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A Review on Study of Cavitations in Hydroulic Turbine

Rajendra Kumar Kaushik[1]; Prakash Kumar Sen[2]; Gopal Sahu[3]; Ritesh Sharma[4]& Shailendra Bohidar[5]

[1]Student, Mechanical Engineering, Kirodimal Institute of Technology, Raigarh (C.G.)
[2,3,4,5]Lecturer, Mechanical Engineering, Kirodimal Institute of Technology, Raigarh (C.G.)

Abstract

Cavitation is the gas liquid region produced by a localized pressure reduction created by internal force in fluid. a brief description of the general features of cavitation phenomenon is given as well as of the main types of cavitations occurring in hydraulic turbines. The work presented here is focused on the most important ones which are the leading edge cavitation due to its erosive power, the bubble cavitation because it affects the machine performance and the draft tube swirl that limits the operation stability. Cavitation is a phenomenon which manifests itself in the pitting of the metallic surfaces of turbine parts because of the formation of cavities. This paper present on the cavitation phenomenon in hydraulic turbine discussed briefly.

Keyword :- Cavitation; Hydraulic Machine; vibration, Erosion.

Introduction

Cavitation is the formation of vapour cavities in a liquid i.e. small liquid free zone ("bubble" or voids") that are the consequence of force acting upon the liquid. Cavitation is a significance cause of wear in some engineering contexts. Collapsing void that implode near to metal surface cause cyclic stress through repeated implosion. This result in surface fatigue of the metal causing a type of wear also called cavitation [1]. Design operation of hydraulic turbines, pumps or pump-turbine are strongly related to cavitation flow phenomena, which may occur in either the rotating runner-impeller or the stationary parts of the machine[2].Cavitations in hydraulic machinery presents unwanted consequences such as flow instabilities excessive vibrations, damage to material surfaces and degradation of machine performance. Unfortunately, these problems are becoming more Important because the propensity for cavitation is being enhanced. In first place, the growth of the turbine output power is based on the reduction of dimensions to decrease the cost of its components. Hence, the speeds are being increased and the cavitation number is thereby decreased. In second place, there is a trend to operate the turbines in conditions from their best efficiency point imposed by the deregulation of the hydropower generation market and cavitation phenomena are more prone to occur at off design operating conditions. Therefore, the combination of both factors is certainly promoting the risk of cavitation problems in hydraulic machines[3].

2. Cavitation in hydraulic turbine

2.1. Turbine type and configuration

Cavitation plays an important role in reaction water turbines such as Kaplan, Francis and Pump-Turbine. The main difference between Kaplan and Francis turbines is the design of the runner which is, respectively, axial and radial. For the reversible Pump-Turbine, the runner has a

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radial design with low specific speed and it can operate in turbine or in pump mode. The rest of the machine components comprising the penstock, spiral casing, stay vanes, guide vanes, draft tube, shaft, alternator and bearings are analogous for any particular design. In Fig. 2, a schematic of a Kaplan turbine is shown on the left and a cross section of a Francis runner with its downstream reservoir is shown on the right.

2.2. Turbine setting level

The setting level of the machine is the distance Hs indicated in Fig.1 that determines the pressure field in relation to the vapour pressure threshold. For instance, bubble cavitation can appear even at the best efficiency point of the machine because it has a strong dependence on this level. Thus, the cavitation coefficient of a hydraulic turbine depends on this parameter . The International Electrotechnical Commission (ICE) recommends to use the Thoma number or plant cavitation number σ_p defined as

$$\sigma_p = \frac{NPSE}{E},$$

where E is the specific energy and NPSE is the net positive suction specific energy that in turn can also be calculated as

$$NPSE = \frac{p_I}{\rho} + g(Z_I - Z_{\text{ref}}) + \frac{1}{2}C_I^2 - \frac{p_v}{\rho}$$

