ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 11, May 2014

Reliability of turbo-machinery through condition monitoring

B. Uma Devi [1], S. Srinivas Prasad [2], B. Arun babu[3], [4]P. Mohan swaroop
[1] M Tech Student, Department of Aeronautical Engineering, MLR Institute of Technology, Hyderabad
[2] Professor & Head, Department of Aeronautical Engineering, MLR Institute of Technology, Hyderabad,
[3]Manager, AIMIL LTD , Hyderabad
[4]Senior Engineer AIMIL LTD , Hyderabad

Abstract*— over the year's machinery health management has become vital part of the plant operation. Earlier day's machinery maintenance is only focused on reactive maintenance. In later stages, Vibration Monitoring is a critical component of any Predictive Maintenance (PDM) Practices. Vibration Monitoring and subsequent analysis has helped in indentifying an earlier consequence of breakdowns. [1]The idea of performing Predictive Maintenance to perform maintenance on the machines they exhibit signs of mechanical failure has become known as Condition Based Maintenance (CBM). Condition Based Monitoring System (CBMS) is proven technology to be less costly than the failure. A simple Consequence of Failure Analysis (CFA) is made to justify preventive maintenance activities. This evolutionary process of machinery maintenance has allowed the maintenance operation to more "Proactive" than reactive in their maintenance tasking, This paper pertains to one such study made at M/s KSK MAHANADI POWER COMPANY LTD, , who are the power generators in India, on a Turbine which extremely critical for their production. We have observed the machinery health condition based on vibration measurements and observed the shaft crack on a turbine by using the vibration analysis which really helped us in identifying a failure sequence on a turbine which focuses the importance of vibration analysis to reduce the induced vibrations on a turbine and Significant reduction in the vibration levels and which increased the machinery availability for production. The test has been carried out with the help of M/s Aimil Ltd (Instrument Providers) and M/s ACME (Service Providers).

***Index Terms*— Predictive Maintenance (PDM), Condition Based Maintenance (CBM), Consequence of Failure Analysis (CFA), Condition Based Monitoring System (CBMS).**

I. INTRODUCTION

Vibration Analysis was carried by KSK MAHANADI POWER COMPANY LTD, at NARIYARA for conducting detailed vibration analysis of 600 MW STG UNIT-3. With the help of M/s. AIMIL and M/s ACME vibration specialists visited the site for detailed Vibration analysis. This Unit was rolled for the First time to rated speed and subsequently it was Loaded up to 135 MW. At that time, both the Shaft & Bearing Pedestal vibration were within limits and was exhibiting a stable and satisfactory behavior. Over speed test and Electrical tests were carried out on the Generator. After conducting all these tests upon re-starting, the vibration behavior of this Unit changed dramatically. i.e., up to FSNL (Full speed No Load) the behavior of the unit is stable but the moment the Unit is synchronized for loading the Shaft vibrations are increasing significantly to Trip values at LP & Generator bearings and causing the unit to trip. The present analysis was carried out to probe the cause of high vibrations during loading. The shaft vibration was collected from Bentley Nevada Online Vibration Monitoring System and the bearing housing vibration was collected from the field with a portable FFT Analyzer.

II.MANUSCRIPT BODY

A. *BRIEF DESCRIPTION* Vibration

1. *Frequency*

The cyclic movement in a given unit of time. The units of frequency are: RPM = revolutions or cycles per minute.
Hertz (Hz) = revolutions or cycle per second.
These are related by the formula:
F = frequency in hertz = RPM/60.

2. Amplitude

The magnitude of dynamic motion of vibration. Amplitude is typically expressed in terms of either Peak to Peak: 0 to Peak: RMS (Root Mean Square).

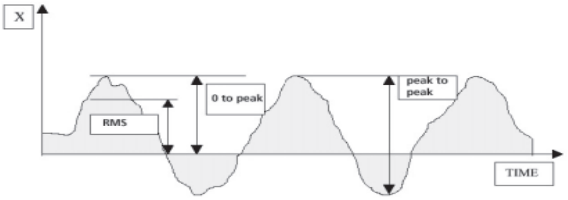


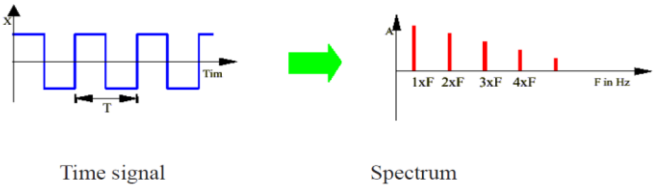
Fig 1. On a sine wave identifying the P-P,0-P,& RMS

The sketch below illustrates the relationship of these three units of measurement associated with amplitude.

Harmonics

These are the vibration signals having frequencies that are exact multiples of the fundamental frequency (i.e. 1 x F, 2 x F, 3 x F etc.).

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 11, May 2014

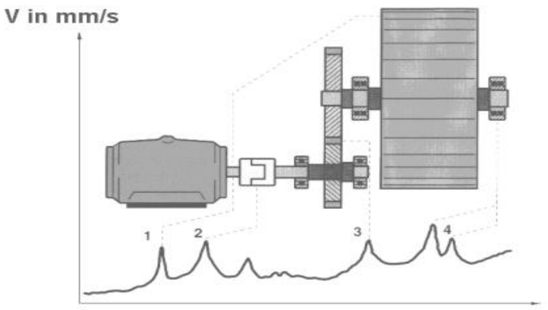


Time signal Spectrum

Fig- 2. Converting time signal to spectrum

B. *Vibration frequency spectrum*

Machinery vibration consists of various frequency components as illustrated below. The amplitude of each frequency components provides an indication of the condition of a particular rotating element within the machine. Simply stated, a vibration frequency spectrum converts a vibration signal into a true amplitude representation of the individual frequency components. Since most machinery faults are displayed at or near a frequency component associated with running speed the ability to display and analyse the spectrum as components of frequency is extremely important.



