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Effects of Cavitation in Hydraulic Machines

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Abstract: Cavitation is a phenomenon of forming of vapour bubbles of a flowing liquid in a region where the pressure of the liquid falls below its vapour pressure and the sudden collapsing of the vapour bubble in a region of higher pressure. This collapsing is due to the fluid pressure which is higher then the pressure inside the bubbles. When the vapour bubbles collapse, a very high pressure is produced. The metallic surfaces above which these vapour bubbles collapse, is subjected to high pressure which causes pitting action on surface. Cavitation is undesirable because it causes the extensive erosion of the rotating blades, additional noise from the resultant knocking and vibrations, and a significant reduction of efficiency because it distorts the flow pattern. Cavitation is a important problem in hydraulic machine which has the negative effect on their performance and may cause damages. In the present paper, a brief description of the general features of cavitation phenomenon is given.
Key words: Cavitation, Vapour bubble, Pitting, Erosion, Hydraulic machine.

I. INTRODUCTION

Cavitation is the formation of vapour cavities in a liquid, small liquid-free zones ("bubbles" or "voids"), that are the consequence of forces acting upon the liquid[1]. It usually occurs when a liquid is subjected to rapid changes of pressure that cause the formation of cavities in the liquid where the pressure is relatively low. When subjected to higher pressure, the voids implode and can generate an intense shockwave. Cavitation is a significant cause of wear in some engineering contexts. Collapsing voids that implode near to a metal surface cause cyclic stress through repeated implosion. This results in surface fatigue of the metal causing a type of wear also called "cavitation". The most common examples of this kind of wear are to pump impellers, and bends where a sudden change in the direction of liquid occurs. Cavitation is usually divided into two classes of behaviour: inertial (or transient) cavitation and non-inertial cavitation. Inertial cavitation is the process where a void or bubble in a liquid rapidly collapses, producing a shock wave. Inertial cavitation can occur in nature in the water stream in river, waterfall. In man-made objects, it can occur in control valves, pumps, propellers and Impellers.

Non-inertial cavitation is the process in which a bubble in a fluid is forced to oscillate in size or shape due to some form of energy input, such as an acoustic field. Such cavitation is often employed in ultrasonic cleaning baths and can also be observed in pumps, propellers, etc. Since the shock waves formed by collapse of the voids are strong enough to cause significant damage to moving parts, cavitation is usually an undesirable phenomenon. It is very often specifically avoided in the design of machines such as turbines or propellers, and eliminating cavitation is a major field in the study of fluid dynamics. However, it is sometimes useful and does not cause damage when the bubbles collapse away from machinery, such as in super cavitation[2]. Cavitation has various bad effects on hydraulic machine therefore it must be avoided.

II. EFFECTS OF CAVITATION

The effects of cavitation are hydraulic (low efficiency due to flow instability) and mechanical (surface damage, noise and vibration). In addition, it may also lead to surface erosion[3]. It is difficult to avoid cavitation in hydro turbines which cannot be avoided completely but can be reduced. Computing two-phase cavitating flows is a big challenge since the cavitating bubbles or clouds have very complicated dynamics[4]. Cavitation has also become a concern in the renewable energy sector as it may occur on the blade surface of tidal stream turbine[5]. Although the collapse of a small cavity is a relatively low-energy event, highly localized collapses can erode metals, such as steel, over time. The pitting on turbine blade is as shown in the Figure 1.

Fig. 1: Cavitation on turbine blade.

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The pitting caused by the collapse of cavities produces great wear on components and can dramatically shorten a propeller or pump's lifetime. After a surface is initially affected by cavitation, it tends to erode at an faster rate. The cavitation pits increase the turbulence of the flow of the fluid and create crevices that act as nucleation sites for additional cavitation bubbles. The pits also increase the components' surface area and leave behind residual stresses. This makes the surface more prone to stress corrosion.

III. CAVITATION EROSION

Cavitation erosion is the process of surface deterioration and surface material loss due to the generation of vapor or gas pockets inside the flow of liquid. These pockets are formed due to low pressure well below the saturation vapor pressure of the liquid and erosion caused by the bombardment of vapor bubbles on the surface. Cavitation erosion can occur on the surfaces of metals and non metals. It may produce undesirable noise levels and reduce the useful life of very valuable property. In the case of pumps, cavitation erosion risks are increased by a smaller inlet pipe diameter and inlet restrictions, combined with higher liquid viscosity.
Cavitation erosion can damage and destroy critical and valuable equipment, such as industrial/military/power station equipment and parts, such as pump impellers, delicately balanced high-speed propellers and turbine blades, causing failures leading to potential risk of life and injury for workers and others like loss of revenue, due to equipment downtime and the extra costs of failure analysis, repair and replacement.

