CONSTRUCTION AND EVALUATION OF PID AUTOMATIC CONTROL SYSTEM FOR IRRIGATION CANALS AT LABORATORY SCALE

CONSTRUCTION ET EVALUATION DU SYSTEME DE CONTROLE AUTOMATIQUE PID DES CANAUX D'IRRIGATION AU NIVEAU DE LABORATOIRE

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ABSTRACT

Increasing limitation of water resources requires optimum use of available water and performance improvement of systems. Providing higher flexibility in water delivery and reducing water losses are important factors to achieve them. Studies indicate that high performance improvement could be achieved by suitable control systems. Structures automation is one of the main options for improving operations in irrigation canals. PID control systems are typical samples of automatizing canal operation control. For local development of automatic control system technology and its application, the facilities must first be constructed and tested in laboratory scale, then, if the performance was acceptable, it could be introduced to the irrigation canals. In this research, the PID control systems are constructed and investigated. Initial gate opening and target depth constitute the input of the program and the output is gate opening. The PID control system compares the measured water depth and target value in the canal reach and calculates the gate opening accordingly. To study the performance of the PID control systems, different scenarios of flow variations were tested. MAE, IAE, and SRT indicators and graph of depth variations versus time are used for evaluating the performance of the system. Two initial discharges of 5 and 10lit/s were considered. The results showed that the performance of the developed PID control systems are appropriate and it could be introduced in irrigation canals. However, PID downstream control system showed better performance compared to PID upstream control system.

Key words: *Irrigation canals, automatic control, upstream and downstream control, flow variation, laboratory flume.*

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RESUME ET CONCLUSIONS

La limitation croissante des ressources en eau exige une utilisation optimale de l'eau disponible et l'amélioration de la performance des systèmes existants. Pour réaliser ces objectifs, il est nécessaire de rendre une plus grande flexibilité à la distribution de l'eau et de réduire les pertes d'eau. Les études indiquent que l'amélioration de la performance peut être réalisée par les systèmes de contrôle adéquats. Les ouvrages d'automatisation est l'une des principales options d'améliorer l'exploitation des canaux d'irrigation. Les systèmes de contrôle PID en amont et en aval sont des échantillons typiques des systèmes de contrôle automatique. Pour le développement local du système des technologies de contrôle automatique et son application, les installations doivent d'abord être construits et testés en laboratoire. Ensuite, si la performance de ce système est acceptable, il pourrait être utilisé dans les canaux d'irrigation. Dans cette recherche, les systèmes de contrôle PID en amont et en aval sont conçus, construits, testés et étudiés. Le logiciel du système est le système de contrôle automatique PID. L'ouverture initiale de la vanne et la profondeur cible constitue l'entrée du programme. Le système de contrôle PID compare la profondeur d'eau mesurée et la valeur cible et ensuite calcule l'ouverture de la vanne. Pour étudier la performance des systèmes de contrôle PID, différents scénarios de variations de débit ont été examinés. Les indicateurs MAE, IAE et SRT et les variations graphiques de la profondeur par rapport au temps ont été utilisés pour évaluer la performance du système. Deux débits initiaux de 5 et 10lit/s ont été tenus en compte. Les résultats ont montré que la performance du système de contrôle automatique PID est appropriée et il pourrait être appliqué dans les canaux d'irrigation. Cependant, le système de contrôle PID en aval marche bien par rapport au système de contrôle PID en amont.

