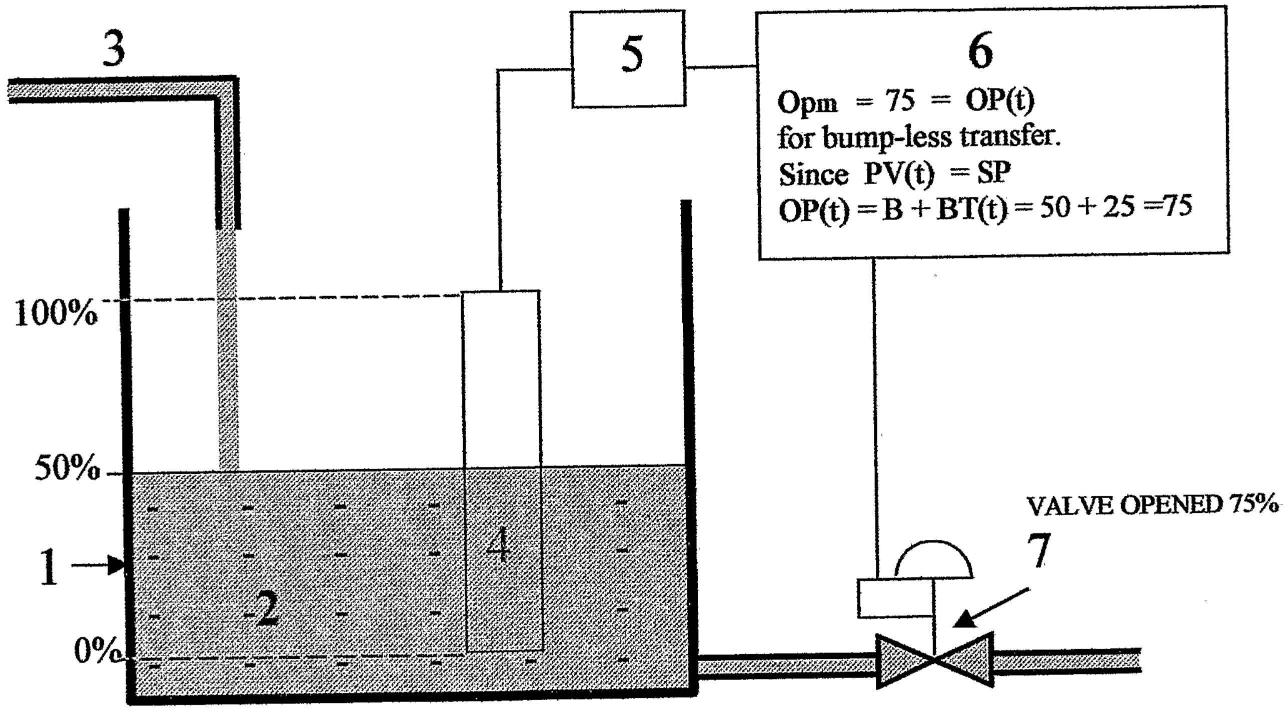
It is also claimed that in the light of this disclosure, other variations and embodiments within the scope of the present invention will now readily be apparent to those skilled in the art, and shall be considered as falling within the ambit of this invention.

