Orbit-An effective Diagnostic Tool for High Speed Turbo Machines

Author 1: VIJAYKRISHNAN, Condition Monitoring consultant, SANA info tech and industrial services, vijaynow@yahoo.com

Author 2: KEYVAN EHSANI FARD, Condition Monitoring executive manager, SANA info tech and industrial services, ehsani_fard@hotmail.com

Key words: Condition Based Maintenance-Turbo machines-Orbit

SUMMARY

Fault diagnosis through vibrometering in turbo machines is not like usual as in these machines usual spectrums give fundamental peaks only (1*RPM, 2*RPM, ..) for every fault and phase measurement is not possible as no rotary part is available. That's why ORBIT analysis is highly important for turbo machines fault diagnose.

In the following article, after a discussion in Condition Based Maintenance and it's requirements, a real case study about an Air Compressor in utility plant of BIPC (Bandar Imam Petrochemical Co.- Mahshahr, Iran) is introduced and role of orbit analysis in fault diagnose is cleared.
INTRODUCTION
The increasing demand for maximum utilization of installed plant equipment has envisaged change in the maintenance philosophy from that of a time based maintenance to that of running the equipment till the end of its useful life through a condition based maintenance.

Condition Base Maintenance
The increasing demand for maximum utilization of installed plant equipment has envisaged change in the maintenance philosophy from that of a time based maintenance to that of running the equipment till the end of its useful life through a condition based maintenance.
Nowadays less people have to get better results in a shorter time, measuring on machines that do not have the same mechanical redundancies as older, slower and more massive constructions. Working harder cannot do that, as we have to make faster decisions with the tools available. Today's maintenance staffs want as much hard evidence as they can to prove that they are preventing downtime costs by stopping a process to replace a bearing or for any other corrections to be carried out. They also want extra data to improve on High RPM applications like Turbo Compressors and Turbines in Process, Petro-chemical Plants & Refineries, where the typical Time Wave Form, Orbit Analysis and Bode Plots are to be carried out as more data is better to make an accurate evaluation. Consultants in Condition Based Maintenance are in demand and often help in preventing failures by pinpointing the exact defects through such Analysis. The definition of what constitutes a “failure” for a piece of equipment is normally broadened to include speed and load reductions which impact production.

The advantages of condition-based maintenance over preventive maintenance are given below:

- Unnecessary stopping and opening of equipment is avoided.
- Probable defects are known prior to the stoppage.
- Equipment outage can be planned in advance for efficient and effective utilization of resources.

Orbit-An effective Diagnostic Tool for High Speed Turbo machines
Equipment life extension through trend monitoring.

**ORBIT ANALYSIS**

ORBIT analysis is an examined method for fault diagnosis of Turbo machines. Some of the reasons are as follows:

- Most of the time rotating parts of a turbo machines are not accessible. So, data collection using site results faults that based on the machine design could be not acceptable (Bearing absolute method is not accepted usually).

- Almost all Turbo machines use proximity probes for monitoring the amplitude (Displacement) of the rotating shaft. Using connected gauges is possible. In case an analyzer like Schenck vibroport-30 or a higher level instrument be available checking the gauges and parallel data collection is also possible. Besides, in case an oscilloscope be available, getting time waveform from horizontal and vertical channel results in getting ORBIT waveform which is due to mixing X and Y channel of oscilloscope automatically.

- Using ORBIT analysis almost all common faults of a Turbo machine can be detected preventively. With no fault horizontal and vertical time waveforms are sinusoidal, so the resulting ORBIT is nearly a circle. Different faults can change the shape of circle into an ellipse, change the smoothness of the shape, bend it and/or truncate the shape (following case).

**CASE STUDY**

The case study considered is an Air Compressor carried out at one of our Client's site during Implementation of Condition Based Maintenance in a Large Petro Chemical Complex. All the evidence was made available to prevent a breakdown but still the failure was unavoidable basically due to production constraints and lack of confidence in Condition Based Maintenance.

