Effect of Sand Erosion on Turbine Components: A Case Study of Kali Gandaki “A” Hydroelectric Project (144 MW), Nepal

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Abstract: In high sediment laden river projects or silt affected power stations, the frequency of repair and maintenance of underwater parts is comparatively higher which leads to increase the overall forced outages per year for repair The extent of the major maintenance will depend on the operating condition such as suspended sediment load passing through the turbine and how the machine was loaded during the operation. This paper illustrates the analysis of sediments, effect of sand erosion and maintenance of turbine of Kali Gandaki “A” Hydroelectric Plant (144 MW). The paper also describes the repair methods used for different turbine components to minimize the effects induced by sediment erosion.

Keywords: Sand erosion, Maintenance, Runner, Guide vanes, Facing plates, Labyrinth rings, HVOF coating, Nepal.

Introduction

Sediment induced high turbine wear problem in the hydraulic machinery is one of the major problem in the O & M of the hydroelectric projects in sediment laden rivers. Excessive turbine wear causes turbine operational problem with unit outage, drop in turbine efficiency, generation loss, and eventually the loss in revenue (B. Thapa, 2004). Despite elaborate de-silting arrangements, silt passes through generating units at the rate of thousands of tons per day (Naidu, 1999).

In spite of taking sediment consideration during detail engineering design of hydropower plants, sand erosion will continue to create problems during the operation and maintenance of the plant. The erosion is further exacerbated by cavitations phenomenon. Because of various physical conditions present in the water flow system, a cycle of cavitation is induced on under components of turbine. As the metal surface deteriorates, the damage rate accelerates rapidly. Without timely repair, the cavitation process can result in the total destruction of the surface under attack. Repair and Maintenance of the turbine component is essential at predetermined time interval to ensure the reliable operation of the plant with least shutdown of the machine so that any component does not exceed the life expectancy of the equipment. Experience of running hydropower stations in sediment-laden rivers has shown that even after careful project planning and control measures from construction to commissioning, unexpected problems do occur during operation of the plant resulting in low generation (Sharma, 2010).

Preventive maintenance is one of the techniques which are design to improve equipment life and minimize the unplanned maintenance activities in power plant. It is the scheduled maintenance where the parameters and time are set for inspection, repair and replacement of the equipment or component. Generally, it includes daily, weekly and monthly checks as per the maintenance schedules.

After certain years of operation in flood seasons, it is required to inspect or check the underwater components of turbine for fatigue defect, wear pattern, clearances between mating parts of component or any deviation from original set parameters, etc. Major maintenance, like overhauling of the machine, need to be carried out to repair or replace the worn or damaged parts of turbine component.

The state-of-the-art of the materials for turbine is one of the parameters that determine production possibility like weldability, machinability, etc. for reducing the forced outages of the unit. The erosion resistance of material can be improved by either making material surface extremely hard (for example metals and ceramic) or by making the surface tough but with extremely low elastic modulus so that kinetic energy of particle harmlessly dissipate such as rubber (B. Thapa, 2004).

The present study elaborates the repair and maintenance of turbine parts at Kali Gandaki “A” Hydroelectric Plant through collection of secondary data such as sediment data, discharge records, yearly overhauling records, maintenance log sheets, repair works, annual progress report, etc.

Case Study of Kali Gandaki “A” Hydroelectric Plant

General

Kali Gandaki “A” Hydroelectric Plant, a 144 MW Run-of-River scheme is design to generate about 842 gigawatt-hours (GWh) of electrical energy per annum. The main component of project comprises of; a concrete gravity diversion dam of about 100 meters in length and 43 meters of height, open surface desander, tunnel of about 6 kilometer length and 7.4 meter diameter and a surface powerhouse. With utilization of a net head of 115 meters and the rated discharge of 141 m^3/s feeds three Francis type turbines having capacity of each unit 48 MW with rated speed 300 rpm and specific speed of 174.5 m-KW is installed in the powerhouse. The power plant has been in commercial operation since August 2002 and the effect of sediment had been appeared in runners, guide vanes, facing plates, labyrinth rings and other under water components.

Problem Origin

The opening problem of main inlet valve (Butterfly type) was observed at Unit 1 on July 17, 2003. It was observed that there was a huge pressure difference between upstream (Penstock side) and downstream (spiral case) due to wear of turbine component parts causing huge water leakage from spiral casing to draft tube causing pressure drop in spiral case side.

The first inspection of the Unit 1 was carried out on dated 8th August 2003 and measurements were noted for different parts of turbine. It was found that the clearance gap between guide vane and facing plate was 1.35 mm where as the design value is 0.6 mm. Similarly, the clearance gap between runner and wearing ring on head cover side was 1.65 mm where design value is 1.25 mm. Turbine inspection of Unit 2 and Unit 3 were also carried out during the year 2003 and also found the severe damage on turbine components as in Unit 1.

