

Shaft vibration analysis by shaft center line method

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Abstract: Vibration monitoring methods of most critical equipment like main turbine and compressors always play important role in preventive maintenance and also management consideration in big plants. there are a number of traditional methods like monitoring the overall data from Bently Nevada systems and also the time wave form (TWF) or fast Fourier transform (FFT) monitoring. Shaft center line monitoring method also can play an important role. There are a number of arguments both in favor of and against this method between people who work in preventive maintenance. in this paper I first try to introduce this method clearly and accurately after that I will start to explain a case history that I was in touch directly. during these two steps I try to explain some common mistakes that may accrue by condition monitoring people during the process and sometimes I did it by myself, these mistakes may one of the reasons that sometimes this method seems not effective.

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Key words: shaft centerline position, attitude angle, journal bearing, sleeve bearing, tilting pad, steam turbine, main compressor, multistage compressor, condition monitoring, non-contact probe.

1. Introduction

The importance of shaft centerline position:

The shaft of the turbine or compressor located in the bearing. the center of the bearing always is in same position because bearing consider as a stationary part after installation but shaft centerline moving in a vertical position. before starting the process of start up for compressor and warming up the steam turbine the shaft centerline is below the bearing centerline that call sleep condition of the main shaft (figure 1).

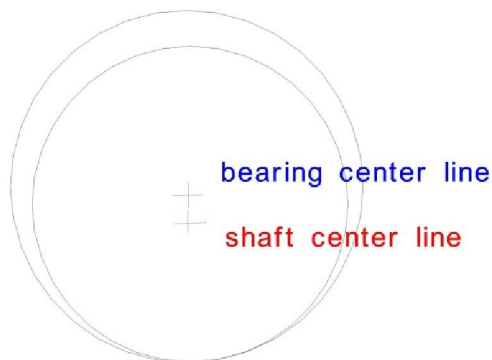


Figure 1. bearing center line and shaft center line position in shaft sleep condition.

After starting the oil pump of the compressor, this centrifugal pump start to injection the oil to the bearing and the huge shaft of compressor start to moving upward little by little then, the new shaft centerline moving over bearing center line in a vertical line. shown in figure 2.

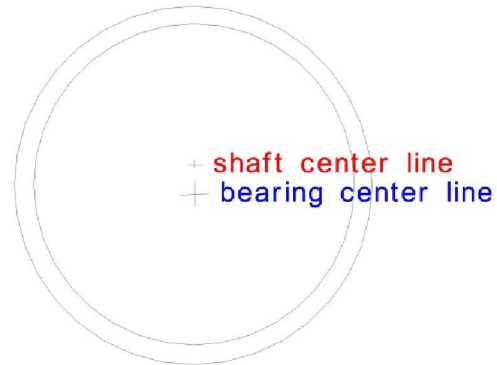


Figure 2. bearing center line and shaft center line position before operation.

the shaft centerline is always over the bearing center line during the turbo compressor operation. and of course the shaft centerline will change its position during operation. first of all I will explain the process of monitoring changing the in shaft center line.

The case bearing or housing bearing for most critical equipment is usually thick and the piezoelectric or velocity contact type vibration probe cannot representing the real shaft vibration because of damping phenomena. the condition monitoring system of these type of machine usually non-contact type probe. a typical none contact probe shown in figure 3. two non-contact probe install with 45 degree over the main shaft shown in figure 4. the installation group calibrate the distance of the probe with shaft due to the material of shaft and also probe sensitivity and length of the cables. the probe sensitivity for our non-contact

probe is 200 mv/mils called scale factor. it means the probe translate each mils with 200 mv. one mils is unite of distance equal to 25.4 micron usually use in maintenance groups. and mv is equal of 0.001 volt [1].



figure 3. non-contact type probe with 200 mv/mils sensitivity [1]

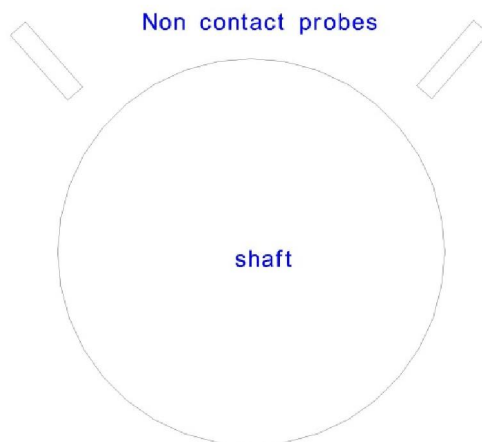


figure4. bently Nevada non-contact probe location.