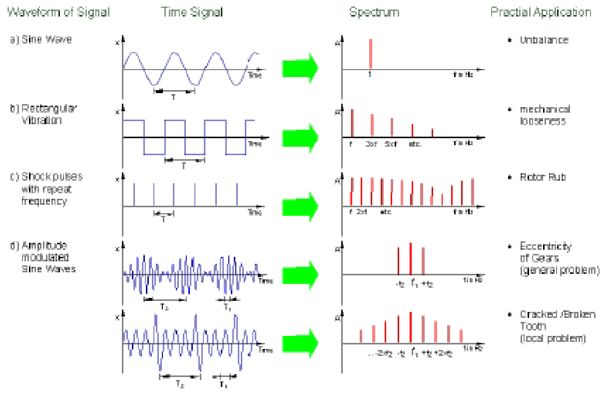


Fig-3 how we are converting the time wave form toFFT

1. *FFT (Fast Fourier Transform)*

FFT is predominantly the most used tool in analysis of spectral data with respect to vibration analysis of machine components. Fourier transform is a mathematical operation which decomposes a time domain function into its frequency domain components.

Fault Detection

As we have discussed the main objective of a vibration monitoring program is the detection of incipient machine failures. The methodologies associated with fault prediction usually involve comparing current vibration information with a vibration description of that machine or a similar machine in satisfactory operating condition.

This comparison is made by two methods:

1. Comparison to industrial standards - ISO 10816 - 3
2. Comparison to a previously measured reading.

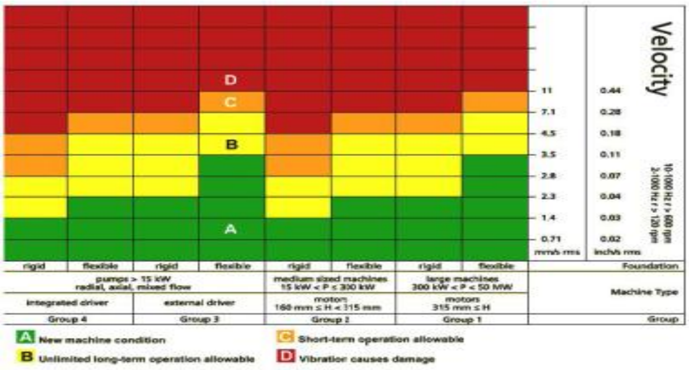


Fig-4: ISO 1086-3 vibration standards

C. *INSTRUMENT USED FOR ANALYSIS*

The following equipments were used to carry out the Vibration analysis: ON-LINE SHAFT VIBRATION

Hardware: French Make OROS Model OR-36 - MOBIPACK 16 Channel Analyzer for measurement of "Shaft Vibration" from online vibration Monitor.

Software: Orb iGATE BEARING HOUSING (FIELD) VIBRATION

Hardware: PRUFTECHNIK Make Vib Xpert – 2 Channel FFT Analyzer for "Bearing Housing" Measurement from the field. Software: OMNITREND

1. 600 MW T.G. SET

Turbine Rpm: 3000
Generator Rpm: 3000

MACHINE LINE SKETCH

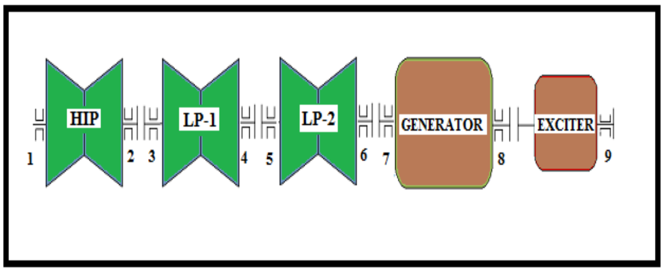


Fig 5: turbine line sketch

OVERALL RMS VIBRATION VELOCITY IN MM/SEC – AT FSNL

HIGHEST AMPLITUDES AND HEALTH CONDITION (AT 530 MW LOAD CONDITION)		
LOCATION	RMS VELOCITY(mm/sec)	HEALTH CONDITION
HIP TURBINE	0.7	Satisfactory
LP-A TURBINE	1.6	Satisfactory
LP-B TURBINE	4.9	Satisfactory
GENERATOR	4.5	Satisfactory
EXCITER	1.8	Satisfactory

ISO 10816- VIBRATION STANDARDS

Velocity measurements can be categorized as follows:

Class I machines may be separated driver and driven, or coupled units comprising operating machinery up to approximately 15kW (approx 20hp).
Class II machinery (electrical motors 15kW(20hp) to 75kW(100hp), *without special foundations*, or *Rigidly mounted* engines or machines up to 300kW (400hp) *mounted on special foundations*
Class III machines are large prime movers and other large machinery with large rotating assemblies *mounted on rigid and heavy foundations* which are reasonably stiff in the direction of vibration.
Class IV includes large prime movers and other large machinery with large rotating assemblies *mounted on foundations which are relatively soft in the direction of the measured vibration* (i.e., turbine generators and gas turbines greater than 10MW (approx. 13500hp) output.