Since Plant in Operation and Maintenance activities started on 10th June 2002, it was felt necessary to give priority to check turbine and its components parts wear by sand /silt abrasion and erosion. It was observed that the original design of the turbine components does not keep a stable operation during floods seasons, it was felt an overhaul and repair of the turbine is required every year for all the 3 turbines. As the forced outage of plant directly related to the revenue of the plant due to long shut down of the machine, the solution for counter measure to resist the sand erosion was introduced by using hard coating on turbine components in year 2004. The aim of introducing coating technology is to resist erosion so that overhaul interval could extent at least for 3 flood seasons. Since the year 2004, the coating on different erosion vulnerable turbine parts have been implemented during overhauling though the result are not so satisfactory as it depends on the operational condition of the plant, applying procedure, properties of coating powder with respect to base material of turbine components, etc.

Sediment data

The highest flood in Kali Gandaki River observed in the past 100 years is about 4,500 m^3/s at the dam site and the ever-recorded minimum flow is about 40 m^3/s in the dry season. The sediment concentration varies from 20 ppm (0.02 kg/ m^3) in the dry season to sometimes 50,000 ppm (50 kg/m^3) in the wet season from June to September (Mitsui and Co, 2005). The average annual suspended sediment loads (DBM, Morrison Knudsen, 1998) considered during detail design of turbine is as follows:

- Total in the Kali Gandaki River measured at dam site 65 mill. tons/year
- Total entering the sedimentation basins 5.9 mill. tons/year
- Total passing through the turbines 2.8 mill. tons/year

The design of the sedimentation basins is based on the following criteria:

- 100% of sediments with particle size larger than 0.2 mm are excluded.
- 95% of sediments with particle size larger than 0.15 mm are excluded.
- Approximately 70% of sediments with particle size larger than 0.10 mm are excluded.

The data of Suspended Sediment Concentration (SSL) and river discharges were collected for 3 years (Jan 2011- Dec 2013) (KGA sediment laboratory, 2013). Daily generation, discharge and running hours of the machine was obtained from the generation log sheet of the plant. The suspended load passing through the machine was calculated by knowing the sediment data and running hours of the machine. The sediment load and river discharge for years 2011, 2012 and 2013 are shown in Table and Figure 1-3 below.

Month	River Discharge (m^3/sec)	Tons /Month (10^4)
January	63.96	0.04
February	55.55	0.08
March	52.82	0.15
April	57.19	0.25
May	104.65	1.74
June	303.84	96.14
July	1030.6	615.87
August	1088.07	588.12
September	704.36	284.74
October	279.3	8.90
November	132.06	1.27
December	88.84	0.27

Table 1: Sediment load in the year of 2011.

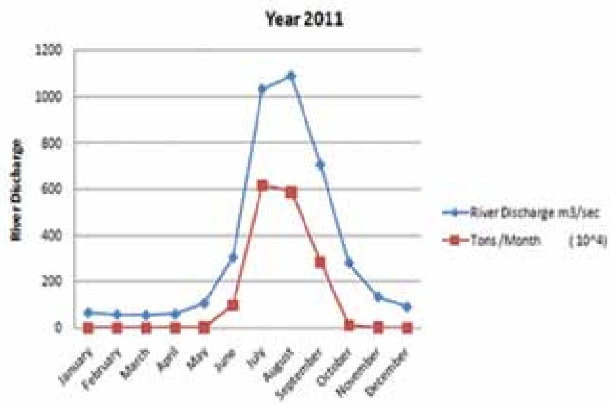


Figure 1: Monthly variation of SSL and river discharge for year 2011

Month	River Discharge (m^3/sec)	Tons /Month (10^4)
January	63.56	0.10
February	58.46	0.20
March	55.59	0.26
April	70.88	0.61
May	99.91	1.88
June	308.43	221.76
July	913.82	876.43
August	936.39	569.22
September	733.88	188.88
October	208.17	5.22
November	104.82	0.23
December	74.17	0.16

Table 2: Sediment load in the year of 2012.

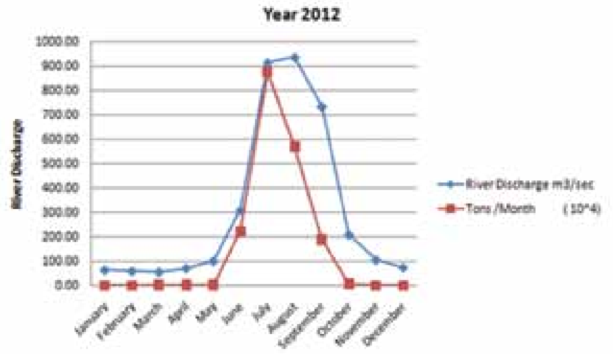


Figure 2: Monthly variation of SSL and river discharge for year 2012.

