Upstream influence on the Francis turbine full-load surge Part I: Runner blade cavitation vs. penstock response

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Abstract. Full-load surge (FLS) can occur in some hydropower plants with Francis-type turbines or pump-turbines in case of high discharge. A vapor-filled cavity is formed in the center of the draft tube flow due to counter-rotating swirl downstream of the runner. FLS is an unstable interaction between the volume of this cavity and the pressure and discharge at the runner exit. Various theoretical models for such a feedback mechanism have been set up so far. Those models differ with regard to which flow variable is subject to the mass-flow gain. Müller (2014) added a new concept: based on observations on a reduced-scale model, he proposed that feedback from pressure-dependent cavitation at the runner outlet could cause instability. For the same case, Wack (2020) confirmed in a CFD study the destabilizing effect of runner blade cavitation assuming constant turbine inflow, without feedback from the penstock. A 1D model reproducing Wack's simulation with regard to stability was also set up (Dörfler 2022). Two effects are missing in that setting: the discharge-driven variation of runner exit swirl and the dissipation of oscillation power across the runner. The present study is about a necessary extension of the 1D model. The boundary condition of constant runner discharge is replaced by a head-dependent discharge according to the turbine characteristics and penstock response, assuming an 8m long intake pipe. With this modification, the pulsation of cavity volume due to the variable angular momentum flux released into the draft tube now consists of two components: pressure variation times cavitation gain factor Ψ, and discharge variation times mass flow gain factor χ. The extended model has the stability limit shifted to significantly lower cavitation number - closer to the experimental limit, but with approximately the same frequency. It results each one of the two effects – runner discharge variation as well as runner blade cavitation – can cause instability.

1. Introduction

Full-load surge (FLS) is a self-excited pulsation which affects the entire water-conducting system connected to a Francis turbine or pump-turbine. It is caused by feedback between the flow conditions in the draft tube and the cavitation volume of the draft tube vortex at very high load. Numerical prediction of FLS by unsteady CFD is possible [5][6] but too expensive for general industrial use; therefore several attempts for a simpler approach via 1D modelling have been undertaken so far. Common feature of most such models is the use of two global parameters, describing the derivatives of the (steady-state) cavitation volume V_C by the draft tube pressure head H_{DT} and discharge Q

$$C_C = - dV_C/dH_{DT} \text{ (cavitation compliance) and } \chi = -dV_C/dQ \text{ (mass flow gain factor)} \quad (1)$$