or

$$NPSE = \frac{p_a}{\rho} - gH_S + \frac{1}{2}C_I^2 - \frac{p_v}{\rho}.$$

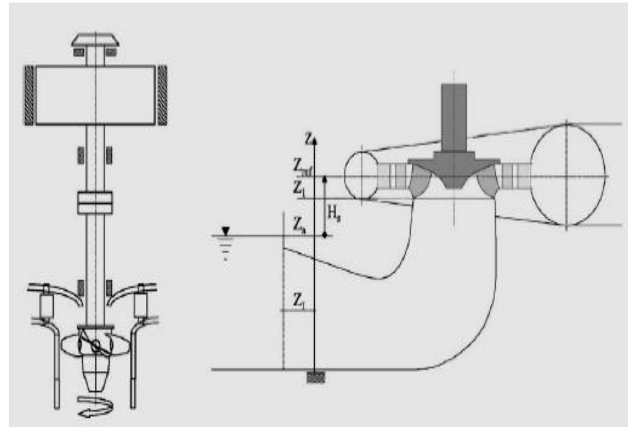


Fig. 1. (Left) Schematic of a Kaplan turbine and its mechanical configuration. (Right) Schematic of a Francis runner, draft tube and downstream reservoir[4].

2.3 the main type of cavitation

The main forms of cavitation that can arise on Francis turbines are briefly described in the following paragraphs.

2.3.1. Leading edge cavitation

It takes the form of an attached cavity on the suction side of the runner blades due to operation at a higher head than the machine design head when the incidence angle of the inlet flow is positive and largely deviated from the design value. It can also occur on the pressure side during operation at a lower head than the machine design head when the incidence angle is negative . If unstable, this is a very aggressive type of cavitation that is likely to deeply erode the blades and to provoke pressure fluctuations. Shown in fig.2

2.3.2Travelling bubble cavitation

See in Figs.2. It takes the form of separated bubbles attached to the blade suction side near the mid-chord next to the trailing edge. These travelling bubbles appear due to a low plant cavitation number σ_p and they grow with load reaching their maximum when the machine operates in overload condition with the highest flow rate. This is a severe and noisy type of cavitation that reduces significantly the machine efficiency and that can provoke erosion if the bubbles collapse on the blade.

3.4.3. Draft tube swirl

It is a cavitation vortex-core flow that is formed just below the runner cone in the centre of the draft tube. Its volume depends on $\square_p$ and it appears at partial load land at overload due to the residual circumferential velocity component of the flow discharged from the runner. This vortex rotates in the same direction as the runner at part load and in the opposite direction at overload. From 50% up to 80% of the best efficiency flow rate, the vortex core takes a helical shape and presents a precession rotation at 0.25–0.35 times the runner rotating speed. In this case, circumferential pressure pulsations are generated at this low frequency. Strong fluctuations may occur if the precession frequency matches one of the free natural oscillation frequencies of the draft tube or penstock.

3.4.4. Inter-blade vortex cavitation

This is formed by secondary vortices located in the channels between blades that arise due to the flow separation provoked by the incidence variation from the hub to the band. They can attach to the intersection of the blade inlet-edge with the crown or mid-way of the crown between the blades close to the suction side. Only if their tip is in touch with the runner surface they can result in erosion[5].

