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Elements of an Effective Repair Program for Cavitation Damages in Hydraulic Turbines

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Abstract: In this study, various repair methods have been discussed with reference to the cavitation damages in hydraulic turbines. The study is focused on the fact that timely and proper repair of the cavitation damages results in the better performance and increased efficiency of the equipment. On the other hand, if left un-repaired or improperly repaired, these damages cause further deterioration of the equipment. The aim of the study is to provide an overview of the various traditional and modern techniques to the power plant maintenance crew. Various repair methods have been discussed with their merits and demerits. Outlay of an effective repair program that can be integrated with on-line monitoring system is presented. A software approach to integrate repair program with an on-line vibration monitoring system is also proposed. The study is expected to provide better understanding of cavitation repair methodologies based on the plant operating conditions and various turbine construction materials.

Key words: Cavitation, erosion, welding, thermal spray

INTRODUCTION

Cavitation, in general is defined as the formation of the bubbles or voids in the liquids due to rapid pressure changes. These bubbles implode and as a result a large amplitude shockwave is emitted (Avellan and Farhat, 1989). Repetitive collapse of vapor cavities in liquid can yield severe erosion if this occurs near solid surface. This erosion is observed on blades of hydraulic machines or blade profiles (Couty and Farhat, 2001).

The cavitation damages even if repaired create a series of other economic considerations for maintenance planners. These include increase in the amount and cost of repairs, distortion of material due to excessive welding and the increased intensity of plant outages.

Traditionally, the maintenance of hydropower plants in Pakistan as well as other countries of this region is being carried out without any specific repair program. Cavitation damages are frequently observed and are repaired during every periodic outage.

Welding is being utilized as the only repair method without analyzing the extent of damages. No further studies are being made to investigate the causes of cavitation and the utilization of newer repair techniques. In contrast, the developed countries are utilizing several advanced repair techniques based on type and extent of damage.

Maintenance without proper investigation and planning results in increase in cost and outage time. In addition repair without a comprehensive repair program cause the damage to occur again and again.

It is therefore considered imperative for power plant maintainers to hold cavitation repair program in a logical and methodical manner. Carefully planned repair program with well-defined methods helps in maximizing equipment life and to maintain high availability of the equipment.

A comprehensive maintenance program should not only provide appropriate method of repair but also guide to what and when to repair, how much the welding should be and how to avoid further damages?

The fundamental research on the damage mechanisms and metallic materials development in multiphase flow is very important for the construction of large hydropower stations. Such research has resulted in development of various repair methods such as welding, non-fused material use, welding by solid plates and thermal spray methods. Cavitation repair methods by welding and thermal spray coatings have been well studied and presented by Kumar *et al.* (2005) and Rodrigue (1986).

The repair methods were discussed in detail along with their applications with a special focus on development of new repair techniques other than welding. Also guidelines are provided for an effective repair program, which not only addresses the choice of optimum

repair method, but also associates other aspects of repair process. The program can be integrated with the on-line monitoring system of the plant and simple software can be developed to suggest the best repair method.

The objective of this discussion is to provide an overview of already developed advanced and modern techniques in the field. The effort is made to introduce developing countries to the advancement in repair techniques and the elements of repair program to be utilized.

DAMAGES CAUSED BY CAVITATION

Examination of the runner of a hydraulic turbine or the impeller of a pump often discloses pitted areas in various stages of development. Pitted areas may also be found on turbine or pump water passage surfaces where water velocities are high. This damage is generally termed cavitation erosion or impingement erosion. Because of various physical conditions present in the water flow system; a cycle of cavitation is induced. The cycle of formation and collapse of bubble occurs at high frequency and the dynamic stresses generated can cause the damage of the material by fatigue (Schwetzke and Kreye, 1996). The damages caused by cavitation, if summarized are:

- Erosion of material from the turbine parts.
- Distortion of blade angle.
- Loss of efficiency due to erosion/distortion.
- Outage of unit for repairs associating loss of revenue and repair costs.

