THE NAVIGATIONAL CONTROL MODEL FOR ICE–COVERED CANAL AND APPLICATIONS

HAN YAN-CHENG[1], LUO HUI[2], SU XIAO -CHENG [3], LU JING-WEI[2]
1 School of Resources and Environment, University of Jinan, Jinan, 250022, China
2 Shandong Provincial Bureau for Construction and Administration of South-to-North Water Diversion Project,Jinan 250013,China
3 School of Resources and Environment, University of Jinan, Jinan, 250022, China
E-mail: 1stu_hanyc@ujn.edu.cn , 3 stu_suxc@ujn.edu.cn

ABSTRACT

In Semi-cold regions, the canal water is flow under ice cover and the ice is float on the water. The speed of water level dropping and rising must be controlled strictly to prevent ice break. But in the classic PID control, on the one hand the goal water level is a fixed horizontal line, so the error is large at start and brings large overshot which make ice cover break easily. On the other hand, the control processes and speed can not accurately predict before control which cause the control process as expected. In this paper, a new navigational and guiding canal control algorithm is proposed. In this method, a dynamic navigational goal of water level is set before. Through this controller, the control process will follow the guiding, and the water level change process is controlled well as we expected. The simulations show that the water fluctuation and overshoot are smaller.

Keywords: *Navigational; PID; Canal; Transmission of Water. Control；Ice Cover*

1. INTRODUCTION

In northern China, climate controlled by the Mongolian high pressure cold air, the weather is colder in winter. Temperature will be dropped to below 0°C in most part of north China after October. Because the water surface freezing, the water conveyance will become very difficult for open channels. But with the rapid development of northern cities, the water demands have sharply increased. The urban water shortage problem is very sharp in most northern cities. More and more large water diversion projects have built or is building in recent decades, such as South-to-North Water Diversion Project, Yellow-River to QingDao Water project, WanJiaZhai Water Diversion Project from Yellow-River, etc. It is needed to conveyance water under ice cover for all these projects.

Now the automatic control methods and technologies are very common in open channel diversion and distribution projects, such as EL-FLO Algorithms, used in Corning and Coalinga canal In California[1,2]; Sogreah PID method used in Kirkukadhaim main canal in Iraq, Cupatitzio-Tepalcatepec project In Mexico[2,4]; The P+PR control method used in Yuma Desalting Plant Bypass Drain Canal(Arizona), Umattilla Basin(Washington), Dolored Project(Colorado)[2,4,5]. In recent years, many new canal control methods are modified or created to improved the quality of canal control flow such as Robust Fractional-Order PI Controller[3], Improved Proportional-Integral(PI) Controller[6], Smith Prediction[7], Linear Quadratic Regulator theory[8]， Automatic Tuning of PI Controllers[9].

But these canal control Algorithms are designed mainly for non-ice-cover channel, they are not suitable for ice-cover open channel. Because for non-ice-cover channel, the rapid rise of water level is not a problem, but for channels in cold area in winter, the water flows under the ice-cover and ice float on water surface, both the rise or drop of water level need to be controlled strictly. When the water drop rapidly, the ice cover will collapse easily which can cause ice jam. By contraries, if the water level rises rapidly, the ice cover will be damaged by the force of water tensile, and the water overflow upon the ice cover, and the new freezing ice layer will come into being, which cause the ice-jam eventually. So the rise speed of water level of canals ice covered must be controlled too. But in the classic PID or variant control method such as P+PR, ELFLO plus algorithms, the level dropping or rising speed is not known before finishing control, which lead to overshooting of water level in control processes [1]. This state is dangerous in winter, because rapidly water rise or drop cause ice cover break which lead to ice jam. In this paper, a new navigational and guiding control algorithm is proposed.

2. NAVIGATIONAL CANAL PID CONTROL METHOD (NCP)

2.1 Classic Canal PID Control Model

The classic canal PID control can be expressed as:

$$u(t) = K_p\left[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_D\frac{de(t)}{dt}\right] \quad (1)$$

Expressed as discrete format:

$$u(k) = K_p e(k) + K_i \sum_{j=0}^{k} e(j) + K_d[e(k) - e(k-1)] \quad （2）$$

Above, k, sampling serial number， $k = 0,1,2\ldots$ ； K_p ， proportion coefficient ； K_i ， integral coefficient； K_d Differential coefficient; $e(\cdot)$, the error of current level and goal level, it express as:

$$e(k) = Z_c(k) - Z_g \quad (3)$$

$Z_c(k)$ is current water level, Z_g is goal water level.

In classic PID control, the error $e(k)$ is the difference of final goal level and current level and the goal level is a fixed horizontal line (Figure 1). So the error can be large at start and bring large change and overshot of water level easily which make ice cover break.

