Recent Trends in "Predictive Maintenance" & Significance of Transient Data Analysis & its Applications in Turbine Generator

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SYNOPSIS :
Transient data reveals much about the condition of machine which steady state data cannot. New technologies make this information much more available for evaluating the mechanical integrity of a machine train. Presently, machinery audits do not use transient data. Recent surveys at various stations indicate that throughout the power generation industry, simplicity is preferred over completeness in machine audits. This is most clearly shown by the number of rotating machinery Predictive Maintenance programs in which only static, steady state vibration amplitude is trended, while important transient vibration data is not even acquired. Efforts have been made to explain what transient data is, its importance, & the types of plots used for its display and its effective utilization for analysis. A Case Study highlighting the presence of rotor instabilities on account of shaft proceeding towards the bearing center at a speed of 2957 rpm, experienced in a 100 MW unit, is presented by the author in this paper to show significance of measurement of transient data & its effective utilization in power station's rotating machinery for resolving complex & chronic problems of turbine generators.

GLOSSARY:
SAC: Shaft Average Centerline,
MW: Megawatts
ER/EC: Eccentricity ratio
SAF: Synchronous Amplification factor: A measure of the rotor susceptibility to vibration when rotational speed is equal to a rotor lateral natural frequency.
SQDS: Synchronous Quadrature Dynamic stiffness: Inversely related to the synchronous amplification factor . It is an indicator of rotor damping

1.0 INTRODUCTION
Vibration data can be acquired from a machine when it is operating at constant speed / load, and both are changing. Each is important for understanding the machine's condition. Steady state data, acquired under constant machine conditions, is an essential part of most machinery predictive maintenance programs. However, many of these programs neglect to obtain important data from startups & shutdowns i. e transient data. A machine's vibration response, as it changes speed, tells us much about the nature of the forces and stiffness acting on it. This perspective cannot be supplied by steady state data.

What Transient Data is & why it's important: -
Transient data is the unsteady-state response of a dynamic system to a changing excitation. Transient data is amplitude, phase, frequency, position & process data & depends on two main factors namely.

i) **Speed dependent: -** It is experienced that small change in speed in operating frequency range from 47.5 HZ to 51.5 HZ can change the location of rotor in the bearing clearances & subsequently loading on the bearing.

ii) **Load dependent:-**It is also experienced that a small change in the electrical & mechanical load on the machine affects the location of rotor in the bearing clearance & subsequently bearing loading due to changes in EC (eccentricity ratio) value.

Necessity of Transient Data:
The performance of vibration analysis on critical machines during the transient event is a common practice due to following reasons

a) To determine machine condition before & after overhaul
b) To determine the effect of disturbances on machine during normal operation

c) To verify Machine Design & specification

Transient data can identify: -Slow roll speed, Slow roll vector, Mode shapes, Balance resonance speeds, Synchronous amplification factor, Synchronous quadrature dynamic stiffness, Load, Rubs, Instabilities & Shaft cracks:

2.0 TRANSIENT DATA FORMATS:-

The most common presentation plots used for transient data analysis are:-

a) Polar & Bode Plots
b) Orbit Analysis
c) Shaft average centerline analysis
d) D C Gap Voltage Plot
e) Full Spectrum (negative/positive spectrum)
f)APHT (Amplitude/Phase/Time)
g) Spectrum Cascade/waterfall

a) ***Polar & Bode Plots:*** **are** used to document the presence of balance resonance and to determine Synchronous Amplification factor(s) of the rotor/bearing/support system for the assessment of damping in the system.

b) ***Orbit Plot /Time base plots***: - are used to examine phase lag angle, confirm overall amplitudes, frequency, shape (form) of dynamic motion of the rotor. An Orbit plot shows the dynamic, two-dimensional path of the average shaft centerline motion of a machine component observed by XY transducers, in the plane of those transducers.

c) ***Shaft Average Centerline Plot:*** is used to track the location of the shaft average centerline with respect to geometrical bearing centerline. We can have reliable information pertaining to what is happening to rotor lift / radial position during startup & shutdown of the machine as well as during thermal abnormality or load changes.

