AUTOMATIC SLIDING GATE USED TO CONTROL WATER LEVEL OF A CHANNEL IN FLAT URBAN AREA

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Abstract - Automatic gate is a control structure which can work by its self without an operator. The application of automatic gate is wide; however one of the most important applications is for controlling water level of a stream or channel, especially at a drainage area which is topographically flat. Currently, the automatic sliding gate equipped with pump, sensor, control and motor is being constructed in a scaled physical model in the Laboratory of Fluid Mechanics of UTHM. This model will be used to verify the result from simulating the mathematical model in which it has been developed.

Keywords - Automatic sliding gate; water level control, flat urban area; mathematical model; physical model

I. INTRODUCTION

Consequence of floods in flat urban area have resulted negative impacts to the people life, property damage and loss of money. For example, district of Batu Pahat was hit by a huge flood on December 19, 2006 and then followed a mega disaster on January 12, 2007 where more than 70% of whole areas of Batu Pahat were flooded (Tjahjanto et. al., 2007).

Many reasons might cause these floods such as rainfall intensity was too high, capacity of the available reservoirs were insufficient to store rain water, cross section of rivers were not able to flow the peak flow, and most of areas of Batu Pahat are low and flat that cause the system of river is not capable to discharge storm water direct to the sea. The head of water in the river is low compared to the sea level that makes the river flow sluggish and induces back water and overflow to the lower areas.

II. AUTOMATIC SLIDING GATE

Automatic sliding gate is a hydraulic structure used to control water level in a channel or river. This gate contains of sliding gate as the main structure and pump, motor and belt, PLC and sensor as the component structure.

A. Structure of Sliding Gate

The sliding gate is the simplest type of flat gate which is largely used as a control device in irrigation canal, reservoir spillway etc. It consists basically on a gate that slides along side guides embedded or fastened to the concrete. Slide gate requires little maintenance because its operation is safe. Other distinguished characteristics of the slide gates are the uniform transmission of the hydrostatic load to the concrete and the absence
of vibration in partial openings due to the large friction force developed between the sliding surfaces. The equations for design sliding gates (Erbisti, 2004):

\[ W = \frac{1}{2} \gamma B \left( H^2 - h^2 \right) \]  
\[ f = \frac{\alpha a^4}{\pi^2} \]  
\[ y_k = \frac{2h}{3\sqrt{n} \left[ k^{3/2} - (k-1)^{3/2} \right]} \]  
\[ t_w = \frac{F}{2h_w \tau_{adm}} \text{, } h_w = 1/12L \]  
\[ t_f = t_w \text{, } w_f = 1/5h_w \]  

B. Pump and Piping System

Pumping system is another important part in the automatic sliding gate system. It is because, in flat area, flood and water stagnant can happen. For overcoming those problems, the pumping system will transfer the water in the upstream area to the downstream area through the pipe system. The water does not flow through the gate as the gate closes automatically (Figure 2). The following is procedure to analyze the pumping system (Bankston et. al, 1994):

\[ Q = 0.864ab \sqrt{gh_0 \left( \frac{h_0 - a}{h_0 + 15a} \right)^{0.072}} \]  
\[ \text{Total Head} = \text{Lift} + \text{Velocity Head} + \text{Friction Head}. \]  
\[ \text{Lift} = \text{vertical distance between the level of water’s surface and point of discharge at the end of pump.} \]  
\[ \text{Velocity head (ft)} = \frac{V^2 (ft / s)}{64} \]  
\[ f = 0.2083 \left( \frac{h}{C} \right)^{0.852} \left( \frac{q}{d_n^{0.852}} \right)^{4.8655} \]  