Month	River Discharge (m^3/sec)	Tons /Month (10^4)
January	63.09	0.16
February	60.40	0.30
March	58.34	0.35
April	72.42	0.55
May	128.76	6.82
June	588.14	380.46
July	1152.37	654.17
August	897.06	322.18
September	490.88	97.34
October	253.73	9.19
November	133.24	0.56
December	87.98	0.28

Table 3: Sediment load in the year of 2013.

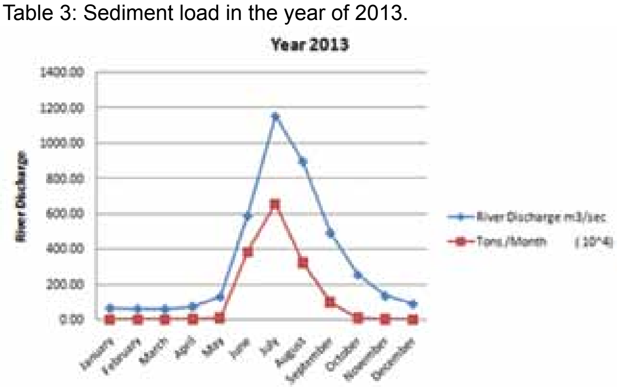


Figure 3: Monthly variation of SSL and river discharge for year 2013.

The river discharge (m^3/sec) and SSL data were collected during the year 2011, 2012 and 2013 and found the maximum suspended sediment load passing through the turbine are in the month of June, July and August. These huge sediment load pass through turbines is one of major factor causing severe erosion.

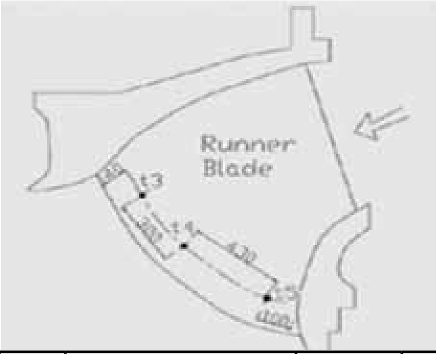
Effect of Sand Erosion on Turbine Components

The inspection and measurement data of the turbine components during the annual maintenance of machines were collected for the year of 2003 to 2013. Till the year 2014 from commissioning of the, the total five major turbine maintenance of the Unit 1 has been carried out. The first overhaul of Unit 1 was carried out from 12 September, 2003 to 27 October, 2003 with turbine operational running hours 7768 hours and energy generation of 236.64 GWh after commissioning of 18 April, 2002. During the installation, Unit 1 had HVOF coated runner expect guide vanes, facing plates, wearing ring and guide vane bushes. After one year of operation, turbine components were replaced with non-coated runner during the first overhauling of Unit 1 in year 2003 after 7,768 running hours with energy generation of 236.6 GWh after commissioning of 18 May, 2003.

The overhauling of the same unit was carried out after 3 years of operation in 2006 after 14,264 running hours with energy generation of 513.78 GWh. It was observed that the damage of turbine components without HVOF coating were more severe than HVOF coated turbine components due to sand erosion.

Comparison has been made to observe the effect of sand erosion on turbine components by taking the reference measuring data during overhauling of the year 2003 and 2006 of Unit 1. The Table 4 shows the compared values of guide vane clearance and runner out let thickness. The outlet thicknesses of the all 13 runner blades were measured in three positions i.e. near to crown (t3), middle (t4) and near to band (t5) and average value of them were considered. Similarly average value of side clearance guide vanes with lower and upper facing plates were considered for observation.

During the overhauling on year 2006, turbine components were replaced with HVOF coated facing plates, bushes for guide vanes and runner with non-coated guide vanes and wearing ring.



Sr. No.	Unite 1 Measured component Description	Design value in mm	Measured value during	
1			Year 2003	Year 2006
	Guide vane side clearance w.r.t facing plates			
	upstream clearance	0.3	1.35	2.29
	Down clearance		1.16	3.72
2	Runner thickness			
	Outlet t3	20.3	19.47	20.05
	Outlet t4	16.9	16.81	16.75
	Outlet t5	17.3	15.55	14.56

Table 4: Comparison of clearance and runner thickness values of unit 1.

Photo 1 (a, b) shows the photos of damages due to sand erosion of non-coated and coated turbine components. Since then practice of applying HVOF coating on under components of all machines has been implemented to resist the sand erosion during maintenance of turbine.

