

A REVIEW ON “STUDY OF DIFFERENT METHODS TO CONTROL THE SLURRY EROSION IN HYDRO-POWER PLANTS

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Abstract-Slurry erosive of hydro turbine runners is a complex phenomenon, which depends upon different parameters such as silt size and shape, slurry concentration, velocity of water, impingement angle of silt particles and base material properties. The performance of hydropower plant is severely affected by the presence of sand particles in river water. The efficiency of the turbine decreases with the increase in the erosive wear. This paper describes the innovative work of various researchers in the field of Slurry erosion of hydropower plants. Based on literature survey, various aspects related to slurry erosion in hydro turbines, different causes for the decreased performance of the hydro turbines and suitable remedies proposed by various investigators have been discussed.

Keywords: Slurry erosion, hydro turbine blades, sand particles, several coatings.

1. INTRODUCTION

Turbine is the most important part of hydro power plant which converts the potential energy of water into mechanical energy. The turbine runners in a water turbine are constantly exposed to water and dynamic forces. The presence of silt in water erodes the turbine runner blades. Erosion of turbine decreases the performance of turbine, life of the turbine as well as loss of power generation.

Slurry erosion of turbine components is a very serious problem in most of the hydraulic power plants all around the world especially in those situated in Himalayan region of India[3,4]. High head Pelton and Francis turbines are most affected by sand erosion. The hydraulic turbine components, which are mainly affected by slurry erosion are guide vanes, top and bottom ring liners, runner blades, inlet valve seals, etc[2]. Among all the parts, runner blades of turbine are most affected. The degradation of these parts results in considerable reduction of performance of the power plant. It also leads to reduced lifetime which in turn reduces time between overhauls[22].

Silt erosion of hydro turbines is a very acute problem and leads to huge losses to the hydropower industry. It depends on various parameters like silt size, hardness, concentration, velocity of water etc. so, it is very difficult to find common cause and remedy for slurry erosion[1]. Hydro-abrasive erosion in hydroelectric power plants occurs particularly in the Himalayan region where, during monsoon, silt content of water passing through turbine varies from 1000 to 10000 ppm[13]. Due to repair, reduced efficiency and outages in rainy monsoon seasons, Indian hydro power plants located in Himalayas operate in loss of US\$ 120-150 million a year[14]. Figure 1.1 shows the slurry erosion of turbine blades.



48MW Francis Turbine at Kaligandaki Power Plant, Nepal[24]



250MW Francis Turbine at Nathpa Jhakri Power Plant, India[25]



23MW Francis Turbine at Chawa PowerPlant, Peru[26]

Figure-[1.1]Sediment erosion in Francis turbine runners from various Power plant.

2. SLURRY AND SLURRY EROSION:

A slurry can be described as a mixture of solid particles in a liquid (usually water) of such a consistency that it can be readily pumped. The term "slurry erosion" is strictly defined as that type of wear, or loss of mass, that is experienced by a material exposed to a high-velocity stream of slurry[50].

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2.1. Wear and its types:

Wear is related to interactions between surfaces and specifically the removal and deformation of material on a surface as a result of mechanical action of the opposite surface[50].

- Adhesive wear
- Abrasive wear
- Surface fatigue
- Fretting wear
- Erosive wear

2.1.1. Adhesive Wear:

Adhesive wear can be found between surfaces during frictional contact and generally refers to unwanted displacement and attachment of wear debris and material compounds from one surface to another[50].

2.1.2. Abrasive wear:

Abrasive wear occurs when a hard rough surface slides across a softer surface. ASTM International (formerly American Society for Testing and Materials) defines it as the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface[50].

2.1.3. Surface fatigue:

Surface fatigue is a process by which the surface of a material is weakened by cyclic loading, which is one type of general material fatigue. Fatigue wear is produced when the wear particles are detached by cyclic crack growth of microcracks on the surface. These microcracks are either superficial cracks or subsurface cracks.

2.1.4. Fretting wear:

Fretting wear is the repeated cyclical rubbing between two surfaces. Over a period of time fretting which will remove material from one or both surfaces in contact. It occurs typically in bearings, although most bearings have their surfaces hardened to resist the problem[50].

2.1.5. Erosive wear:

Erosive wear is caused by the impact of particles of solid or liquid against the surface of an object. The impacting particles gradually remove material from the surface through repeated deformations and cutting actions. It is a widely encountered mechanism in industry. The erosive wear mainly depends upon parameters like, impact angle, velocity of solid particles, particle size and shape and solid concentration. Slurry erosion occurs when a slurry(mixture) of some liquid and silt particles flows over the surface of a material at high speed. The solid particles suspended in the slurry strike over the surface at high velocity and as a result removes the material on the surface[49].

3. PARAMETERS EFFECTING THE SLURRY EROSION:

3.1. Velocity of solid particles:

It is the velocity of solid particles striking the target surface. The erosion rate is directly proportional to the velocity of solid particles. As the velocity of solid particles increase, their kinetic energy increases erosion[49].

