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Cavitation Instabilities of Pumps: From Linear Analysis to Experimental Observations

[1]Satoshi Watanabe

[1]Department of Mechanical Engineering, Kyushu University, Japan
Email: fmnabe@mech.kyushu-u.ac.jp

Abstract: Cavitation is one of the inevitable problems in high-speed turbopumps. The present study focuses on flow instabilities due to cavitation in pumps, especially on so-called cavitation surge. Cavitation surge is one-dimensional flow instability involving whole pumping system, and therefore it should be avoided for reliable operation of pumps. Prediction of onset of cavitation surge is really important. Past linear stability analyses have shown that cavitation instabilities are caused by a negative damping of the system through positive mass flow gain factor, the increase of cavity volume in response to the increase of incidence angle, i.e., the decrease of flow rate (ref. Tsujimoto et al, 2001, AIAA J. Prop. & Power). Nevertheless, the onset condition of cavitation surge is not yet been able to be explained.

In the present study, the linear stability analysis of cavitation surge will be re-introduced for better understanding of the onset condition. Importance of unsteady response of cavity has been shown clearly by assuming the 1st order time lag and dead time in response of cavity against flow fluctuations. More specifically, the phase lag in cavitation compliance, the delay of cavity response against pump inlet pressure fluctuation, plays an important role of positive damping; cavitation surge would occur when the negative damping effect of mass flow gain factor overcomes the positive damping of phase lag (ref. Watanabe and Tsujimoto, 2020, ISROMAC2020).

Next, experimental activities on cavitation surge being made in Kyushu University will be introduced (ref. Morii et al., 2019, IJFMS). The onset range and flow behaviors of cavitation surge at low flow rates in a turbopump with inducer will be mainly focused on. The significance of inlet back flow and back flow cavitation will be shown through a high-speed camera observation and flow measurements. The effect of adding further damping to the pumping system on cavitation surge will also be shown as a part of the validation of stability analysis (ref. Tanaka et. al, 2020, ISROMAC2020).

To enhance the operatable range of pumps, it is important to suppress cavitation surge. Key consideration for it is to suppress/weaken the inlet back flow. Reduced-diameter suction pipe, whose diameter is smaller than the tip diameter of inducer, has been proposed as one of the passive suppression devices of cavitation surge (ref. Tanaka et al., 2017, TFEC9). The experimental evidence of suppression effect of the device will be finally presented.

Keywords: Turbopump, Inducer, Cavitation surge, Inlet backflow, Stability analysis.