C. Belt and Motor System

Belts are used in conveying systems and in the transmission of power over comparatively long distances. It often happens that this element can be used as a replacement for gears, shafts, bearings and other relatively rigid power-transmission device. In many cases their use simplifies the design of a machine and substantially reduces the cost. In automatic sliding gates system, belt and motor systems is used to lift up and down the sliding gate. The equation of belt and motor system design can be described as follows (Rahman R. A. et. al., 2001):

\[ L = \pi (r_1 + r_2) + 2X + \left( \frac{r_1 - r_2}{X} \right) \]  
\[ P = (T_1 - T_2) \nu \]  
\[ \frac{T_1}{T_2} = e \left( \frac{\mu \theta}{\sin \beta} \right) \]  
\[ \theta = \left( 180^\circ - 2 \alpha \right) \frac{\pi}{180} \text{(rad)} \]  
\[ \sin \alpha = \frac{r_1 - r_2}{X} \]  
\[ n = \frac{N_2}{N_1} = \frac{d_1}{d_2} \]  
\[ \nu_2 = \frac{\pi d_2 N_2}{60} \]  
\[ \nu_1 = \frac{\pi d_1 N_1}{60} \]  

List of symbols

\( W \)  \text{water thrust}  
\( f \)  \text{maximum deflection}  
\( y_k \)  \text{depth of the horizontal beams}  
\( t_w \)  \text{thickness of web}  
\( F \)  \text{water load on the horizontal beam}  
\( h_w \)  \text{depth of web}  
\( L \)  \text{length}  
\( \tau_{adm} \)  \text{allowable shear stress}  
\( t_f \)  \text{thickness of flanges}  
\( w_f \)  \text{width of flanges}  
\( Q \)  \text{the slide gate discharge}  
\( a \)  \text{the slide gate opening}  
\( b \)  \text{the slide gate length}  
\( h_o \)  \text{the upstream water depth}  
\( g \)  \text{gravitational acceleration}  
\( V \)  \text{velocity}  
\( f \)  \text{friction head}  
\( C \)  \text{Haven – Williams roughness constant}  
\( q \)  \text{volume flow (gal/min)}  
\( d_n \)  \text{inside hydraulic diameter (inches)}  
\( A \)  \text{area section of the duct (m², ft²)}  
\( P \)  \text{wetted perimeter of the duct (m, ft)}  
\( r_1 \)  \text{radial of driven pulley}  
\( r_2 \)  \text{radial of driver pulley}  
\( X \)  \text{distance between two center points of pulley}  
\( T_f \)  \text{Tight side tension of belts}  
\( T_L \)  \text{Loose side tension of belts}  
\( \theta \)  \text{Angle of contact}
Control system in automatic sliding gates has two main parts that are programmable logic controller (PLC) and water level sensors. A programmable logic controller (PLC) is a special form of microprocessor-based controller that uses a programmable memory to store instruction and to implement function. Water level sensor will be used in automatic sliding gate as an input devices, and motors and pump, as an output device. Water level sensor is just required to give a signal when the level of water in channel reaches a particular level (Bolton, 2003). The following is procedure to design the control system:

1. Determine the level measurement type of sensor (continuous level or point level/multi-point level).
2. Determine the measuring rage that sensor can measure.
3. Determine the sum of the inputs and outputs signal of PLC.
4. Determine of programming language of PLC.

III. RESEARCH METHODOLOGY

The elements of research methodology are as follows (Figure 1):

1. Data Collection
2. Building Mathematical Model
3. Running the Mathematical Model
4. Building the Physical Model
5. Running the Physical Model
6. Verification of the Mathematical Model using Physical Model

Mechanism operation of Automatic Sliding Gate is:

1. The desired critical water level is set up first in the PCL controller.
2. Sensor system using water level sensor is applied to detect the water level in the channel and send the data to PLC controller.
3. When the sensor sends data that is matching with the critical water level, and then PCL controller sends order to the motor to move down (close) the gate and sends order to the pump to start pumping
4. When the sensor sends data that is matching with the save water level, then PCL controller sends orders to the motor to move up (open) the gate and sends order to the pump to stop pumping.

IV. MATHEMATICAL MODEL

Mathematical Model of Automatic Sliding Gate is the result from calculation of design of sliding gate; analyze of piping and pumping system; design of belt and motor system; and design of control system. This model will be used to build the Physical Model of Automatic Sliding Gate. Table 1, 2 and 3 shows the result of Mathematical Model.