The opening and closing problem of Unit 2 inlet valve had been observed as a major operational problem since from its commissioning time. Since then it had been practiced to open the inlet valve by using chain pulley and hydraulic press as shown in Photo 2.

On January 2005, inspection of Unit 2 was carried by dewatering the unit and observed severe damaged on turbine parts. At this time, pieces of clothes were used to stop the water leakage turbine parts and to maintain the upstream and downstream water pressure as shown in Photo 3.

Photo 1.b: Coated runner and facing plate

Photo 1.a: Non coated runner

The first overhaul of Unit 2 was carried out from 8 July, 2005 to 24 August, 2005 with turbine operational running hours 21262 hours and energy generation of 723 GWh after commissioning on 23 May, 2002. Before overhauling of the Unit 2, the two previous inspections were carried out to observe the damage on turbine components. Table 5 shows the measured values of runner blade thickness during respective inspections and overhauling.

Photo 2: Photos of opening of inlet valve by using 3 ton chain block and 20 ton hydraulic press.

Unit 2	**Design value in mm**	**Measured values in mm**		
		Oct 2003	**Jan 2005**	**Aug 2005**
Operating hours		8,500	16,500	21262
Frequency of Flood seasons		2	3	3.5
Runner thickness		Inspection	Inspection	Overhauling
Outlet t3	20.3	19.27	18.76	18.5
Outlet t4	16.9	15.92	14.94	14.62
Outlet t5	17.3	14.5	13.29	11.93

Table 5: Runner thickness during inspection and overhauling.

It was observed that the maximum abrasion rate on vane thickness after three flood season is at runner outlet i.e. 5.37 mm (17.3 - 11.93). Apart from runner, severe damaged were observed on guide vanes, bushes for guide vanes, facing plates and other under water components. Photo 4 shows the damaged turbine components due to sand erosion. During the overhauling on year 2005, turbine components were replaced with HVOF coated runner, non-coated facing plates and wearing rings, HVOF coated lower bushes for guide vanes, non coated upper bushes and guide vanes and wearing ring. Till year 2014, four overhauling were made on Unit 2 with different sequence of replacing parts.

Photo 3: Photos of damaged turbine parts due to sand erosion and placing of cloth pieces.

Photo 5: Photos of damage of runner and facing plates of Unit No. 2

In year 2013, overhauling of Unit 2 data were collected which was overhauled after two flood year of operation after 13,400 running hours with energy generation of 545.56 GWh. The operated runner and its accessories during two flood seasons were previously repaired at local fabricator workshop by machining, welding and grinding in year 2011 which was coated with HVOF. During the repair of turbine components in year 2013, HVOF was not re-applied on runner and guide vanes due to difficulties to maintain the clearance gap between matting surfaces of turbine parts.

During the annual maintenance on year 2013, runner and its accessories were taken out and found there were significant amount of damages of runner, facing plates, labyrinth rings and guide vanes. Photo 5 shows the damages of runner and guide vanes and facing plates.

Similarly, the first overhaul of Unit 3 was carried out from 28 August 2005 to 27 September 2005 with turbine operational running hours 1602 hours and energy generation of 565 GWh after commissioning on 31 March 2002. In Unit 3, the operational problem of inlet valve was also noticed during the operation of the plant due to pressure difference between upstream and downstream of spiral case since commissioning period.

The Table 6 shows the evaluation of sand erosion on Unit 2 turbine had made after three flood seasons and running hours 21,264 analyzed by Dr. J Sato.

Turbine Design and Material

The steel structures of the spiral casing, covers, stay ring, draft tube, etc., are made from fine grained, carbon steel. The runner is of a cast construction of 13% chrome, 4% nickel steel (SCS6) having weight of 7100 Kg. The major (outer) diameter of runner is 2564 mm and minor (inner) diameter of runner is 2306 mm and the total height of runner is 1260 mm. The thickness of runner outer blade is varies from 17.30 mm to 20.30 mm. The turbine shaft and the intermediate shaft are being made of forged open-hearth carbon with integrally forged flanged.

