RESEARCH ON THE UPPER CHAMBER VOLUME OF SURGE TANK OF A DIVERSION TYPE-HYDROPOWER STATION WITH MID-INFLOW

YongSu Jo, GyongIl Sin, CholGyong Kim, UnChol Ri**

HamHung University of Hydraulics and Power, Ham Hung, DPRK

*Correspondence: UnChol Ri, HamHung University of Hydraulics and Power, Ham Hung, D P R of Korea
+E-mail address: riunchol@163.com

Abstract:

Mid-inflow is the flow into the middle of the headrace tunnel that can be effectively used in the electric power generation. The mid-inflow makes differences of velocities and head losses in the headrace tunnel between two sides and influences the water level oscillation in surge tank consequently. An analytical formula of the upper chamber volume of the surge tank with an expansion chamber considering the effect of mid-inflow is established and the accuracy of the formula is evaluated through comparisons to numerical analysis. With installation data, the influence of mid-inflow on the upper chamber volume is discussed.

Key words:
Hydropower plant, Surge tank, Mid-inflow, Upper chamber, Water level oscillation

0. INTRODUCTION
For diversion-type hydropower stations that have a fairly long headrace tunnel the surge tank with expansion, the chamber is chosen easily by the designer to reduce the amplitude of water level oscillations giving a good environment to the pressure tunnel as well as to penstock. Many scholars such as Liu, Vereide studied the water level oscillation in chamber surge tank in terms of volumes of the upper chamber and down chamber [4, 6].

In other to use water in catchment area out of the main reservoir for hydropower plant intake in the middle of the headrace tunnel is designed. The existence of an influence of the inflow on the water level oscillation is obvious and described by researchers [2]. But their studies limited to the influence on the stability of water level oscillation in the surge tank and the upsurge water volume in the upper chamber by sudden load rejection is not uncovered. Assumptions in deriving the formula of upper chamber volume are introduced: (1) The sectional area of the riser is ignorable, and (2) The sectional area of the upper chamber is infinite.

1. BASIC EQUATIONS
The diversion-type hydropower station with mid-inflow is shown in Fig.1.

Fig. 1 Diversion power system with mid-inflow
The governing equations describing the mass oscillation of the whole body of water in the tunnel and surge tank is based upon two fundamental equations: (i) the dynamic equation and (ii) the equation of continuity.

(i) Dynamic equation:

\[ Z + \beta_1(Q - Q_m)^2 + \beta_2 Q^2 + \frac{(L_1 + L_2)}{A_1 A_2} \frac{dQ}{dt} = 0 \]  

(ii) Continuity equation:

\[ y - m_r - \frac{1}{Q_0} \frac{dV}{dt} = 0 \]  

Where \( Q \) is the flow rate after mid-intake, \( Q_m \) is mid-inflow rate, \( Z \) is water level in surge tank (upward direction is positive), \( L_1, L_2, A_1, A_2, \beta_1, \beta_2 \) are lengths, sectional areas and coefficients of head loss of the tunnel in both sides, \( V \) is water volume in surge tank, \( y = Q/Q_0 \), \( m_r \) is relative load rejection.

Introducing \( \varepsilon_0 = \frac{(L_1 + L_2)}{A_1 A_2} \frac{Q_0}{g h_{t,0}} \), \( T = \frac{Q_0}{\varepsilon_0} \), \( a = \beta_1 + \beta_2 \), \( b = -2 \beta_1 \frac{Q_m}{Q_0} \) and \( c = \beta_1 \left( \frac{Q_m}{Q_0} \right)^2 \)

two equations above are simplified.

\[ \frac{Z}{h_{t,0}} + (ay^2 + by + c) + \frac{dy}{dT} = 0 \]

\[ y - m_r - \frac{1}{\varepsilon_0} \frac{dV}{dT} = 0 \]

According to the above assumptions, upsurge by sudden load rejection is reached at the maximum level \( (Zu) \) immediately after load rejection.

Hence the equation (6) can be written with \( Zu \):

\[ \frac{1}{\varepsilon_0} \frac{dV}{dT} = \frac{Zu}{h_{t,0}} - (ay^2 + by + c) \]  

For a sudden load rejection from 1 to \( m_r \), of relative discharge, upsurge water volume in expansion chamber is increased from 0 to \( V_u \).

