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Cavitation in Kaplan Turbines – A Review

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Abstract—*Hydropower contributes 16% of total electricity generation in world and turbine being the power conversion component in hydropower plant; it becomes the goal of design of the turbine to cover all the factors that affect the turbine in any manner. Among such factors, Cavitation is a destructive phenomenon in which formation of cavity and very high local pressure whose magnitude may be as high as 7000 atm, are repeated many thousand times a second, causing pitting on the metallic surface of runner blades or draft tube. The damage, then followed by fatigue and corrosion, leads to failure of component. The present paper provides a brief description of general features of cavitation phenomenon and various aspects related to cavitation in hydro turbines, based on the literature. In the scope of this work, the cavitation affected regions, damage patterns*
over Kaplan turbine due to cavitation are identified and methods for prevention and repair are listed. It also highlights the role of anti-cavitating material coatings on parts of turbine in saving them from damage due to cavitation. An attempt has been made to identify industrial approach, through study of patent records, towards manufacturing of anti cavitating turbine parts.

Keywords*: Cavitation,Kaplan turbine,Damage,Repair*

1. INTRODUCTION

Hydroelectric energy is a renewable energy and as it only requires water it is clean too. Turbines are conversing components which convert hydraulic energy to electrical energy. In present, mechanical efficiency of turbines has reached to 95%. However, reaching such efficiencies is a complex task and requires high engineering efforts. [1]

The ideal power that can be derived from flowing water at a site is given by:

$P = \gamma QH$ Eq. (1)

Where P is power in KW, γ is specific weight of liquid in N/m^3, Q is flow rate in m^3/s and H is gross head in m.

2. TYPES OF TURBINE USED IN HYDROELECTRICITY GENERATION

- Impulse Turbine
- Reaction Turbine

Impulse Turbines are high head, low discharge, and low specific speed and operate at atmospheric pressure, while the reaction turbines operate under low and medium head with high specific speed and operate under variable pressure**.**

3. CAVITATION

The appearance of vapor cavities inside an initially homogeneous liquid medium occurs in very different situations. It can present various features according to the flow configuration and flow properties of the liquid. It can be defined as the breakdown of a liquid medium under very low pressure. This makes cavitation relevant to the field of continuum mechanics and it applies to cases in which the liquid is either static or in motion. The concept of vapor pressure is best considered from view point of classical thermodynamics. In the phase diagram (fig. 1) for, say, water, the curve from the triple point T_r to the critical point C separates the liquid and vapor domains. Crossing that curve is representative of a reversible transformation under static (or equilibrium) conditions, i.e. evaporation or condensation of the fluid at pressure P_v, known as vapor pressure. This is a function of the temperature T.

Following from this, cavitation in a liquid can be made occur by lowering the pressure at an approximately constant temperature, as often happens locally in real flows. Cavitation thus appears similar to boiling, except that the driving mechanism is not a temperature change but a pressure change, generally control by the flow of dynamics. [2]

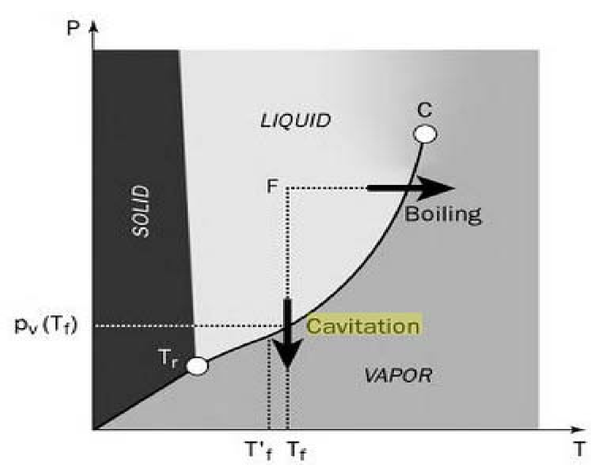

Fig. 1: Phase diagram

Hydraulic turbines, where reliability, long life and efficiency are all so very important, the effects of cavitation must be considered.

Two types of cavitation may be in evidence,

(i) on the suction surfaces of the runner blades at outlet which can cause severe blade erosion; and

(ii) A twisting "rope-type" cavity that appears in the draft tube at off-design operating conditions.