Photo 4: Photos of damaged components of Unit 3

S. No.	Turbine parts	Material used	Result	Effect of Erosion on parts	
				2003	2005
1	Runner	SCS6 (13, 4 Cr/Ni)	Ripple observed in surface of whole flow passage	^	^
	Crown inner side	SCS6	Less erosion	<	<
	Band Inner side	SCS6	Ripple progressing. Inlet of reaction side is locally bored likely due to the combined abrasion and cavitation erosion during partial load operation	< + ^	< + ^
	Vane inlet	SCS6	Local abrasion at the joints with the crown and band due to vortices	^	^
	Vane Middle	SCS6	Less abrasion	<	<
	Vane Outlet	SCS6	Serve abrasion on vane outlet of reaction side and band outlet.	>>	>>
2	Guide vanes	JIS G5121 SCS5-T	Serve abrasion in terms of gaps between facing plates and stem bushes	^	>>
	Stem flange	SCS5	Abrasion	^	>>
	Vane surface	SCS5	Less abrasion except tail and shutter surface	< + ^	< + ^
	Lower surface	SCS5	Sever abrasion	>>	>>
	Upper surface	SCS5	Less abrasion than that of Lower surface	< + ^	< + ^
	Shutter surface	SCS5	Abrasion at inlet side while outlet side shows ripple		
3	Guide vane stem lower bush	Bronze casting (BC6) +oil less	Bronze is not suitable for abrasion	>>	>>
4	Guide vane stem upper bush	Bronze casting (BC6) +oil less	Bronze is not suitable for abrasion	^	^
5	Lower facing plate	SUS 410	Severe abrasion on side gaps	>>	>>
6	Upper facing plate	SUS 410	Less abrasion than lower facing plates	^	^
7	Upper wearing ring	SCS1	Abrasion is influenced by the deterioration of upper facing plate	^	^ + >>
8	Lower wearing ring	SCS1	Less abrasion than lower upper wearing ring	< + ^	^

Table 6: Evaluation of sand erosion.

Notation: < less abrasion, ^ rapid abrasion, > > severe abrasion

The guide vanes are operated by two servomotors, pressurized by the accumulator of the governor oil pressure system. These are mounted and supported by upper and lower stem bushes. The total number of guide vanes are 20 no. per unit. The total length and shutter width of guide vane is 1308 mm and 486 mm respectively. The weight of each guide vanes is 250 Kg having material of JIS G5121 SCS5-T. Wicket gate shafts and all moving parts of the operating mechanism run in self-lubricating bushings. A friction device (shear pin) is equipped for each wicket gate so that vanes with broken or displaced link have a stable hydraulic position and not allowed to touch the runner or to cause cascading failure of the other guide vanes. The lower stem bushes provide supports for rotating of guide vanes. These are made of bronze with self-lubricating component (graphite) having weight of 9.5 Kg each.

The wearing Rings for Head cover and Bottom Ring are made of JIS G5121 SCS1. The facing plates are installed between the guide vanes and covers to make the joint leakage –free and made of 13/4Cr-Ni stainless steel (SUS403 stainless steel).

The turbine bearing is designed as a guide bearing with removable segments with bearing metal. The entire thrust from rotating parts and the hydraulic load is taken by the upper generator thrust bearing. The bearing oil circulation is activated by the rotation of the shaft. The cooling of guide bearing is by means of two external oil-to-water heat exchangers, one as a permanent stand-by.

A direct contact type of shaft seal is used and to protect the shaft seal against sand erosion, pressurized filtrated lubricating water is supplied to system. A separate standstill inflatable shaft seal is provided to prevent entrance of operational water from the tail water side into the sealing during unit standstill.

To avoid removing the generator rotor during replacement of runner, labyrinth seal, etc., the turbine assembly design allows the turbine runner to be removed by either of the following two alternate procedures. The first procedure is removal of the runner from downwards after having removed the draft tube cone through a recess in the turbine foundation. The labyrinth seal rings, guide vanes, cover wear plates (guard rings) and other vulnerable parts exposed to sand erosion are also be accessed and removed downwards after having removed the runner. The second alternate procedure is removal of the runner upwards after having removed the turbine intermediate shaft, the head cover, guide bearing and shaft-seal. The disassembly of turbine components during overhauling of the Unit 2 in year 2013 is shown in Photo 6.

Photo 6: Photos of removing the intermediate shaft and head cover from turbine pit side

Turbine Repair and Maintenance

After the every flood season, In KGA plant, it has been practice to repair the underwater components of the turbines one by one during their annual maintenance (overhauling) period. Damaged or eroded runners and their components of turbines are taken out and repaired at fabricator workshop or at site as per the volume and precision of work's nature. During disassembly time, all the turbine parts were inspected and measured their size, gap, clearance, etc, and prepared the repair plan accordingly. Table 7 shows the Repair/Coating plan made by KGA Company during the overhauling period in year 2005.

As per the information provided by local fabricator and KGA maintenance staffs, the following procedures were applied to repair the turbine components;

Before starting any welding work on the blades, Non-destructive tests were carried out to detect the defects. If porosity, cracks, blowholes, or any type of defect were found, grinding was done. MPT or DPT tests had been repeatedly done until all defects were removed.

The runner was preheated up to temperature range 80 -100^{o} C. Laser type thermometer was used to detect the temperature during pre heating process. Electric oven was used to ensure the regular and uniform heating. Welding electrode having composition of chromium 13% and Nickel 4% were used (like ESAB OK 68.00) to build welding layer on runner. Before welding on runner, welding rods were baked on electric oven at a temperature 2500 C. After each layer of welding, the surface was roughly ground and NDT tested.