Average eccentricity ratio is a relative measure of the shaft's position between the center of the bearing & the bearing wall. A decreasing eccentricity ratio can indicate a potential stability problem & increasing eccentricity ratio can damage the bearing.

d) ***DC Gap voltage plot***: -is used to show changes in gap voltage from a proximity transducer with respect to time or shaft speed. Excessive changes in position can lead to thrust bearing failure or rotor -to-stator rubs.

e) ***Full spectrum:*** **-** The FFT X &Y vibration transducer signals (direct part & quadrature part of an FFT input) are useful because vibration components are identified not only in term of frequency & amplitude but also in term of their direction of precession.

f) ***APHT Plots***: shows variation of phase & amplitude with time. Shaft crack detection methodology uses this plot as a useful tool to monitor 1X & 2X amplitude & phase.

g) ***Spectrum Cascade & waterfall***: are used to track changes in spectral content during start-up or coast-down or over a period of time. They show individual frequency spectra as a function of RPM (Cascade) or time (Waterfall).

3.0 CASE STUDY USING TRANSIENT & STEADY STATE DATA ANALYSIS

3.1 Introduction & History:-

BTPS is situated near New Delhi, India & having five units with an installed capacity of 705 MW. TG#2 Russian make, comprises of several turbine casings & rotors (HP, LP & Generator) and are supported by six Journal bearings alongwith with an additional journal bearing provided for main exciter as shown in Fig No 1.

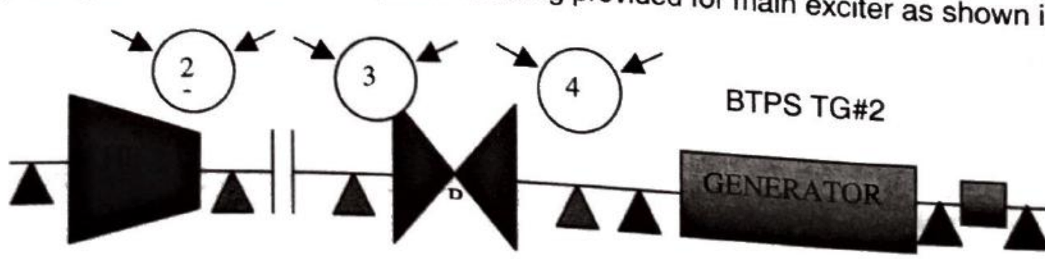


Fig No 1

Turbine generators are supported on a foundation block, which is made of a concrete structure and a steel fabrication. Turbine generator bearings are equipped with on-line pedestal vibration monitoring system. The unit was operating normally since last 2 years with maximum vibration level of the order 55-60 microns pk-pk at (Bearing 2H&3V) which is close to upper zone of satisfactory limits as per international standard for casing vibration limits.

On 8th April 1998, the bearing no 2 & 3 vibration levels suddenly increased to an unacceptable limit i.e. 190 micron pk-pk. The pedestal vibration signatures revealed that ½ X rpm is predominantly present at BRG No 2, 3 & 4 which could be due to rubbing between stationary & rotating parts, instability, higher order looseness & heavy misalignment. The machine was tripped and rolled again to reassess the vibration behavior. After a few hrs of operation the machine had repeated the same behavior. Therefore unit was shutdown for inspection.

3.2 *Observations:-*

The 10th April machine was stripped. On inspection following were observed.

- Bearing no 2,3,4, & 5 inspected & found OK.
- Coupling Guard near bearing No 2&3 found loose.
- One oil guard near Bearing 4 &5 found free & resting on the Generator coupling.
- HP shaft expansion bellow checked by DPT & found OK. HP & LP rotors sandblasted
- Further, complete alignment of all rotors was checked to find out the exact cause of ½ X rpm vibration. In fact nothing could be concluded with available pedestal vibration signatures & operation parameters.

BTPS was advised to install Proximity pickups at all the turbine bearings for better understanding and for identification of root cause. Accordingly, the proximity pickups & associated Transient data Manager were installed for the identification of root cause.

