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Analytical solutions for determining extreme water levels in surge tank of hydropower station under combined operating conditions

Bingbao Wang[a,b], Wencheng Guo[a,c,*], Jiandong Yang[a]

[a] *State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan, 430072, China*
[b] *Zhongnan Engineering Corporation Limited, Power Construction Corporation of China, Changsha, 410014, China*
[c] *Maha Fluid Power Research Center, Department of Agricultural and Biological Engineering, Purdue University, West Lafayette, 47907, USA*

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ABSTRACT

Combined operating condition usually refers to the control operating condition under which the highest and lowest water levels occur in a surge tank of hydropower station. In this paper, with the basic equations of surge analysis and nonlinear vibrational asymptotic method, analytical expressions of the worst superimposition time of surge waves in an upstream surge tank under four typical combined operating conditions (i.e. load-acceptance-then-rejection, successive load rejection, successive load acceptance and load-rejection-then-acceptance) are derived firstly. Then using these expressions, the analytical extreme water levels are determined. The analytical solutions are verified with numerical simulation results. Finally, the effect of the hydraulic resistance coefficient of surge tank on the control operating condition is investigated. The results indicate that: The analytical solutions for determining extreme water levels in surge tank under various combined operating conditions are accurate due to the good agreements between the analytical results and the numerical results. With the increase of the hydraulic resistance coefficient of surge tank, the control operating condition for the highest water level shifts from load-acceptance-then-rejection condition to successive load rejection condition, and the control operating condition for the lowest water level shifts from load-rejection-then-acceptance condition to successive load acceptance condition.

1. Introduction

It is well recognized that surge tank is an important measure of pressure reduction for hydropower station (as shown in Fig. 1) [1–4]. Since the influence of the water level fluctuation in surge tank, the transient processes are significantly different from the case without surge tank [5,6]. During the different operating conditions and their transition processes, the wave fluctuation and wave superimposition phenomena are complicated and have significant influence on the safe and stable operation of hydropower station.

Combined operating condition (COC) refers to the operating condition that has two actions of the unit load. The first load action is called the initial operating condition, and the second load action is called the superimposition operating

* Corresponding author. Fax: +8602768772310.
E-mail address: wench@whu.edu.cn (W. Guo).

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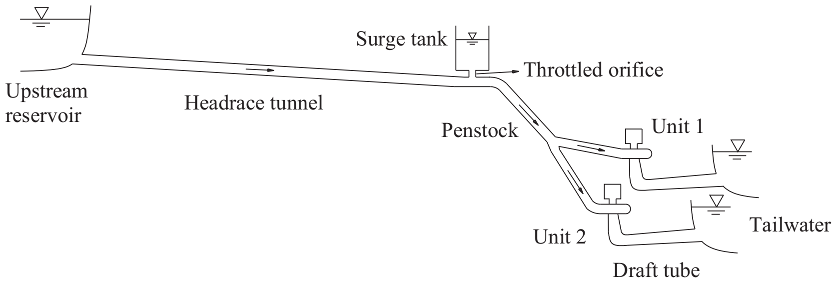

Fig. 1. Pipelines and power generation system of hydropower station with one upstream surge tank and two units.

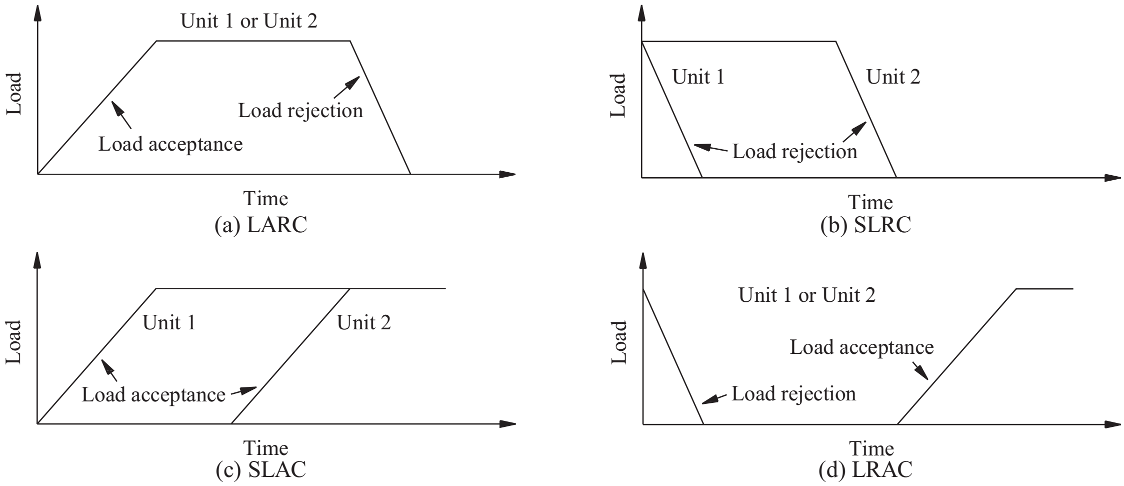

Fig. 2. Schematic of load change processes of the four typical COCs.

condition. The time that the initial operating condition transfers into the superimposition operating condition is called the superimposition time. So the superimposition time is the end time of the initial operating condition and the start time of the superimposition operating condition. This kind operating conditions are more dangerous than single operating conditions and usually lead to the highest and lowest water levels in surge tank. Moreover, the water level characteristics of COC are obviously different under different superimposition time. The extreme water levels occur if the superimposition time is the worst superimposition time. In the design of surge tank, in order to avoid the exposure of bottom plate and the overtopping, the bottom should be lower than the lowest water level and the top should be higher than the highest water level. Hence, the design of the height and elevation of surge tank mainly depends on the water level characteristics of COCs under the worst superimposition time.

For the hydropower station with one upstream surge tank and two units shown in Fig. 1, there are four typical COCs, i.e. load-acceptance-then-rejection condition (LARC), successive load rejection condition (SLRC), successive load acceptance condition (SLAC) and load-rejection-then-acceptance condition (LRAC). The schematic of load change processes of the four typical COCs is shown in Fig. 2.

For the four typical COCs, LARC and SLRC are related with the highest water levels in surge tank, and SLAC and LRAC are related with the lowest water levels in surge tank. The key issues of the analytical solutions for determining extreme water levels in surge tank of under COCs exist in the following two aspects: (1) the determination of the worst superimposition time of surge waves; (2) the determination of the control operating conditions for the highest water level from LARC and SLRC, and for the lowest water level from SLAC and LRAC. As to the above two issues, some research works have been done. In References [7–9], two moments were selected as the worst superimposition time under LARC. The first one is the time when the inflow into the surge tank equals to the rated flow of the turbine, and the second one is the time when the inflow into the surge tank reaches the maximum value. Furthermore, the analytical expressions for the highest water level in surge tank were developed based on the selected superimposition time. However, the differences between the analytically calculated results and measured results ranges from tens of centimeters to several meters, which are too large and cannot be accepted in the practical applications. A similar study in [10] shows that the highest water level in upstream surge tank decreases with the increase of the hydraulic resistance coefficient. Consequently, the control operating condition for the highest water level changes from the LARC to SLRC. Therefore, we believe that it is possible for both SLAC and LRAC to become the control operating condition for the lowest water level in surge tank, but the relationship between the control