Water Conservation by means of an Automatic Water Level Control System

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In the light of the dominant importance of water to the Republic of South Africa and to Southern Africa generally, the necessity arose for the development of an automatic water level control system which was applied to the Driel Barrage in the Tugela River. The principle of Proportional, Integral and Derivative sensing has been employed successfully in different spheres of science and industry, but its application to control large hydraulic structures such as radial gates on dams is, however, uncommon and constitutes the theme of this paper. A PID-automatic controller was designed and installed and three different methods were employed for determining the optimum parameter settings which control its efficient functioning. These comprise direct calculation, analogue computer simulation and actual practical tests on site. The final parameter settings resulted in efficient and effective automatic water level control to within a spectrum of 3-4 cm at full supply level at incoming flows and floods ranging from 8-700 m³/s. These results were due to the mechanism actually reacting to a water level change of as small as 1 mm.

Nomenclature

D	= Damping factor
$\frac{d}{dt} = s$	= Operator
F_{PID}	= Transfer function of the PID-controlling system
F_s	= Transfer function of the controlled system
F_i	= Transfer function of the change in river inflow at 1,5 km upstream
g	= Acceleration due to gravity
H	= Height of water level above the sill
i	= River inflow changes
I	= Integral controller
I−	= Integral portion
K_p	= Proportional constant
K_I	= Integral constant
K_D	= Derivative constant
K_s	= Steady-state transfer constant of the controlled system
K_i	= Integral constant of the controlled system
P	= Proportional controller
P−	= Proportional portion
q_A	= Actual gate discharge
q_D	= Desired gate discharge
t	= Time (continuing)
T_t	= Travel time or dead-time of propagating wave
T	= Time constant
T_n	= Reset time
T_v	= Derivative action time constant
T_{in}	= Time constant of the exponential inflow hydrograph
T_i	= Integral time
T_u	= Effective dead-time
v	= Flow velocity
x	= Controlled variable (upstream water level)
x_i	= Input signal
x_0	= Output signal
x_I	= Dampened upstream water level
x_d	= Control deviation
y	= Gate adjustment ($y \propto q_A$)
w	= Set-point or command variable

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Introduction

The manual control of crest gates and other outlet devices on dams and reservoirs is costly, complicated and prone to over-control, resulting in downstream damage and waterloss[1,2].

A water bailiff has to keep a close watch on the water level at all times while simultaneously regulating the flood control gates or other outlet devices. This important but difficult and unpleasant task has to be performed not only during daytime but also at night, weekends, public holidays and often during stormy and rainy conditions.

The water bailiff is furthermore confronted with several other unknown factors such as: size of incoming flood, floodshape, time at which a flood enters the dam basin, and time of flood recession. Therefore he is not always able to conserve water in the best interest of the country.

These basic facts underline the importance of and necessity for a completely self-contained automatic control system for regulating seasonal flows, while pre-warning signals of exceptional floods from upstream situated weirs could be transmitted to these automatic control systems for efficient flood routing and water conservation.

An automatic control installation should be capable of sensing a flood in all its phases prior to activating the discharge mechanisms for optimum release. Functionally its design depends upon the continuous sensing of the water level and its three major charateristics, viz.: The present instantaneous level or Proportional element P; the past values in water level measurement experienced or the Integral element I and the future growth of water level changes or the Derivative element D. Its function incorporates the important feed-back principle vital for an automatic closed-loop installation. This feed-back signal is the gate mechanism's reply to the controller's instruction.

Past experience concerning the unsuccessful application of simple proportional or "step-wise" control showed that these methods cannot be classified as automatic water level control because they exclude the important feed-back principle and are therefore not closed-loops[3]. These systems which prescribe a particular gate opening for different basin water levels within a detailed range, have proved unsuccessful and unreliable. A considerable risk is involved in the application of simple "step-wise" control which depends on limit switches and timers. The system cannot function automatically because no pre-warning charateristics are available for predicting further flow increases or the expected recession of an inflow hydrograph.

The author claims that the Driel Barrage is known to be the only installation in South Africa which is at present functioning automatically. It has proved itself over more than 8 years of continuous operation in the control of normal and abnormal flows of as high as 700 m^3/s which operating step-wise control installations were unable to equal.

Theoretical background of automatic gate control system

The change in water level is not only a function of the magnitude and rate of inflow but is also related to the shape, length, surface area, dead-time, roughness and slope of the dam basin. If the water level is to be controlled automatically to a set level, these variables have little influence on a water level increment. Consequently the water level is a reflection of changes in river inflows and can therefore be identified by an inflow hydrograph. For Driel Barrage the resulting water level rise produced by both inflowing rivers – the Tugela and the Mlambonja – would deviate from any particular level, in accordance with figure 1.

P-Controller:
In a proportional controller, the output signal x_0 is proportional to the input signal x_i. The output signal x_0 acts according to the instantaneous, existing and present command of the input signal x_i. The P-controller is not influenced by past commands and is furthermore unable to predict future input expectations[4].
Thus $x_0 = K_p x_i$.

I-Controller:
The integral controller produces an output signal x_0 which is the integral $\int x_i dt$ of the input signals from time $t = 0$ up to $t = t_A$. This is represented by the area AOA′. The I-controller adjusts its output signal x_0 according to the summation of the past applied input signals x_i. This controller is therefore capable of "looking back" into the past input experiences. Here again predicting the future and sensing the present instantaneous condition is beyond the I-controller's reach.
Thus $x_0 = K_I \int x_i dt$.

