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"IMPROVEMENTS TO OPENING AND CLOSING APPRAISAL METHOD OF LOW PRESSURE STEAM TURBINE PERFORMANCE PREDICATION"

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ABSTRACT

Dismantling the steam turbine for inspection is very expensive, and need lot of performance data and information for making the decision of overhauling. In this regard condition monitoring of every subsystem is necessary to understand the degradation of different unit working together. Performance prediction of steam turbine depends on vibration analysis and oil debris analysis presents in the lubrication system, which reduce turbine efficiency and affect power generation.

This paper discuss the problem occurs in turbine such as deposits on blades and erosion of internal clearances, which causes deterioration in performance. However, to restore performance during a turbine maintenance outage, the turbine components which contribute to the performance loss. This need to be identified by conducting a turbine steam path appraisal.

Keywords: low pressure turbine; steam losses; performance; steam path appraisal.

INTRODUCTION

Steam turbines are the mainstay of electricity production worldwide. Today's competitive electricity generation market has increased the pressure to keep power generation plant on line as and when required. A steam path appraisal should include a detailed visual inspection of the steam path components and clearance measurements of the packings; and tip spill strips. The visual inspection should evaluate and quantify the performance impact of degradation effects such as erosion, deposits, damage peening, etc.Clearance measurements at multiple circumferential positions of the diaphragm packing, tip radial spill strips, and end shaft packing should be used to quantify the effect of increased clearances. With this information, decisions can be made based on the economics associated with the repair and replacement of turbine components, and the priority of necessary repair work.

The steam path appraisal should categorize the identified stage performance losses in to six components: excess diaphragm packing leakage loss, excess radial tip spill strip leakages loss, nozzle recoverable and unrecoverable losses, and bucket recoverable and unrecoverable losses. Recoverable losses are defined as those that can be recovered by cleaning, dressing, repair of the components, or replacement of clearance controls. The uncover able loss is that part of the performance loss that can only be recovered by replacement or repairs with new or repairs components, such as new or repairs diaphragms or buckets. To identify turbine internal problems causing deterioration in performance, and assist in planning maintenance required to address the problems. However, to restore performance during a turbine maintenance outage, the turbine components contributing to the performance loss need to be identified. This can best be done by conducting a turbine steam path appraisal.

STEAM PATH APPRAISAL

During the maintenance overhaul the mechanical condition of the turbine, particularly the steam path components, must be established. A steam path appraisal is used to identify and quantify mechanisms contributing to unit damage.

Historical Data Review

The appraisal effort can be enhanced significantly, and overhaul critical path avoided, if a data package is provided in advance of the unit opening. The data package should include, as a minimum, the following data:

- Steam cycle heat balance(s)
- Performance data collected as described in performance evaluation
- Turbine cross-section drawing
- Past inspection reports
- Past preventive maintenance records
- Past corrective maintenance records.

METHOLOGIES OF STEAM PATH APPRAISAL

A thorough review of the turbine performance and maintenance history is one of the most important aspects of the work. Corrective maintenance records, if properly analyzed, can provide useful trends of component failure and insight into root-cause of failure. Past problems tend to be repeated if not recognized, understood, and actively prevented. This same study is helpful in identifying where the existing test and analysis programs have failed to predict the observed condition of the unit. The study subsequently allows practical suggestions for improving the data monitoring systems. After the historical data has been reviewed and evaluated, the appraisal should be planned so that problems suggested by the review can be properly investigated.

Opening Appraisal

In order generate meaningful repair recommendations, and to provide baseline data for efficiency comparisons, an appraisal of mechanical conditions prior to performing any repair work should be performed. The appraisal can best be started by timing the Appraisal Engineer’s arrival prior to the removal of the rotor. This permits an important horizontal joint and stationary component/rotor relationship inspection. Radial spring-backed packing, J-strips, and tip seal clearance measurements are required for the appraisal, and these readings must be taken before the rotor is removed. The appraisal value would be further enhanced by the participation of one or more plant engineers who will benefit from a clear awareness of loss mechanisms, analyses of observed conditions, and the investigation into repairs, potential improvements, and upgrades. In addition to its educational value is the fact that equipment owners/users tend to have a greater intuitive insight into potentially unusual operating conditions which may relate to identified damage. Still a further reason for owner/user participation is the generation of team synergy which frequently results in flashes of insight which may not occurs in individual inspections.