The equipment is isothermal type high speed centrifugal Compressor, horizontally split type casing, mounted on the base plate supplied by Mitsui Shipbuilding & Engineering Co. Ltd.
The side of the casing consists of the suction nozzle, diffusers, coolers, return channel discharge spiral and a space for a Rotor.

The rotor consists of a shaft on which 7 stages of impellers, shaft bushing, thrust collars, shaft coupling and the like are fitted. The impeller is double shrouded type, of which the main disk and shroud are welded together. The rotor is supported by the bearing equipped on each side of the compressor casing and is turned by a turbine (driver) through the shaft end coupling.

DETAILS OF AIR COMPRESSOR

Machine Description: TURBINE DRIVEN CENTRIFUGAL COMPRESSOR

Operating speed of Compressor: 10750

Type of Driver: Steam Turbine

Rated KW: 2970

Capacity: 23000 Cubic meters / Hr

Suction conditions: Pr. – 0.99 Kg/sq.cm, Temp. + 48 to 52 Degrees C.

Delivery Conditions: Pr. – 10.63 Kg/sq.cm, Temp. + 101 Degrees C.

Coupling: Flexible and diaphragm

Type of bearing:

(Discharge side) Compressor Drive end - Tilting pad type Journal Bearing

(Suction Side) Compressor Non-drive end- Tilting pad type Journal Bearing & Thrust bearing

Vibration Monitoring system: Bently Nevada 7200 series

(Alert level 45 microns & Danger Level 70Microns)
Portable instruments used for Analysis:

1. Schenck Vibroport - Model 30
2. Textronik Oscilloscope

History of the Machine

The plant has four compressor units. All the four units are in continuous operation. Before the failure, the compressor was running at full capacity.

For 2 months the vibration levels were above the Alarm value (45 microns) in the control panel at the Compressor drive end location. The records of data taken from control panel are shown in Table 1/1. Vibration spectrum taken using Vibroport Model 30, indicated clearly 1 x RPM Peak at location 3 (compressor coupling side) as shown in Fig-1. But decision regarding the cause of high Vibration could not be identified from the spectrum. Phase measurements were not possible as no part of the shaft is accessible.

This problem was brought to the Author's notice and we decided to use the available tools to analyze the High Vibration. It was decided to use a two-channel instrument for recording the Orbit. This was not readily available in the Complex as it was under repair. The above mentioned model Oscilloscope was available but the Critical Machinery Department, which carries out regular Vibration Monitoring throughout the Complex were not conversant with Orbit Analysis but cooperated for carrying out the Analysis.
**Table 1: Vibration Data Sheet**

<table>
<thead>
<tr>
<th>MACHINE NAME:</th>
<th>Air Compressor</th>
<th>DATE:</th>
<th>26.06.02</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUSTOMER NAME:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MACHINE DETAILS</th>
<th>MACHINE MOUNTINGS</th>
<th>Y/N</th>
<th>TYPE OF BEARING</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRIVE</td>
<td>INTER</td>
<td>DRIVEN</td>
<td>AT GROUND LEVEL</td>
</tr>
<tr>
<td>RPM</td>
<td>10714</td>
<td>-</td>
<td>10714</td>
</tr>
<tr>
<td>KW</td>
<td>2570</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CLASS</td>
<td>ON STEEL FLOOR</td>
<td>Y</td>
<td>G.B. RATIO</td>
</tr>
<tr>
<td>MAX. D.</td>
<td>68µm</td>
<td>ON VIBR DAMPERS</td>
<td>N</td>
</tr>
</tbody>
</table>

**OBSERVATIONS:**

**ADDITIONAL DETAILS:**

- **D:** Displacement in microns (Pk-Pk)
- **V:** Velocity in mm/sec (RMS)
- **a:** Acceleration in g
- **gSE:** Gravitational Spike Energy in gSE
- **H:** Horizontal
- **V:** Vertical
- **A:** Axial