Mots clés : *Canaux d'irrigation, contrôle automatique, contrôle en amont et en aval, variation de débit, canal de laboratoire.*

1. INTRODUCTION

Automation is one of the ways for improving the efficiency and flexibility of water delivery in canal systems. PID upstream and downstream control systems are two prevalent and appropriate systems for adjusting water level at target value, which were developed by Sogreah (Rogers and Goussard, 1998). In PID control system, water level can be regulated both upstream and downstream ends of the reach. In PID upstream and downstream control systems, water level must be measured at upstream and downstream ends of the reach, respectively. Changde *et al*., (2007) used mathematical model of PID algorithms in a canal in Heby province in China. The canal was about 130 km long, which was divided to 13 reaches with the range of capacity from 170 m^3/s to 60 m^3/s. The PID control system was also used in Colorado (Burt *et al*., 1998), Pakistan (Munir *et al*., 2007), and France (Litrico *et al*., 2007). In Iran, mathematical models of PID upstream and downstream control systems were developed and connected with ICSS model, then tested and evaluated in E_1-R_1 canal of Dez irrigation network (Monem and Massah, 2001). For local development of this technology and its application in irrigation canals, first, the system must be constructed and evaluated at the laboratory level and if the performance was acceptable, it could be introduced in irrigation canals.

2. MATERIAL AND METHODS

2.1 Physical Model

All experiments were carried out in a rectangular laboratory flume, with dimensions of 0.3 × 0.45 × 10 m (Fig. 1). For downstream flow variation, a manually operated overflow gate was established at the end of the reach while upstream flow variation was performed by a manually control valve. In upstream PID control system, water depth is measured in upstream of the automatic gate and in downstream PID control system water depth is measured in downstream of the automatic gate (Figs. 2 and 3). Three ultrasonic sensors were designed and constructed for measuring gate opening and water levels. One for measuring the gate opening, another for measuring water depth at the upstream of the gate, and the third for measuring water depth at the downstream of the gate. There are three electronic boards in this system: the motherboard for reducing the number of inputs, the interface board for converting the data to USB and the driver board for controlling the motor operation. A program is written in MATLAB environment, which calculates the amount of variation in gate opening using the PID control logic. The initial gate opening and depth of water constitute the input of this program and the output is the amount of gate opening required to stabilize water level at the target value. The LABVIEW program serves as a medium between the output of the developed PID control logic program (the software of the system) and system hardware.

Fig. 1. Laboratory flume, depth and gate opening sensors, motor, and slide gate (Canal de laboratoire, profondeur et détecteurs d'ouverture de la porte, moteur, porte coulissante et)

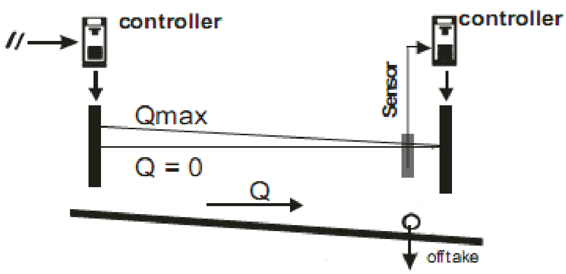

Fig. 2. Upstream control system (Rijo and Arranja, 2005) (Système de contrôle en amont (Rijo and Arranja)

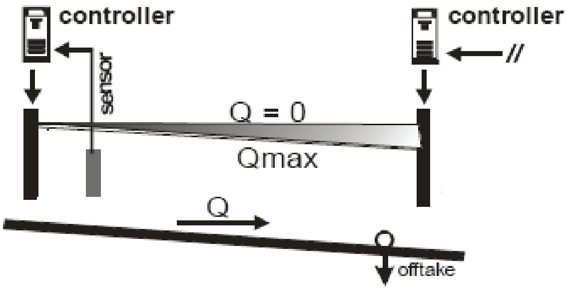

Fig. 3. Downstream control system (Rijo and Arranja, 2005) (Système de contrôle en aval (Rijo and Arranja, 2005)

2.2 Software of system

The software of the system connects PID control logics to the system hardware and calculates the amount of gate opening. PID control logic is combination of Proportional, Integral, and Derivative controllers. The P controller is the main and simplest controller, which calculates the gate opening based on difference between water level and set point. In addition, as water level exit from the dead band the Integral controller is added to proportional controller, which controls the average of deviations from target depth and the function of derivative controller is to predict the future behavior of the water level by considering the speed of changes and avoid from any sudden changes in water level caused by extra changing of the gate. The dead band is a margin around target depth which defines as a percentage of target depth and defined as ± 5 per cent in this study. Total control action of PID controller is given by equation No. 1:

$$\text{Gate Opening} = k_p (Y_t - Y) + k_i \int_0^t (Y_t - Y) + k_d \frac{d}{dt}(Y_t - Y) \quad (1)$$

where Y_t is target depth, k_p is proportional coefficient, k_i is integral coefficient, k_d is derivative coefficient, and Y is the depth at the upstream/downstream end of the reach in PID upstream/ downstream control system.