D-Controller:
A derivative controller produces an output signal x_0 proportional to the differential dx_i/dt. This is measured by the tangent at say point A with inclination dx_i/dt. The output signal x_0 acts according to the instantaneous changes of the input signal x_i and therefore measures the possible change in command which could be expected in the immediate future. This controller ignores the present and past input signals and is only directed towards the future.
Thus $x_0 = K_D \, dx_i/dt$.

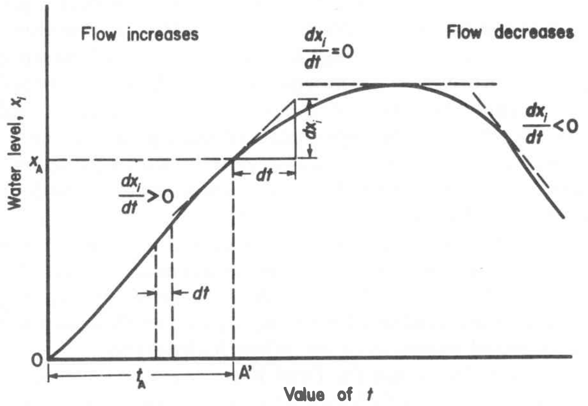

Figure 1

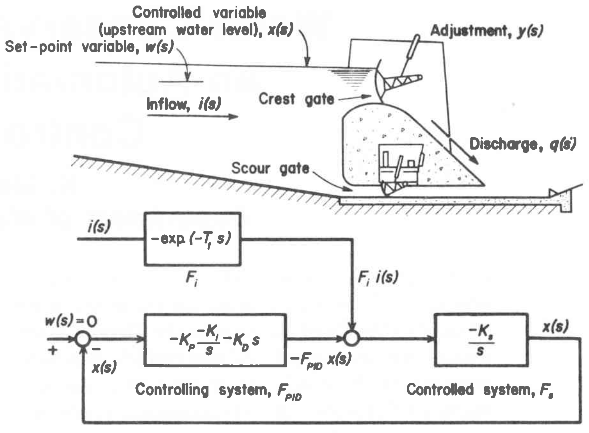

Figure 2

By definition a "closed-loop" consists of a "controlling" and a "controlled" system[4]. The float, PID-control elements, together with the three position controller and the outlet gates and operating mechanism constitute the components of the "controlling system" while the barrage characteristics (length, size, surface area, roughness, slope etc.) is defined as the "controlled system" in the "closed-loop," figure 2.

The PID-controller possesses the combined characteristics of the three individual types. The D-component produces a correction to the water level earlier than would be possible with a P- or PI-controller. For the D-controller $F_D = -K_D.s$.

The following equation is derived after equating the input and output relationship from the transfer functions F_{PID}, F_s and F_i, i.e.

$$x(s) = -i(s). \frac{F_s.F_i}{(1 + F_s.F_{PID})} + \frac{w(s).F_s.F_{PID}}{(1 + F_s.F_{PID})} \qquad (1)$$

Generally the set-point value is kept constant at the desired full supply level, yielding $w(s) = 0$ and

$$x(s) = \frac{-i(s).F_s.F_i}{(1 + F_s.F_{PID})}$$

After utilising the transfer functions F_s, F_i and F_{PID} and furthermore considering that:
$K_I = K_p/T_n$ and $K_D = K_p.T_v$, where T_n is the reset time and T_v the derivative time, the water level and inflow relationship can be described as:

$$\frac{x(s)}{i(s)} = \frac{s.K_s.T_n.\exp.(-T_t.s)}{s^2.T_n(K_p.K_s.T_v - 1) + s.K_pK_s.T_n + K_p.K_s} \qquad (2)$$

The preceding equation includes the controlled system parameter K_s as well as the parameters K_p, T_n and T_v of the controlling system[4]. It should be realised that these parameters are not constant but vary over the whole range of inflows. The inclusion of the D-characteristic shows that the desired mathematical transformation into the time-domain is described by a non-linear partial differential equation of higher order. This necessary transformation is complex and does not yield a practical solution. Furthermore, the controller parameters K_p, T_n and T_v are dependent upon the steady-state transfer factor K_s. This factor, on the other hand, is dependent upon the size and length of the controlled system as well as on the magnitude of the river inflow.

Configuration and design considerations of the Driel Barrage system

Driel Barrage is impounding the Tugela River beyond the confluence of the Tugela and Mlambonja Rivers near the town Bergville in Natal. It is part of the mighty Tugela-Vaal Project and was designed and constructed by the Department of Water Affairs.

The closed-loop diagram functions as follows: In figure 3 a float measures the water level, x, in relation to the set-point value w. The difference, x_d, activates the PID-controller which generates an output signal,. representing the "desired discharge". This signal is compared to a feed-back signal of which the residual signal drives a three-position controller to generate an "open" or "close" command to the gates. This results in a change in the "actual discharge" (due to gate movement) which changes the water level x, thus defining a new "desired discharge" value. This is again compared to the "actual discharge" and a repetition of the above procedure is followed through the cycle until the "actual" and the "desired discharge" are identical.