IV. THOMA CAVITATION NUMBER

Prof. D. Thoma suggested a dimensionless number, called as Thoma's cavitation factor 'σ'[6]. Typical sigma curve is shown in Figure 2. It can be seen that as σ decreases, initially there is no effect on the efficiency. With further decrease in σ, efficiency first increases then decreases sharply. Accordingly, critical value of sigma (σcr) is defined and it is recommended to run the machines (pump/turbines) above σcr for cavitation free operation.

$$\sigma = (H_b - H_s)/H = (H_{atm} - H_v - H_s)/H$$

Where, Hb is barometric pressure head in meter of water, Hs is suction pressure at the outlet of reaction turbine, H is a net head on the turbine.

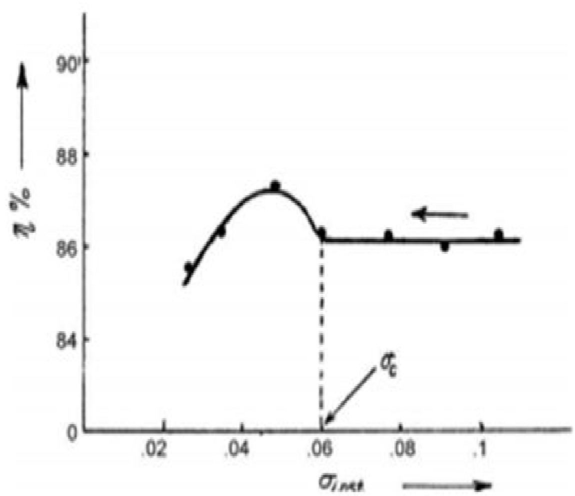

Fig. 2: Cavitation number v/s efficiency.

V. TYPES OF CAVITATION

Different types of cavitation usually found in different machines based on their operating conditions are mentioned here.

A. Attach Cavities

Cavitation can take the form of macro-cavities that develops and gets attached on a solid wall placed in the flow as shown in Figure 3. Sheet cavitation, is characterized by thin stable cavities with smooth and transparent interfaces. At their rear part, the cavity closure presents a slight and weak pulsation due to the shedding of small cavitation vortices so that it represents a low risk of erosion. The attach cavities further disintegrate in either two forms i.e. cloud cavitation wherein small vapour bubbles are formed or in ring vortices[7].

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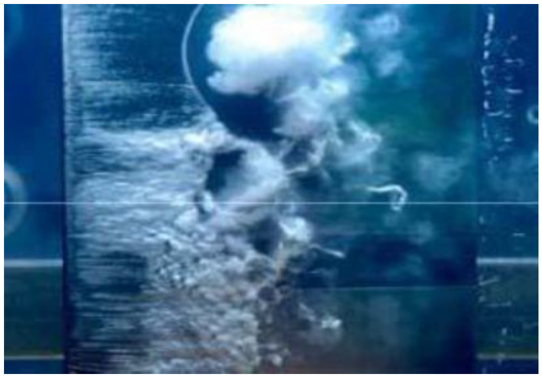

Fig. 3: Attach Cavities.

B. Vortex Cavitation

Flow regions with concentrated vorticity can develop cavitation in their central cores due to the low pressures generated. In vortex cavitation the cavities are found in the cores of vortices that form in zones of high shear. The cavities may appear as traveling cavities or as a fixed cavity. In all of these three types of cavitation, a particular liquid element passes through the cavitation zone only once[8]. A typical example of such types of cavitation can develop if Von Karman vortex-shedding as shown in Figure 4 occurs at the trailing edge of a hydrofoil.

Fig. 4: Von-Karman vortex shedding.

C. Travelling Bubbles

Travelling bubbles cavitation is composed of individual transient cavities or bubbles that form in the liquid and move with the liquid as they expand, shrink, and then collapse. Such traveling transient bubbles may appear at the low-pressure points along a solid boundary or in the liquid interior either at the cores of moving vortices or in the high-turbulence region in a turbulent shear field. the deformation and fission caused by the interaction of the bubble with the nearby solid surface and with the pressure gradients and shear in the flow play a very important role in the dynamics and acoustics of travelling bubble cavitation[9].

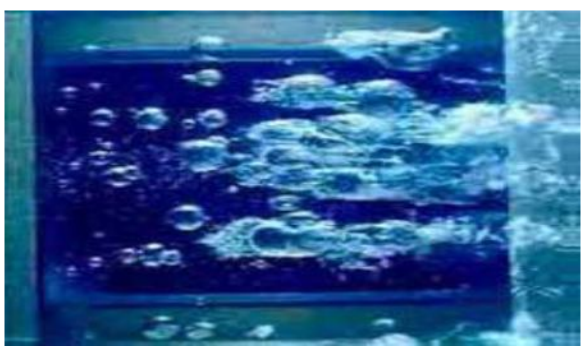

Fig 5: Bubbles cavitation.