Related typical zone boundary limits are outlined as follows:

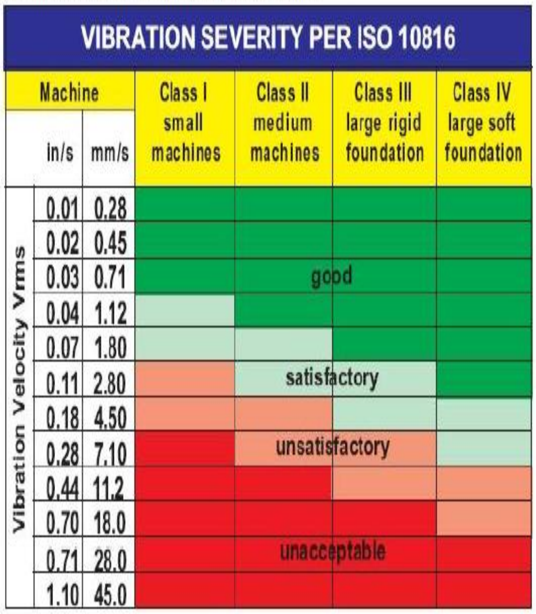


Fig -6: ISO 10816 Machine classes & vibration severity

D. VIBRATION DATA SHAFT VIBRATION DISPLACEMENT IN MICRONS

SHAFT VIBRATION DISPLACEMENT IN MICRONS

LOCATION	PROBE	FSNL	AFTER SYN	17 MW	20 MW 09.38 AM	20 MW 09.39 AM
HP FRONT BEARING	X	31	31	43	51	58
	Y	33	34	63	81	83
HIP REAR BEARING	X	56	48	49	55	74
	Y	61	59	76	80	72
LP-A FRONT BEARING	X	16	17	49	66	75
	Y	18	19	63	87	111
LP-A REAR BEARING	X	22	27	49	61	72
	Y	32	34	82	101	123
LP-B FRONT BEARING	X	43	42	116	171	236
	Y	38	37	167	243	291
LP-B REAR BEARING	X	24	20	92	134	164
	Y	30	20	135	212	264
GENERATOR FRONT BEARING	X	25	17	101	150	163
	Y	43	37	145	211	229
GENERATOR REAR BEARING	X	22	22	77	111	112
	Y	70	66	201	259	263

Table 1: shaft vibration displacement in microns

SHAFT VIBRATION PHASE DATA (1 X AMPLITUDE AND ANGLE) LOAD

LOCATION	PROBE	FSNL		20 MW 09.39 AM	
		1X AMP	PHASE	1X AMP	PHASE
HP FRONT BEARING	X	15	24	29	331
	Y	15	231	17	174
HIP REAR BEARING	X	47	56	39	67
	Y	56	339	37	124
LP-1 FRONT BEARING	X	11	332	25	253
	Y	8	29	29	170
LP-1 REAR BEARING	X	12	279	37	359
	Y	25	173	37	250
LP-2 FRONT BEARING	X	32	30	105	332
	Y	27	332	123	246
LP-2 REAR BEARING	X	12	227	72	44
	Y	26	177	58	315
GENERATOR FRONT BEARING	X	20	132	68	57
	Y	39	43	71	336
GENERATOR REAR BEARING	X	13	235	23	183
	Y	61	87	67	38

Table 2: Shaft vibration phase data (1X Amplitude and Angle) Load

BEARING HOUSING VIBRATION (RMS VELOCITY IN MM/SEC).

LOCATION	ORIENTATION	FSNL
HIP FRONT BEARING	HORIZONTAL	0.5
	VERTICAL	0.3
	AXIAL	0.3
HIP REAR BEARING	HORIZONTAL	0.5
	VERTICAL	0.7
	AXIAL	0.7
LP-A FRONT BEARING	HORIZONTAL	0.3
	VERTICAL	1.3
	AXIAL	0.6
LP-A REAR BEARING	HORIZONTAL	0.3
	VERTICAL	0.9
	AXIAL	1.6
LP-B FRONT BEARING	HORIZONTAL	1.2
	VERTICAL	4.9
	AXIAL	4.2
LP-B REAR BEARING	HORIZONTAL	0.7
	VERTICAL	4.5
	AXIAL	2.8
GENERATOR FRONT BEARING	HORIZONTAL	0.9
	VERTICAL	3.5
	AXIAL	2.0
GENERATOR REAR BEARING	HORIZONTAL	2.2
	VERTICAL	2.6
	AXIAL	1.4
EXCITER BEARING	HORIZONTAL	0.7
	VERTICAL	1.4
	AXIAL	1.8

Table 3: Bearing Housing vibrations in velocity

With reference to the overall values from the above tables we observe high displacement and velocity values in the LP-B front bearing and LP-B rear bearing.