2.2 Navigational Canal PID Control Method

In Navigational Canal PID Control, The feedback control processes is same as classic PID formula (1), but the goal is a dynamic navigational target process (as Figure 2). It is a gradual approaching line (or curve line), and the gradual degree can be set according to ice and hydro-geological conditions.

$$e(k) = Z_c(k) - Z_d(k) \quad (4)$$

In every step the error equal to the difference of current water level and dynamic temp target. Given the final target water level, $Z_g \pm \delta$, and the current level from monitoring instrument, $Z_c(k)$. The dynamic temp target level can be computed as:

1) IF $Z_c(k) < Z_g - \delta$, then

$$Z_d(k) = Z_d(k-1) + \Delta b \quad (5)$$

2) IF $Z_c(k) > Z_g + \delta$, additionally

$$Z_d(k) = Z_d(k-1) - \Delta b \quad (6)$$

Above, $Z_d(k)$,the dynamic temp target level of k step; Z_g ,the final target level; Δb ,step length; δ ,dead zone of final target level.

For avoiding frequent operating gate, setting dead zone is required. If the water level comes into dead zone, the gate operation is forbidden. It can be shown:

3) If $Z_g + \delta \le Z_c(k) \ge Z_g - \delta$, then

$$Z_d(k) = Z_g, \text{ (into dead zone)} \quad (7)$$

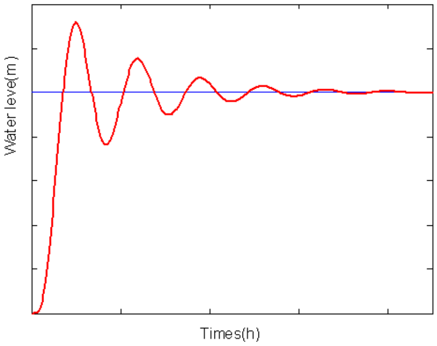

Figure 1: The Goal Water Of Classic PID Control

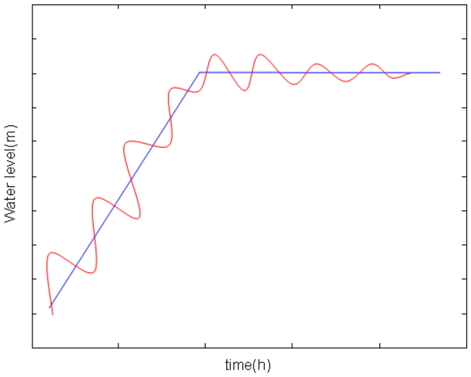

Figure 2: The Goal Water-level Of Navigational Canal PID

It is shown that using NCP Control method, all processes are same as classic PID canal control except the target is dynamic and temporary. In each step the temporary target is going towards final target water level step by step. If there is only one step, the dynamic target water level becomes the final target water level and the Navigational Canal PID Control will become into classic PID canal control. So the classic PID canal control method is a special type of navigational canal PID control mode, and it is multi-step task.

3. THE DEVELOPMENT TO IMPROVE NCP CONTROL EFFECT

3.1 Using Integral Separation To Improving Controlling Effect

In the control of PID, the function of integral coefficient is to eliminate the steady-state error, but it also increases the overshoot. Therefore, integral separation techniques are adopted in this Navigational Canal PID Control Method.

If $|Z_g - Z_d(k)| > \varepsilon$ then K_i (integral coefficient) is smaller or zero.

If $|Z_g - Z_d(k)| \le \varepsilon$ then $K_i > 0$

A better method is setting Integral coefficient according to the error. When error is big, the integral coefficient smaller, the error is small , the integral coefficient bigger. So the integral coefficient can multiply a parameter λ . The control mode is expressed as:

$$u(k) = K_p e(k) + \lambda \cdot K_i \sum_{j=0}^{k} e(j) + K_d[e(k) - e(k-1)] \qquad （8）$$

3.2 NCP Control Method Combination With Other Control Method

In addition to combination with integral separation control method , we can combine NCP method with Fuzzy Control[10],Smith Prediction control [7](etc.) to improve the effect of canal control also. The method is similar to above.

4. SETTING STEP LENGTH Δb

The step size can be fixed or unfixed. To fixed step size control, the step size is a constant in all control processes. For some canal, the stable control and quick response all needed, it is required unfixed

$$Z = Z_b + h_w + d_{ice} \qquad (12)$$

In which, Z_b =bed elevation(m); h_w =depth of flow(m); d_{ice} =submerged thickness of ice-cover.

