Shaft Eccentricity and Bearing Forces

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Plant

Equate Petrochemical Company, commissioned in 1997, is the biggest petrochemical plant in Kuwait. The plant comprises 5 units and produces the basic petrochemicals such as Ethylene, polyethylene, polypropylene and ethylene glycol.

Case

The polyethylene unit operates three Cycle-gas Compressors, all driven by Induction motor. These Compressors are used to circulate Ethylene gas through the reactor beds. On February 15,1999, the compressor in line-2 was taken for a short shutdown, to inspect the Motor internals and the bearings. The inspection was initiated, followed the reported high vibration on the motor, during the previous startup attempts.

The Single stage overhung, AC Compressor, driven by 6705HP motor, operates at 2995 rpm. The Compressor handles Ethylene gas with inlet capacity 29455ACPM at a total head of 18.6 psia. The motor operates above its first system critical (2400 rpm) and is supported on pivoted shoe journal bearings.

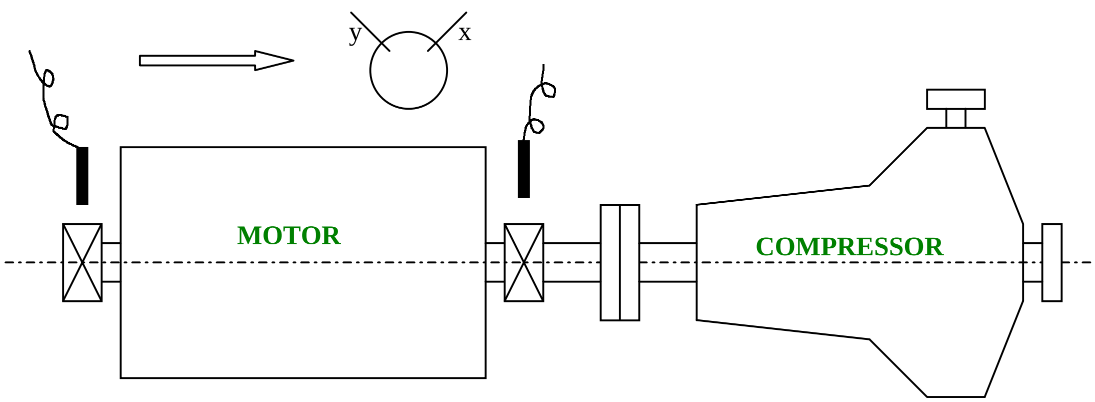

Fig 1. Line-2, AC Compressor Machine train

The Machine is equipped with Bently Nevada 1800 Monitoring system and the vibration signals along with the process variables are fed to the DCS, in the control room, wherefrom the alarms and the trips are initiated. The data are also routed and stored in the PI Server (plant Information server) and made available plant wide, to generate /analyze historical trends of vibration and process variables.

Vibration data during the start-up and steady state was collected using a Bently Nevada ADRE. During the outage the Motor outboard bearing assembly was replaced and the machine was put online on 17/2/99.

Machine Behavior

Transient data

The Machine started off normally and the vibration amplitudes during the critical speed and at the running speed remained within the limit. The maximum vibration level observed at the Motor outboard was 1.85mils(47microns), at the critical speed. The vibration level at the rated speed, immediately after start-up, settled down to 35microns, which was high as compared to the normal start-ups.
The Bode plot shows split resonance on both the bearings. No sub synchronous and non-synchronous components were detected.

