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

Article Info

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

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.

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.

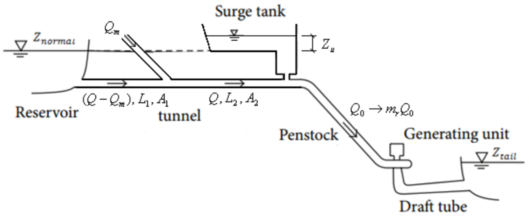


Fig. 1 Diversion power system with mid-inflow

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:

$$Z+\beta_1\cdot(Q-Q_m)^2+\beta_2 Q^2+(\frac{L_1}{A_1}+\frac{L_2}{A_2})\frac{Q_0}{g}\frac{dy}{dt}=0 \quad (1)$$

(ii) Continuity equation:

$$y-m_r-\frac{1}{Q_0}\frac{dV}{dt}=0 \quad (2)$$

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, β_1, β_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

$$\varepsilon_0=(\frac{L_1}{A_1}+\frac{L_2}{A_2})\frac{Q_0}{gh_{t,0}},\ T=\frac{Q_0}{\varepsilon_0},\ a=\beta_1+\beta_2,$$

$$b=-2\beta_1\frac{Q_m}{Q_0} \text{ and } c=\beta_1(\frac{Q_m}{Q_0})^2$$

two equations above are simplified.

$$\frac{Z}{h_{t,0}}+(ay^2+by+c)+\frac{dy}{dT}=0 \quad (3)$$

$$y-m_r-\frac{1}{\varepsilon_0}\frac{dV}{dT}=0 \quad (4)$$

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

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

$$\frac{Z}{h_{t,0}}+(ay^2+by+c)+\frac{dy}{dV}\varepsilon_0(y-m_r)=0 \quad (5)$$

Separating dy and dV to both side:

$$\frac{1}{\varepsilon_0}dV=\frac{-y+m_r}{\frac{Z}{h_{t,0}}+(ay^2+by+c)}dy \quad (6)$$

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 Z_u :

$$\frac{1}{\varepsilon_0}dV=\frac{-y+m_r}{\frac{Z_u}{h_{t,0}}+(ay^2+by+c)}dy$$

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 V_u and from 1 to m_r, respectively, can be written:

$$\int_0^{V_u}\frac{1}{\varepsilon_0}dV=\int_1^{m_r}\frac{-y+m_r}{\frac{Z}{h_{t,0}}+(ay^2+by+c)}dy \quad (7)$$

Integrating both sides respectively results in:

$$\frac{1}{\varepsilon_0}V_u=\frac{1}{2a}\ln(\frac{a+b+c'}{am_r^{\ 2}+bm_r+c'})+\frac{m_r+\frac{b}{2a}}{a\cdot\sqrt{\frac{c'}{a}-\frac{b^2}{4a^2}}}\cdot\left[\arctan(\frac{m_r+\frac{b}{2a}}{\sqrt{\frac{c'}{a}-\frac{b^2}{4a^2}}})-\arctan(\frac{1+\frac{b}{2a}}{\sqrt{\frac{c'}{a}-\frac{b^2}{4a^2}}})\right] \quad (8)$$

From equation (8) V_u can be calculated:

$$V_u=\varepsilon_0\cdot\left\{\frac{1}{2a}\ln(\frac{a+b+c'}{am_r^{\ 2}+bm_r+c'})+\frac{m_r+\frac{b}{2a}}{a\cdot\sqrt{\frac{c'}{a}-\frac{b^2}{4a^2}}}\cdot\left[\arctan(\frac{m_r+\frac{b}{2a}}{\sqrt{\frac{c'}{a}-\frac{b^2}{4a^2}}})-\arctan(\frac{1+\frac{b}{2a}}{\sqrt{\frac{c'}{a}-\frac{b^2}{4a^2}}})\right]\right\} \quad (9)$$

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 1: Summary of the installation data

Installation data		
Length of tunnel	L_1	18000m
	L_2	6000m
Diameter of tunnel	D_1	4m
	D_2	4.2m
Discharge	Q_0	$40m^3/s$
	Q_m	$5m^3/s$