The erosion damages even if repaired create a series of other economic considerations for maintenance planners viz.

- Cavitation damages tend to accelerate; therefore increasing the time between repairs can substantially increase the amount and cost of repairs that must be made.

Table 1: Cavitation damages at Tarbela powerhouse

Unit No.	Cavitation location	Damage size (mm)	Outage of unit (Days)	Repair method
1	Blade 7, LPS leading edge	170×80×4	15	Welding
	Blade 2, LPS trailing edge	220×40×1		
3	Blade 6, LPS trailing edge	220×75×2.5	15	Welding
	Blade 2, LPS leading edge	110×100×1		
3	Blade 3, LPS trailing edge	260×50×15		
	Blade 1, Runner band	300×30×1	15	Welding
5	Blade 3, LPS trailing edge	480×180×15	20	Welding
	Blade 7, LPS trailing edge	480×210×13.5		
5	Blade 4, LPS trailing edge	130×100×12	20	Welding
	Blade 5, LPS leading edge	220×100×1		
9	Blade 1, LPS leading edge	630×100×4	15	Welding

Data acquired from annual shutdown reports of the respective units, LPS: Low Pressure Side

- If the time between repairs is lengthened, additional care will be needed to prevent distortion because of the increased amount of weld material to be added. Blade distortion may adversely influence unit performance and may reduce the life of runner.
- Frequent repairs without other maintenance work on the turbine or in other words specific outage for cavitation repairs results in reduced availability and of possible lost generation or capacity benefits.

A brief history of cavitation damages occurred in recent years at Tarbela Powerhouse in Pakistan is shown in Table 1.

CAVITATION DAMAGE REPAIR

The repair of cavitation pitting damage on turbines is considered an essential part of a hydro plant maintenance program. It has been a regular feature of the periodic shutdowns to carryout such repair. The cavitation damages, if left un-repaired, or if improperly repaired, increase the extent of damage, usually at an accelerating rate and eventually lead to an extended and costly outage of the unit.

To minimize the adverse problems caused by cavitation, an effective repair program is deemed necessary. The main objectives of such a program are:

- Restoration of the original conditions of runner and other equipment.
- Correction of shape irregularities.
- Evasion of blade shape distortion and its affects on further damage.

REPAIR METHODS

Weld repairs: Welding is considered as the most common and the most successful method of repairing cavitation damage on hydraulic turbines. Two weld repair processes generally used for cavitation repair are: (1) Gas Metal Arc Welding (GMAW) or Metal-inert Gas (MIG) welding and (2) Shielded Metal Arc Welding (SMAW) or stick electrode welding (Rodrigue, 1986).

The important features of these processes are shown in Table 2.

Table 2: Features of weld processes

GMAW	SMAW
Rapid application of weld metal	Suitable for small amount of welds.
Lower heat input required	Facilitates over head welding
Better weld quality with no slag inclusion and reduced excess weld.	Suitable for welding areas such as junction of runner bucket to band
Ventilation required during welding	Less ventilation required.

Due to the condition of most cavitated surfaces, damage generally can not be repaired by directly filling the pitted areas. The pitted surface is usually undercut to remove the damaged area and to provide a surface that can be adequately cleaned before filling repair. The resulting space is normally filled by welding with a common stainless steel alloy such as 308 or 309 L.

Weld repairs are dependent on the type of plant, material of the runner and the intensity of damage. Prior to weld application following parameters should be analyzed in detail:

- Composition of base material.
- Weld material.
- Weld process.
- Repair procedure.

Various steps for repair by welding are as follows:

- Initial dimensional checks.
- Structural support for welding to avoid distortion.
- Preheat of weld area to avoid hydrogen cracking.
- Weld application.
- Blade profile adjustment.
- Weld inspection.
- Removal of supports.

Non -fused materials: Various non-fused materials have been used for cavitation damage repairs. These include:

- Epoxies.
- Ceramics.
- Neoprene.
- Urethane.