The cavitation performance of hydraulic turbines can be correlated with the Thoma coefficient, σ defined as

$$\sigma = \frac{H_s}{H_e} = \frac{(P_a - P_v)/(\rho g - z)}{H_e} \quad \textbf{Eq. (2)}$$

Where H_s is the net positive suction head (NPSH), the amount of head needed to avoid cavitation, the difference in elevation, z, and P_v is the vapor pressure of the water**.**[3]

The value of σ at this turning point is called critical cavitation factor σ_c. The value of σ_c for different turbines may be determined with the help of following empirical relationships:

For Francis turbines: σ_c

$$\sigma_c = .625\left(\frac{Ns}{380.78}\right)^2 \quad \textbf{Eq. (3)}$$

For Propeller turbines: σ_c

$$\sigma_c = .28 + \left[\frac{1}{7.5}\left(\frac{Ns}{380.78}\right)^3\right] \quad \textbf{Eq. (4)}$$

The value of σ from equation (2) is compared with the value of σ_c from equation (3) and (4) and if it is greater than σ_c, cavitation will not occur in that turbine**. [4]**

4. DAMAGE DUE TO CAVITATION

Perhaps the most ubiquitous engineering problem caused by cavitation is the material damage that cavitation bubbles can cause when they collapse in the vicinity of a solid surface. Cavitation bubble collapse is a violent process that generates highly localized, large-amplitude shock waves and micro jets. [5]

Damages caused by cavitation if summarized are:

- Erosion of material from turbine parts.
- Distortion of blade angle
- Loss of efficiency due to erosion/distortion

4.1 Cavitation Erosion

cavitation erosion in hydro turbines occurs as a result of the steady erosion of particles from the turbine surface. Typical metal losses experienced in the hydro-generating industry can average approximately 5kg/m2 /10,000 hours and repair is scheduled generally at 40,000 hours. It has been observed that pitting depth has exceeded 40 mm on hydro-turbine runner surfaces. metal losses up to 200kg is not uncommon. [6]

As studied that ductile materials show no weight loss for long periods but brittle materials exhibit weight loss early in the process.. [7]

4.2 Different locations in Kaplan turbine at which cavitation occurs

- Tip Clearance Cavitation Chamber
- Tip Vortex Cavitation
- Leading Edge Cavitation
- Hub Cavitation

5. THEORETICAL INVESTIGATION

Cavitation can appear in hydraulic turbines under different forms depending on hydraulic designs and the operating conditions. In Kaplan turbine the main types are leading edge cavitation, hub cavitation, tip vortex cavitation, tip clearance cavitation and draft tube swirl, Leading edge or inlet cavitation is usually a very aggressive type that is likely to erode the blades deeply. Traveling bubble cavitation is noisy type of cavitation that reduces machine efficiency and provokes blade erosion.

5.1 Rayleigh-Plesset Equation

The Rayleigh-Plesset equation is usually derived by considering the dynamics of the bubble radius, *R*

$$\frac{p_b(t) - p_\infty(t)}{\rho_l} = \frac{d^2R}{dt^2} + \frac{3}{2}\left(\frac{dR}{dT}\right)^2 \frac{4v_l}{R}\left(\frac{dR}{dT}\right) + \frac{2S}{\rho_l R} \quad \text{Eq. (5)}$$

Where,

p_b is the pressure within the bubble, assumed to be uniform

$p_\infty(t)$ is the external pressure infinitely far from the bubble

ρ_l is the density of the surrounding liquid, assumed to be constant

$R(t)$ is the radius of the bubble

v_l is the kinematic viscosity of the surrounding liquid, assumed to be constant

S is the surface tension of the bubble

6. EXPERIMENTAL INVESTIGATION

Escalera et al (2006) carried out experimental invest- tigation in order to evaluate the detection of cavitation in actual turbines. The methodology was based on the analysis of structural vibrations, acoustic emissions and hydrodynamic pressures measured in the machine. [7] M. Angul et al experimentally investigated vibrations, noise and pressure fluctuations on a Kaplan turbine operating at on-cam cavitating conditions using methodology in which Signals were processed with Fast Fourier Transform (FFT) analysis. [8]

Kaveh Amiri et al investigated unsteady pressure distribution on the runner of reaction turbines. It can be used to evaluate the runner performance and investigate the flow condition in blade channel. [9]

Antonio et al studied real-time detection of cavitation for hydraulic turbo machines using image processing system. [10]

B. sirok et al visualized cavitation in water with aid of computer-aided visualization method.[11]

Natasha A. Chang et al found that low frequency tones can take place during the inception and growth of a cavitating bubble while working on Incepting cavitation acoustic emissions due to vortex stretching. [12]

L motycak et al investigated tip vortex cavitation in Kaplan turbine runner Fig(2-5) and found that to avoid the tip vortex cavitation pitting, the design of the runner blade could be changed. [13]