The controllable gates belong to the inter boundaries. If the Zj representative upstream water

step size control, in which the step size is larger at the beginning control process, and decrease along with the water level reaching gradually the final target. For some canal which the drop speeds are limited strictly, so the step size can be computed as:

$$\Delta b = \omega \cdot F \cdot T \qquad （9）$$

Above, F, the maximal limited drop speed of water level (m/h); T, the periods of sample (h); ω , the coefficient of speed, it can be set 0.6-1.0.

5. THE SIMULATION OF CONTROL PROCESSES AND APPLICATION UNDER ICE-COVER

5.1 The Simulation

The simulation process is express as Figure 3.

The simulation of conveyance canal control with floating ice-cover is one dimension unsteady flow problem of open channel with gate and pump. The Saint-Venant equation sets in which the ice resistance is considered are expressed[11]:

Continuity equation:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \qquad (10)$$

Momentum equation:

$$\rho \frac{\partial Q}{\partial t} + \rho\left(\frac{2Q}{gA}\frac{\partial Q}{\partial x} - \frac{Q^2}{A^2}\frac{\partial A}{\partial x}\right) + \rho g A \frac{\partial Z}{\partial x} + (p_i \tau_i + p_b \tau_b) = 0 \qquad (11)$$

Above, x = distance(m); t = time(s); Q = flow rate(m3/s); q =inflow (m3/s/m); A =flow area;

g =gravity of water (m/s2); ρ =density of flow; ρ_i = density of ice; p_b , p_i =wetted perimeter formed by the channel bed and ice cover respectively; τ_b, τ_i =shear stress at the channel bed and ice cover respectively; Z =water level (m), it can be computed

level and Zj+1 represents downstream water level of controlling gate, the flow computing formula is

$$Q = ube\sqrt{Z_j - Z_{j+1}} \qquad (13)$$

In which, , b =width of gate(m); u =coefficient of flow; e =opening of gate(m).

The continuity condition can be expressed $Q_j^{n+1} = Q_{j+1}^{n+1}$, discrete mode is

$$Q_j^n + \Delta Q_j = Q_{j+1}^n + \Delta Q_{j+1} \qquad (14)$$

j -node number; n -time series; Q_j^n -flow-rate before gate; Q_{j+1}^n flow-rate after gate, Z_j^n -water level before gate; Z_{j+1}^n-water level after gate; C -coefficient of discharge(including submergence factor); B -width of gate; a -gate opening. The process of simulation of fuzzy self-adapting control shows as Figure 3.

The general methods solve Saint-Venant equations are characteristics method and implicitly finite difference scheme method. Here use persimmon implicit difference format. Details, see[1,5].

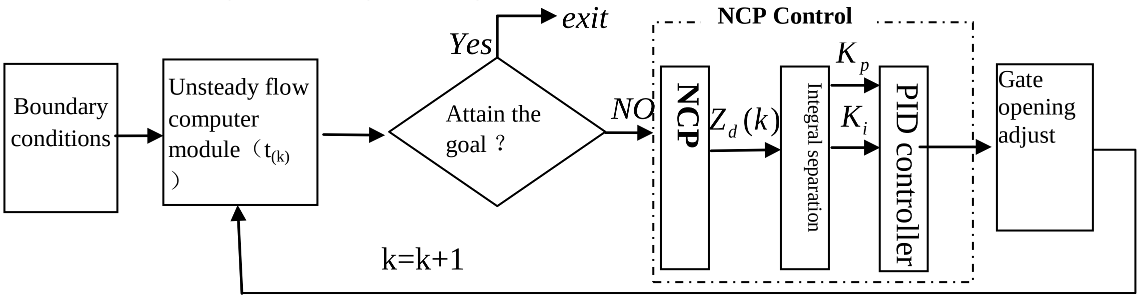

Figure 3: Schematic Plan Of Control Simulation Process

Table 1: Integral Separate Parameters λ Values

$e(k)$	$e(k)>1.2$	$0.8>e(k)\le 1.2$	$0.5>e(k)\le 0.8$	$0.3>e(k)\le 0.5$	$0.2>e(k)\le 0.3$	$0.1>e(k)\le 0.2$	$e(k)\le 0.1$
λ	0	0.1	0.3	0.5	0.9	1.5	3