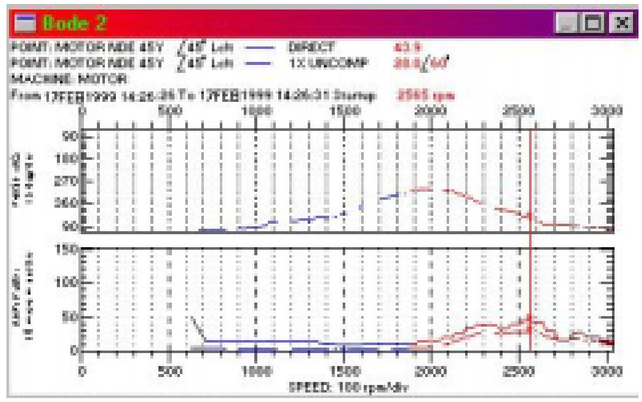

Fig 2. Bode plot of Motor outboard Y-probe

However, the Vibration behavior at the steady state started showing unprecedented fluctuation.

Steady state data

The Fluctuation of vibration level at the Motor Outboard was gradual and initially the vibration amplitudes increased more than 2mils and started reducing, but the fluctuation persisted. The loading cycle of this compressor is normally 4 to 6 hours.

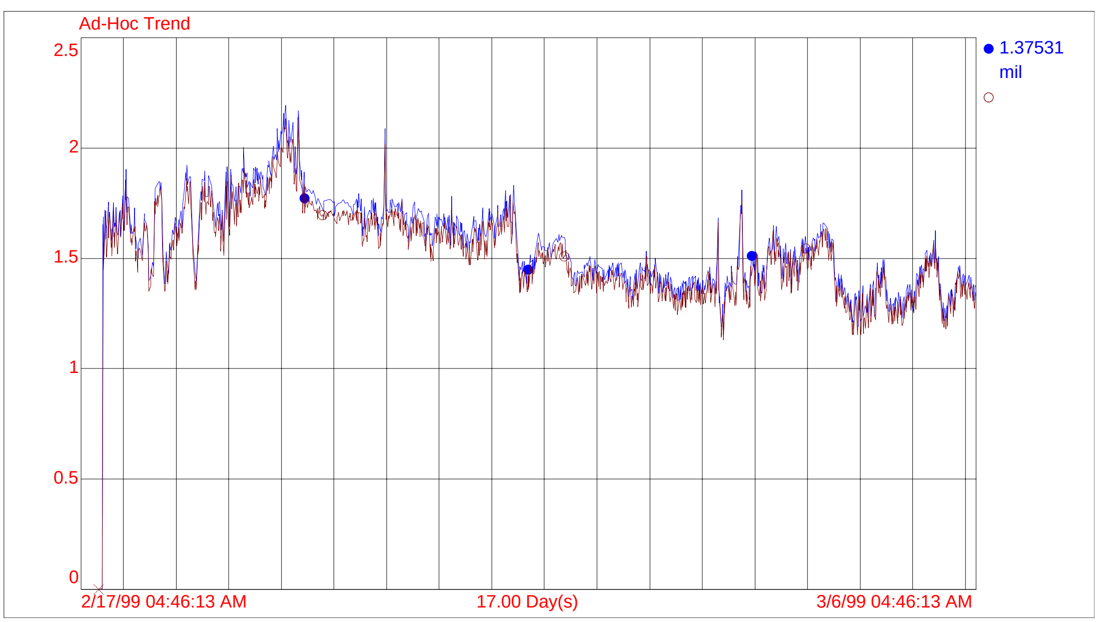

Fig 3. Trend plot of the Motor Outboard Vibration

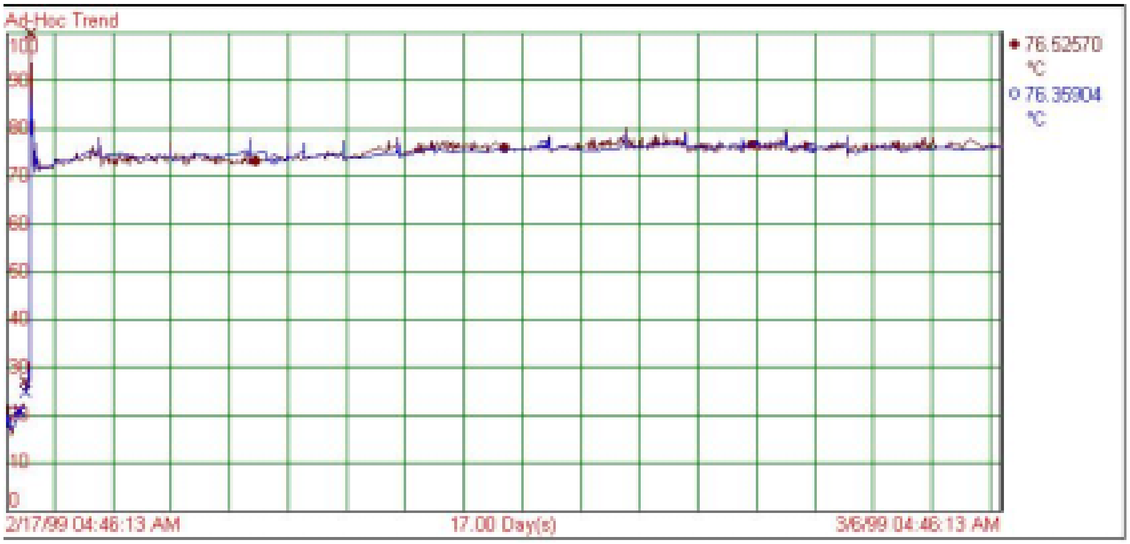

Fig 4. Trend plot of the Motor Outboard Bearing Temperature

Fig.3 and Fig.4 show the trend data of the Vibration and bearing temperature at Motor Outboard. The normal Vibration level on this machine is less than 0.7mils-.The Overall Vibration level as well as the bearing temperature is observed more than the normal levels. The Vibration level during the loading went to a maximum of 2.2mils and started falling off, once the load was stabilized.

The process was stabilized after about 6 hours and the data presented represents vibration and the process data, sampled as specific time intervals. Vibration data was collected for almost 10 hours at different time intervals

Analysis

1. Process data

Though, contribution from any process abnormality, all the way to the Motor outboard was a remote possibility, process variables were also included for the analysis. The process data at the same timestamp as that of the vibration data were extracted from the PI server and trended. The trend data showed no process abnormalities except the small variations, which was normal during the loading cycle.