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

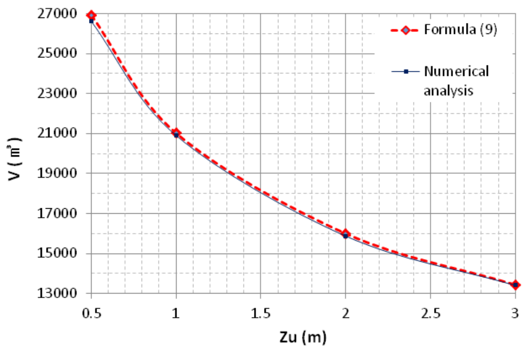
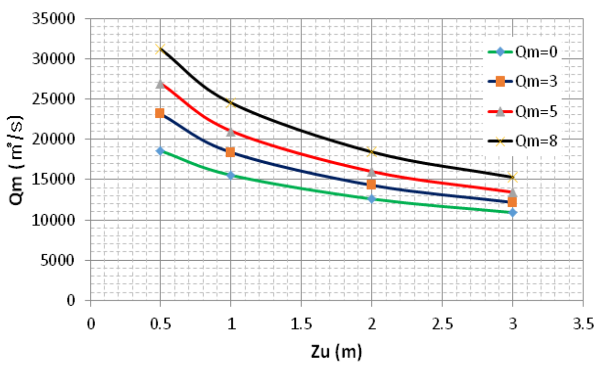
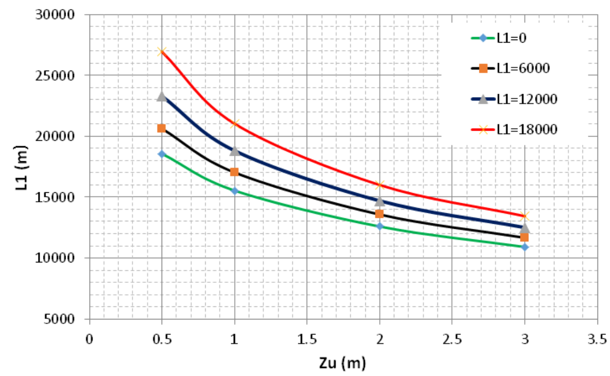


Fig. 2 Upper chamber volume

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)



A)



B)

Fig. 3 Upper chamber volume with different inflow rate Qm (a) and distance from reservoir L^1 (b)

CONCLUSIONS

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

REFERENCES

[1]. Chaudhary, M.H. (1987), "Applied Hydraulic Transients", Van Nostrand Reinhold Co., New York, U.S.A.

[2]. Jakobsen, B.F. (1956), "Surge Tanks", Trans. ASCE (85):1357-1382.

[3]. France, P.W. (1996), "Finite element solution for mass oscillations in a surge tank on sudden valve opening", Advances in Engineering Software, 26(3): 185–187.

[4]. Liu, B.H. (1995), "Hydraulic calculation and operation condition selection of the surge chamber with long-distance diversion tunnel", Journal of Hydroelectric Engineering, 51(4): 47–55.
[5]. Mosonyi, E. (1957), "Water power development", Publishing House of Hungarian Academy of Sciences, Budapest, Hungary.
[6]. Vereide, K., Richter, W., Zenz, G. & Lia, L. (2015), "Surge tank research in Austria and Norway", Wasser Wirtschaft Extra 1:58-62.
[7]. Billeter, P., Portner, Ch., Blötz, A. and Hager, M.(1996), "Coupled Numerical and Physical Simulation of the Surge Tank Dynamics for the Refurbishment of a High Head Power Plant", Proc. Int. Conf. Modeling, Testing & Monitoring for Hydro Power plants - II, Lausanne : 41 – 50.
[8]. Richter, W., Schneider, J., Knoblauch, H., Zenz, G. (2014), "Behavior of Long Chambers in Surge Tanks", In: Proc. of 18th International Seminar on Hydropower plants, Vienna.
[9]. Muris Torlak1, Adis Bubalo, Ejub Džaferović. (2015), "Numerical Analysis of Water Elevation in a Hydropower Plant Surge Tank", 6th IAHR International Meeting of the Workgroup on Cavitation and Dynamic Problems in Hydraulic Machinery and Systems, September 9-11.
[10]. Calamak, M., Bozkus, Z.(2012), " Numerical investigation of operation levels in a surge tank of small hydropower plant", 10th International Congress on advances in civil engineering, Ankara.