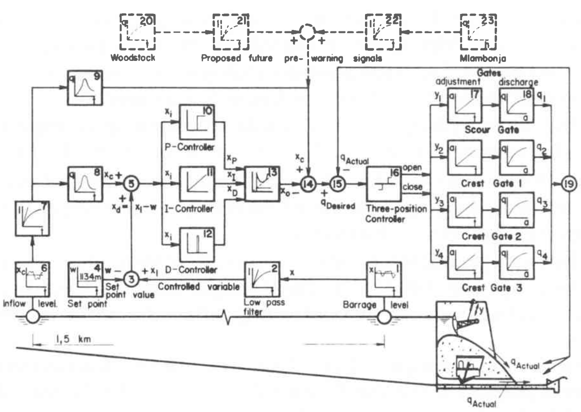

Figure 3 – Block-diagram representation of automatic control at Driel Barrage

The diagram further shows future additional flood warning signals, from the proposed Woodstock Dam and the Mlambonja gauging weir, to Driel Barrage. These will enable exact flow readings to be transmitted sufficiently in advance to the automatic control at Driel Barrage – finally achieving optimum control. Presently, flood warnings are received from the inflow float located 1,5 km upstream of Driel Barrage, transmitting the dx_c/dt factor to the closed loop.

A short description of the installation follows: A float continuously measures the water level x while a potentiometer, driven from the float, chain and sprocket drive, senses the float position electrically. Its output is transduced into a 4-20 mA signal which is supervised for any malfunction of the potentiometer and transducer unit. All measurements involving water level, gate position and gate discharge are supervised and possible defects are indicated by a signal lamp and alarm. Any malfunction can thus be assessed in optimum time and rectified immediately[5].

Apart from this signal being used for telemetry control from a remote control centre as well as for water level indication and registration, its main function is to trigger the automatic control in the closed loop – block 1. This water level signal, however, includes undesirable distortions caused by high frequency wave motion, wind effects etc. A low pass filter unit (block 2) with an adjustable time-constant dampens these frequency variations, yielding an acceptable x_l value to the summing point 3.

The adjustable set-point (block 4) is normally set by an operator to a desired predetermined value. Summing point 3 compares the proportional positive oriented voltage signal of the water level x_l with the negative set-point signal w, such that: $x_d = (x_l - w)$. The residual voltage signal then feeds into summing point 5.

As already mentioned, the closed loop incorporates an additional safeguard. This consists of a float which measures mainly rapid water level rises (dx_c/dt) due to high floods entering the dam basin. This float is 1,5 km upstream from Driel Barrage situated at the Tugela and Mlambonja Rivers' confluence. A rapid inflow level change with respect to time (dx_c/dt) is measured in functional blocks 8 and 9. This instrument incorporates adjustable limits and is presently set to 20 cm/h which was dictated by the exceptionally high flood recorded on 29 October 1966. As soon as this value is exceeded, coarse gate control or simultaneous gate operation follows. Furthermore this disturbance signal dx_c/dt influences the closed loop at the two summing points 14 and 5. In the first, (14), it results in an immediate change in the "actual discharge", this change preceding all other signals. Before its effect is compensated for by the changing Barrage level, it provides a second signal representing a fraction of the dx_c/dt value from functional block 8 to the summing point 5. This precaution ensures that both water level measurements are operative, with a time lag between the upstream level and the Barrage level.

The resulting "trimmed" signal x_d from summing point 3 together with the dx_c/dt signal serves as input to the proportional, integral, and derivative control elements shown in blocks 10, 11 and 12, with respective adjustable parameters K_p, T_n and T_v. To achieve optimum gate control for normal dry-seasonal inflows of between 8 and 20 m^3/s as well as for maximum inflow increases of 215 $m^3/s/h$, the closed loop is equipped with two "discharge-dependent proportional amplification adjustments". This involves the automatic switch-over from proportional amplification K_{p1} to K_{p2} when inflows exceed 250 m^3/s, reverting automatically at inflows below 250 m^3/s.

The individual output signal of every controller is now added in functional block 13, which is then summated to the dx_c/dt signal in summing point 14. The residual final signal activates the "desired discharge q_D" which is compared with the actual discharge q_A in summing point 15. The latter being derived from the actual gate position. The value of $(q_D - q_A)$ is fed into the three position controller (block 16), which, in turn, impulses an open command to the scour (bottom) and crest gates (top, see figure 3) operating mechanisms in sequence. With decreasing inflows the sequence of gate operation reverses.

A feature of this system is that all sensed values (water levels, gate position and discharge) required for the indicating instruments and the PID-controller are connected to the main supply, via a stand-by battery which is continuously charged. Any power failure at the Barrage is immediately rectified by a 75 KVA stand-by generator set.

Furthermore the gate position potentiometers are attached to the gate driving shafts and provide the 4-20 mA analogue signal which is required for control, supervision, indication and registration, (block 17). In addition, a second potentiometer which is connected to each gate position potentiometer converts the 4-20 mA signal into a gate discharge signal. These individual signals are summated to generate the actual discharge q_A (block 18). Should the three pumps operate, their constant flow discharges are duly added. The total actual discharge is registered in summing point 19 which serves as feed-back to summing point 15 where it is compared to the desired discharge.

The scour and crest gates (size 12 × 12,2 m clear opening, weight 55 ton) can be controlled from the local control cubicle in the pier; from the remote-automatic control panel with selector switch on either "Manual" or "Automatic" or with telemetry control from the Jagersrust control centre. The installation incorporates several other features such as sequence of gate operation and synchronous and coarse gate control, in addition to the already mentioned back-up feature of controlling the gate by telemetry from the Jagersrust control centre. A very important feature is the automatic selection of functional gates. As soon as a gate becomes inoperative and does not respond to the controller's command an alarm is triggered and the next gate is selected. The panel interior consists of easy removable "plug-in prints" fitted with diodes and measuring sockets for fault indication and signal strength respectively.