Outage Considerations

While the turbine is out of service for maintenance, the steam path appraisal is used to review and establish engineering guidelines addressing methods to improve efficiency and reliability. While all critical areas of the turbine are subject to evaluation, some of the areas normally under review and consideration would be the following:

- Tighter packing seal clearances
- Reduced tip seal clearances
- Packing and tip seal material changes where beneficial.
- Upgrade of components in the seal areas
- Upgrades in inlet bell seals or snout rings

Packing Rubs

Two major events occurs that cause seal damage in turbines: distortion and vibration. Due to thermal gradients during startup, turbine inner shells, diaphragms, blade rings, and packing boxes distort and become eccentric. This distortion results in lower half stationary components moving upward towards the rotor. During start-up and shutdown, the turbine rotor is susceptible to vibration as it is brought through its critical speeds. Even though the end bearing vibration may not be excessive, the more critical center span is subject to large deflection. This vibration, in conjunction with thermal distortion of stationary components, results in reduced clearances, interference, and packing rubs. The friction resulting from the packing rub causes localized heating of the rotor, which creates a temporary bow. Because the rotor/diaphragm is already in an interference condition, this rub-induced rotor bow exacerbates the packing rub.

When a packing rub occurs, conventional spring backed packing can, to a limited extent, move with the shaft. Rotating blade tips, which are attached to the bowed rotor, interfere with stationary tip seals, which are rigid and therefore receive significant damage due to packing rubs. As important as the temporary rub-induced rotor bow is the fact that most major stationary turbine components become permanently distorted as they age. This permanent distortion is greatly exacerbated by transient thermal distortion related to startup.

Distortion Effects

Distortion measurements also identify undocumented machining deviations on the rotor and stationary components as well as previously unidentified design changes. This investigation also provides an opportunity to permanently update the history of the turbine internals. Recorded outage measurements should typically consist of the following items:

- Critical rotor diameters
- Packing/spring-backed seal casing bores
- Diaphragm/blade ring bores
- Tip seal bores

Closing Appraisal

After all outage-related repairs and changes have been completed; a closing appraisal is done prior to closing the unit. This appraisal normally evaluates the same parameters as described in Opening Appraisal and Steam Path Examination sections as well as the following items:

- Alignment data(tops off versus tops on)
- Axial and radial clearances
- Condition of the rotor steam path
- Condition of stationary components including diaphragms and/or blade rings

During the closing appraisal, an estimate and quantification by mechanism of anticipated thermal efficiency improvement is performed. This provides a reference for the observed data during the verification of results once the turbine is in operation.

CASE STUDY:-

The data collected during steam path appraisal i.e. losses, recovery recorded of opening and closing audits is recorded and remaining loss in steam turbine after capital overhauling in shown in tabulated in given below.

THE INTERSTAGE PACKING

The opening audit loss due to increased inter-stage packing clearances was 47.4kW and the heat degrade 0.74kJ/kWh.Most of the tooth circumference, of both inter stage of LP stages, was found with a rounded tooth profile, which passes more flow. The closing audit loss when compared to original design clearances were 98.8kW and the heat rate degrades 1.54 kJ/kWh.This has gain losses as clearances were not corrected in respect to design.