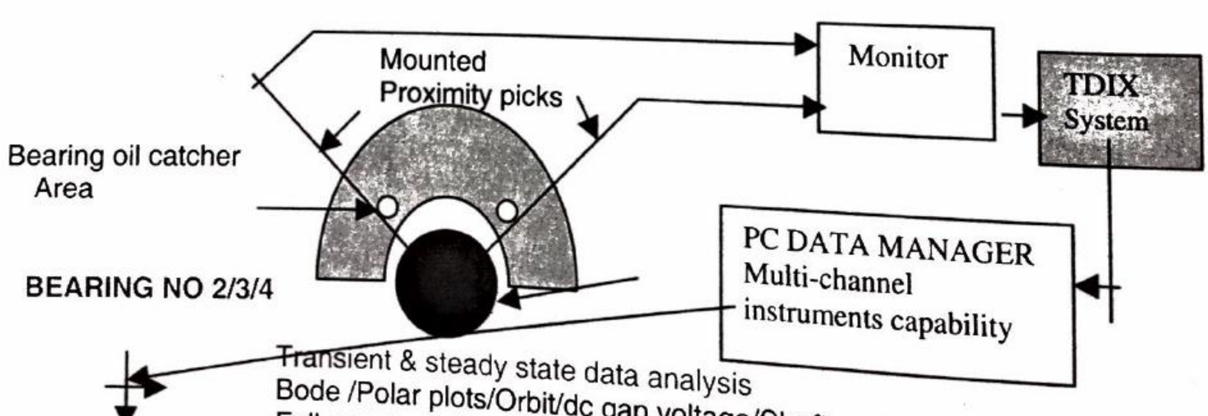
3.3 Vibration Measurements & Diagnostics Analysis

The machine was rolled after overhauling on 31st May'98. During start up data acquisition, it was noticed that shaft vibration readings at bearing no 2, 3, & 4 touched the value of 300 microns pk-pk amplitude. The bearings' pedestal vibration readings recorded high (of the order of maximum 70 microns pk-pk) which had a tendency to rise with rise in grid frequencies. The amplitudes at Bearing 2, 3 were more than normal and it called for in-depth analysis of the diagnostics plots available in the system.

	TRANSIENT DATA ANALYSIS				STEADY STATE DATA		
	31 ST MAY 98				1 ST June 9 8 / 9 Th June 98		
	BRG NO 2	BRG N03	BRGNO 4	PEED	BRGNO 2	BRG N03	BRG NO 4
ER	0.17	0.7	0.89	2919	0.3	0.9	0.8
Orbit Plots	The ½ is predominant. A small internal loop with forward precession Orbit is highly preloaded Shape of orbit at various speeds, in the shape of banana flat at one side. Forward precession in all speed ranges	Slow roll vector is considered to be an acceptable Orbit is pre-stressed & highly preloaded Forward precession	Slow roll vector is considered to be an acceptable Orbit is pre-stressed & highly preloaded Forward precession	2919	The ½ is predominant. A small internal loop with forward precession ½ x rpm = 50 1 x rpm = 215 2 x rpm = 20	1 x rpm is predominant Orbit shape is constant ½ x rpm = 20 1x rpm=100 1 x rpm = 240	

Half spectrum Plot	½ x rpm = 100 1 x rpm = 220 1.5 x rpm = 18 2 x rpm = 25		→ →	2955 2957	½ x rpm = 50 1 x rpm = 215 2 x rpm = 20	1x rpm = 250 1x rpm=100 ½ xrpm=40; ½xrpm =30
	1 x rpm = 210 2 x rpm = 20		→ →	2476	½ x rpm = 280 1 x rpm = 210	1x rpm=240 1x rpm=100 1.5x rpm =18
	½ x rpm = 360 1 x rpm = 240 1.5 x rpm = 40 2 x rpm = 15		←	2988	1.5 x rpm =25 2 x rpm = 20	
	½ x rpm = 360 1 x rpm = 240 1.5 x rpm = 40 2 x rpm = 15		←	2990		1x rpm = 250 1x rpm=100
	½ x rpm = 100 1 x rpm = 240 1.5 x rpm =15 2 x rpm = 25		←	3014		
	½ x rpm = 360 1 x rpm = 240 1.5 x rpm =40 2 x rpm = 20		←	3062		
	½ x rpm = 5 1 x rpm = 260 1.5 x rpm =40			3102		

ER: Eccentricity ratio



The pedestal vibration signatures indicated that the ½ x rpm is still predominant in bearing no 2H & bearing 3V. The shaft vibration measurements & transient data formats as shown above were used for the analysis of ½ x rpm vibration problem, which were not available earlier.