3.2. Impact angle:

It is the angle between the direction of solid particle impinging on the surface and the plane of the surface. It is a major factor which affects the rate of erosion wear. But it highly depends upon the nature of surface on which the particle is striking[49].

3.3. Particle size and shape:

Particle size and shape is also a major factor in determining the erosion rate. The particles in the slurry can be of any type depending upon the nature of the latter[49]. But it is seen that particles with sharp edges erode the material more readily.

3.4. Solid concentration:

It is the amount of solid particles by weight or by volume present in the fluid. As the solid concentration increases the wear rate also increases as more solid particle come in contact with the surface. The concentrations can vary from 2% to 50% depending upon the nature of the slurry. At very high concentrations the velocity of particles striking the surface decreases as a result of increased particle interaction[49].

4. PROBLEM OF SLURRY EROSION IN HYDROPOWER PLANTS

The hydro power plants suffer from a very big problem of slurry erosion as the sand particle flow along the water. The sand particles not only reduce the efficiency of the turbines but also destroy the turbine components. This problem mainly occurs

due to heavy rains in the monsoons[49].To overcome this problem, several types of coatings have been used by various researchers.

4.1. Coating:

It is a process of spreading a layer of material over a base material to protect it from damage like erosion, corrosion, etc. The base material over which the layer is spread is known as substrate. There are a number of techniques used for coating which are discussed as follows:

- Electroplating
- Physical vapour deposition
- Chemical vapour deposition
- Thermal spray
- Nano-Structured Coatings

4.1.1.Electroplating:

It is the process of changing surface properties of a material by deposition of a layer of some other material with the help of electric current. There are two materials dip into a solution known as electrolyte which carries metal salts. One of the material carries negative charge acting as a cathode and is the object over which coating is to be done. The other object carrying positive charge made up of material to be coated on the cathode acts as anode. When direct current is supplied to anode the metal ions are dissolved in the electrolyte and get deposited on the cathode. In this way the positively charged ions are reduced into metallic form[49].

4.1.2. Physical vapour deposition:

It is the process of depositing thin films of metal in the vapour form on a substrate by its condensation. Very fine coatings of the order of 10 μm can be obtained by this process. The metal to be deposited is initially converted into vapour phase. Thereafter those vapours are allowed to be transferred on the substrate which then react with the latter to form a thin film of the coating[49].

4.1.3. Chemical vapour deposition:

It is a process of depositing material from a gaseous phase by reaction on the heated substrate. Chemical Vapour Deposition (CVD) process is a versatile process that can be used for the deposition of nearly any metal as well as non metal such as carbon or silicon [52]. The first step is the production of metal vapours. Several chemical reactions can be used: thermal decomposition, pyrolysis, reduction, oxidation, nitridation etc. The main reaction is carried out in a separate reactor. The vapours thus formed are transferred to the coating chamber where the sample is mounted and maintained at high temperature.

4.1.4. Thermal spray coatings:

Thermal spraying is a process in which molten metal is deposited on a substrate by spraying.The coating particles are fed in powder or wire form, heated to molten state and sprayed on the substrate at high velocity in micrometer sized particles. Electrical arc discharge or combustion serve as the source of energy from thermal spraying. The sprayed particles are accumulated on to the surface of the substrate forming a layer of coating of the material. The quality of coating is measured in terms of its porosity, oxide content, macro hardness, surface roughness, etc[49].There are a number of thermal spray coatings:

- Plasma spraying
- Detonation spraying
- Wire arc spraying
- Flame spraying
- High velocity oxy-fuel coating spraying (HVOF)

4.1.5. Nano-structured coatings:

Nano-structured coatings composed of crystalline/amorphous nano-phase mixture have recently attracted increasing interests in fundamental research and industrial applications, because of the possibilities of synthesizing a surface protection layer with unique physical and chemical properties that are often not attained in the bulk materials [51].

5.LITERATURE SURVEY

Slurry erosion is a great problem in many fields like thermal power plant, hydropower plants,etc. Engineers have been working in this field from a long time and many remedies have been found to overcome this problem. Erosion wear depends upon a number of factors which if controlled can reduce great amount of wear in all the fields[49]. Some of the work done by the engineers have been summarised in this chapter.

Grewal et al. [1] had discussed the performance of hydropower plant which was rigorously affected by the presence of sand particles in river water. Degree of degradation drastically depends on the level of operating parameters (velocity,

impingement angle, concentration, particle size and shape), which was further related to erosion mechanism. They investigated the effect of some of these operating parameters on erosion mechanism by using hydro turbine steel, CA6NM (13Cr4Ni). SEM and XRD techniques were used to check the morphology and variation in martensite and austenite phases of the eroded surfaces.

Goyal et al. [2] deposited WC–10Co–4Cr and $\text{Al}_2\text{O}_3+13\text{TiO}_2$ coatings on CF8M turbine steel by HVOF spray process and studied their performance under slurry erosion conditions. The bare steel and $\text{Al}_2\text{O}_3+13\text{TiO}_2$ coating showed ductile and brittle mechanisms respectively under slurry erosion, whereas the WC–10Co–4Cr coating exhibit mixed behavior (mainly ductile). WC–10Co–4Cr coating was found to be useful to increase the slurry erosion resistance of steel remarkably.