Table 1 Opening Audit of Total Interstage Packing for LPT casing

Description	Power Loss kW	Change In G.T.H.R kJ/kWh
LP Turb	26.7	0.42
LP Gen	20.7	0.32
Turbine Total	47.4	0.74

Table 2 Opening Audit of Interstage Packing for LP Casing

Description	Leakage Flow Kg/s	Average Clearance mm	Corrected Average Clearance mm	Wear mm	Stage Efficiency Loss %	Power Loss kW	Change In G.T.H.R kJ/kWh
Stage2	2.1637	1.875	1.875	-0.125	-0.01	-1.6	-0.03
Stage3	1.5158	2.250	2.250	0.250	0.14	19.5	0.30
Stage4	0.8191	1.800	1.800	-0.200	-0.02	-3.1	-0.05
Stage5	0.4955	2.200	2.200	0.200	0.04	8.2	0.13
Stage6	0.1978	2.225	2.225	0.225	0.02	3.8	0.06
Total						26.7	0.42

Table 3 Closing Audit of Total Interstage Packing for LPT casing

Description	Power Loss kW	Change In G.T.H.R kJ/kWh
LP Turb	25.4	0.40
LP Gen	73.4	1.14
Turbine Total	98.8	1.54

Table 4 Closing Audit of Total Interstage Packing for LP casing

Description	Leakage Flow Kg/s	Average Clearance Mm	Corrected Average Clearance mm	Wear mm	Stage Efficiency Loss %	Power Loss kW	Change In G.T.H.R kJ/kWh
Stage2	2.2012	1.975	1.975	-0.025	0.02	1.9	0.03
Stage3	1.3337	1.900	1.900	-0.100	-0.02	-2.8	-0.04
Stage4	0.9274	2.300	2.300	0.300	0.07	9.4	0.15
Stage5	0.5266	2.550	2.550	0.550	0.08	14.4	0.22
Stage6	0.1927	2.175	2.175	0.175	0.01	2.6	0.04
Total						25.4	0.40

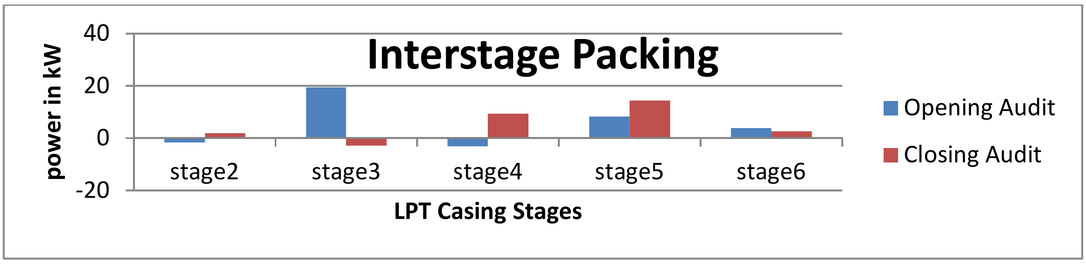

Figure 1 Opening Audit Vs Closing Audit for Inter Stages Packing of power losses in KW for LP casing

Table 5 Opening Audit of Total Interstage Packing for LPG casing

Description	Leakage Flow Kg/s	Average Clearance Mm	Corrected Average Clearance mm	Wear mm	Stage Efficiency Loss %	Power Loss kW	Change In G.T.H.R kJ/kWh
Stage2	2.3260	2.100	2.100	0.100	0.11	13.5	0.21
Stage3	1.3072	1.800	1.800	-0.200	-0.04	-6.1	-0.09
Stage4	0.9241	2.225	2.225	0.225	0.07	9.0	0.14
Stage5	0.4587	1.925	1.925	-0.075	0.00	0.8	0.01
Stage6	0.1966	2.200	2.200	0.200	0.02	3.5	0.05
Total						20.7	0.32

Table 6 Closing Audit of Total Interstage Packing for LPG casing

Description	Leakage Flow Kg/s	Average Clearance Mm	Corrected Average Clearance mm	Wear mm	Stage Efficiency Loss %	Power Loss kW	Change In G.T.H.R kJ/kWh
Stage2	2.4904	2.425	2.425	0.425	0.24	28.8	0.45
Stage3	1.4811	2.225	2.225	0.225	0.11	15.3	0.24
Stage4	0.8894	2.125	2.125	0.125	0.04	5.0	0.08
Stage5	0.5416	2.700	2.700	0.700	0.09	17.3	0.27
Stage6	0.2126	2.650	2.650	0.650	0.03	7.0	0.11
Total						73.4	1.14