Process Trend:-

No.	Time	IGV Opening	Mass Flow	Motor Current	Suction Presure	Brg.Temp
1	2/17/99 14:30	40.66733932	386.0097961	94.43223572	7.676381588	43.9824028
2	2/17/99 14:35	59.99938965	401.9990234	95.95191956	7.924175262	79.05123138
3	2/17/99 14:44	59.99938965	428.6314087	98.48316956	8.266348839	73.55028534
4	2/17/99 14:45	59.99938965	431.62323	98.76753235	8.304788589	74.07134247
5	2/17/99 14:56	59.99938965	462.9641113	101.7462997	8.707457542	77.11569977
6	2/17/99 15:01	59.99938965	479.7380981	103.3405685	8.957849503	72.7845993
7	2/17/99 15:12	54.86698914	511.078949	106.3193359	9.495598793	76.86551666
	The machine was stabilized at around 17Feb1999 22:00 hours					

8	2/17/99 23:20	71.99926758	329.3760986	89.37216949	7.900234699	72.4953537
9	2/17/99 23:29	71.99926758	431.0992432	100.099823	9.142612457	72.51251221
10	2/18/99 12:00	23.20017052	1122.449463	163.7938995	24.21921921	74.82366943
11	2/18/99 12:19	23.20017052	1122.425537	163.8482361	24.22993279	74.89588165
12	2/18/99 12:21	23.20017052	1122.423096	163.8535919	24.23314095	74.90299988
13	2/18/99 12:26	23.20017052	1122.417603	163.8661957	24.24069023	74.91973877

Fig 5. Process Data imported from PI server

The vibration level continued to show fluctuation and the bearing temperature remained at around 76 deg with no increasing trend. As the levels, were less than the alarm setpoints, the machine was allowed to operate till the next emergency shutdown was scheduled. The Vibration levels and the bearing temperature were kept under close monitoring.