Three methods were applied for determining the optimum K_p, T_n and T_v settings for the PID-controller shown in figure 3.

1. Calculating the K_i, T_i and T_u values for a controlled system without self-regulation for determining the PID-controller parameters K_p, T_n and K_v, using the Ziegler-Nichols criterion[6].
2. Simulation of the Barrage characteristics on an analogue computer for determining optimum parameter settings.
3. Applying practical test results recorded at Driel Barrage during the period of severest floods from January 1976 to May 1977. Adjustments were made to individual components of the PID-controller to achieve optimum K_p, T_n and T_v values.

The elaborate first method will not be dealt with in this paper but is more fully described in reference (6).

However, if summarised the resulting calculated parameters when used with the Ziegler-Nichols empirical formulae determine the unknown factors K_p, T_n and T_v. These are presented graphically in figure 4 for the entire range of barrage discharges. The curve shows that K_p increases while T_n and T_v decreases with increased inflow, the latter two having exponential characteristics.

Since the scour gate handles the majority of normal barrage inflows (approximately 97% when referred to a time basis) it is imperative that the PID-controller should be adjusted to provide optimum control on this gate for this particular range of flows. Furthermore, throughout 9 months of the year inflows were measured to below 20 m^3/s. It is therefore evident that the initial choice of T_n and T_v is dominated by the scour gate flows. Furthermore, the reset time T_n and the derivative action time constant T_v, are independent of the particular K_p-value; only one T_n and T_v setting can be made to satisfy the flows independent of K_{p1} or K_{p2}.

From these calculations[6] the following parameter adjustments could be affected. Flow range 0-250 m^3/s; $K_{p1} = 10 - 15$ $m^3/s/cm$, flow range 250 – 2 500 m^3/s, $K_{p2} = 50 - 75$ $m^3/s/cm$, $T_n = 1\,920$ secs and $T_v = 400$ secs.

At this stage it is clear that, although these values are only scientifically guided approximates, they provide a valuable tool for determining an initial parameter setting; the optimum settings being possible only after the installation is analysed on a long term basis.

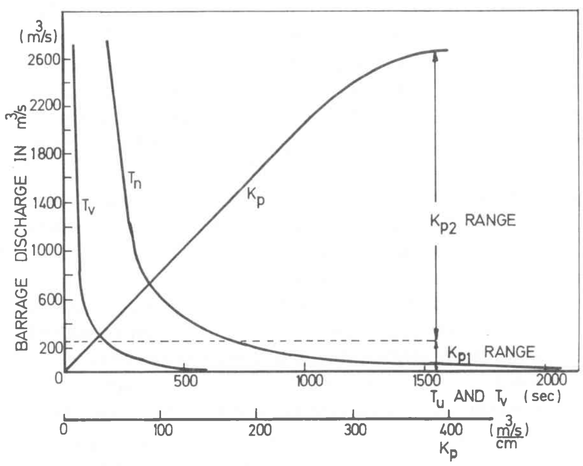

Figure 4

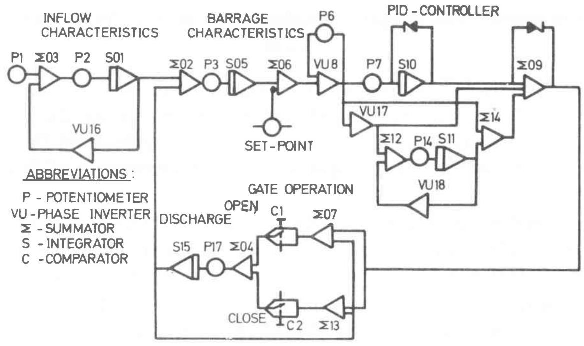

Figure 5

The second method was by simulation of the automatic control on an analogue computer.

Here Barrage and gate charateristics were simulated to determine their effect on and the dynamic behaviour of the overall automatic control installation. A number of tests were conducted at the firm Metrawatt in Nürnberg, Western Germany. A Telefunken RA.742 transistorised analogue computer, of which the circuit diagram is shown in figure 5, was used.

The inflow hydrograph was simulated assuming an expotential characteristic with an adjustable time constant T_{in} (T inflow). Potentiometer setting for simulating the shape and size of the inflow hydrograph was based on relevant hydrological data supported by actual observation.

The barrage characteristics, however, were simulated over the inflow range 100-3 000 m^3/s. These ranges were not to exceed a 10 cm water level rise by controlling either the scour or crest gates.

The individual elements of the PID-controller were adjusted by potentiometer P6 for the P-controller, P7 for the I-controller and P14 for the D-controller, the parameters as already defined being K_p, T_n and T_v respectively. The results of seven analogue tests are given in the corresponding curves[5] shown in figures 6a to 6g.

Analogue computer test results

Test result No. 1 (figure 6a) clearly shows that a maximum overshoot of 13% gate discharge was obtained due to the reset action of the integral controller. It stresses the advantage of the I-controller which cancels the off-set action of the P-controller and reverts the water level back to the desired full supply level. The I-controller provided a satisfactory and stable control, limiting the water level rise to 3,5 cm. The imperative I-action which still functioned after the P-element had already disappeared, reduced the off-set effects until the water level reached its original steady-state condition.

In comparison test No. 2 (figure 6b) reflects very unstable control. This is due to the strong reaction of the I-controller at a small proportional amplification. A reduction of the reset-time T_n produces a faster rising transfer function and hence a stronger interaction of integral control. This reset action reduces the off-set in a shorter period, but is associated with the unavoidable effect of instability. The P-portion which has stabilising characteristics, is always desirable in correct proportion.