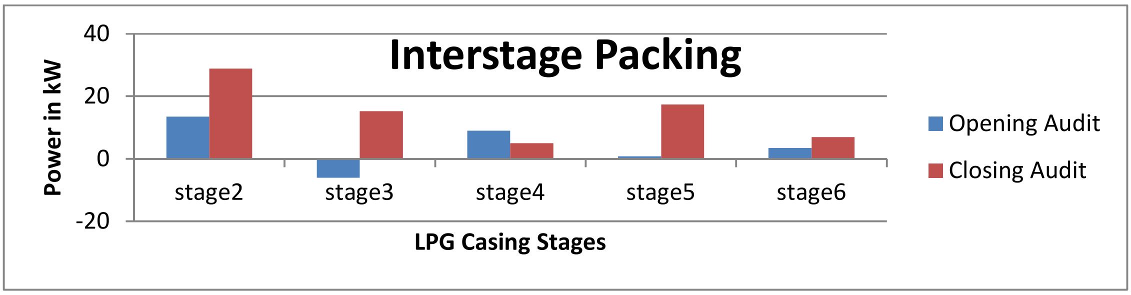

Figure 2 Opening Audit Vs Closing Audit for Inter Stages Packing of power losses in KW for LP casing

END PACKING

The opening audit loss due to increased end packing clearances was -5.8kW and the total heat rate degraded -0.09kJ/kWh.This closing audit loss due to increased end packing clearances was -5.7kW and the total heat degraded -0.09kJ/kWh.

Table 7 Opening Audit of Total Shaft End Packing for LPT casing

Description	Power Loss kW	Change In G.T.H.R kJ/kWh
LP Turb	3.3	0.05
LP Gen	-9.1	-0.14
Turbine Total	-5.8	-0.09

Table 8 Opening Audit of Total Shaft End Packing for LP casing

Packing Description	Seal	Leakage Flow Kg/s	Average Clearance mm	Corrected Average Clearance mm	Wear mm	Power Loss Kw	Change In G.T.H.R kJ/kWh
LP Exhaust(N5)	1	-0.1146	0.917	0.917	0.317	3.1	0.05
	2	0.0960	0.543	0.543	-0.057	0.2	0.00
	Total					3.3	0.05
Total						3.3	0.05

Table 9 Closing Audit of Total Shaft End Packing for LPT casing

Description	Power Loss kW	Change In G.T.H.R kJ/kWh
LP Turb	3.3	0.05
LP Gen	-9.0	-0.14
Turbine Total	-5.7	-0.09

Table 10 Closing Audit of Total Shaft End Packing for LP casing

Packing Description	Seal	Leakage Flow Kg/s	Average Clearance mm	Corrected Average Clearance mm	Wear mm	Power Loss kW	Change In G.T.H.R kJ/kWh
LP Exhaust(N5)	1	-0.1131	0.917	0.917	0.317	2.9	0.05
	2	0.0947	0.543	0.543	-0.057	0.4	0.01
	Total					3.3	0.05
Total						3.3	0.05