2. Vibration Phase data

The amplitude fluctuation could be attributed to any rub and local heating of the rotor, creating thermal unbalance along with the mechanical unbalance. **As the resultant of the thermal and the mechanical unbalance, is not a fixed vector in the shaft rotating shaft reference frame, 1X phase angle is also expected to change along with the amplitude**. But, no significant shift of 1X rpm phase angle was observed and the vibration levels were also acceptable **The Bode plot of the 2X component also ruled out the existence of shaft asymmetry due to any shaft crack.**

Vibration Trend:

No.	*Time*	Motor Outboard Vibration X Probe		Motor Outboard Vibration Y Probe	
		Overall	*1X Rpm ,Phase*	*Overall*	*1X Rpm ,Phase*
1	2/17/99 14:30	15.5	10.3@187	15.3	10.4@94
2	2/17/99 14:35	36.6	33.6@176	34.9	31.6@90
3	2/17/99 14:44	45.1	39.4@189	42.1	36.3@88
4	2/17/99 14:45	44.8	41.4@176	41.7	38.3@86
5	2/17/99 14:56	46	40.2@177	42.8	37.9@89
6	2/17/99 15:01	45.5	40.8@179	43	38.9@90
7	2/17/99 15:12	42.3	39.7@180	39.8	36.3@92
	The machine was stabilized at around 17Feb1999 22:00 hours				
8	2/17/99 23:20	47.7	44.5@175	46.4	43.5@86
9	2/17/99 23:39	47.9	46.4@176	46.1	43.4@88
10	2/18/99 12:00	47.2	45@179	45.2	42.1@89
11	2/18/99 12:19	46.2	43.1@178	43.8	41.5@89
12	2/18/99 12:21	44.1	42.1@177	42.3	39.4@88
13	2/18/99 12:26	44.5	41@179	42.7	40@89

Fig6. Amplitude and phase data after motor reached rated speed

3.Shaft Centerline data

Shaft eccentricity plot shows shaft equilibrium position inside the bearing. The net static forces on the shaft at this position should be zero during steady state condition.

The data from the ADRE was imported to excel sheet, to generate a trend plot of the shaft position, at the same timestamps as that of the above process and phase data. **The plot at Motor outboard showed abnormal variation in the shaft attitude angle. The shaft movement is shown in the fig 7.**

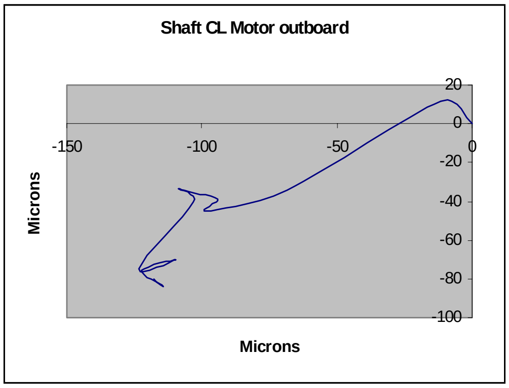

Fig 7. CL including start-up

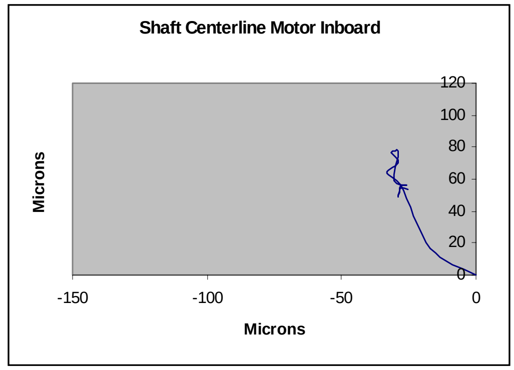

Fig 8. CL including start-up

Fig 8 shows the shaft CL plot at Motor Inboard, where the shaft position is normal compared to the Motor Outboard-Fig 7. The plots of the Compressor bearings were also normal. As the source of the abnormal behavior was obviously pointing towards the outboard bearing, it was decided to open and inspect the Motor Outboard assembly.