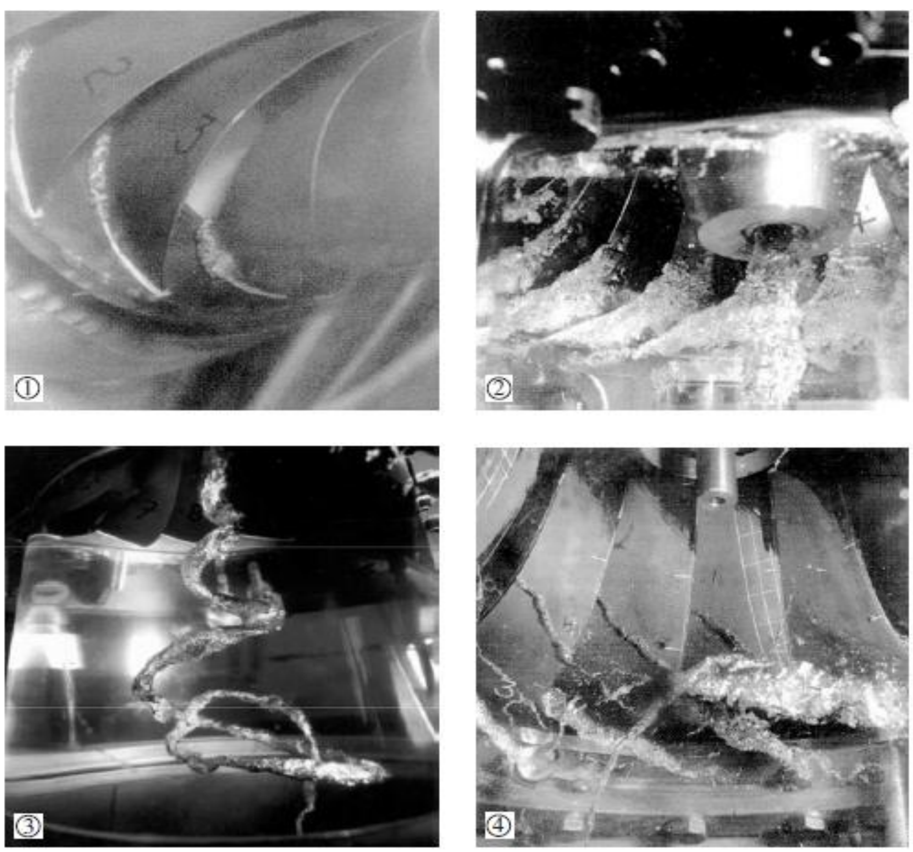


Fig. 2. Main types of cavitation in Francis turbines: (1) leading edge cavitation, (2) travelling bubble cavitation, (3)draft tube swirl and (4) inter-blade vortex cavitation[6].

3. Cavitation – erosion in hydroturbine

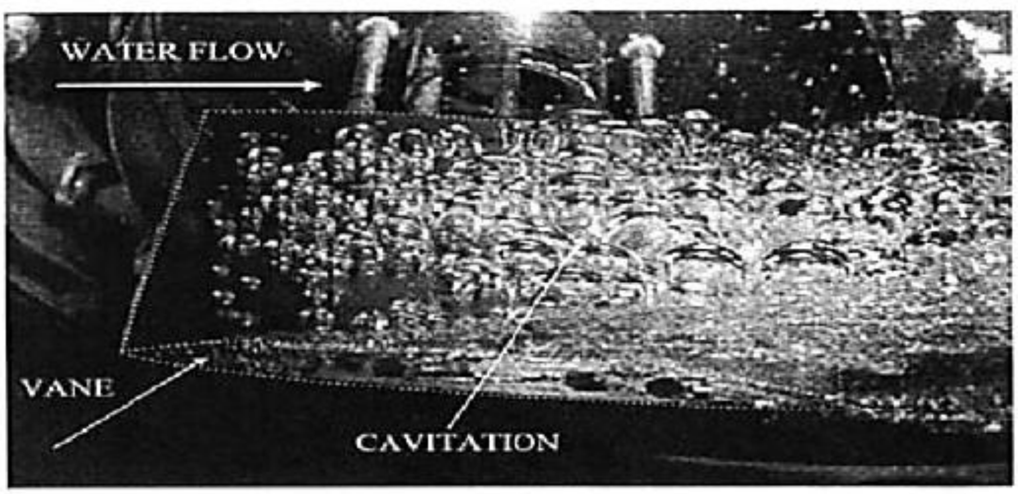
Also known as "pitting" erosion, cavitation on hydro – turbines occurs as a result of the steady erosion of particles from the turbine surface, Pitting depth exceeding 40mm in depth has been observed on hydro-turbine runner surfaces. Typical metal losses experienced in the hydro-generating industry can average approximately 5kg/m2 /10,000 hours (generally repair is scheduled at 40,000 hours). For a turbine runner over a period of several years, metal losses up to 200kg is not uncommon .Up to 90% of hydro-turbines suffer cavitation damage to some extent. To study the cavitation erosion, three types of devices have usually been used. These are the rotating disk, the hydrodynamic tunnel and a vibratory device which produces cavitation. Cavitation-erosion is most likely to occur on the low pressure side of the turbine runner blades. Damages caused by cavitation if summarized are erosion of material from turbine parts.

1.Distortion of blade angle

2.Loss of efficiency due to erosion/distortion [7].

4. Theoretical investigations

Cavitation can be observed in a wide variety of propulsion and power systems like pumps nozzles, injectors, marine propellers, hydrofoils and underwater bodies. Cavitation can appear in hydraulic turbines under different forms depending on hydraulic designs and the operating conditions. In Francis turbine the main types are leading edge cavitation, travelling bubble cavitation, 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.