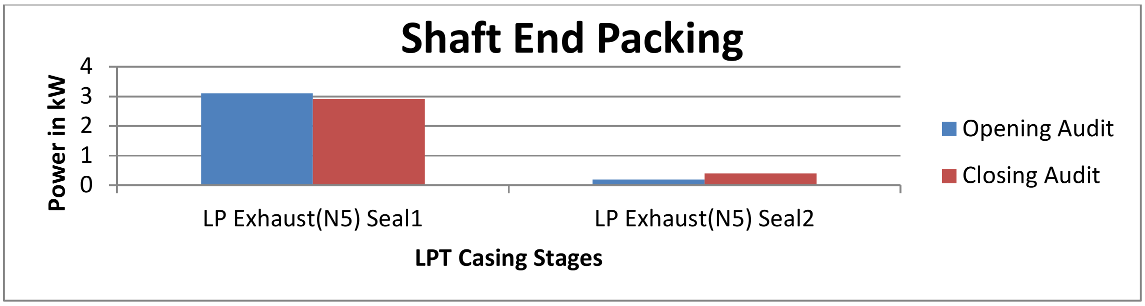

Figure 3 Opening Audit Vs Closing Audit for Shaft End Packing of power losses in KW for LP casing

Table 11 Opening Audit of Total Shaft End Packing for LPG casing

Packing Description	Seal	Leakage Flow Kg/s	Average Clearance mm	Corrected Average Clearance mm	Wear mm	Power Loss kW	Change In G.T.H.R kJ/kWh
LP Exhaust(N6)	1	-0.0394	0.211	0.211	-0.389	-4.4	-0.07
	2	0.1455	1.010	1.010	0.410	-4.6	-0.07
	Total					-9.1	-0.14
Total						-9.1	-0.14

Table 12 Closing Audit of Total Shaft End Packing for LPG casing

Packing Description	Seal	Leakage Flow Kg/s	Average Clearance mm	Corrected Average Clearance mm	Wear mm	Power Loss kW	Change In G.T.H.R kJ/kWh
LP Exhaust(N6)	1	-0.0389	0.211	0.211	-0.389	-4.5	-0.07
	2	0.1436	1.010	1.010	0.410	-4.5	-0.07
	Total					-9.0	-0.14
Total						-9.0	-0.14

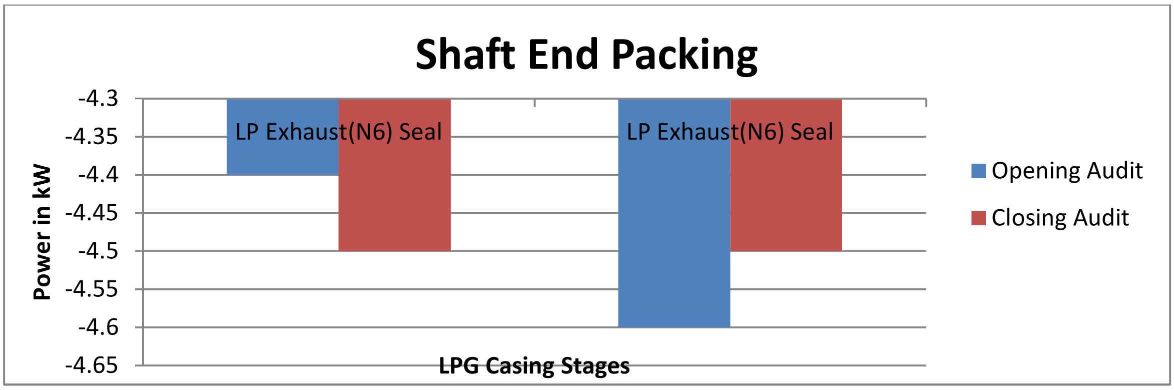

Figure 4 Opening Audit Vs Closing Audit for Shaft End Packing of power losses in KW for LP casing

TIP SPILL STRIPS

The opening audit loss due to increased Tip Spill Strips clearances was 89.4kW and the to heat rate degraded 1.39kJ/kWh.This closing audit loss due to increased Tip Spill Strips clearances was 109.2kW and the heat degraded 1.7kJ/kWh.