2.3 Determination of k_p, k_i, and k_d coefficients

For determining k_p, k_i and k_d coefficients, a wide range of downstream flow variations with different values of these coefficients were tested. The initial values of coefficients were selected as suggested in literature. The indicators and flow depth variations were analyzed, and the coefficient values which provide smooth action of control system for two initial flows of 5 and 10 l/s were determined (Table 1). For this purpose, k_i and k_d values were first set to zero. Then, by changing k_p value, the physical model was operated and system behavior observed. The values of MAE indicator were analyzed and k_p value that provides minimum MAD was determined. At the next stage, the k_d value was considered zero and by changing k_i value, physical model was operated and the values of IAE calculated. The value of k_i that provide minimum IAE was determined. Finally, experiments performed for various k_d value and SRT indicator calculated. The Minimum value of STR yields the best k_d.

Table 1. k_p, k_i, and k_d values using physical model (k_p, k_i, et k_d valeurs à l'aide du modèle physique)

PID upstream control system						PID downstream control system					
Q=10 l/s			Q=5 l/s			Q=10 l/s			Q=5 l/s		
kd	ki	kp	kd	ki	kp	kd	ki	kp	kd	ki	kp
0.0001	0.001	0.14	0.0001	0.001	0.1	0.0001	0.001	0.1	0.0001	0.001	0.1

2.4 Automatic Control System Evaluation

SRT (System Response Time), MAE (Maximum Absolute Error), and IAE (Integral of Absolute magnitude of Error), indicators were used for automatic control system evaluation. The SRT indicator is the time span from the point in which the water level deviates from the dead band, to the time when the water level is again regulated within it. MAE and IAE indicators, defined by the ASCE Task Committee, are given by equations No. 2 and 3, respectively (Clemens et al., 1998).

$$MAE = \frac{\max(|Y_t - Y|)}{Y_t} \quad 2$$

$$IAE = \frac{\frac{\Delta t}{T}\sum_{0}^{T}(|Y_t - Y|)}{Y_t} \quad 3$$

where Y = observed water surface, Y_t = target depth, Δt = measured time step, and T = operation period. The smaller value of these indicators, the better the performance of the system.

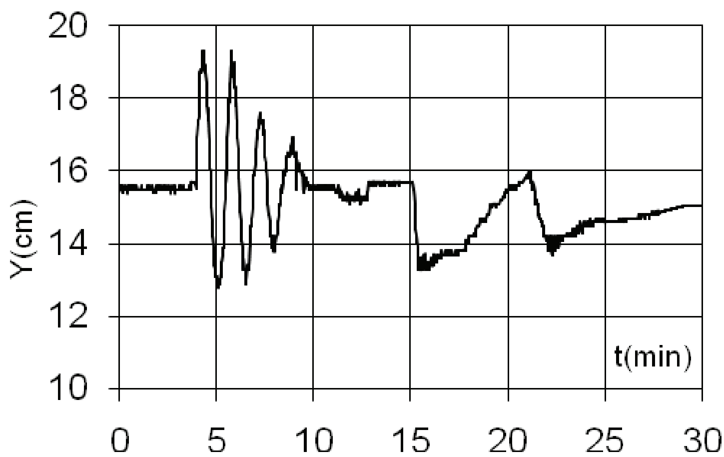

Fig. 4. Depth change in sudden operation by upstream PID controller (Q = 5lit/s) (Changement de profondeur en opération coup par régulateur PID en amont (Q = 5lit/s))