F*ig.3 Fluid flow on a blade under cavitation[8]*

Draft tube swirl generates low frequency pressure pulsations that in case of hydraulic resonance can cause strong vibrations on the turbine and even on the power-house. Von Karman vortex cavitation produces structural vibrations at the trailing edge of vanes. provided information about cavitation, cavitation repair, cavitation damage inspection, cause of pitting, runner modifications, cavitation pitting locations, methods of cavitation pitting repair and areas of high stress runner. Typical areas of cavitation pitting were found as shown in Figure.4[9].

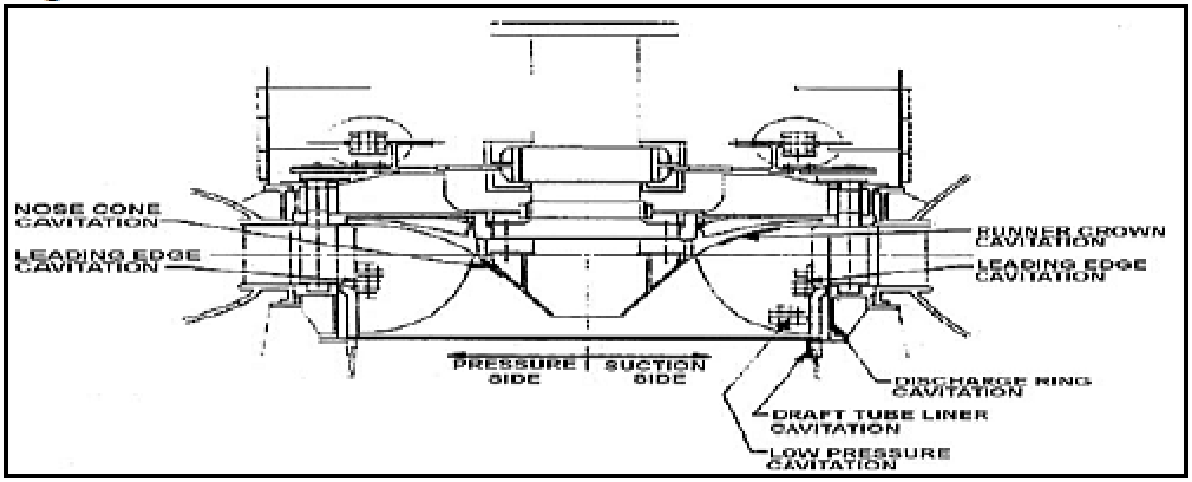


Fig. 4 Francis turbine- typical area of cavitation pitting[10]

A comparative study between various cavitation erosion situations was carried out to verify the ability of this vortex cavitation generator to produce realistic cavitation erosion with respect to that observed in hydraulic machinery. Hardened superficial layers in specimens exposed to flow cavitation were found a thicker than those in vibratory cavitation, which leads to higher erosion rates. Far hat et al. the benefits of the cavitation monitoring in hydraulic turbines using a vibratory approach. This technique was used in a large Francis turbine in order to validate as light modification of its distributor, which was intended to reduce the cavitation aggressiveness and related erosion[11].

Table.1Description of the turbines and the type of cavitation investigated.

Size of machine	Type of turbine	Type of cavitations	N(rpm)	Z_b(-)	Z_v(+)
prototype	Kaplan	Leading edge	125	6	24
	Francis1	Leading edge	250	15	24
	Francis2	Draft tube swirl	250	15	24
	Pump-turbine	Draft tube swirl	600	7	16
model	Francis	bubble	947	19	20

Conclusion

A survey of the different types of caviation featured by hydraulic machinery has been carried out. .Cavitation is a phenomenon of formation of vapor bubbles in low pressure regions and collapse in high pressure regions. Cavitation can present different forms in hydraulic turbines depending on the machine design and the operating condition. As a result, high vibration levels, instabilities and erosion can occur which invalidates the machine operation and cause damage. The types of cavitation of major interest in hydraulic turbines are the inlet leading edge cavitation, the outlet bubble cavitation and the draft tube swirl, which have been described after introducing the basic cavitation phenomena. Since cavitation induces structural vibrations, acoustic emissions and hydrodynamic pressures, Unstable leading edge cavitation produces vibrations on the runner blades that propagate through the mechanical system. It is difficult to avoid cavitation completely in hydraulic turbines but can be reduced to economic acceptable level. It is therefore, required experimental and theoretical studies for studying the impact of cavitation in hydro turbine.

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