Table 13 Opening Audit of Total Tip Spill Strips for LPT casing

Description	Power Loss kW	Change In G.T.H.R kJ/kWh
LP Turb	51.0	0.79
LP Gen	38.4	0.60
Turbine Total	89.4	1.39

Table 14 Opening Audit of Total Tip Spill Strips for LP casing

Description	Leakage Flow Kg/s	Average Clearance mm	Corrected Average Clearance mm	Wear mm	Stage Efficiency Loss %	Power Loss kW	Change In G.T.H.R kJ/kWh
Stage1	1.4167	2.075	2.075	0.875	0.31	32.0	0.50
Stage2	0.8446	1.875	1.875	0.675	0.16	19.0	0.29
Total						51.0	0.79

Table 15 Closing Audit of Total Tip Spill Strips for LPT casing

Description	Power Loss kW	Change In G.T.H.R kJ/kWh
LP Turb	54.5	0.85
LP Gen	54.7	0.85
Turbine Total	109.2	1.7

Table 16 Closing Audit of Total Tip Spill Strips for LP casing

Description	Leakage Flow Kg/s	Average Clearance mm	Corrected Average Clearance mm	Wear mm	Stage Efficiency Loss %	Power Loss kW	Change In G.T.H.R kJ/kWh
Stage1	1.3830	2.075	2.075	0.875	0.29	30.1	0.47
Stage2	0.9262	2.125	2.125	0.925	0.20	24.4	0.38
Total						54.5	0.85

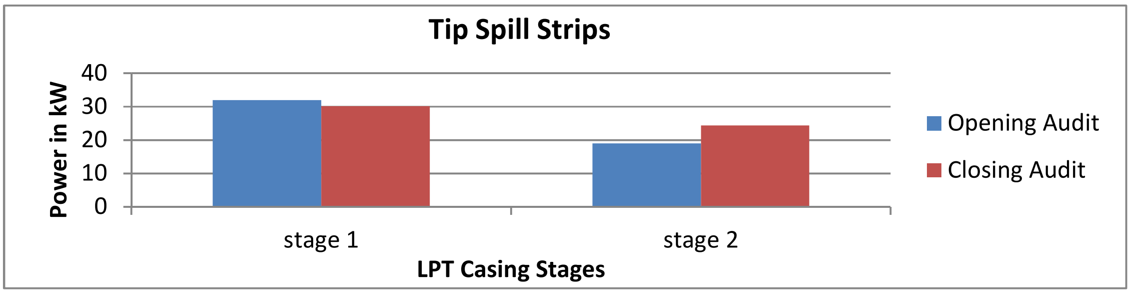

Figure 5 Opening Audit Vs Closing Audit for Tip Spill Strips of power losses in KW for LP casing

Table 17 Opening Audit of Total Tip Spill Strips for LPG casing

Description	Leakage Flow Kg/s	Average Clearance mm	Corrected Average Clearance mm	Wear mm	Stage Efficiency Loss %	Power Loss kW	Change In G.T.H.R kJ/kWh
Stage1	1.2571	1.825	1.825	0.625	0.22	22.9	0.36
Stage2	0.7918	1.750	1.750	0.550	0.13	15.4	0.24
Total						38.4	0.60

Table 18 Closing Audit of Total Tip Spill Strips for LPG casing

Description	Leakage Flow Kg/s	Average Clearance mm	Corrected Average Clearance mm	Wear mm	Stage Efficiency Loss %	Power Loss kW	Change In G.T.H.R kJ/kWh
Stage1	1.4597	2.200	2.200	1.000	0.33	34.4	0.54
Stage2	0.8634	1.970	1.970	0.770	0.17	20.2	0.31
Total						54.7	0.85