With the help of vertical lathe machine, machine was done by keeping 2 mm allowance for final machining. A final NDT or MPT test was carried out to detect the possible defects after rough machining.

S. No.	Turbine Components	Materials	Method of Repairing	Remarks
1	Runner	13% chrome, 4% nickel steel (SCS6)	Welding Machining HVOF Coating	Non-coated Previous used Runner
2	Guide Vanes	JIS G5121 SCS5-T	Welding Machining HVOF coating	Non-coated Previous used Guide vanes
3	Upper Guide vane bushes	Bronze casting (BC6) + Oil less	Machining SUS ring fitting	Fitting stainless steel on top of previous used bushes
4	Lower guide vane bushes	Bronze casting (BC6) + Oil less	Machining SUS ring fitting	Fitting stainless steel on top of previous used bushes
5	Upper wearing ring	JIS G5121 SCS1	Welding Machining HVOF coating	Previous used non coated ring
6	Lower wearing ring	JIS G5121 SCS1	Machining HVOF coating	New non coated ring
7	Upper facing plates	SUS 410	Welding Machining HVOF coating	Previous used non coated ring
8	Lower facing plates	SUS 410	Welding Machining HVOF coating	Previous used non coated ring

Table 7: Repair plan during overhauling of the machine.

After completion of the runner and grinding, a stress relieving process was carried out at a temperature 570 - 590^{o} C. The heat treatment was performed on the complete runner in a single operation using electric oven with appropriate monitoring devices. The following procedure was adopted for stress relieving;

- The welded runner was kept in the electric oven in vertical position.
- Heat the runner according to the heating rate of 50^{o} C per hour up to 570 - 590^{o} C. After reaching the specified temperature the runner was kept up to 2 hours.
- Switch off the runner and cooled it according to the cooling rate of 30^{o} C per hour in the oven until temperature falls to the ambient temperature.

Final machining of the runner was carried out as per the specification provided by the KGA Company. Finally the runner was tested for dynamic balance and final grinding with polishing was carried out.

Similarly, repair of guide vanes were done by welding and machining. Heat treatment process was performed on the complete guide vanes in a single operation by using electric oven. The guide vanes were straightened on a hydraulic press after heat treatment by applying not more than 600 kg-m force.

Summary of procedure for repairing of runner and guide vanes are as follows;

1. Preparation of mandrel, jigs and templates.
2. Pre NDT testing.
3. Pre-heat runner up to 80° C to 120° C temperature.
4. Welding on runner upper and lower seal side for runner. Welding on collar and shutter for guide vanes (Welding electrode OK 68 –ESAB India/5300-L & T/ 13/4 Cr/Ni-Bohler or equivalent depends on material parent quality).
5. During the welding, the welded metal temperature does not exceed more than 200°C whereas inter-pass head is up to 150° C and re-backing heat is up to 250° C).
6. The welding is done by dividing periphery in equal size and one after another side.
7. The welding temperature is decreased slowly by using glass wool.
8. The welding length is not more than 400 mm length in one side during welding.
9. The runner blades are built-up with welding in eructed, erosion portion. In case of the runner blade is less than 3 mm, the runner blade should cut and joined with the same base metal plates in same places, same profiles and thickness.
10. Machining on vertical lathe machine. During machining, the alignment is checked by dial indicator (0.01 mm accuracy).
11. Rough machining and grinding.
12. NDT testing.
13. Post heat treatment of runner and guide vanes to release the stress on parts.
14. Final machining, grinding ad polishing.
15. Check final measurement by using inside outside micrometers, vernier calipers and vernier tape.

The wearing ring and facing plates are designed to replace after the dismantling. So it is difficult to repair due to its less thickness. During repair, it was found the facing plates and wearing that were had some deformation during welding and heating process.

In KGA, HVOF coating have been used in different underwater components of turbine to resist against sand erosion. Photo 7 shows the coating area of runner and guide vane for HVOF coating during the repair works.

Before coating with HVOF, surface preparation was carried out by using special aluminum grits. Pre heating was performed around 40 to 60° C in order to remove moisture content in the coating surface. Finally, powder spraying was carried out by hand to coat out up to thickness 0.3 mm to 0.5 mm with the help of coating machine and rotating turn table. After repair of the damaged turbine parts, assembly of turbine was carried out. Assembly of turbine was done in reverse order of the disassembly.