4.0 ANALYSIS CONCLUSION & RECOMMENDATIONS

The shaft average centerline plots, taken during transient condition as well as during the steady state condition indicated that eccentricity ratio at bearing no 2 was very low which appeared to occur at about 1056 rpm. However, the eccentricity ratio at bearing no 3 & bearing no 4 was very high with a value of 0.8 to 0.94 respectively. This concludes that bearing no 2 is not providing any support to the rotor, while bearing no 3 & bearing no 4 are highly preloaded at all speed range as well as during steady state condition.

The reason for bearing 2 not loaded is of extreme tilting of pedestal of bearing 2 & 3 towards HP, which is caused by forces exerted by the LP casing expansion & HP/LP coupling dynamic misalignment. This seems very true since bearing no 3 carries a heavy load. It is also noticed that rotor becomes unstable between the speed range of 2957 rpm to 3000 rpm, and exciting ½ x component at bearing no 2 only. From the shaft average centerline plot analysis, it seems that bearing no 2 eccentricity ratio, in the operating frequency range is hunting & creating instabilities on account of shaft proceeding towards bearing center at a speed of 2957, whereas as eccentricity ratio at bearing no 3 & bearing 4 remaining constant.

In order to overcome this problem, following was suggested

- The first method, tried, was to change the bearing lubricant temperature when machine was under operation but it proved to be ineffective.
- The second method was suggested to lift bearing no 2 to increase loading or create controlled misalignment with due care not to increase too much pre-loading on the rotor

5.0 IMPLEMENTATION OF RECOMMENDED ACTION PLAN

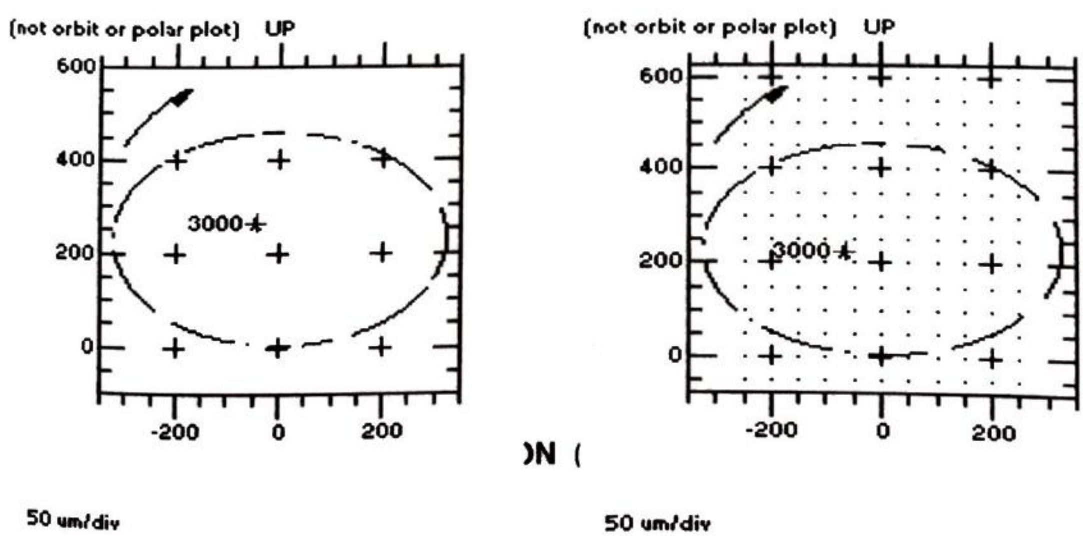
- Bearing No 2 was inspected and found OK.
- The bearing No 2 was lifted by 0.15 mm to increase the loading.