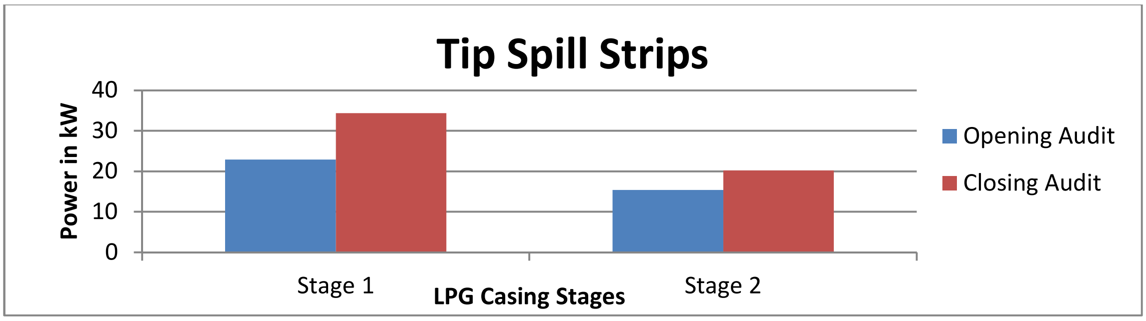

Figure 5 Opening Audit Vs Closing Audit for Tip Spill Strips of power losses in KW for LP casing.

SURFACE ROUGHNESS

The opening audit evaluation of the surface roughness showed a loss of 2924.5kW and an increase in heat rate of 45.63.Surface Roughness of closing audit loss when compared to original design was 1441.9kW and an increase in heat rate of 22.46kJ/kWh. COH recovered 5221.6Kw.

Table 19 Opening Audit of Total Surface Roughness for LPT casing

Description	Power Loss kW	Change In G.T.H.R kJ/kWh
LP Turb	1418.0	22.12
LP Gen	1506.5	23.51
Turbine Total	2924.5	45.63

Table 20 Opening Audit of Total Surface Roughness for LP casing

Description	Stage Efficiency Loss %	Power Loss kW	Change In G.T.H.R. kJ/kWh
Stage1	3.39	352.8	5.49
Stage2	3.43	417.1	6.49
Stage3	2.09	301.5	4.69
Stage4	1.09	147.1	2.29
Stage5	0.47	88.8	1.38
Stage6	0.50	110.6	1.72
Total		1418.0	22.12

Table 21 Closing Audit of Total Surface Roughness for LPT casing

Description	Power Loss kW	Change In G.T.H.R kJ/kWh
LP Turb	693.2	10.80
LP Gen	748.7	11.66
Turbine Total	1441.9	22.46

Table 22 Closing Audit of Total Surface Roughness for LP casing

Description	Stage Efficiency Loss %	Power Loss kW	Change In G.T.H.R. kJ/kWh
Stage1	2.16	224.7	3.50
Stage2	1.49	180.6	2.81
Stage3	1.12	161.5	2.51
Stage4	0.70	94.8	1.47
Stage5	0.15	28.5	0.44
Stage6	0.01	3.1	0.05
Total		693.2	10.80

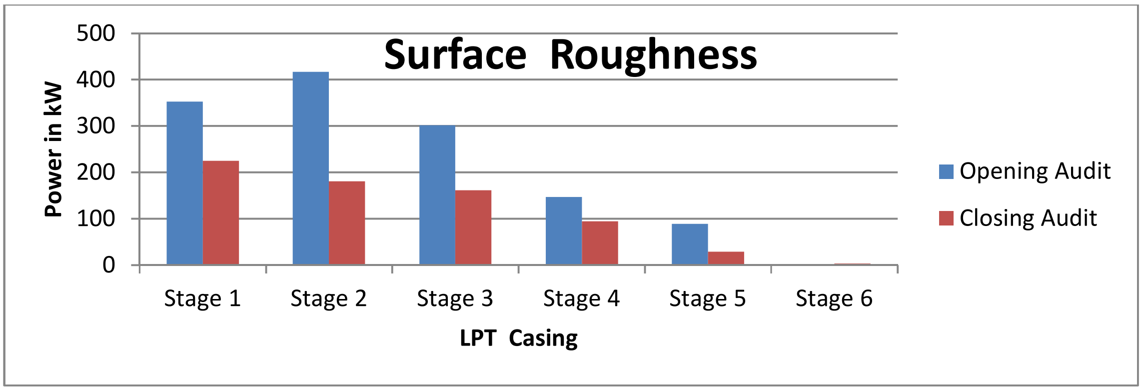

Figure 7 Opening Audit Vs Closing Audit for Surface Roughness of power losses in KW for LP casing