Motor bearing Assembly

The bearing is a pivoted Shoe Journal bearing with five pads and load-between-pads (LBP) arrangement. The measured bearing clearance varies from 120 Mic to 150 Mic. The bearing assembly with pad arrangement is shown in the Fig 9.

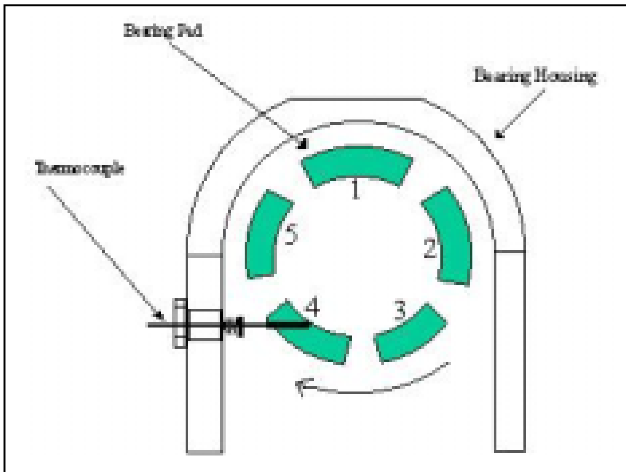

Fig 9. Bearing assembly

As shown in the figure, **the bottom left pad at its trailing portion has got a small hole on the backside, for accommodating bearing thermocouple.** All the shoes were identical, except the Bottom left shoe labeled #4. This shoe, therefore, should be positioned with the hole aligned to the thermocouple, as depicted in the figure.

Findings

The bearing assembly was inspected and it was observed that the Bottom left pad was inadvertently placed upside down, with the hole at the leading portion. So the thermocouple, during installation, not being aligned with the hole, had pre-loaded the shoe excessively, preventing it from functioning.

The shoes were put back in the right position and the machine was put on line on 30/4/99.

Fig.10 and Fig.11 shows the final vibration and the bearing temperature trend levels. The Vibration levels resumed to normal and the fluctuation also vanished. The Bearing temperature reduced from the 76deg to normal 67 deg.