However, the repair by this method has not proved to be very successful. The major difficulty with non-fused materials for cavitation pitting repair is achieving a satisfactory bond to the parent material. In this regard, general recommendations are as follows:

- Cleanliness of surface must be ensured.
- Temperature and humidity level must be maintained to the recommended conditions.
- The application surface should be made rough for better bonding.
- Sufficient cure time must be provided.

Repairs by welding with solid plate: Welding solid plate over the damaged areas can also repair cavitation pitting. However, the method is restricted to the areas exposed to less vibration and dynamic loading. This type of repair is applied to thick sections and the amount

of weld is not extensive (when compared to filling the damaged area with weld material).

This method of repair is not considered suitable for parent metals of stainless steel unless the repair is associated with a blade profile change or a change in the method of operating the unit.

Thermal spray processes: Extensive weld repair can introduce stresses in the area being repaired and can damage the component. It is therefore imperative to look for newer techniques of repair. One promising technique being utilized in the recent times is spraying of metallic or non-metallic materials over a surface.

The cavitation and erosion resistance of thermal spray coating has been investigated and presented by Kumar *et al.* (2005).

The common thermal spray processes (Jeffrey *et al.*, 1997) are as follows:

Combustion gas spraying: The process that uses the heat from a chemical reaction is known as combustion gas spraying or flame spraying. Any material that does not sublime (does not transform directly from a solid to gas) and has a melting temperature of less than 5000°F may be flame sprayed.

Combustion wire flame spray: Drive rollers mechanically draw combustion wire flame spray feedstock material into the rear of a spray gun. The feedstock proceeds through a nozzle where it is melted in a coaxial flame of burning gas. Following gases can be combined with oxygen for use in flame spraying: acetylene, Methylacetylene-Propadiene Stabilized (MPS), propane, hydrogen, or natural gas. Acetylene is the gas most widely used because of higher flame temperature. To accomplish spraying, the flame is surrounded with a stream of compressed gas-usually air-to atomize the molten material and to propel it onto the substrate.

Combustion powder flame spray: This process is similar to the wire process but the powder feedstock is stored in a hopper that can either be integral to the gun or externally connected to the gun. A carrier gas is used to convey the powder into the oxygen fuel gas stream where the powder is melted and carried by the flame onto the substrate.

Plasma spray: Plasma spray technology uses a plasma-forming gas (usually either argon or nitrogen) as both the heat source and the propelling agent for the coating. Powder spray material is injected in the hot plasma stream, in which it is melted and projected at high velocity onto a

prepared substrate. The resulting coatings are generally dense and strongly bonded with high integrity (AWS, 1985).

High Velocity Oxyfuel (HVOF) spray: The HVOF process efficiently uses high kinetic energy and controlled heat output to produce dense, very-low-porosity coatings that exhibit high bond strength. The HVOF gun consists of a nozzle to mix the combustion gases, an air-cooled combustion chamber and an external nozzle (air cap). The process gases enter through several coaxial annular openings. Air, fuel, oxygen and the remaining process air surround a central flow of powder and carrier gas. This focuses the spray stream and prevents the powder from contacting the gun walls. The oxygen and fuel burn as they enter the rear portion of the combustion chamber. Most of the process air is used to cool the combustion chamber and, in the process, is preheated before entering the air cap. As it enters, the process gas forms a thin boundary layer that minimizes the contact of the flame with the walls of the air cap and helps to reduce the quantity of heat transferred to the air cap. Hot gases, with combustion temperature of up to 6000°F exit through a converging nozzle, with a gas velocity approaching to 4500 ft sec⁻¹ (March and Hubble, 1996).

Thermal spray coatings are generally limited in the thickness of material that can be deposited. This limit can be as low as 0.030 in for plasma spray and HVOF coating processes (Irons, 1992). However, in some cases 1 in thick coatings have been applied (Musil *et al.*, 1996). Due to thickness limitations, deep cavitation damage would have to be repaired by welding, but thermal spray coatings could be applied to the welded surface to provide additional protection to the component. Thermal spray coatings could also be applied directly to properly clean and roughened surfaces that do not require weld repair.