Table 23 Opening Audit of Total Surface Roughness for LPG casing

Description	Stage Efficiency Loss %	Power Loss kW	Change In G.T.H.R. kJ/kWh
Stage1	3.48	361.7	5.63
Stage2	3.61	439.5	6.84
Stage3	2.15	309.5	4.82
Stage4	1.26	170.4	2.65
Stage5	0.50	93.6	1.46
Stage6	0.59	131.9	2.05
Total		1506.5	23.51

Table 24 Closing Audit of Total Surface Roughness for LPG casing

Description	Stage Efficiency Loss %	Power Loss kW	Change In G.T.H.R. kJ/kWh
Stage1	2.18	227.0	3.53
Stage2	1.47	178.8	2.78
Stage3	1.15	165.0	2.57
Stage4	0.90	121.6	1.89
Stage5	0.27	51.2	0.80
Stage6	0.02	5.0	0.08
Total		748.7	11.66

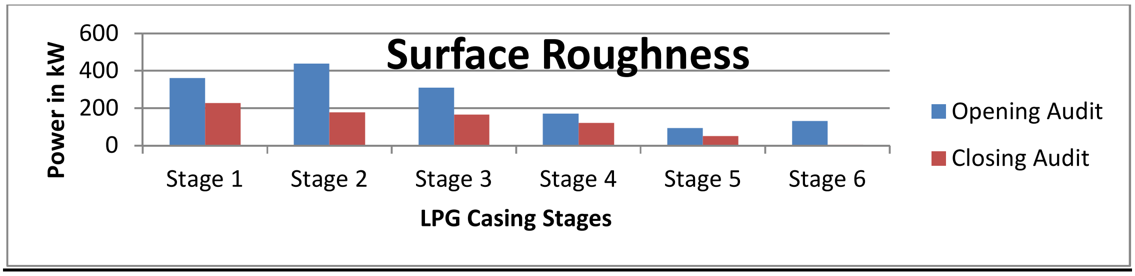

Figure 8 Opening Audit Vs Closing Audit for Surface Roughness of power losses in KW for LP casing

COVER DEPOSITS

Cover deposit observed in LP Turbine and removed by sand blasting. The opening audit evaluation of the cover deposits showed a loss of 10.4 kW and an increase in heat rate of 0.09 kJ/kWh.

RESULT AND DISCUSSION

From the above discussions, several conclusions about maintenance and overhaul of steam turbines have been made:
- There have been numerous causes of steam turbine failures worldwide. Typically, the highest frequency events have been loss of lube oil incidents, the highest severity events have been over speed events, and the higher frequency and higher severity events have been blade/bucket failures, particularly in the LP section of the turbine where they experienced a number of failure mechanisms (Stress corrosion cracking, erosion) which ultimately led to failure. As such, steam turbine maintenance and overhaul efforts should be directed toward diagnosing and mitigating these types of events. To insure is that the maintenance tasks and frequencies should be prioritized towards the portions of the steam turbine that have the highest risk-the highest probability and consequence of failure. This usually means protecting the steam turbine from over speeds, water induction, loss of lube oil, corrosive steam, and sticking valves that could cause major damage to the turbine, and conducting internal inspections of the turbine flow path, shells and rotors for failure mechanism damage (creep, erosion, corrosion, fatigue, thermal fatigue, Stress corrosion cracking) in order to detect the damage early enough to prevent a subsequent major failure.

CONCLUSION

Steam path damage, particularly of turbine blade is recognized as a leading cause of steam turbine. Conventionally Turbine problems cost as much as generation cost per year. Failures of blades, disc and rotors in thermal steam turbines represent a serious economic loss. Turbine problems such as deposition and erosion of blades can result in severe efficiency losses, resulting in significant economic penalties. The objective of this work is to provide guidelines and helps to identify the damage or failure of steam turbine components. These determine the root cause, and choose immediate and long-term actions to reduce and prevent recurrence of the problem.

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