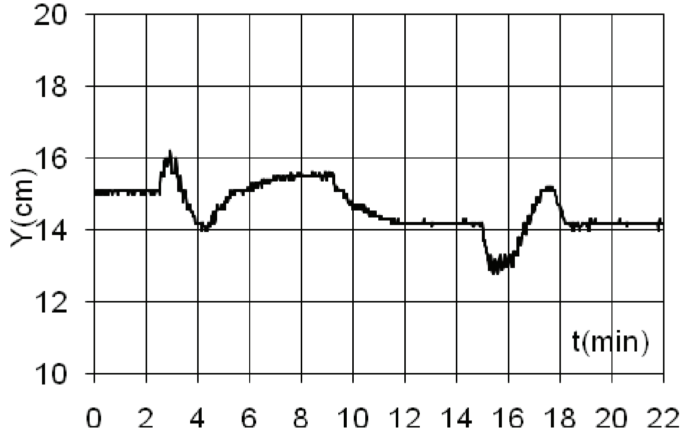

Fig. 5. Depth change in gradual operation by upstream PID controller (Q = 5lit/s) (Changement de profondeur en opération graduelle par régulateur PID en amont (Q = 5lit/s))

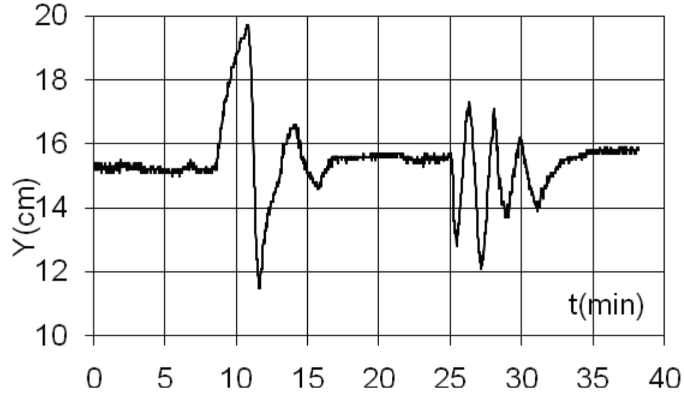

Fig. 6. Depth change in sudden operation by upstream PID controller (Q = 10 lit/s) (Changement de profondeur en opération coup par régulateur PID en amont (Q = 10 lit/s))

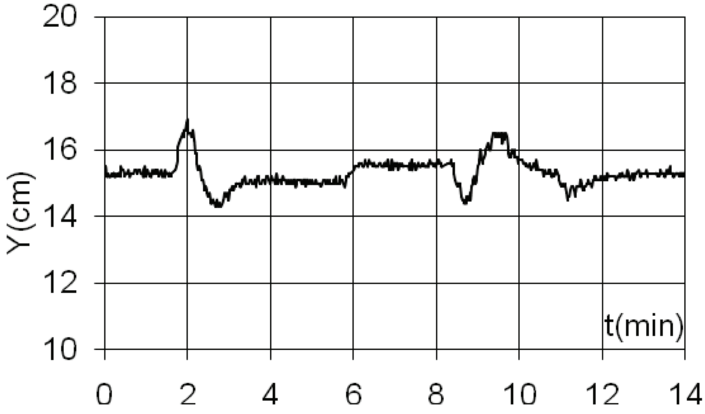

Fig. 7. Depth change in gradual operation by upstream PID controller (Q = 10 lit/s) (Changement de profondeur en opération graduelle par régulateur PID en amont (Q = 10 lit/s))