Cavitation damage repair approach: Rotating equipment such as turbines is subjected to heavy vibrations and dynamic stresses. Excessive repairs to a turbine can reduce its performance and operating life. Extensive weld repairs can result in runner Blade distortion, acceleration of further cavitation damage and possible reduction of turbine efficiency. Also, structural cracking could be observed at areas under heavy stresses.

In order to achieve maximum operating life, good efficiency and high availability of the equipment cavitation pitting repairs should be done in a logical and methodical manner. The basic steps of such a repair program could be:

- Inspection of equipment.
- Identification of cavitation causes.

- Planning of optimum repair.
- Implementation of repairs.

ELEMENTS OF AN EFFECTIVE REPAIR PROGRAM

It is difficult for all practical purposes to give explicit recommendations for the elements of an appropriate cavitation repair program. Each plant or unit can have individual characteristics and therefore should be evaluated on an individual base. However following factors can be helpful in formatting a logical and effective repair program (Anonymous, 2000):

Cavitation damage inspection: Periodic inspection of a turbine for cavitation damage is an essential part of turbine maintenance. During the initial period of turbine operation, frequent inspections are important to diagnose and repair the cavitation damages at an early stage. The units could be inspected after 1500, 4000 and 8000 h of operation, depending upon the manufacturer recommendations. The subsequent inspection can then be planned depending upon the extent of damages being observed however the frequency of inspection should not be less frequent than every 24,000 operating hours or every 4 years. In all cases monitoring the cavitation aggressiveness appears as a useful tool for an optimal operation of hydro turbines and allows extending inspections and repairs intervals.

Frequency of repairs: Traditionally in Pakistan, it is believed that repairing all the damages in each outage is the best approach. However planning repairs based on aggressiveness of cavitation is always a good solution. Nevertheless, while making decisions about frequency of repair, following factors should be considered:

- Economical aspects with reference to loss of revenues, labor and supervision for repair and material costs.
- Effect of increased time intervals between repairs. Increasing the time between repairs may substantially increase the amount and cost of repairs.
- Effect of additional repair material on blade angle and loading conditions, in case of increased time interval.
- Too frequent repairs may be optimized with other maintenance work on the plant.

Identifying cause of cavitation: Identifying the cause of cavitation pitting on turbine equipment is helpful in deciding the best approach of repairs. Although the identification is not very simple in many cases, nevertheless the need for an effort to investigate the

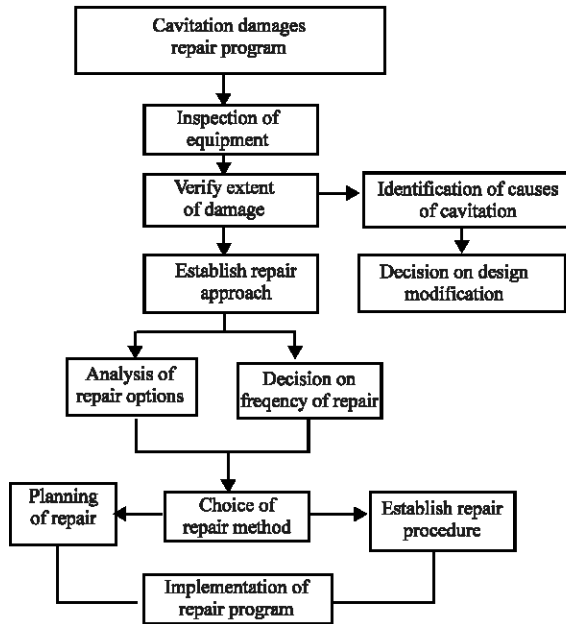


Fig. 1: Flow chart of repair program

cause is always recommended. Input from the turbine manufacturer in assessing the cause of pitting is always considered helpful.

Planning of repair program: After inspecting and assessing the cause of damage, a plan on the best approach for cavitation repairs must be developed. The effects of delaying repairs must be considered and the best option amongst the available repair solutions must be selected. Consequently, to reduce the frequency of repairs and prolong the operating life of the runner, attempts at runner blade shape or profile correction should be initiated.