Fig. 2: Tip Clearance Cavitation Chamber

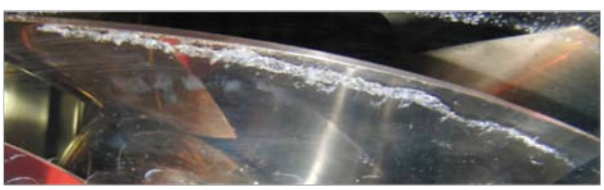

Fig. 3: Tip Vortex Cavitation

Fig. 4: Leading Edge Cavitation

Fig. 5: Hub Cavitation

7. NUMERICAL STUDIES

Jain et al studied two types of methodologies in which Steady state simulation has been used to determine the efficiency and unsteady state simulations are conducted to know the transient behavior of the flow because the nature of flow in turbine is unsteady in nature due to rotating of the runner. [14]

Motycak et al investigated various information regarding the real flow field including CFD analysis of the runner draft tube interaction detailed measurement of the velocity at the downstream of the runner by differential probe measurement and the velocity measurement downstream of the draft tube by Particle Image Velocimetry (PIV).[15]

Jain et al studied among the turbulence model, k-w shear stress transport model has been found to give better convergence and turbine performance compared with standard k-e, Renormalization group (RNG) k-e. SST model has been successful in giving accurate results for cases where there are adverse pressure gradient flows and where separation of flow occurs. [16]

Santiago et al employed steady and unsteady simulation for the numerical analysis of the Francis turbine. Boundary conditions were mass flow inlet and opening with pressure outlet with solid surfaces as walls for both types of simulation. He stated that this type of boundary condition represents real flow in the turbine. [17]

PENG Yu-cheng et al studied cavitation on the surface of the guide vane in this The RANS equations are solved in the computational domain comprising the flow passages from the inlet of the spiral case to the outlet of the draft tube. [18]

D Jost et al employed numerical flow simulation and did efficiency prediction for axial turbines by advanced turbulence models in Kaplan turbine. [19]

Dr. Vishnu Prasad employed numerical simulation for flow characteristics of axial flow hydraulic turbine runner and found that the most of local flow parameters like velocities and flow angles at inlet and outlet are affected by the operating regimes of turbine. [20]

Harsh Vats et al investigated the combined effect of cavitation and silt erosion in Francis turbine The

efficiencies of the turbine were calculated using CFD approach. [21]

Tarun Singh Tanwar et al employed Flow simulation and did static structural analysis of a radial turbine using CFD approach. [22]

8. CAVITATION DAMAGE REPAIR

To maximize equipment life and to maintain high availability and good operating efficiency, cavitation pitting repairs should be done in a logical and methodical manner. The basic steps of such a repair program are as follows: [23]

- Inspection
- Identify cause of pitting
- Plan best approach to repairs
- Perform repairs

When the decision is reached to proceed with cavitation pitting repairs, it is necessary to determine the method to be used for repairs and whether or not blade profile corrections should be made. The various methods for undertaking repairs include:

- Fill damaged area with weld material
- Fill damaged area with non-fused materials
- Weld plates over the damaged area
- Remove damaged section and replace with new forced plates welded in place

8.1 Repair Methods

- Weld Repair
- Non-Fused Materials
- Surface hardening

8.1.1 Weld Repair

Weld Process Two processes are used for cavitation repair welds:

- Gas metal arc welding (GMAW) or MIG welding
- Shielded metal arc welding (SMAW) or stick electrode

8.1.2 Non-Fused materials

Various non-fused materials have been used for cavitation damage repairs. These include: Epoxies, Ceramics, metal, spraying, Neoprene, Urethane.

8.1.3 Surface hardening

Vasile et al investigated the influence of surface hardening on the cavitation resistance of austenitic stainless steel welds. The results didn't demonstrate an increase of the cavitation erosion resistance of welded layers hardened by peening. [24]

9. PATENTS

9.1 PCT/US2004/034931

Gray et al invented Erosion resistant coating processes and material improvements for line-of-sight applications. The erosion resistant coating composition includes nanostructured grains of tungsten carbide (WC) and/or submicron sized grains of WC embedded into a cobalt chromium (CoCr) binder matrix. A high velocity air fuel thermal spray process (HVAF) is used to create thick coatings in excess of about 500 microns with high percentages of primary carbide for longer life better erosion resistant coatings. These materials and processes are especially suited for hydroelectric turbine components.

9.2 13/806714

Prigent et al invented a method for protecting a component of a hydraulic machine against erosion comprises steps involving preparing, in the flat state, several sheets of polymerized synthetic material, in applying a coat of adhesive to one side of each sheet 300 and in laying the sheets on the surface of the component that is to be covered with the layer of coating.

10. CONCLUSION

Due to Cavitation, vapor bubbles occurs in low pressure regions and they collapse in high pressure regions and because of this cavitation erosion occurs in different part of turbine. Thought it could be detected by various methods and could be minimized to economic level but cannot be completely removed. We can use various repair methods prevent turbine parts from cavitation.