In test No. 3 (figure 6c) the effect of the P-portion was increased, while the instability of the I-portion was reduced; bigger K_p and T_n adjustments increase stability. The D-portion was excluded in test No. 3, stable control being evident with an overshoot of only 15%, but associated with a water level rise of 6 cm. However, the T_n value had to be increased to provide stability since the D-portion was excluded.

Test No. 4 (figure 6d) with the D-portion operative again

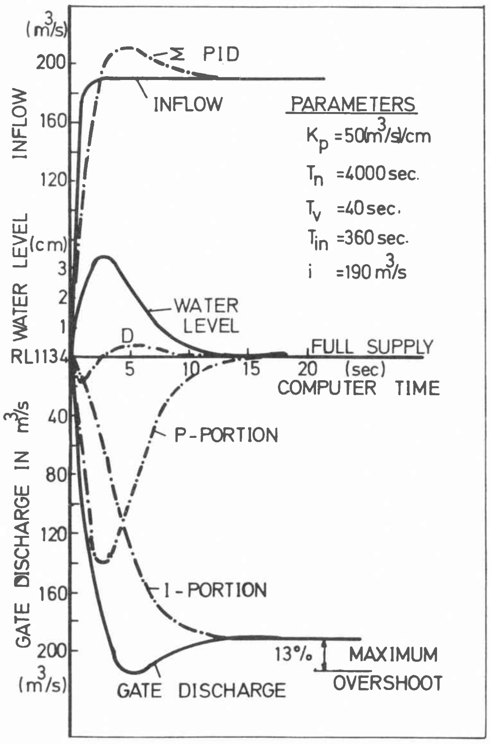

Figure 6a

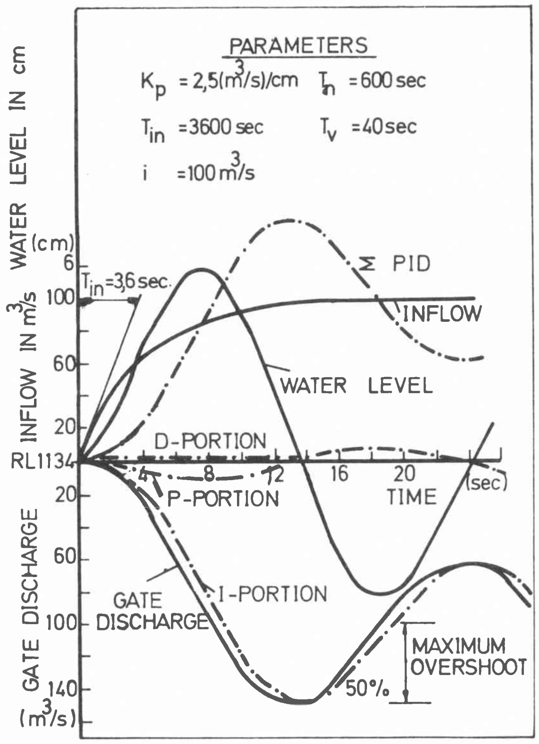

Figure 6b

reflected increased stability with corresponding stabilisation time reduced from 22 to 15 seconds. The I-controller, assisted by the D-controller, reduced the water level rise to 3,8 cm. The D-portion produced a correction earlier than was possible with proportional action only. Furthermore derivative action has no direct effect on off-set, but provides a stabilising influence with a reduction in maximum overshoot. These results also stressed the fact that the preliminary K_p, T_n and T_v settings provide a stable control for handling inflows through the scour gate. With identical parameter settings but at half the inflow a perfectly stable control was obtained in test No. 5 (figure 6e) showing a 9% overshoot and a water level increase of only 2 cm.