VI. CONCLUSION

Cavitation is a phenomenon of formation of vapor bubbles in low pressure regions and collapse in high pressure regions, high pressure is produced and metallic surfaces are subjected to high local stresses. Cavitation can present different forms in hydraulic turbines depending on the machine design and the operating condition. Hence due to high vibration levels, instabilities and erosion can occur in the machine operation and cause damage. It is difficult to avoid cavitation completely in hydraulic turbines but can be reduced to economic acceptable level.

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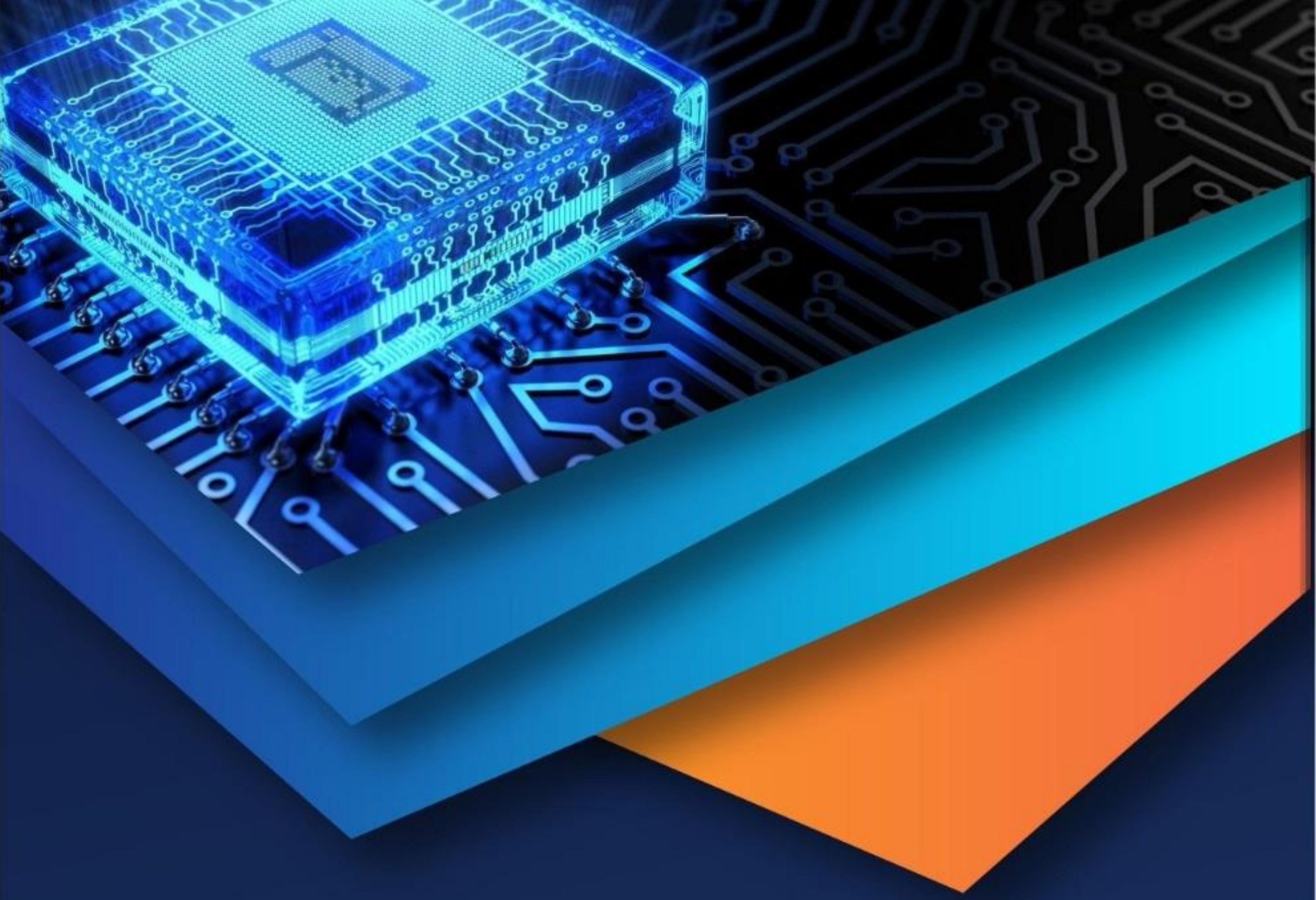

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