H.S. Grewala et al. [12] deposited Ni based thermal spray coatings on a commonly used hydro-turbine steel (CA6NM), with Al_2O_3 mixed in different proportions. Coatings were developed using high velocity flame spray process (HVFS). Slurry erosion performance of prepared coated and bare steel was investigated using a specially designed jet type test rig with sand as erodent particles. To investigate the effect of concentration on erosion behavior, sand was mixed in water at two different levels, 0.1 wt % and 0.5 wt %. It was observed that all the coatings helped in improving the erosion resistance of the steel with one containing 40 wt % Al_2O_3 showing the maximum improvement.

Barron et al. [29] investigated that the cryogenic treatment of steels facilitates the formation of fine eta carbides in the martensite structure. The iron or substitutional atoms expand and contract. Further, the carbon atoms shift slightly due to lattice deformation as a result of cryogenic treatment thus, enhances the wear resistance.

Huang et al. [30] studied the change in microstructure of tool steel before and after cryogenic treatment. Cryogenic treatment can facilitate the formation of carbon clustering and increase the carbide density in the subsequent heat treatment. This result in increase in wear resistance of tool steels.

Desale et al. [36] shows the effect of erodent properties on slurry erosion. Experiments have been performed in a pot tester to evaluate the wear of two ductile materials namely, AA6063 and AISI 304L steel. Solid–liquid mixtures of similar particle sizes of three different natural erodent namely, quartz, alumina and silicon carbide have been used to evaluate the mass loss of the two target materials at different impact angles. The result shows that the maximum angle for erosion is a function of target material properties and does not depend on the erodent. The erosion rate of ductile materials varies with the erodent properties other than its size and hardness. The effect of erodent properties namely, shape and density is more dominant at shallow impact angles compared to higher impact angles.

Chattopadhyay et al. [37] had examined that the turbine runners demonstrate an unusually high rate of wear in river water with a high silt concentration. Cast ferritic stainless steel of CA6NM type was the normal turbine runner material. The slurry erosion characteristics of stellite 6, 15 wt.% Cr-15 wt.% Mn stainless steel, type 316L stainless steel and CA6NM were evaluated. The different wear rates of the alloys were explained in terms of the microstructure, hardness and work-hardening rate.

Romo et al. [43] compared the cavitation and slurry erosion resistances of Stellite 6 coatings and 13-4 stainless steel in laboratory. The Cavitation Resistance (CR) was measured according to ASTM G32 standard and the Slurry Erosion Resistance (SER) was tested in a high-velocity erosion tester under several impact angles. The results showed that the coatings improved the CR 15 times when compared to bare stainless steel. The SER of the coatings was also higher for all the impingement angles tested, the highest erosion rate being observed at 45° . The main wear mechanisms were micro-cracking in case of cavitation tests, whereas micro-cutting and micro-ploughing in case of slurry erosion tests.

Roman et al. [41] reported the development of a new erosion resistant coating NEYRCO—a composite coating with ceramic and organic matter base, designed to combine hardness and ductility. They carried out a series of model tests in a specially designed test rig to find the effectiveness of the coating against erosion. Surface examinations of the samples subjected to same erosive condition showed that the coated samples gave better performance as compared with the uncoated samples.

Harpreet Singh et al. [45] investigated the Slurry Erosion Behavior of Plasma Thermal Sprayed (50%) WC-Co-Cr and Ni-Cr-B-Si Coatings of Different Thickness on CA6NM Turbine Steel Material. The comparison has been done for mass loss for coated and uncoated materials at different conditions. The study reveals that the impact velocity, slurry concentration and impact angle are most significant among various factors influencing the wear rate of these coatings. After a fix time weight loss on samples are compared. This technique helps in saving time and resources for a large number of experimental trials and successfully predicts the wear rate of the coatings both within and beyond the experimental domain. The coated samples show better results as compared to uncoated. SEM analysis gives the information about the surface topography of samples.

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6. CONCLUSIONS:

Stainless steels of grades 304, 316 and 420 are normally used for the turbines of the power plants. They not only resist erosion wear but also are very safe in corrosive environments[49]. To enhance the performance of these materials different types of coatings have been adopted by different researchers and concluded that:

1. Sand concentration in water is found to be most important factor in the erosion wear. The more sand concentration increases the erosion rate.
2. The other important factor is velocity with which the water is striking on the impeller blades of turbine. The erosion of material increases with the increase in velocity of water.
3. Erosion wear also depends upon the type of coatings applied on the base material. WC-Co-Cr and Ni-Cr-B-Si Coatings, WC-10Co-4Cr and $Al_2O_3+13TiO_2$ coatings on CF8M turbine steel by HVOF spray process have more resistance against erosion than bare material.
4. The impingement angle is also a dominating factor in erosion wear. It has been found that the maximum wear takes place at an angle of 90 degree.

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