Integration of both sides from 0 to \( m_r \), respectively, can be written:

\[ \int_0^1 \frac{1}{\varepsilon_0} \frac{dV}{dT} \left[ \frac{m_r + \frac{b}{2a}}{\frac{m_r + \frac{b}{2a}}{c' - \frac{b^2}{4a^2}} - \arctan(\frac{1 + b}{\sqrt{a - 4a^2}})} \right] \]

From equation (8) \( V_u \) can be calculated:

\[ V_u = \varepsilon_0 \left[ \frac{1}{2a} \ln\left(\frac{a + b + c'}{am' + bm' + c'}\right) + \frac{m_r + \frac{b}{2a}}{c' - \frac{b^2}{4a^2}} \right] \]

Where \( h_{t,0} \) is head loss in total length of tunnel before load rejection.

Combining equations (3) and (4) leads to:

\[ \frac{Z}{h_{t,0}} + (ay^2 + by + c) + \frac{dy}{dT} \left[ m_r - y \right] = 0 \]  

Separating \( dy \) and \( dV \) to both side:

\[ \frac{1}{\varepsilon_0} V_u = \left[ \frac{m_r + \frac{b}{2a}}{\frac{m_r + \frac{b}{2a}}{c' - \frac{b^2}{4a^2}} - \arctan(\frac{1 + b}{\sqrt{a - 4a^2}})} \right] \]  

\[ \frac{1}{\varepsilon_0} \frac{dV}{dT} = \frac{Zu}{h_{t,0}} - (ay^2 + by + c) \]  

\[ \int_0^1 \frac{1}{\varepsilon_0} \frac{dV}{dT} \left[ \frac{m_r + \frac{b}{2a}}{\frac{m_r + \frac{b}{2a}}{c' - \frac{b^2}{4a^2}} - \arctan(\frac{1 + b}{\sqrt{a - 4a^2}})} \right] \]

\[ V_u = \varepsilon_0 \left[ \frac{1}{2a} \ln\left(\frac{a + b + c'}{am' + bm' + c'}\right) + \frac{m_r + \frac{b}{2a}}{c' - \frac{b^2}{4a^2}} \right] \]

\[ \left[ \frac{m_r + \frac{b}{2a}}{\frac{m_r + \frac{b}{2a}}{c' - \frac{b^2}{4a^2}} - \arctan(\frac{1 + b}{\sqrt{a - 4a^2}})} \right] \]
2. APPLICATION

The purpose of this section is to compare and evaluate the accuracy of the formula presented herein in determining the volume of the upper chamber. The data of the hydraulic installation tested is taken as follow (Table 1):

<table>
<thead>
<tr>
<th>Installation data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of tunnel</td>
<td>L₁ = 18000m</td>
</tr>
<tr>
<td>Diameter of tunnel</td>
<td>D₁ = 4m</td>
</tr>
<tr>
<td>Discharge</td>
<td>Q₀ = 40m³/s</td>
</tr>
<tr>
<td></td>
<td>Qₘ = 5m³/s</td>
</tr>
</tbody>
</table>

The numerical results and the results from the formula (9) derived herein are shown as Fig. 2.

![Fig. 2 Upper chamber volume](image)

As showed in the tables and graphs, the calculation results by the formulas and the numerical results are completely identical. With different combination of mid-inflow the upper chamber volumes are calculated. (Fig. 3)

![Fig. 3 Upper chamber volume with different inflow rate Qₘ (a) and distance from reservoir L₁ (b)](image)

CONCLUSION

Through the research on upper chamber volume of surge tank in a diversion type-hydropower station with mid-inflow the following conclusions are obtained:

- The mid-inflow increases the upper chamber volume of surge tanks on large scale.
- The effect of the mid-inflow on the volume in an increase is getting larger while the inflow is getting closer to the surge tank and lager in rate.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. RI who gave us much valuable helping in the early stages of this work.

AUTHOR CONTRIBUTIONS

Authors equally contributed.

ORCID

UnChol Ri
http://orcid.org/0000-0002-4474-3389

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