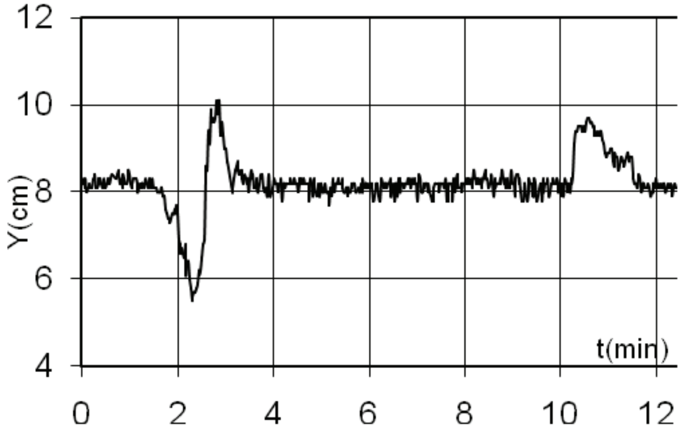

Fig. 8. Depth change in sudden operation by downstream PID controller (Q = 5lit/s) (Changement de profondeur en opération coup par régulateur PID aval (Q = 5lit/s))

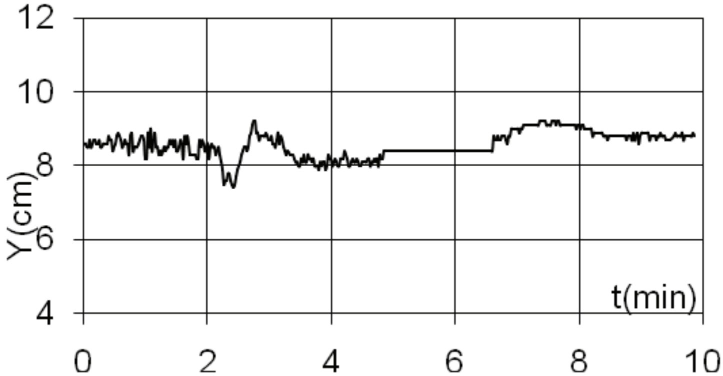

Fig. 9. Depth change in gradual operation by downstream PID controller (Q = 5lit/s) (Changement de profondeur en opération graduelle par régulateur PID aval (Q = 5lit/s))

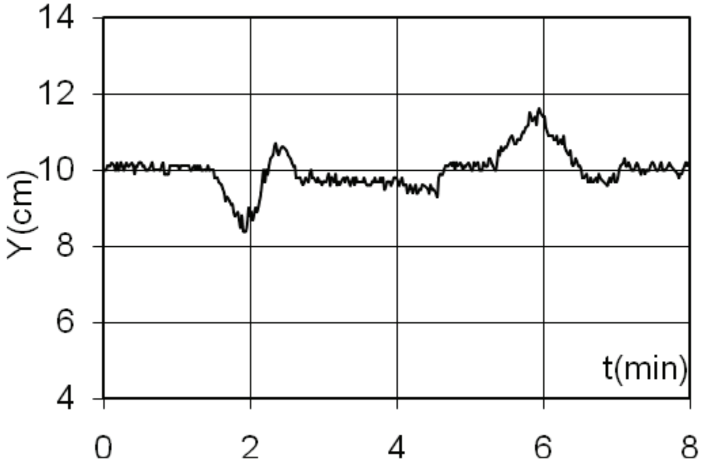

Fig. 10. Depth change in sudden operation by downstream PID controller (Q = 10lit/s) (Changement de profondeur en opération coup par régulateur PID aval (Q = 10lit/s))

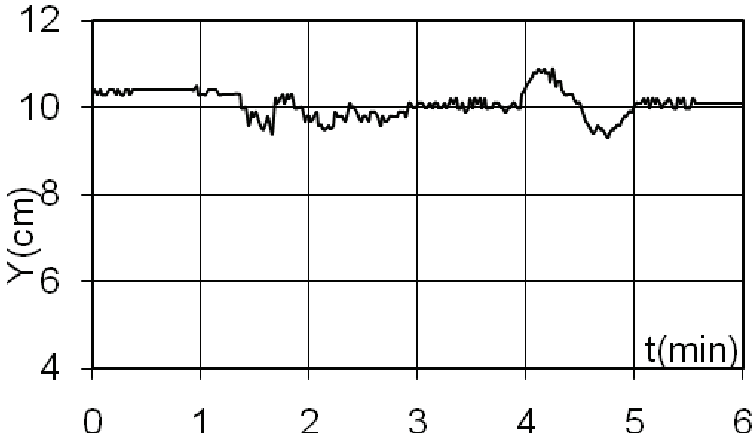

Fig. 11. Depth change in gradual operation by downstream PID controller (Q = 10lit/s) (Changement de profondeur en opération graduelle par régulateur PID aval (Q = 10lit/s))