Repair procedure: Once the repair method is selected the repair procedure should be established and documented. The procedure must define the characteristics of runner material, repair material and effect of repair on the blade. Based on above parameters, a flow chart of a repair program is shown in Fig. 1.

INTEGRATION OF REPAIR PROGRAM WITH VIBRATION MONITORING SYSTEM

An on-line vibration monitoring system is now considered as an important part of modern control system of hydropower plant. Vibration measurement is important with respect to cavitation detection also. Increased vibration levels along with abnormal noises are the fingerprints of cavitation.

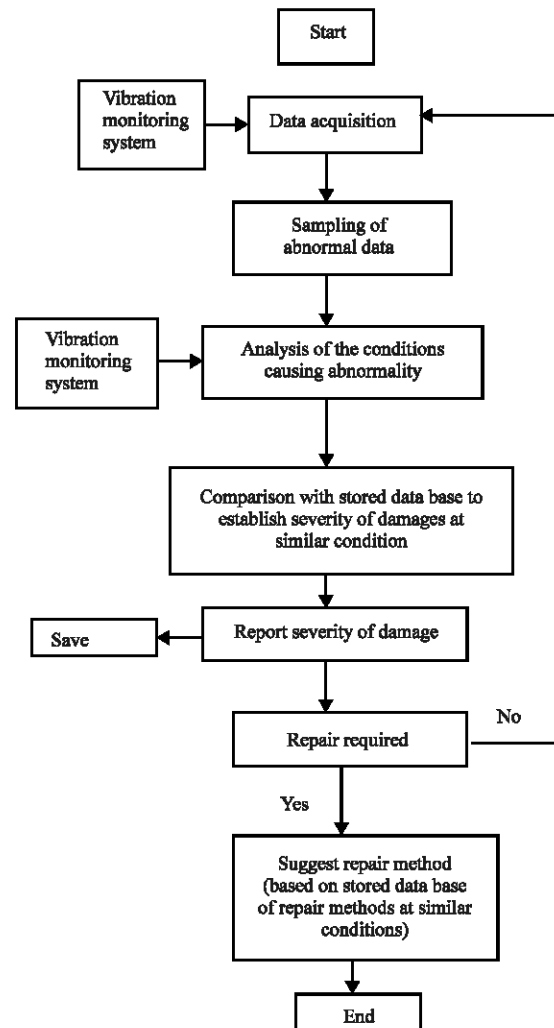


Fig. 2: The software chart

An effective integration of the on-line vibration monitoring program with the cavitation damage repair can be achieved. The idea is to utilize the data from vibration monitoring system as an input to repair program.

Vibration data collected at various levels of plant operation is collected, analyzed and stored by vibration monitoring system. A simple software approach is proposed which obtains the input from vibration monitoring system by identifying abnormal vibration levels. These abnormal values can then be separated from the record and further analyzed, all parameters related to this abnormal value are sampled and the severity of cavitation damage can be estimated based on historical data. A comprehensive data base of possible repair options can be stored in the software for analogy. A flow chart of such software is shown in Fig. 2.

CONCLUSION

Various repair methods and the elements of an effective repair program have been discussed in detail. Repair methods have been analyzed with reference to their applications. Keeping in view, the site-specific nature of the repair method, basic guidelines for the proper choice of repair method have been provided.

A software approach to integrate repair program with an on-line vibration monitoring system is presented. Data from vibration monitoring system is being utilized as an input to the repair program. Proposed software is utilized to analyze the data and to sample the abnormal conditions. The parameters are then compared with an available data base to establish the severity of damages. A repair method can be suggested based on severity of the damage.

It can be established that by proper planning and optimizing the repair program, significant savings in maintenance costs and improvement in the availability of the power plant can be achieved. The study is expected to provide a basic guideline to the plant operators to plan and implement an effective repair program based on the true conditions of the equipment. The choice of best approach of repair with optimized outage frequency is intended for the availability, efficiency and safety of hydropower plant.

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