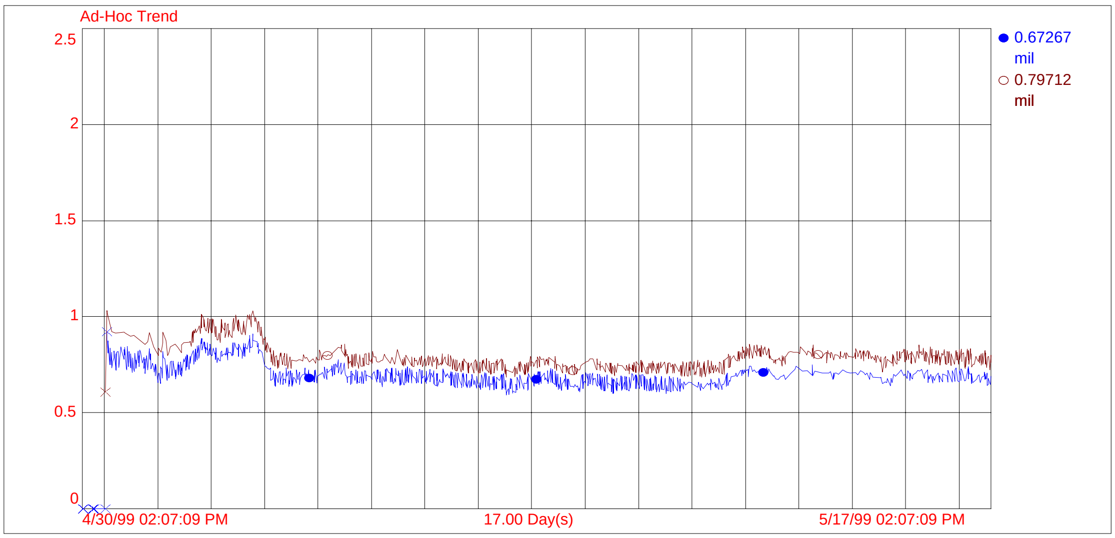

Fig 10. Vibration trend during final run

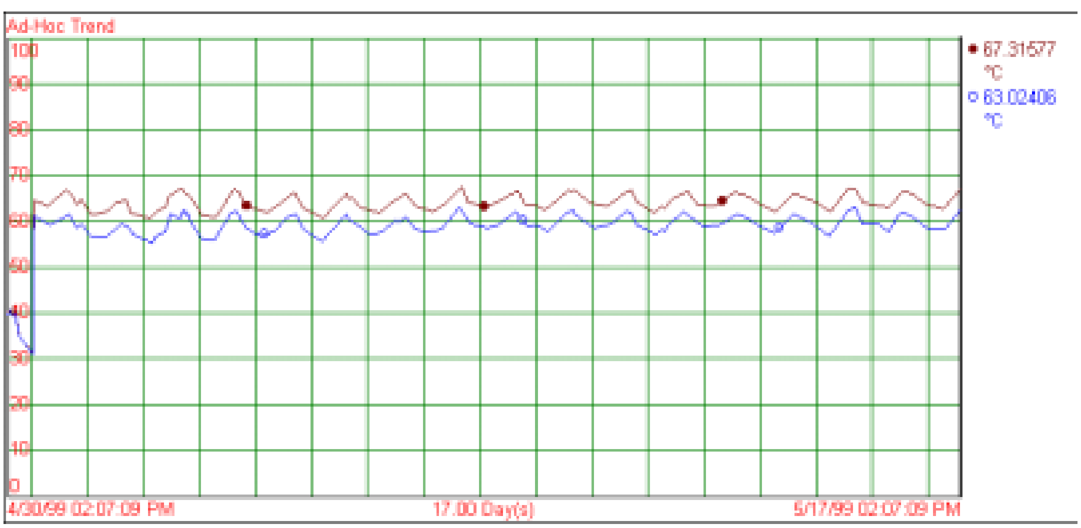

Fig 11. Bearing Temperature trend during final run

Conclusions

The Machine showed no abnormality, except the fluctuation in the vibration levels and a slight increase in the bearing temperature. The absolute levels of the vibration and the bearing temperature were within the limits. The DC gap volt measurements carried out with ADRE and the portable data Analyzer helped in reconstructing the Shaft centerline plots in an Excel Spreadsheet. The shaft centerline data has thus helped in explaining the abnormal fluctuation in the vibration levels.

Forcing the motor for another shutdown calls for the complete unit shutdown. The estimated cost involved in the production loss for the unit is around $300,000 per day. As the time and amount involved for another shutdown is significant, it was decided to run the unit, keeping a watch on the Vibration levels and the Bearing temperature. The Vibration level and the bearing temperature showed no increasing trend, hence, the unit was allowed to run till the next shut down was scheduled.

The Tilted pad bearings are inherently stable due to the low cross-coupled bearing stiffness forces, which results in normally small attitude angles. **The "locked" bottom left shoe has thus modified the hydrodynamic forces in the bearing, introducing the cross-coupled stiffness coefficients**. This has resulted in the varying bearing forces in the bearing. The excessive drift towards the bottom left quadrant of the bearing may be attributed to the reduced load carrying capacity of that "locked" shoe.

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