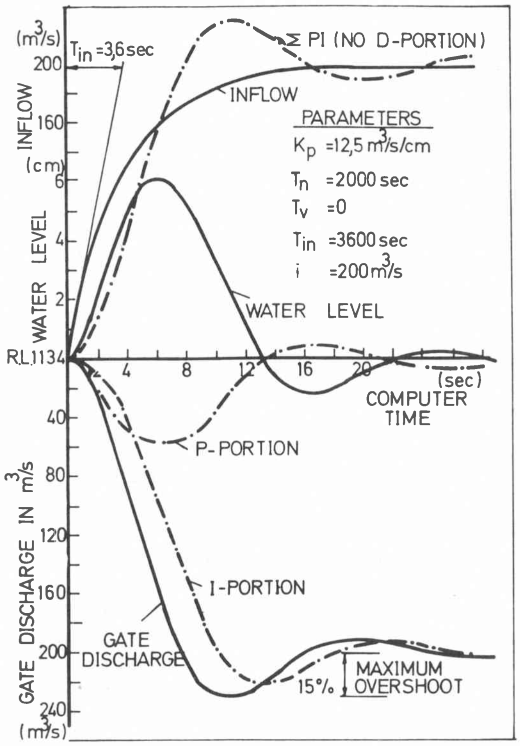

Figure 6c

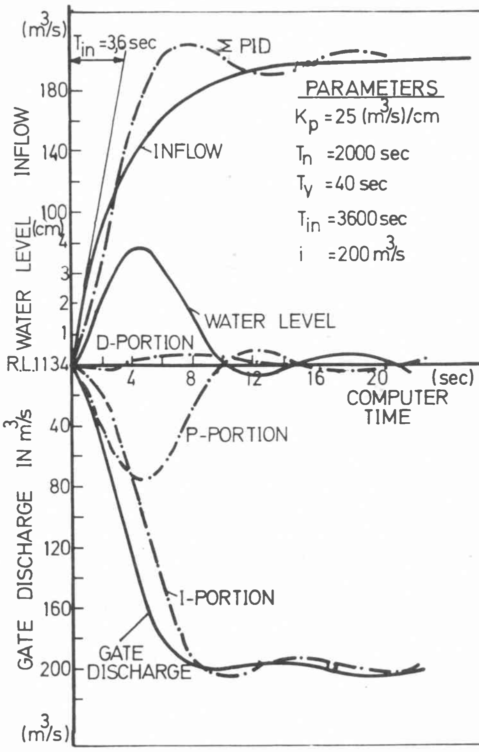

Figure 6d

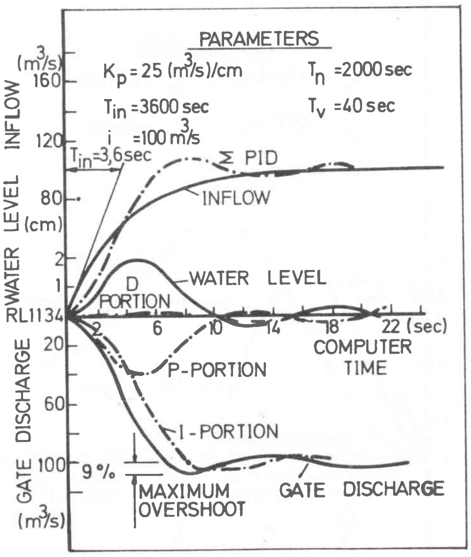

Figure 6e

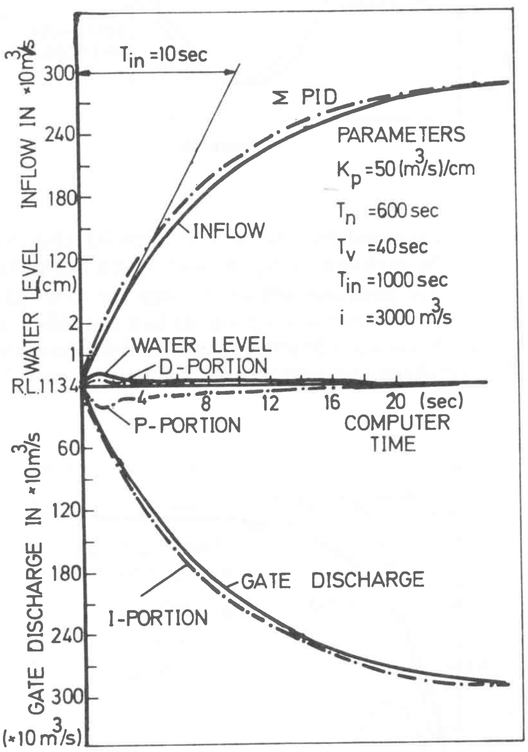

Figure 6f

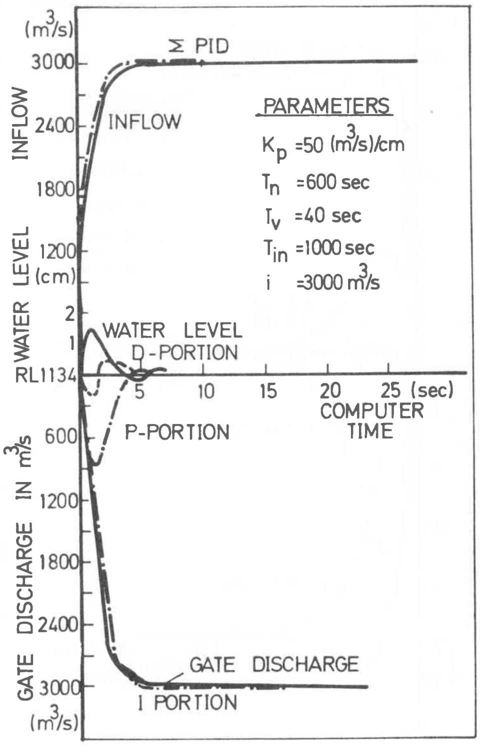

Figure 6g

A design flood of approximately 3 000 m³/s was simulated in tests Nos. 6 and 7 (figures 6f and 6g). The possibility of routing the design flood safely through the Barrage by means of automatic control was checked for two distinct rates of flow increases. Firstly, a flood rise rate representing 3 000 m³/s over a 10 000 seconds and secondly an identical flood but over a much shorter period of 1 000 seconds were simulated. Both tests show that the PID-controller was perfectly capable of handling these floods at a K_p value of 50 (m³/s)/cm aided by a reduced interaction of the I-portion having a T_n setting of 600 secs.

These results clearly revealed that small K_p and big T_n settings are necessary for low river inflows, while the reverse is applicable when inflows approach the design flood. Optimum parameter settings for K_p, T_n and T_v should be chosen to cover the highest percentage inflows during the operational period. It was previously pointed out that inflows of 0-120 m³/s occur over 97% of the annual operational period and it is therefore impractical to select parameters to cope with a 1 in 500 year design flood.

Optimum parameter adjustments, corresponding to the values given in analogue test result No. 1, was recommended, accompanied by a reduction in K_p to a value of 10 (m³/s)/cm for the average daily flows of up to 200 m³/s. Floods could easily be handled by a second amplification factor K_{p2} as pointed out earlier.