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REFERENCES

[1] Santiago Laín, Manuel García, Brian Quintero, Santiago Orrego2, "*CFD Numerical simulations of Francis turbine Simulación numérica (CFD) de turbinas Francis*" Rev. Fac. Ing.Univ. Antioquia N. ° 51 pp. 24-33. Febrero, 2010.

[2] Jean-Pierre Franc, Jean-Marie Miche, "*Fundamentals of cavitation*" 2005

[3] *"Fluid Mechanics and Thermodynamics of Turbo machinery"*, 5e GL Dixon

[4] S. Khurana, Navtej and Hardeep Singh Mann. "*Effect of cavitation on hydraulic turbines"*- A review 2012

[5] Christopher E. Brennen.*"An Introduction to Cavitation Fundamentals"*, By, California Institute of Technology, Pasadena, California, USA

[6] Simoneau R, Pétrin MC, "*Cavitation Damage of Hydraulic Turbines, Canadian Electrical Association Workshop"*

[7] Escalera X, Egusquiza E, Farhat M Avellan, F Coussirat M, *"Detection of cavitation in hydraulic turbines"*.Mechanical Systems and Signal Processing ,(2006) 20 983–1007

[8] M. Angulo, C. Lucino and S. Liscia, "*Experimental investigation of vibrations, noise and pressure fluctuations on a Kaplan turbine operating at on-cam cavitating conditions"*. 5th International Workshop on Cavitation and Dynamic Problems in Hydraulic Machinery, September 8-11, 2013, Lausanne, Switzerland

[9] Kaveh Amiri, Michel Cervantes, Berhanu Mulu and Mehrdad Raisee, "*Experimental Study of Fluid Structure Interaction in a Kaplan Turbine Runner Blade"*. 5th International Workshop on Cavitation and Dynamic Problems in Hydraulic Machinery,September 8-11, 2013, Lausanne, Switzerland

[10] Antonio Baldassarre, Maurizio De Lucia and Paolo Nesi, "*Detection of Cavitation for Hydraulic Turbomachines. Real-Time Imaging"* 4, 403–416 (1998).

[11] B. Širok, M. Novak, M. Hočevar, J. Prost, "*Visualization Monitoring Of Cavitation In Water Turbines"*.

[12] Natasha A. Chang, Steven L. Ceccio. "*Incepting cavitation acoustic emissions due to vortex stretching*". Proceedings of the 7th International Symposium on Cavitation CAV2009 – Paper No. 183 August 17-22, 2009, Ann Arbor, Michigan, USA
[13] L motycak, A Skotak and R Kupcik, "Kaplan turbine tip vortex cavitation – analysis and prevention". IAHRSymposiumonHydraulicMachineryandSystems Earth and Environmental Science 15 (2012) 032060
[14] (Jain, S., R. P. Saini, and A. Kumar. 2010. "*Cfd Approach for Prediction of Efficiency of Francis Turbine*"
[15] Motycak, L.A.Skotak, and J. Obrovsky. 2010. "*Conditions of Kaplan Turbine Cfd Analysis*".
[16] "*CFD study of different turbulence models in kaplan turbine*"
[17] (Laín, S., M. García, B. Quintero, and S. Orrego. 2010."*CFD Numerical Simulations of Francis Turbines*". Revista Facultad De Ingeniería Universidad De Antioquia (51): 24–33)
[18] Peng Yu-cheng, Chen Xi-yang, CAO Yan, HOU Guo-xiang, ―Numerical study of cavitation on the surface of the guide vane in three gorges hydropower unit",journal of hydro dynamic2010,22(5):703-708.
[19] D Jošt, A Škerlavaj and A Lipej. "Numerical flow simulation and efficiency prediction for axial turbines by advanced turbulence models".
[20] Dr. Vishnu Prasad ."*Numerical simulation for flow characteristics of axial flow hydraulic turbine runner*". 2nd International Conference on Advances in Energy Engineering (ICAEE).
[21] Harsh Vats & R.P. Saini. "*Investigation on combined effect of cavitation and silt erosion on Francis turbine*". International Journal of Mechanical and Production Engineering (IJMPE) ISSN 2315-4489, Vol-1, Iss-1, 2012.
[22] Tarun Singh Tanwar, Dharmendra Hariyani and Manish Dadhich, "*Flow simulation & static structural analysis of a radial turbine*", IJMET Volume 3, Issue 3, September - December (2012), pp. 252-269.
[23] "*Facilities instructions, Standards, & Techniques*" Volume 2-5 Turbine Repair ,2000.
[24] Vasile Cojocaru, Constantin Voirel Campian, Doina Frunzaverde,Ioan Ion, Adrian Cuzmos, Cosmin Dumbrava *"Laboratory tests concerning the influence of surface hardening on the cavitation erosion resistance"*