**At 10714 RPM**

<table>
<thead>
<tr>
<th>Point</th>
<th>Panel readings in microns Pk-Pk</th>
<th>Panel readings using Schenck Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>1 V</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>2 V</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>3 V</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>4 V</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>5 V</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>5 V</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>6 V</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>6 V</td>
</tr>
</tbody>
</table>

Table 1/1-Panel reading data's using Panel gauges and Schenck instrument

**Orbit-An effective Diagnostic Tool for High Speed Turbo machines**
The Time wave form & Orbit Analysis carried out using Oscilloscope showed a truncated wave and Orbit, Refer Figure 2. Such Truncation in Wave Form and Orbit indicates straining of load carrying parts, in this case the coupling. The elliptical shape of the Orbit indicates that Misalignment as the cause of the problem. Hence from the above data’s collected, it was concluded that the coupling misalignment between the Turbine and the Compressor was the cause of High Vibration and recommendations were given to the Customer. As the concept of Analyzing through Orbit and Time wave form was not familiar with Critical Machinery Department and in the Complex, there was reluctance in accepting the recommendations.

They decided to increase the speed and monitor the trend in Panel Readings. When the speed was raised to 11000 rpm the increase in vibration was found to be 70 micron at journal bearing location No. 3 (discharge side of compressor). This further confused the Critical Machinery Department team as they suspected it to be Unbalance. It was decided that the machine will continue to be in operation at 10700rpm, though it was objected by us, for
want of Production and will be stopped on urgent basis for the checking of misalignment (as predicted before) and also check the journal bearing at discharge side of the turbo-compressor.

![Figure 2:Horizontal & Vertical Time waveform and resulted Orbit](image)

**OBSERVATIONS**

1. It was found that the coupling spacer was displaced from its central axis and cracks noticed in the coupling flange.

---

Orbit-An effective Diagnostic Tool for High Speed Turbo machines
2. On disassembly of compressor top casing, the 1\textsuperscript{st} Stage Diffuser vanes were not found and only metallic powder with small broken metal pieces of vanes noticed. All the remaining Diffuser vanes were found to have cracks. There was excess rubbing at rotor surface. The bearing along with the bearing housing at discharge side of compressor was found deformed and also having multiple ring of scratching and impact marks on the inner surface of the bearings. Excess rubbing at the rotor surfaces was noticed. The impeller along with diaphragm and labyrinth was found damaged.

**SEQUENCES OF FAILURE**

1. The coupling misalignment has caused rupture (crack) development in the coupling flange.
2. The rupture in turn lead to further increase in misalignment and subsequently the effect was the bending of the compressor shaft at the Coupling end.
3. The bend shaft has displaced the rotor which in place has caused the rubbing of rotor.
4. This led to the damage of rotor vanes, diaphragm, labyrinth and other parts.
5. Abrupt increase in vibration due to uneven rubbing & damages caused the bearing at the compressor discharge end rip open and the bearing housing damaged.

As the spares were readily available the equipment was brought back to Normal operation within 10 days. The spares & maintenance cost envisaged towards this Breakdown was estimated to $50,000/. This cost does not include the production loss incurred.

**CONCLUSION**

1. The failure of compressor was due to high vibration attributed by misalignment at the initial stage of deterioration of machine and subsequently compound effect of misalignment, excessive rubbing.
2. The compressor unit has no trip system in case the parameters are above the recommended values.

3. It was decided by the management to Train the Critical Machinery Department in Orbit Analysis and to effective implement Condition Based Maintenance in all the Critical Machines.

RECOMMENDATION SUGGESTED

1. The cause and its diagnosis in case of abnormalities like high vibration, high temperature, Noise must be attended on priority.

2. It is necessary to incorporate the trip system in compressor control system of all units, considering the parameters like vibration.

4. The reason for vibration of machine at alert level should be always diagnosed at the first hand and the machine should be brought to normal operating mode.

5. The Rpm of the compressor at the site and the control room should be simulated and re-calibrated to give the correct reading so as to control the varying load.

6. There should be a standby Air compressor.

7. Training in Orbit and Time Wave Form to be provided for Critical Machinery Department.

References: No special reference as the article is due to a real case study.