The resulting PID-controller parameters for optimum control resulting from these tests are therefore as follows: Inflow i = 0-200 m³/s; K_p = 10 (m³/s)/cm; T_n = 4 000 seconds; T_v = 40 seconds.

Actual tests on the installation

The methods described previously, provide a satisfactory preliminary solution for parameter adjustments to achieve effective and stable control. For optimum adjustments to K_p, T_n and T_v it is, however, imperative to subject the installation to actual river flow fluctuations. Consequently long term tests, covering the seasonal flows, were conducted at Driel Barrage where records of gate position, discharge and water level provided sufficient data for implementing the necessary adjustments.

The control was installed in November 1975, the scour and crest gate installation being completed during the same period. Filling of the Barrage only commenced at the beginning of January 1976, the frequent occurrence of floods resulting in the water level rising rapidly to full capacity.

The automatic control installation was switched on and the water level deviation from the desired full supply level was recorded. The installation which was designed to maintain the water level to within a tolerance of 10 cm, performed exceptionally well. Since the float senses the water level to within an accuracy of ±1 mm this level could be kept constant to within a remarkably small deviation of 3-4 cm, being well within the envisaged tolerance of 10 cm, figure 7.

The installation was also tested for operational characteristics, as well as for synchronous and coarse gate control features, by adjusting the set-point value to below full supply level, thereby defining a new desired water level. A command to the gates resulted in an immediate excess discharge, causing the water level to settle at the new value. These tests confirmed that the installation responded satisfactorily in countering these dramatic changes.

Ideal test conditions prevailed during the months of January and February 1976, when strong inflows replaced the released storage rapidly by filling to a level above full supply within only a few hours. During the winter months – April, May and June – the inflow had diminished to such an extent that tests involving excessive storage release were not feasible. Tests had to be extended over long periods, since mandatory slow releases resulted in related level changes.

Finally the automatic controller was initialised using the parameter combinations shown in figure 7.

The 1976 test results show that the flow never exceeded 250 m^3/s and accordingly the installation functioned at a K_p value of 12,5 $(m^3/s)/cm$. Only on 14 February 1977, K_{p2} became operative when a 400 m^3/s flood entered the barrage basin. It is of interest to note here that gates Nos. 2 and 3 provided the required control while gate No. 1 was undergoing maintenance.

During the initial tests on 13 January 1976 the short reset time of T_n = 125 seconds caused frequent gate adjustments per hour. Too many adjustments cause excessive wear on the installation and drive equipment which should be avoided. Fast reaction of the I-element, having a short reset time T_n, was responsible for this unstable and fluctuating behaviour.

The results further reflect an improvement with a reset time increased to 333 seconds. The control stabilised subsequently and the gate adjustments were reduced to 4 per hour. This adjustment also improved the stability at a flow increase of 220 m^3/s on 4 February 1976. It was, however, evident that the integral action still produced sinusoidal fluctuations (March and April records). This element, which at the time had been adjustable to 1 000 seconds, had to be fitted with an additional calibrator in order to extend its range to 10 000 seconds.

An increase in the T_n value on 10 June 1976 showed that even at the low winter flow of 10 m^3/s a considerable improvement was achieved when compared to previous results. The I-element was set to T_n = 4 000 seconds and the D-component to T_v = 100 seconds. This resulted in a satisfactory and stable control with a water level deviation of only 4 cm and one gate adjustment per hour.

With a further increase in T_n to 4 600 seconds on 15 June 1976, even better control was achieved giving one gate adjustment for every two hours of operation. During May 1977 a final T_n setting of 5 000 seconds at a flow of 5 m^3/s was tested and proved to be an optimuim value for Driel Barrage, in that only 9 gate adjustments over 42 hours resulted. This is, however, only true for low winterflows, any increases during the summer requiring a smaller reset time, (figure 7). Analogue computer results Nos. 6 and 7 (figures 6f and 6g) confirm the fact that the reset time T_n has to be reduced for stable control as the flow increased, while small fluctuations are also reduced by decreasing the K_p values.

The different parameter results obtained thus far clearly illustrated that the method of direct calculation served as a first

