18th International Conference
ENGINEERING MECHANICS 2012
Svratka, Czech Republic, May 14 – 17, 2012

pp. 1123–1124
Paper #145

INSTABILITY OF THE SWIRLING FLOWS WITH/WITHOUT CAVITATION

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Abstract: *Swirling flows are very susceptible to instabilities. Very often they are present in draft tubes of hydraulic turbines as so called vortex ropes resulting from spiral vortex breakdown. Moreover the situation can be complicated by cavitation within the core of the vortex. Paper presents various approaches, which were applied to enhance understanding of this problem. Numerical approach to study the linear stability including influence of cavitation is proposed and extensive nonlinear CFD simulations are described.*

Keywords: ***swirling flow, cavitation, stability, vortex breakdown***

1. Introduction

Swirling flow is very susceptible to instability (Lucca-Negro & O., O'Doherty, T., 2001). Rotating flow leaves the turbine runner for off design operating points, which is a result of the mismatch between angular momentum produced by guide vanes and angular momentum utilized by the runner. The instability is manifested as so called vortex breakdown, which can take either form of axisymmetric bubble or spiral vortex breakdown. The spiral form is typical for hydraulic turbine draft tubes, where the resulting spiral coherent structure is called vortex rope. Precessing vortex rope appears with frequency between 20 and 40% of the runner rotational frequency and its sense of rotation depends on the operational point with respect to the best efficiency point. Induced pressure pulsations deteriorate performance of the turbine.

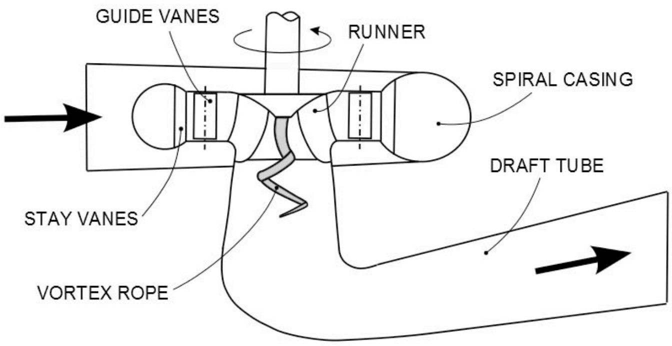

Fig. 1: Francis turbine during part load operation

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2. Analytical approach

Analytical approaches were based on two concepts: study of vortex vector dynamics and investigation of linearized Euler equations (Pochylý et al, 2009). The first approach enables to reveal the role of vorticity vector components on evolution of the spiral vortex breakdown. The latter approach, which is based on perturbation theory also brings quantitative information concerning tendency of the flow towards instability and frequency of possible instabilities.

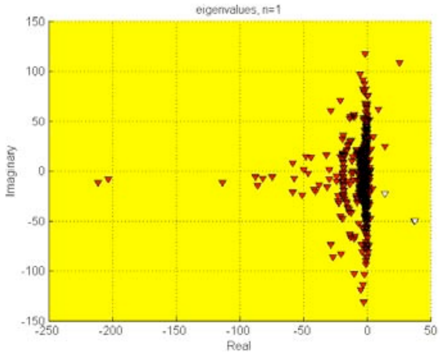

Fig. 2: Eigenvalues of the swirling flow in diffuser

3. Computational and experimental investigation

Experimental research includes measurements of pressure pulsations and flow visualizations. Both types of the vortex rope i.e. cavitating and non-cavitating were observed. Computational investigations combine complex turbulence models coupled with cavitation models (Rudolf et al, 2011).

Fig.3: Cavitating vortex rope (experiment)

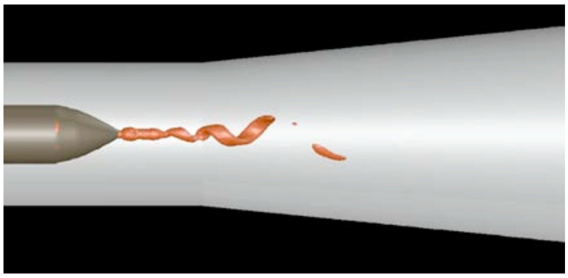

Fig.4: Cavitating vortex rope (simulation)

4. Conclusion

An extensive analytical, computational and experimental research was carried out at Kaplan Dept. of Fluid Engineering aiming on better understanding of the cavitating vortical structures in swirling flow. The main conclusions yet point to velocity gradients of the oncoming flow as the most important parameter in the onset of instability.

Acknowledgement

Czech Science Foundation is gratefully acknowledged for support of the research under project No. 101/09/1715 "Cavitating vortical structures induced by rotating liquid".

References

Lucca-Negro & O., O'Doherty, T. (2001) Vortex breakdown - a review, *Progress in Energy and Combustion Science*, Vol. 27,pp. 431-481.

Pochylý, F., Čermák, L., Rudolf, P.; Habán, V.; Koutník, J. (2009) Assessment of the steady swirling flow stability using amplitude-frequency characteristic, *Proc. of the 3rd IAHR Int. Meeting of the Workgroup on Cavitation and Dynamic Problems in Hydr. Mach. and Systems - part I*, pp.25-34

Rudolf, P.; Hudec, M.; Zubík, P.; Štefan, D. (2011) Experimental measurement and numerical modeling of cavitating flow in converging-diverging nozzle, *Proc. of the Int. Conf. Exp. Fluid Mech. 2011*, pp.423-431