III. ANALYSIS RESULTS

SHAFT VIBRATION GRAPHS

RUNUP PLOTS

SPEED PROFILE DURING RUNUP

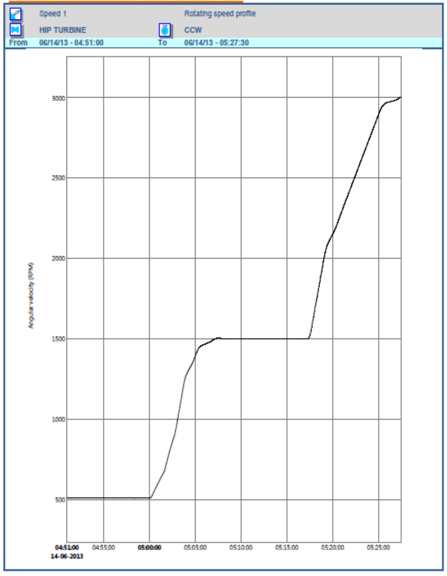
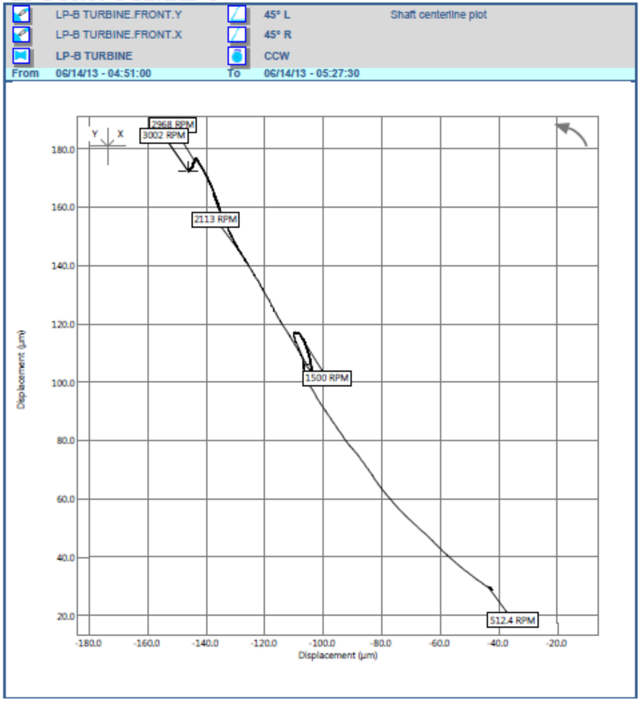


Fig-7: RUN UP plot

Shaft Centerline Plots

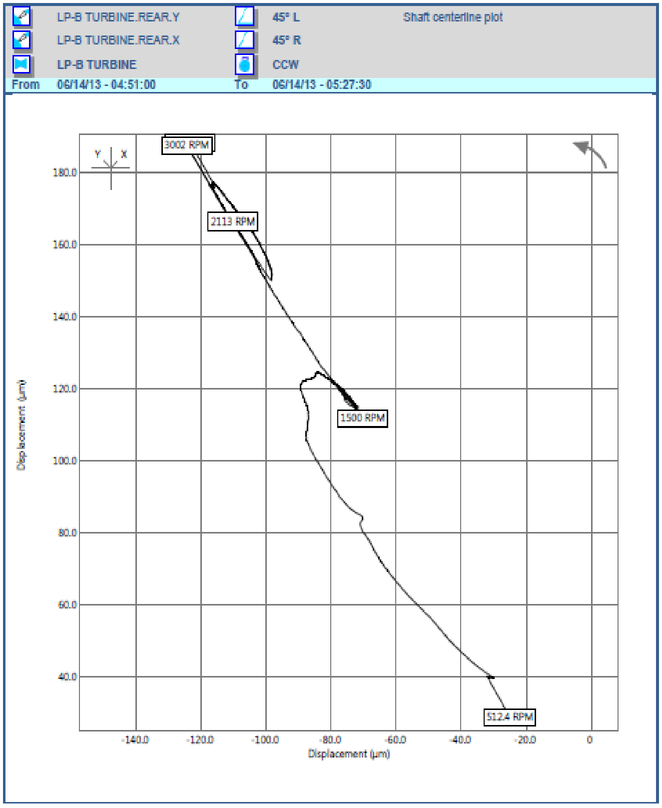
LP-B FRONT BEARING



0.17mm Lift and 0.15mm left moment observed

Fig-8: Shaft center line for LP-B front bearing

LP-B REAR BEARING



0.17mm Lift and 0.12mm left moment observed

Fig-9: shaft center line for LP-B rear bearing

Steady state Condition FFT Full Speed No Load (FSNL) Condition

LP-B FRONT BEARING

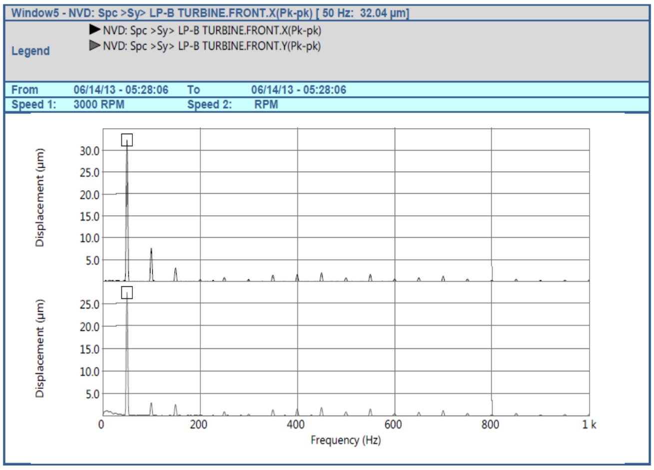

Window5 - NVD: Spc >Sy> LP-B TURBINE.FRONT.X(Pk-pk) [50 Hz: 32.04 µm]
Legend ▶ NVD: Spc >Sy> LP-B TURBINE.FRONT.X(Pk-pk)
▶ NVD: Spc >Sy> LP-B TURBINE.FRONT.Y(Pk-pk)
From 06/14/13 - 05:28:06 To 06/14/13 - 05:28:06
Speed 1: 3000 RPM Speed 2: RPM