Fig. 1



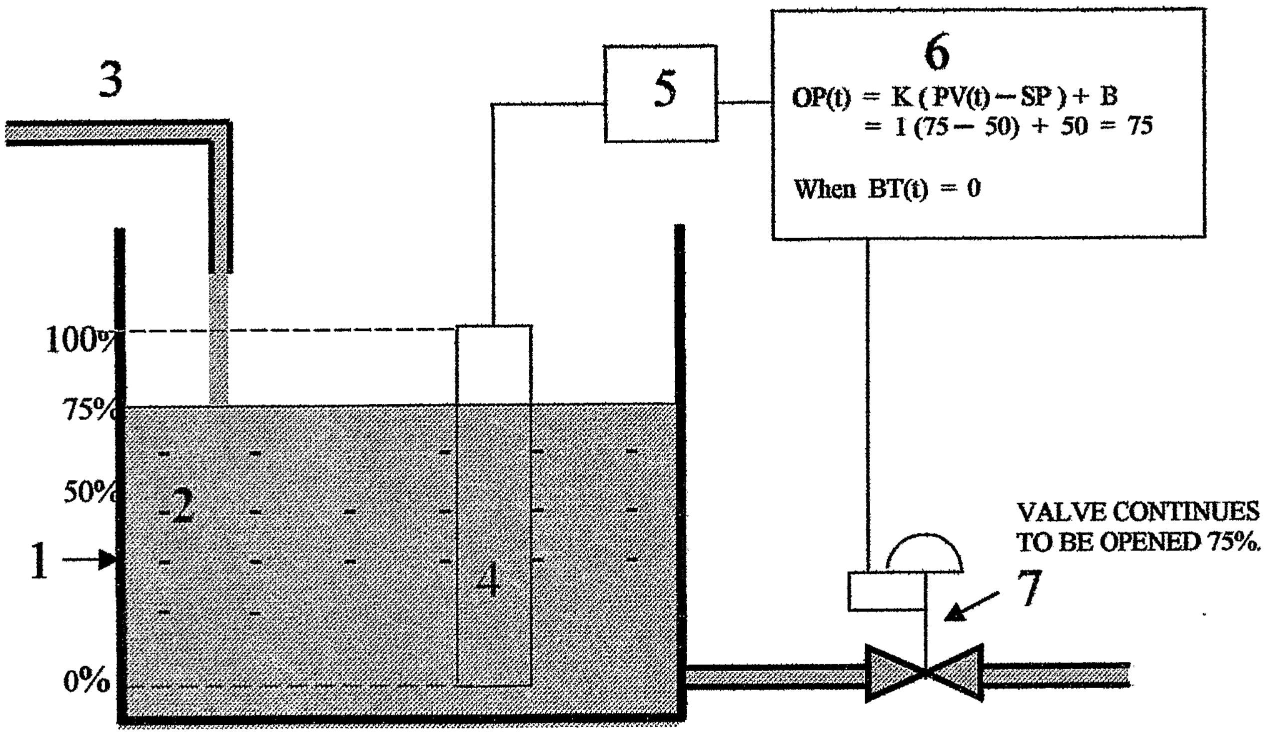
GRAPH A SHOWS A DIRECT ACTING CONTROLLER WITH A GAIN OF 1(100% PB) AND B=50%
GRAPH B SHOWS A REVERSE ACTING CONTROLLER WITH GAIN =1 (100% PB) WHEN B =50%
GRAPH C SHOWS A LOPSIDED DIRECT ACTING CONTROLLER WITH GAIN =1 WHEN B = 75%
GRAPH D SHOWS A LOPSIDED DIRECT ACTING CONTROLLER WITH GAIN =1 WHEN B = 25%
GRAPH E SHOWS A DIRECT ACTING CONTROLLER WITH GAIN= 2 (50%PB) WHEN B=50%

Fig. 2



LEVEL AT THE 50% SET-POINT JUST BEFORE BUMP-LESS TRANSFER TO AUTOMATIC CONTROL WITH THE MAGNITUDE OF BT(t) AUTOMATICALLY SET SO THAT BT(t) + B IS EQUAL TO THE MANUAL OUTPUT TO THE CONTROL VALVE BEFORE THE TRANSFER.

Fig. 3



LEVEL CONTROL AFTER THE BUMP-LESS TRANSFER TERM BT(t) IS REDUCED TO ZERO AUTOMATICALLY, AFTER A TIME INTERVAL THAT DEPENDS ON THE BLEED RATE OF BT(t), CAUSING LEVEL TO SLOWLY RISE TO 75%. THUS KEEPING VALVE OPENED AT 75%.