Observations

Erosion in a hydro turbine is a complex phenomenon which depends upon many factors such as operating conditions (velocity, acceleration, impingement angle, flux rate, medium of flow and temperature), eroding particles (size, shape, hardness and composition) and substrate or base material (chemistry, material property and morphology) (B. Thapa, 2004). From Table 4, it is evident that the runner thickness decreases as turbine operating hours increases or operated in successive flood seasons. It is difficult to predict the particular cause behind the result of increasing eroding pattern on underwater components of turbine. However, from the sediment data of year 2011 to 2013 and from physical inspection and also looking Table 1- 3, it can be said that the silt load entering into turbine is one of the major influence on eroding the turbine components.

It can be observed that damage and the loss of turbine base material are severe due to abrasion/erosion due to sand/silt. It can also be noticed that the damage on facing plates and guide vanes are more severe than other parts of turbine components. Due to wearing on these parts, the side gaps of facing plates and guide vanes become more than the design value as shown in Table 4. One of the reasons for loss of hydraulic efficiency in Francis turbine is due to increase in the clearance gap between facing plates. From Table 6, it can be evident that almost all underwater components of turbine were affected by the sand erosion and in increasing trend.

At normal speed, pressure drop across the guide vane will be approximately 40% of net head at full load and 50% at small opening, which is one of the reason for cross flow and hence erosion takes place at junction of guide vanes (B. Thapa, 2004) . The turbulence erosion, secondary flow erosion, leakage erosion and acceleration erosion are the four types of erosion on guide vane due to sand laden water (Brekke, H 1984). From Photo 4 and Photo 5, it is clearly observed that there is a significant damage of guide vanes and runner outlet. The relative velocity is highest at the outlet of the runner

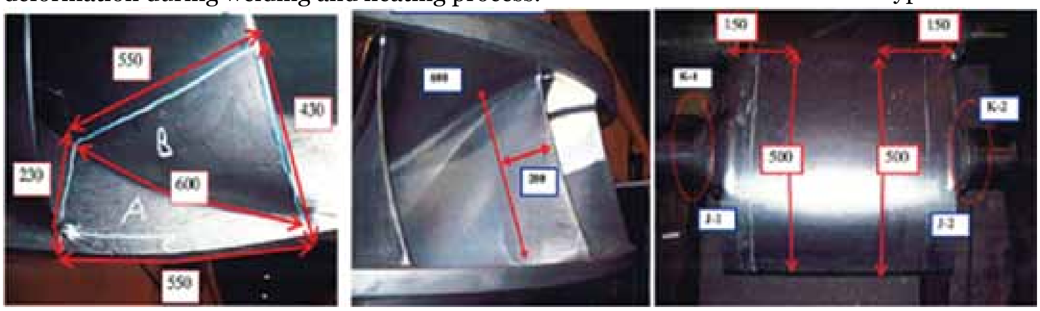


Photo 7: Photos of coating area for runner and guide vanes.

blade. Hence turbulence erosion is always susceptible at the outlet edge of the blade. Because of the effect of centrifugal force, most of particles will move towards outer diameter in the runner outlet and, hence, more effect of erosion is seen there.

The choice of materials for machine design is generally based upon operational condition, operational requirement, production feasibility, price and delivery time (Brekke, H 1984). Since, the operating conditions govern the material selection requirements, a number of mechanical and chemical properties such as yield and tensile strength, low temperature properties, corrosion resistance, hydrogen sulphide resistance, weldability and machinability need to be considered.

The material used for runner, guide vane, facing plates and wear rings of KGA turbine are stainless steel having different content of chromium and nickel. From Table 7, it can be evident that the material used for turbine components are not so satisfactory to resist the erosion due to high sediment content in Kali Gandaki river. To counter the problem of sand erosion, annual repair of turbines and hard coating of a tungsten carbide was applied with the help of High velocity oxy - fuel process on the turbine components at Kali Gandaki “A” HEP.

The repair of damage on turbines is an essential part of a hydro plant maintenance program. An effective repair plan and procedure is necessary to resist the sand erosion problem. Welding and heat treatment are two majors process that should be carried out as per the base material properties. The improperly repaired means the extent of damage will increase with accelerating rate. The damage of turbine component not only decreases the life of machine but also causes the problems in operation and maintenance which lead to long outage of the unit and finally loss in revenue.

During this case study, a survey was carried out at KGA Plant office to collect their views to reduce the downtime during operation and maintenance of turbine. Table 8 shows the ideas of KGA Plant maintenance staff regarding to reduce the down time.