Fig-10: FFT spectrum FSNL for LP-B front beating

LP-B REAR BEARING

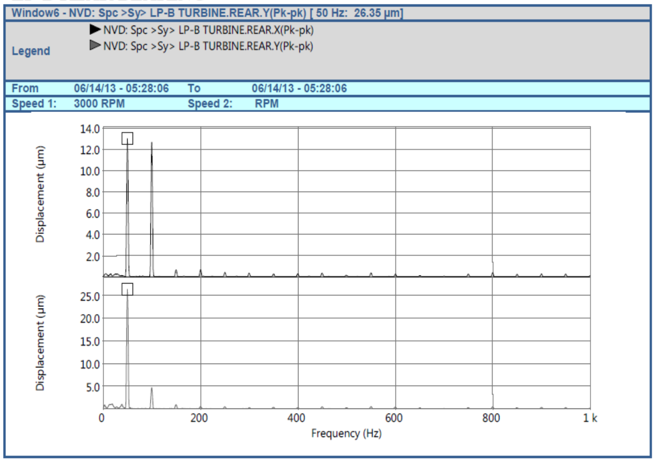

Window6 - NVD: Spc >Sy> LP-B TURBINE.REAR.Y(Pk-pk) [50 Hz: 26.35 µm]
Legend ▶ NVD: Spc >Sy> LP-B TURBINE.REAR.X(Pk-pk)
▶ NVD: Spc >Sy> LP-B TURBINE.REAR.Y(Pk-pk)
From 06/14/13 - 05:28:06 To 06/14/13 - 05:28:06
Speed 1: 3000 RPM Speed 2: RPM

Fig-11: FFT for LP-B rear bearing

FFT Spectrum at 17MW load condition

LP-B FRONT BEARING

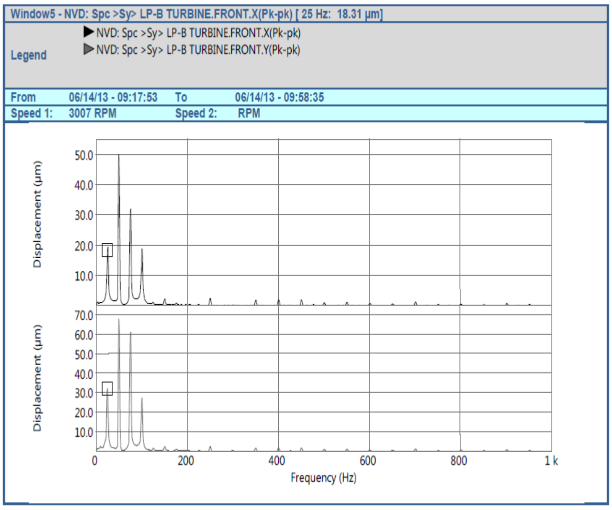
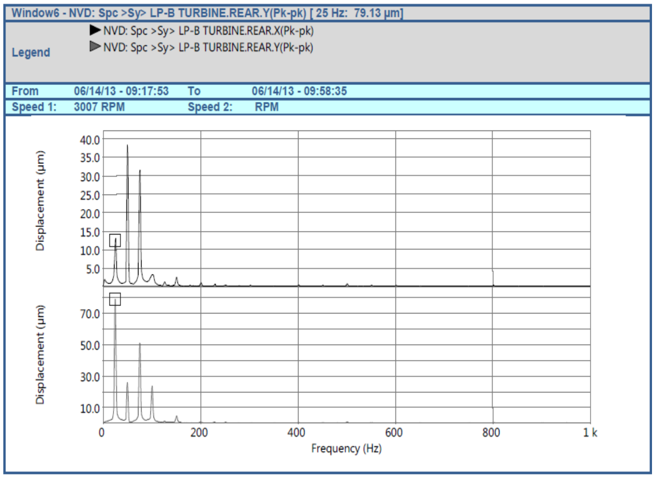

Window5 - NVD: Spc >Sy> LP-B TURBINE.FRONT.X(Pk-pk) [25 Hz: 18.31 µm]
Legend ▶ NVD: Spc >Sy> LP-B TURBINE.FRONT.X(Pk-pk)
▶ NVD: Spc >Sy> LP-B TURBINE.FRONT.Y(Pk-pk)
From 06/14/13 - 09:17:53 To 06/14/13 - 09:58:35
Speed 1: 3007 RPM Speed 2: RPM

Fig-12: FFT @17 MW load condition LP-B front bearing

LP-B REAR BEARING


Window6 - NVD: Spc >Sy> LP-B TURBINE.REAR.Y(Pk-pk) [25 Hz: 79.13 µm]
Legend ▶ NVD: Spc >Sy> LP-B TURBINE.REAR.X(Pk-pk)
▶ NVD: Spc >Sy> LP-B TURBINE.REAR.Y(Pk-pk)
From 06/14/13 - 09:17:53 To 06/14/13 - 09:58:35
Speed 1: 3007 RPM Speed 2: RPM