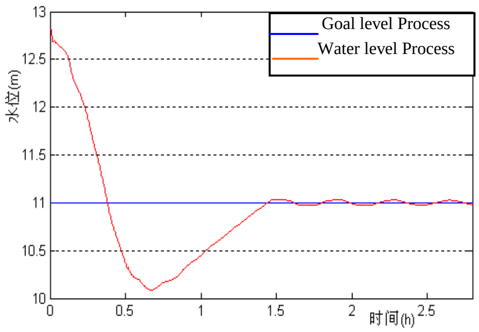

Figure 5: General PID Control Results

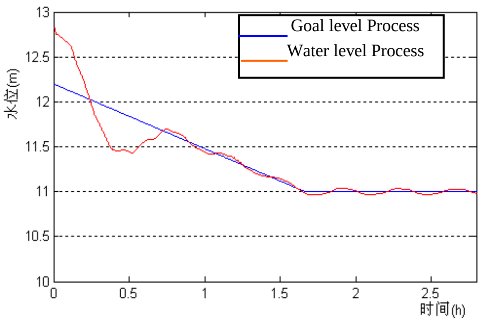

Figure 6: Navigational Canal Control Results

5.2 The Applications

Example: a canal is transmitting water under ice cover in winter, its length 2500m, only one controlling gate, is located 1250m; canal roughness n=0.02,slide slope coefficient m=2.0, bottom slope i=1/10000, the width of bottom, 5.0m；Upstream boundary is flow，Q=10 3/s；The downstream boundary is water level, 8.81m; The opening of gate, 5.0m, the water level in front of gate, 12.82m; The goal level is 11.0 ± 0.02m; dead zone 0.02m.

In simulation, the canal is spitted by 100 sections, and 101 notes. Here, the general canal PID control and navigational canal PID control method are adopted and compared. In classic PID control, The parameters $K_P = 0.2$, $K_i = 0.15$, $K_d = 0.006$. The parameters of λ is used as tables 1. In navigational canal PID control method, K_P、K_i、K_d and λ is same as above. Figure 5 is the results using general

PID control, and Figure 6 is the results using navigational canal PID control method.

6. CONCLUSION

From the results show, using navigational canal control method, the water level change and overshoot is much smaller than general control method. The max dropping speed of water level is half of speed of classic method. In Semi-cold regions, the canal water is transmitted under ice cover and the ice is float on the water. So the water level dropping speed is strictly controlled preventing ice break. This navigational canal Control method is fit to control flow under ice covers.

ACKNOWLEDGEMENT

It is a project supported by The “Five-twelfth” National Science and Technology Support Program of China(Name:The River-Channel-Lake-Reservoir System Operation and Control Key Technology Research of South-to-North Water Diversion Project), and supported by the development of science and technology plan of the Education Department of Shandong Province of China(J10LC57), and supported by the Research Fund for the Doctoral Program of University of Jinan(X1351005).

REFERENCES

[1] Buyalski C P , Falvey H T. Rogers D S: Canal systems automation manual Volume 1 (A Water Resources Technical Publication, U.S. Department of Interior, Bureau of Reclamation, Denver Colo 1991)

[2] David C, Rogers, Jean Goussard: Canal control algorithms currently in use. Journal of Irrigation and Drainage Engineering Vol. 124, No.1, 1998, pp.11-15

[3] Feliu-Batlle,R.Rivas-Perez,L.Sanchez-Rodriguez. Robust Fractional-Order PI Controller Implemented on a Laboratory Hydraulic Canal. Journal of Irrigation and Drainage Engineering .Vol. 135, No.1, 2010, pp. 271-282

[4] K. Pongput and G.P.Merkley: Comparison and Calibration of Canal Gate Automation Algorithms. Journal of Irrigation and Drainage Engineering, ASCE Vol. 123, No. 3, 1997, pp. 222-225

[5] Pierre-Olivier Malaterre, DavidC. Rogers, and Jan Schuurmans: Classification of Canal Control Algorithms. ASCE Journal of Irrigation and Drainage Engineering Vol. 124, No. 1, 1998, pp.3-10

[6] C.M.Burt, R.S. Mills: Improved proportional-integral(PI) logic for canal automation. Journal of Irrigation and Drainage Engineering Vol. 124, No. 1, 1998, pp.53-57

[7] Jean-Lue Deltour, Franck Sanfilippo. Introduction of Smith Prediction into Dynamic Regulation . Journal of Irrigation and Drainage Engineering, Vol. 124, No. 1, 1998, pp.11-15

[8] Balogun, Hubbard: Automatic Control flow using linear quadratic regulator theory . Journal of Hydraulic Engineering, Vol. 114, NO. 1, 1988, pp.75-101

[9] X. Litrico，P.-O Malaterre. Automatic Tuning of PI Controllers for an Irrigation Canal Pool. Journal of Irrigation and Drainage Engineering.Vol. 133, No. 1, 2007, pp.27-37

[10] Han Yan-cheng, Research on Canal Control Models for Long Distance Water Conveyance Systems and Unsteady Flow Simulation, PhD thesis(Chines), TianJin University ,2007

[11] A. M. Wasantha Lal,Hung Tao Shen . Mathematical Model for River Ice Processes, Journal of Hydraulic Engineering. 1991, Vol. 117, No. 7, 1991, pp. 851–867.