Conclusion

The major findings of the present case study of KGA Plant can be summarized as follows;

- Kali Gandaki River contents huge sediment during monsoon season which are highly erosive in nature to damage the underwater components of turbine.
- Remarkable damage and weight loss were found in the turbine components such as runner, guide vanes, facing plates, wearing ring after every flood operation of the machine due to injurious effect of sediment load. In order to achieve the reliability of the unit operation during monsoon season, detail correlation between the river discharge, silt thickness in desander, silt passing through the

S. No	Description of Components	Causes that increases the down time during Operation and Maintenance of turbine
1	Generator oil reservoir & air deflector	To assembly/disassembly turbine parts from turbine pit, first the generator oil reservoir and air deflectors must be removed. It is very heavy and precision also it takes more time. So the design of dismantling of air deflector and bearing housing is one of the causes of delay during overhauling period.
2	No arrangements of devices	There is no any devices to remove and assembly of head cover, tuner, shafts and so. There should be proper arrangements of different devices so that it could be assemble and disasse mble the turbine parts easily. All heavy parts should be carried, lift up and handle by chain block (chain pulley). So there should be less mentally and physically difficult job. If one of the chain blocks gets damaged, it may cause accident of human and also the precision parts. So, proper devices, such as travelling trolley, lifting trolley/device etc should be arranged now.
3	Balancing pipe of Head-cover	There are six nos. of balancing pipes attached on head cover. It has 80 mm nominal diameter. When turbine parts get more wear and tear due to silt/sediment, more water enters inside the runner top. Due to more water inside the head cover, the six no. of balancing pipe cant’ deliver all water and due to heavy silt/ sediment, the balancing pipes get quick erosion. So the balancing pipe size (diameter-nominal) should be design more bigger than the existing one.
4	Runner	In existing runner, there is no design of labyrinth on sealing portion. Due to this, more water enters inside the head cover. If sealing portion is modified as labyrinth type, no more water goes inside the head cover and prevents it from wear and tear of head cover, shaft seal and balancing pipes.
5	Fastening system of facing plates	The facing plates are tightened by flat head bolts. It is tighten from the water contact sides. It has been observed that more erosion was found at gaps between bolt and facing. It is also assumed that the starting of erosion takes place from that point of facing plate. Also facing plates are coated during repair but there is no practice to coat on flat head bolts so may erosion starts from weak surface i.e. from flat head bolts. So it is better to design facing plates to be tightened from inner side i.e. from outside of head cover/bottom ring.
6	Wearing rings	The wearing rings are plane surface types. If it is designed as labyrinth type, no more water enters from the gaps. It prevents wearing of head cover, shaft seal, balancing pipes and also the runner band. The fastening system of wearing rings also have same problem as mentioned in facing plates.
7	Guide Vane Bushes/ bearings	The design of bushes /bearings is self-lubricating. Some graphite is inserted in different points of bushes. The main use of graphite is self lubricating during the operation of guide vanes. But, during the operating time, the graphite is lost. So, it is better to use forced grease lubricating system in bushes to reduce the repair time.
8	General	The existing design of turbine parts is difficult to modification. But if the new arrangements of devices such as trolley travelling way, trolley, lifting devices, travelling mechanism, the turbine overhauling may be easy and fast.

Table 8: Summary of views from KGA Plant maintenance staff.

turbine, operation of the machine and weight loss of turbine parts need to be investigated.

- Weight loss of turbine parts due to silt erosion is a function of base material characteristics. Material selected for underwater components of turbine at KGA Plant has not shown satisfactory performance against sand erosion. For example, bronze is very weak against silt abrasion used for guide vane bushing. The abrasion rate of the runner vane outlet was roughly estimated 5.37 mm/3 rainy seasons. It is the benchmark on sand erosion at KGA Plant.
- Cavitation is other factor that accelerates the damage of the turbine parts. If cavitation occurred, the metal surface is eroded and more influenced by silt abrasion. Damage pattern on band inlet of reaction side likely due to the combined abrasion with cavitation erosion during the partial load operation. So, combined effect of sand erosion and cavitation need to be analyzed by considering the operation philosophy of machine.
- HVOF coating had been applied on turbine parts to resist the sand erosion. Some of the turbine parts where HVOF were applied have shown positive result against sand erosion such as on the runner vane inlet, periphery and seals but at the same time coating on runner outlet, bottom edge of guide vane, facing plate, etc were not effective. HVOF coating may fragile against cavitation. It is necessary to investigate the effectiveness of HVOF coating against the cavitation erosion.
- It took normally 30- 40 days to complete disassembly, repair and assembly of the turbine of KGA Plant, . Overhauling of the turbine was often planned during dry season so that generation loss due to unit shutdown can be avoided. However, it is not always possible to overhaul the turbine without generation loss, as the repair of the machine may sometimes be urgent. So it is not the cost of overhaul only at all times, but it is also the cost of generation loss that needs to be considered while arriving at total cost incurred during overhauling of the turbine. A detail analysis needs to be carried out to optimize maintenance and repair procedure to reduce the downtime of the unit.

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