FFT Spectrum at 20 MW load condition

LP-B FRONT BEARING

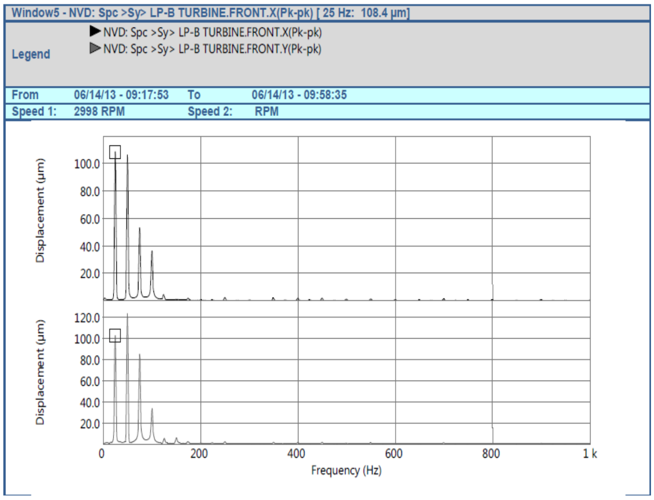

Window5 - NVD: Spc >Sy> LP-B TURBINE.FRONT.X(Pk-pk) [25 Hz: 108.4 µm]
Legend ▶ NVD: Spc >Sy> LP-B TURBINE.FRONT.X(Pk-pk)
▶ NVD: Spc >Sy> LP-B TURBINE.FRONT.Y(Pk-pk)
From 06/14/13 - 09:17:53 To 06/14/13 - 09:58:35
Speed 1: 2998 RPM Speed 2: RPM

Fig-13: FFT @17 MW load condition LP-B rear bearing

LP-B REAR BEARING

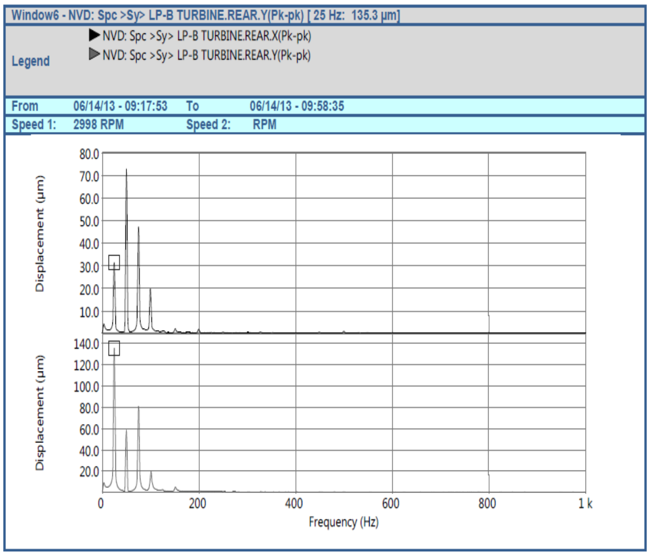

Window6 - NVD: Spc >Sy> LP-B TURBINE.REAR.Y(Pk-pk) [25 Hz: 135.3 µm]
Legend ▶ NVD: Spc >Sy> LP-B TURBINE.REAR.X(Pk-pk)
▶ NVD: Spc >Sy> LP-B TURBINE.REAR.Y(Pk-pk)
From 06/14/13 - 09:17:53 To 06/14/13 - 09:58:35
Speed 1: 2998 RPM Speed 2: RPM

Fig-14: FFT @20 MW load condition LP-B front & rear bearings

Bearing Housing Spectrum

LP-B FRONT BEARING

HORIZONTAL

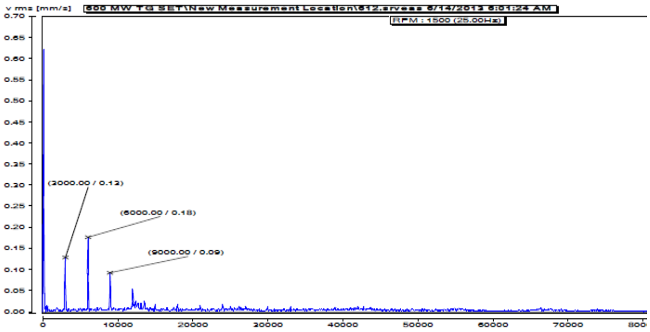
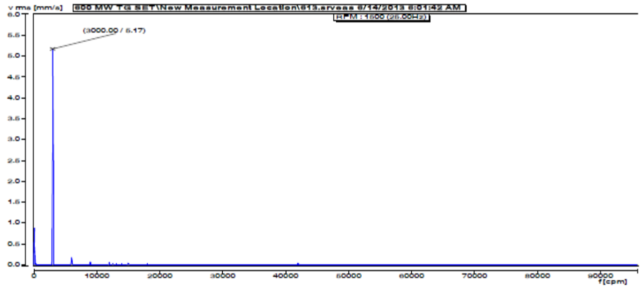


Fig-15: FFT bearing housing @ 20MW load condition LP-B front bearing- Horizontal

VERTICAL



AXIAL

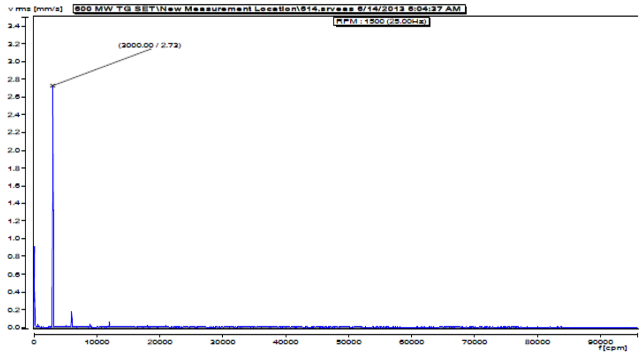
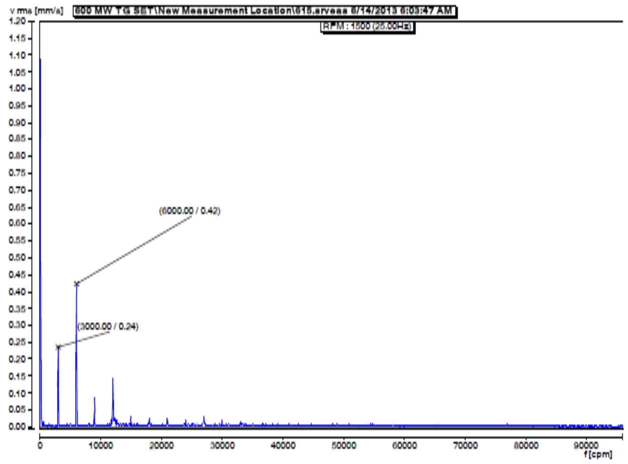