Table 2. Summary of performance indicators in PID upstream control system (Sommaire des indicateurs de performance dans le PID système de contrôle en amont)

	Q=5lit/s				Q=10lit/s			
	Sudden Increase	Sudden Decrease	Gradual Increase	Gradual Decrease	Sudden Increase	Sudden Decrease	Gradual Increase	Gradual Decrease
Yt(cm)	15.5	15.7	15	14.2	15.3	15.6	15.2	15.5
max Y(cm)	19.3	16	16.3	15.1	19.7	17.2	16.9	16.5
min Y(cm)	12.8	13.3	14	12.9	11.5	12.1	14.3	14.4
MAE	0.25	0.15	0.09	0.09	0.29	0.22	0.10	0.07
IAE	0.05	0.06	0.02	0.07	0.05	0.03	0.02	0.02
SRT5%(min)	5.16	12.86	2.1	2.81	5.81	6.33	1.2	2.2

Table 3. Summary of performance indicators in PID dcownstream control system (Sommaire des indicateurs de performance dans le PID système de contrôle dcownstream)

	Q=5lit/s				Q=10lit/s			
	Sudden Increase	Sudden Decrease	Gradual Increase	Gradual Decrease	Sudden Increase	Sudden Decrease	Gradual Increase	Gradual Decrease
Yt(cm)	8.2	8.2	8.4	8.4	10.1	10.1	10.1	10.4
max Y(cm)	9.7	10.1	9.2	9.2	11.6	10.7	10.9	10.5
min Y(cm)	7.8	5.5	8.4	7.4	9.1	8.4	9.3	9.4
MAE	0.18	0.33	0.10	0.12	0.15	0.17	0.08	0.10
IAE	0.03	0.05	0.03	0.03	0.03	0.04	0.02	0.03
SRT5%(min)	1.24	1.73	1.85	1.16	1.58	1.30	1.00	1.08

3. RESULTS AND RECOMMENDATION

The water depth variations at the upstream of the automatic gate are depicted in Figures 4-7 and corresponding indicators are given in Table 2. Also the water depth variation at the downstream of the automatic gate are depicted in Figures 8-11 and corresponding indicators are given in Table 3. For all scenarios to calculate the SRT, the dead band is considered ± 5 %. For application of controllers a margin of ± 0.5 cm is considered, which means that the integral controller is only applied when the water level is out of this range. Figure 6 illustrates the depth variations at the upstream of the automatic gate for sudden deviations with initial flow of 5 l/s. The target depth is 15.5 cm. In reaction to sudden upstream flow increase, flow depth at the upstream of the automatic gate is increased. The water depth was stabilized in the dead band at 5.16 min. Considering the low initial flow and sudden flow variations this value is quite acceptable. The IAE value is 5 % which shows that the average depth deviation during operation period is less than 10 % which is acceptable for canal operation. MAE is 0.25 which shows that the instantaneous maximum depth deviation is 25 %. Although this value seems to be high, the low values of IAE and SRT indicate that the overall performance is acceptable. At the next stage and after adjusting new target depth at 15.7 cm, in reaction to sudden upstream flow decrease, flow depth at the upstream of the automatic gate is decreased. For depth decreasing scenario the control logic stabilized the water depth in the dead band at 12.86 min. The IAE and MAE values are 6 % and 15 %, respectively. The same results were obtained for gradual changes, which represented in Table 2. Similar results were obtained for the initial flow of 10 l/s and almost the same discussions are valid for those scenarios and also for downstream PID control system (Tables 2 and 3).

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