6.0 FINAL RESULTS

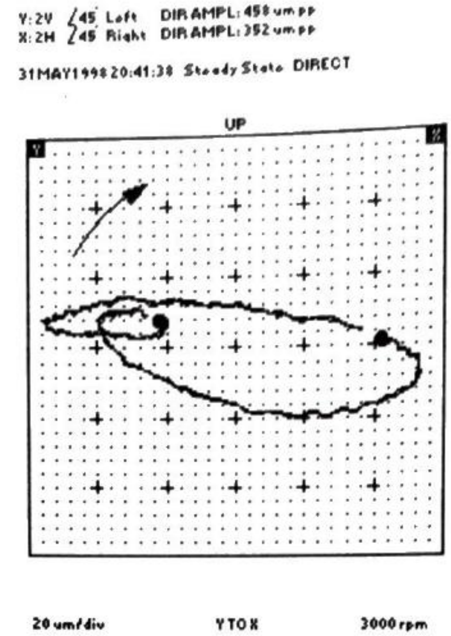
The ½ x rpm component of shaft vibration at bearing 2 caused by rotor instabilities disappeared as can be seen in the full spectrum plots, Average shaft centerline plots & Orbit plots. The rotor became stable and pedestal vibrations also reduced to an acceptable limit

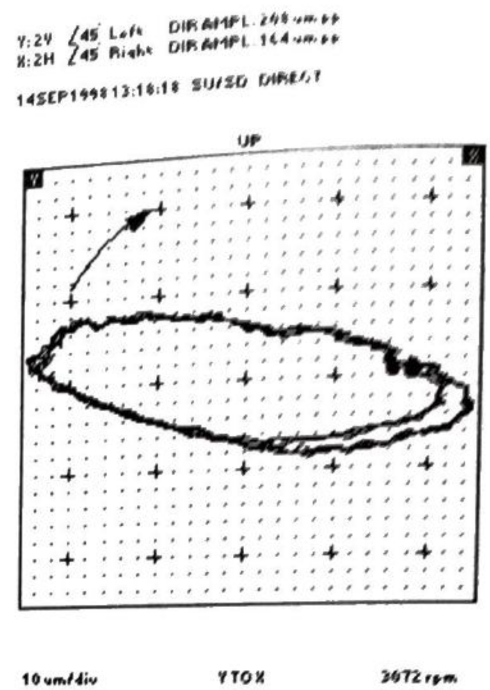
BEFORE & AFTER CORRECTION (shaft centerline plots)

POINT: 2V ∠45 Left REF: -11.1 V	POINT: 2V ∠45 Left REF: -9.91 V
POINT: 2H ∠45 Right REF: -11.3 V	POINT: 2H ∠45 Right REF: -10.03 V
From 31MAY1998 20:40:50 To 31MAY1998 20:4	From 14SEP1998 13:09:49 To 14SEP1998 13:09:



50 um/div	50 um/div



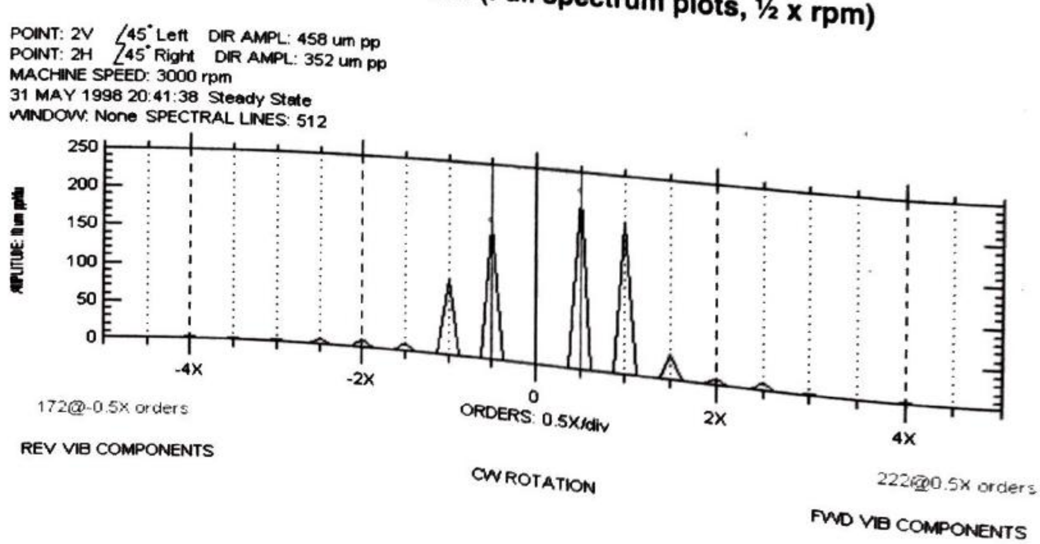


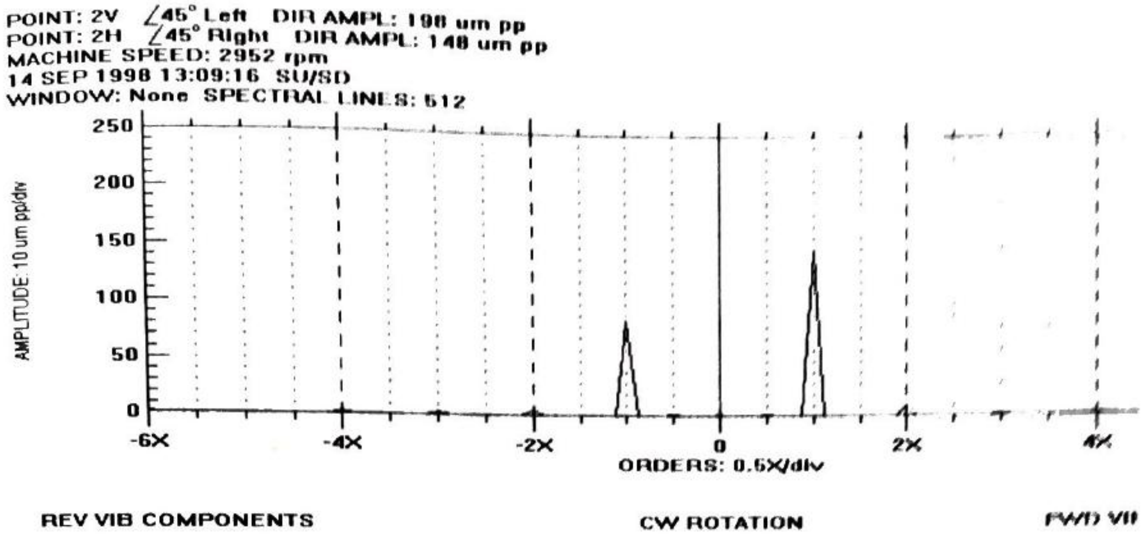
BEOFRE LIFTING 3000RPM				AFTER LIFTING 3000 RPM		
SN	BEARING	ER	SHAFT VIB Y/X	ER	SHAFTVIB Y/X	LOADING
1	BRG NO2 V/H	0.14	458 352	0.205	208 164	IMPROVED
2	BRG NO 3V/H	0.80	396 238	0.80	214 123	CONSTANT
3	BRG NO 4V/H	0.90	95 107	0.90	94 104	CONSTANT

7.0 CONCLUSION

The transient data revealed machine characteristics that were not evident in the steady state data. Although both types of data taken from the same transducers, yet the transient data contained more information. It showed the machine's response over a wide range of rotor speeds, while the steady state data showed its response at only one speed. This proves that use of proximity pickups can be of immense help to the diagnostics engineers for identification of the complex & chronic problems. Shaft centerline data as shown above supported our conclusion. It showed that the rotor is operating near the center of the bearing.

BEFORE & AFTER CORRECTION (Full spectrum plots, ½ x rpm)





8.0 FINAL RECOMMENDATIONS

- To install two non-contact pickups in all the bearings for shaft vibration monitoring as it reveals other machine characteristics, which seismic can not.
- To record transient data as & when they occur & also produce on-load transient data of consistent quality to document the behavior of machine automatically.
- To record pre & post overhauling transient data for comparing & assessing the machine performance because it contains more information than Steady state data

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