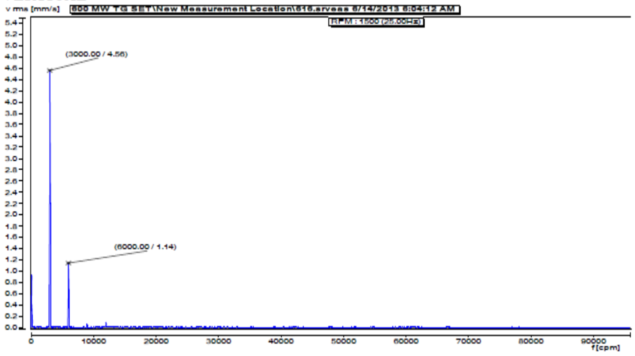
Fig-16: FFT bearing housing @ 20MW load condition LP-B front bearing- Vertical & Axial

LP-B REAR BEARING

HORIZONTAL



VERTICAL



AXIAL

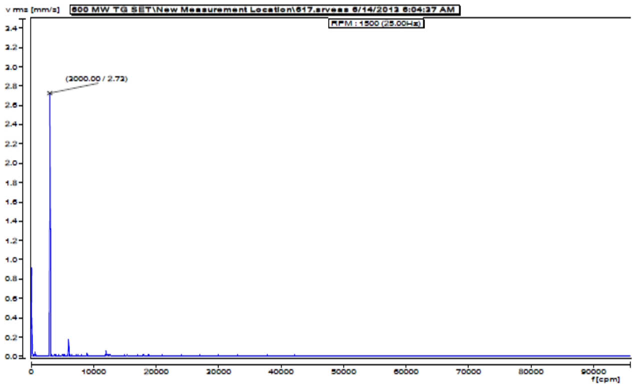
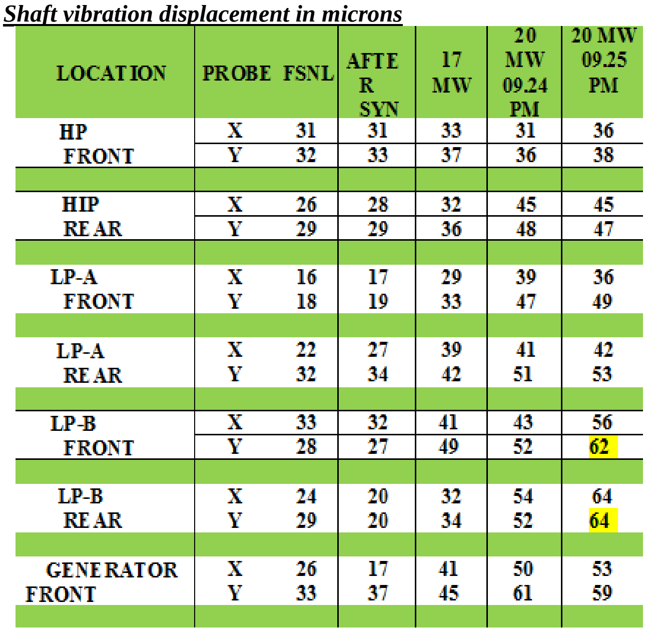


Fig-17: FFT bearing housing @20MW condition LP-B front bearing- Horizontal, Vertical & axial

IV.RESULTS

After observing the table1 and table 3 (at load conditions the vibrations were more and the unit is going to be tripped when the load is increasing) we are clearly noticed that the shaft vibrations are more at HP-B front and rear bearings as 291 and 264 microns. As we decided to go for a spectrum analysis for that points as the vibrations were more. We are started with Run up for identifying the critical speed shown in graph 1. We observed the critical speed around 2100rpm we suggested to not operate at that speed as it may create resonance. Then we have taken shaft centerline plots to identify the shaft moments. Collected the shaft vibrations from the Bently Nevada online monitoring system as the spectrums at different load conditions can be observed clearly in the graphs 4 & 5 were the highest peak is at 15-25 microns which is at FSNL condition. At 17MW and 20 MW loads the spectrums from the graph 6 to 9 indicates the highest peaks from 40 to 140 microns which indicates the vibration is more for the turbine, and the spectrum's clearly indicates the dominating peaks at less than 1X, 1X, 2X,3X and multiples of harmonics. With the help of the spectrums we suspect that there is a problem in shaft, as the machine is tripping when load is increased the O&M has opened the turbine and they have identified the shaft crack has a crack of 63mm after replacing the shaft we have taken the shaft vibrations mentioned in below table 4 and the housing vibrations in table 5. Now the vibration is in control as per the standards.