V. PHYSICAL MODEL

Physical Model of Automatic Sliding Gate is being constructed in the Laboratory of Fluid Mechanics of UTHM based on method of Distorted and Undistorted Models of Hydraulic Scale Models. Size of model based on the result of Mathematical Model in Table 1. This model will be used to verify the result of the mathematical model in which mathematical model has been developed. Figure 2 shows the sketch of Physical Model of Automatic Sliding Gate.

VI. CONCLUSION

Form the result of mathematical model calculation, it is concluded as follows:

1) For structure of sliding gate – if the size of gate increases largely, number of beams which are needed to support the water thrust that acts on the gate also increase.
2) For belt and motor system – for all size of gate, type of belt which is used in the system is V-belt; drive geometry that is used is non reversing open belt and type of motor that is used is DC gear motors.
3) For pumping and control system – for all size of gate, the level measurement in water level sensor that is used in the system is multi point level and the programming language in PLC that is used in the system is ladder diagram.
Figure 1: Flow Chart of Research Methodology

REFERENCE


RESULT OF MATHEMATICAL MODEL

Table 1: Structure of Sliding Gate

<table>
<thead>
<tr>
<th>No</th>
<th>Width, m</th>
<th>Height, m</th>
<th>Flow Rate, m³/s</th>
<th>Water Thrust, kN</th>
<th>Skin Plate</th>
<th>Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max, m</td>
<td>Min, m</td>
<td>Thickness, mm</td>
<td>Max Deflection, mm</td>
</tr>
<tr>
<td>1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.25</td>
<td>0.05</td>
<td>0.0552</td>
<td>0.0589</td>
</tr>
<tr>
<td>2</td>
<td>0.4</td>
<td>0.6</td>
<td>0.55</td>
<td>0.05</td>
<td>0.302</td>
<td>0.589</td>
</tr>
<tr>
<td>3</td>
<td>0.8</td>
<td>1.2</td>
<td>1.15</td>
<td>0.05</td>
<td>1.639</td>
<td>5.18</td>
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</tbody>
</table>

y_k = Distance of beam from water (k=1,2,3,...n); x_L,R = Distance of beam from left; t_w = Thickness of Web; h_w = Depth of Web; t_f = Thickness of Flanges; w_f = Width of Flanges; L = Length

Table 2: Belt and Motor System

<table>
<thead>
<tr>
<th>No</th>
<th>Width, m</th>
<th>Height, m</th>
<th>V-Belt Section</th>
<th>Drive Geometry</th>
<th>Belt Length, cm</th>
<th>Pulley’s Diameter, cm</th>
<th>Type</th>
<th>Output Power, watt</th>
<th>Shaft Speed, rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.2</td>
<td>0.3</td>
<td>A</td>
<td>Nonreversing</td>
<td>51.11</td>
<td>Driver = 2</td>
<td>DC</td>
<td>7.4</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Open Belt</td>
<td></td>
<td>Driven = 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.4</td>
<td>0.6</td>
<td>B</td>
<td></td>
<td>62.44</td>
<td>Driver = 4</td>
<td>DC</td>
<td>71</td>
<td>29</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Driven = 10</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.8</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1060</td>
<td>57</td>
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</tbody>
</table>
Table 3: Pumping and Control System

<table>
<thead>
<tr>
<th>No</th>
<th>Size of Gate</th>
<th>Pumping</th>
<th>Water Level Sensor</th>
<th>PLC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Width, m x Height, m</td>
<td>Type</td>
<td>Flow Rate, m³/s</td>
<td>Total Head, m</td>
</tr>
<tr>
<td>1</td>
<td>0.2 x 0.3</td>
<td>Centrifugal</td>
<td>0.0607</td>
<td>11.27</td>
</tr>
<tr>
<td>2</td>
<td>0.4 x 0.6</td>
<td></td>
<td>0.3322</td>
<td>2.78</td>
</tr>
<tr>
<td>3</td>
<td>0.8 x 1.2</td>
<td>Reactor Feed</td>
<td>1.666</td>
<td>225</td>
</tr>
</tbody>
</table>

L = Length; D = Diameter

Figure 2: Physical Model of Automatic Sliding Gate