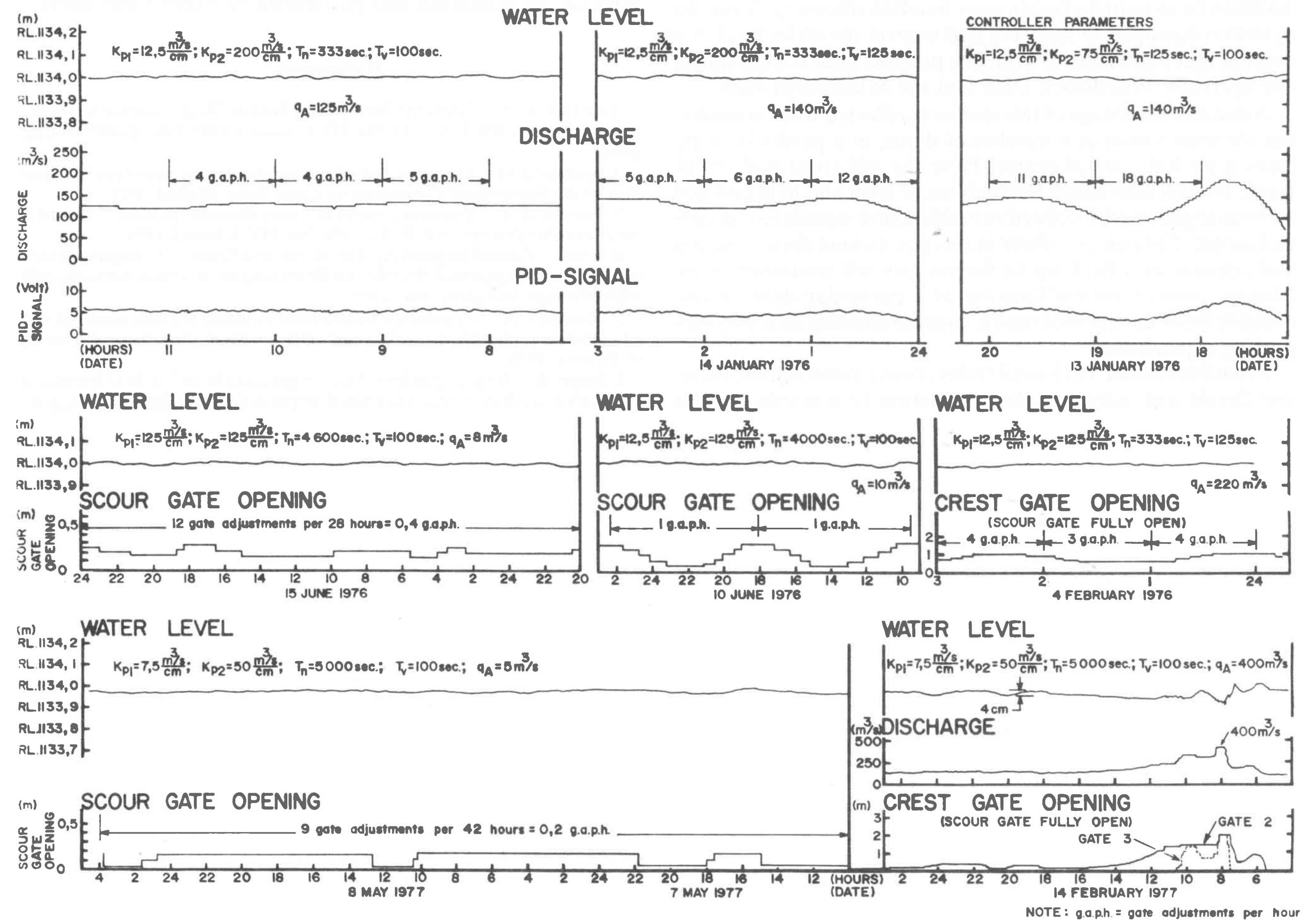

Figure 7

scientifically based guide, while the analogue computer values reflected the overall control effects resulting from different parameter adjustments. These led to the final parameter "streamlining" by in situ tests on the actual installation yielding the following adjusted operational values:

K_{p1} = 7,5 (m^3/s)/cm; K_{p2} = 50 (m^3/s)/cm; T_n = 5 000 seconds; T_v = 100 seconds.

Conclusion

On the majority of dams in the Republic of South Africa any defective gate control due to human error might lead to disastrous consequences and water waste. An automatic controller was developed, installed and tested at Driel Barrage and proved successful and practical by utilising a PID-controller. Two proportional amplifications, K_{p1} and K_{p2}, were found necessary for handling flows and floods below and above 250 m^3/s respectively, covering the entire range of Barrage inflows satisfactorily. K_{p1} produced a stable control on the scour gate while K_{p2} handled the maximum discharge through the flood control gates effectively.

The I-controller, on the other hand, eliminated undue off-set and maintained the water level. The supporting D-controller monitored rapid incoming flows and immediately detected the turning point at which a flood was at a recession and thereby conserved water.

Optimum K_p, T_n and T_v values for the PID-controller were applied successfully, handling the entire range of inflows during the summer and winter periods.

Floods between 250 and 400 m^3/s (normal flows between 20 and 80 m^3/s) were accommodated effectively. This represents a 1 in 3 year flood occurrence, while the average daily flows, in addition to infrequent floods were handled efficiently. Since the system is equipped to conserve and control the water level, it is evident that flood control would be possible after completion of the upstream Woodstock Dam and the Mlambonja weir.

A distinct advantage of this system is reflected when considering the supervision of a number of dams, in a particular area, from a central control centre. Here the self-contained installation at each dam could transmit water level and gate position records together with collective malfunction signals to the control centre. The control officer at this point could then supervise and operate as a back-up to the various self-contained units. Manual control, on malfunction at a particular dam, is also possible from this control centre, thus eliminating staff and supporting expenditure.

From November 1975 until today, heavy rains caused excessive floods and subjected the installation to a severe test. Its performance confirmed the claim that it operated efficiently for a period of 8 years and required only the yearly human intervention for maintenance. For incoming floods the Barrage water level did not exceed a tolerance of 4 cm while an approximate 2 cm margin was maintained during low flows. Furthermore, the system responded to a water level deviation of as small as 1 mm.

The advantages associated with this automatic control installation could be summarised as follows:

1. More effective and efficient control of water level as compared to manual control thus avoiding damage, flood disasters and water loss.
2. Constant full supply level ensures maximum yield of a dam throughout its lifespan, together with maximum pump efficiency where applicable.
3. Reservoirs of the Driel type offer an additional advantage under automatic control. These types, having a small storage capacity without overspill, could be subjected to overstressing of gate structures at high floods, as well as the endangering of earth embankments if late gate opening is implemented.
4. The cost factor is of considerable importance. The total cost of this installation in 1976 amounted to only R40 000 – including approximately R23 000 – being the cost of the remote control gear which is not applicable to all flood control dams.

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