Shaft vibration displacement in microns



LOCATION	PROBE	FSNL	AFTER SYN	17 MW	20 MW 09.24 PM	20 MW 09.25 PM
HP FRONT	X	31	31	33	31	36
	Y	32	33	37	36	38
HIP REAR	X	26	28	32	45	45
	Y	29	29	36	48	47
LP-A FRONT	X	16	17	29	39	36
	Y	18	19	33	47	49
LP-A REAR	X	22	27	39	41	42
	Y	32	34	42	51	53
LP-B FRONT	X	33	32	41	43	56
	Y	28	27	49	52	62
LP-B REAR	X	24	20	32	54	64
	Y	29	20	34	52	64
GENERATOR FRONT	X	26	17	41	50	53
	Y	33	37	45	61	59

Table 4 shaft vibrations collected form online system after replacing the shaft.

BEARING HOUSING VIBRATION (RMS VELOCITY IN MM/SEC).

LOCATION	ORIENTATION	FSNL
Hip Front Bearing	**Horizontal**	**0.4**
	VERTICAL	**0.6**
	AXIAL	**0.2**
Hip Rear Bearing	**Horizontal**	**0.4**
	VERTICAL	**0.5**
	AXIAL	**0.8**
Lp-A Front Bearing	**Horizontal**	**0.5**
	VERTICAL	**0.8**
	AXIAL	**0.6**
Lp-A Rear Bearing	**Horizontal**	**0.3**
	VERTICAL	**0.9**
	AXIAL	**0.6**
Lp-B Front Bearing	**Horizontal**	**0.4**
	VERTICAL	**0.9**
	AXIAL	**1.0**
Lp-B Rear Bearing	**Horizontal**	**0.6**
	VERTICAL	**0.7**
	AXIAL	**0.8**
GENERATOR FRONT BEARING	**HORIZONTAL**	**0.7**
	VERTICAL	**0.9**
	AXIAL	**0.8**
GENERATOR REAR BEARING	**HORIZONTAL**	**0.6**
	VERTICAL	**0.8**
	AXIAL	**1.0**
EXCITER BEARING	**HORIZONTAL**	**0.7**
	VERTICAL	**0.8**
	AXIAL	**0.6**

V.CONCLUSION

With the help of Condition based monitoring we identified the problem before it fails, By comparing the above results tables 4 & 5 the displacement and velocity values were reduced from 296 to 62 microns and 4.9 to 0.9. Turbine is operating in Good condition as per the standards. We can identify the problems of different machines and sort it them before failure by using the Condition based Monitoring.

VI.FUTURE SCOPE

Now the research is carrying by the original manufacturers on the shaft crack which was observed 63mm the research is been carried out in the directions of operation problems, material problem, erection problem, etc. We are awaited to listen from the O&M about the shaft crack, for our future reference.

REFERENCES

[1] An Engineer's Guide to Vibration Analyzers and Dynamic Balancing, Edition 2010 By PRUFTECHNIK, Condition Monitoring, Ismaing, Germany.

[2] Basic Concepts of Turbo Machinery by Graint Ingram, Edition 2012.

[3] Turbo machinery: Design and Theory by Rama S.R. Gorla, Aijaz A. Khan, edition 2003.

[4] Beebe, R (1998a) Predictive maintenance by performance monitoring of plant MFPT Society 52nd Annual Meeting.

[5] Fundamentals of Turbo machinery By Venkanna Edition 2010.

[6] Coade, R W and Nowak, S (1993) Remaining life study of a 350MW HP/IP turbine Conference on pressure vessels and pipe work, Sydney.

[7] Turbo machinery By Earl Logan, Jr., Edition 2011.

[8] Groves, K (1996) Turbine steam path monitoring using plant DPA system unpublished degree major project Monash University.

[9] Haynes, C J; Medina, C A; Fitzgerald, M a (1995) The measurement of HP-IP leakage flow: the largest source of uncertainty in code tests of low pressure turbines PWR-Vol 28 IEEE-ASME Joint Power Generation Conference.

[10] Kuehn, S E (1993) Steam turbine technology keeps pace with demands Power Engineering.

[11] Leyzerovich, L (1997) Large Power Steam Turbines: Design and Operation Vol 2 PennWell ISBN 0 87814 716 0.

[12] McCloskey, T H; Pollard, M A and Schimmels, J N (1995) Development and implementation of a turbine-generator outage interval extension strategy PWR-Vol 28 ASME/IEEE International Joint Power Generation Conference.

[13] Sanders, W P (1989) Efficiency Audit of the turbine steam path, classifying damage and estimating unit losses ASME/IEEE International Joint Power Generation Conference.

[14] Tezel, F H et al (1989) Maintenance scheduling for steam turbine generators ASME/IEEE International Joint Power Generation Conference.

[15] Vetter, H & Schwiemler, G (1989) First turbine inspection after a 15-year operating period VGB KRAFTWERKSTECHNIK.

[16] ASME (1985) Simplified procedures for routine performance tests of steam turbines ANSI PTC 6S report 1974, reaffirmed 1985.

[17] Beebe, R (1995) Machine condition monitoring MCM Consultants. ISBN 0 646 250884

AUTHOR BIOGRAPHY

1. B. Uma Devi: Pursuing M. Tech in MLRIT (JNTU H), project under the guidance of Dr. S. Srinivas Prasad, Areas of interest vibrations, Thermal

2. Srinivasa Prasad S got PhD from Osmania University Hyderabad. Working as a Professor and Head in Department of Aeronautical Engineering, MLR Institute of Technology, Hyderabad. Areas of interests are Aerodynamics, Turbo machinery, Propulsion.

3. B. Arun Babu- Manager at M/s Aimil Ltd.

4. P. Mohan Swaroop- Senior engineer at M/s Aimil Ltd