If we introduce X and Y axis in the direction of the noncontact probes then we draw the final circle with the center of shaft center line just before operation (due to the machinery installation) and the radial of distance between shaft center and bearing center. this circle call allowable circle the shaft center line always should be inside the allowable circle otherwise the touch will accrue between shaft and bearing because of geometry considerations. and also the shaft center line position have a direction with the center of this circle this line have a degree with axis Y call attitude angle that should be between 20 to 50 in optimal condition [2].

The shaft center line position calculated with following formula:

Center line position = Gap (from bently Nevada monitoring system)- gap initial (installation time)/scale factor [3] (1)

Gaps usually is in volt and scale factor is in mv/mils then we should change the unit to volt/mils.

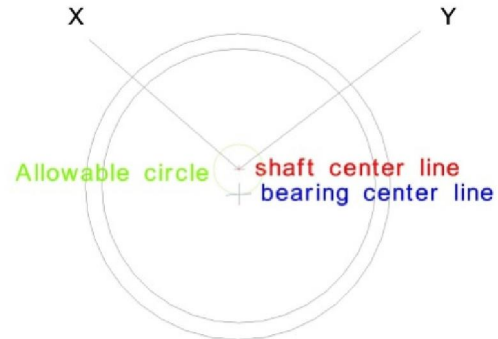


Figure 5. allowable circle position.

The common mistake accrue when we get the numbers of voltage from probe installation group or machinery group that is the numbers must be accurate enough with 0.01 volt otherwise it will make the geometry method useless and cause unreliable conclusion [4]. The method have some appendix. one of them is Er number that introduce as the following formula:

Er=the center line displacement to shaft center/radial bearing clearance (2)

The center line displacement to shaft center calculate by geometric method from the mentioned method and also radial bearing clearance is the clearance that machinery group installing the bearing in installation time. Er should be always between 0 and 1 if Er is more than 0.7 the mechanical system of bearing is stable otherwise the bearing system probably unstable. and closer monitoring should be program for the turbine and compressor [5]. The stability of the system is always a function of Er, RPM of the main shaft and clearance of the bearing [6].

2. Abbreviations and Acronyms

fast Fourier transform	FFT
time wave form	TWF
Bently Nevada connection	BNC
Condition monitoring	CM
Preventive maintenance	PM
Non drive end	NDE
Drive end	DE

3. Experimental details

The bently Nevada monitoring system related to MPC-C-8001 that operate in 11000 RPM working like

this. The overall vibration measure in micrometer peak to peak (p-p) the alert limit is 20 micron and the danger is 40 then, less than 20 is good and between 20 and 40 is fair then alarm lamp will appear in BNC board in substation (alert condition) and more than 40 is rough condition and compressor will automatically trip to protect the rotary and stationary part of turbo compressor.



figure 7. MPC-C-8001



figure 6. bently Nevada 3500 series machinery monitoring system [1].

The overall vibration trend did not show any considerable increase the last data was almost constant with previous vibration measured during last 6 month. but the PM group reporting some abnormal noise from drive end bearing of compressor (point number 3). the last vibration data reported as following:

Table 1. vibration displacement micrometer peak to peak MPC-C-8001.

MPC-C-8001	POINT 1-turbine NDE	POINT 2-turbine DE	POINT 3-compressor DE	POINT 4-compressor NDE
Horizontal	5.39	7.053	13.18	12.22
Vertical	9.29	13.94	11.58	7.48
axial	7.03	6.07	7.09	6.08

All the traditional vibration analysis system was constant the phase almost was same in different position and points also the axial movement analysis show nothing abnormal. the TWF and FFT analysis only reliable in radial direction (horizontal or vertical

). all TWF, FFT measured by easy viber data collector (VMI) and analyzed with spectra pro software that we used in our CM group. the turbine side TWF was still in constant shape as following:

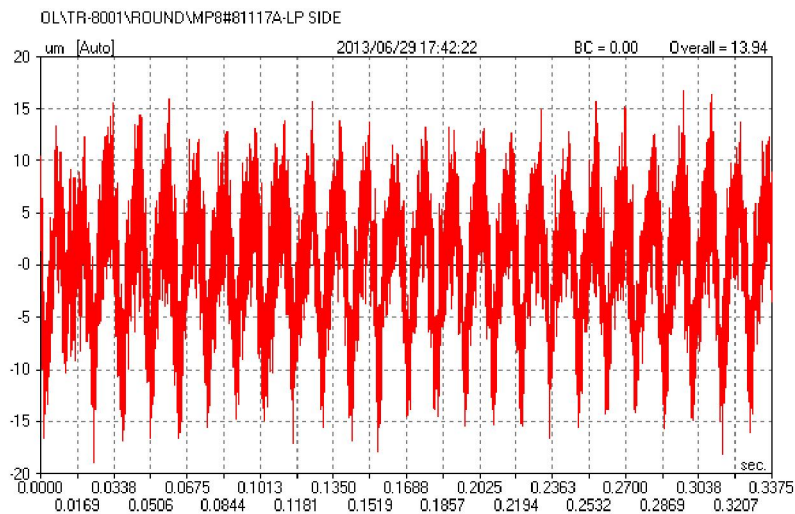


Figure 8. TWF steam turbine low pressure side.

The symmetry still exist also the carrier and high frequency ride wave (modulation) is also like previous signals. these data all related to POINT 2-turbine DE in vertical position the FFT also same as previous signals.

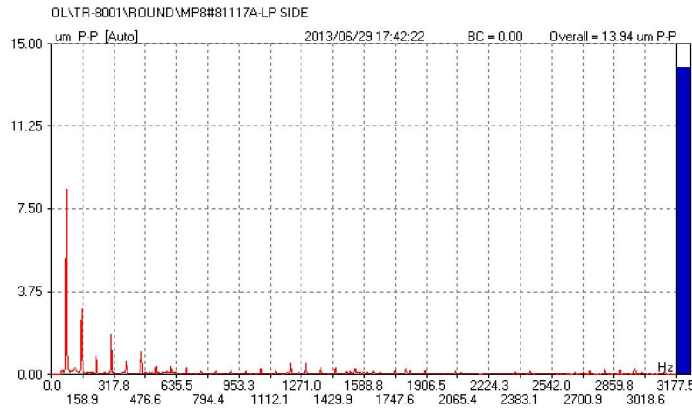


Figure 9. FFT steam turbine low pressure side.

The compressor side TWF show some stronger impact in bearing system but the amplitude of impact not too much to allow us any recommendation for checking bearing systems in point 3. point 4 was

remain steady in shape of both TWF and FFT. also the FFT form remain constant in all position and direction. the first two diagrams related to point 3 horizontal direction.

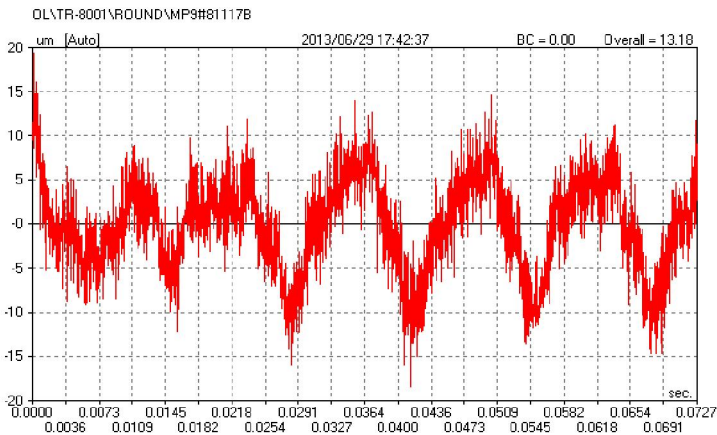


Figure 10. TWF point 3 horizontal direction



Figure 11. FFT point 3 horizontal direction

The following two diagrams related to point 3 vertical direction. The cursor can help us to better understanding the scale between time and amplitude.

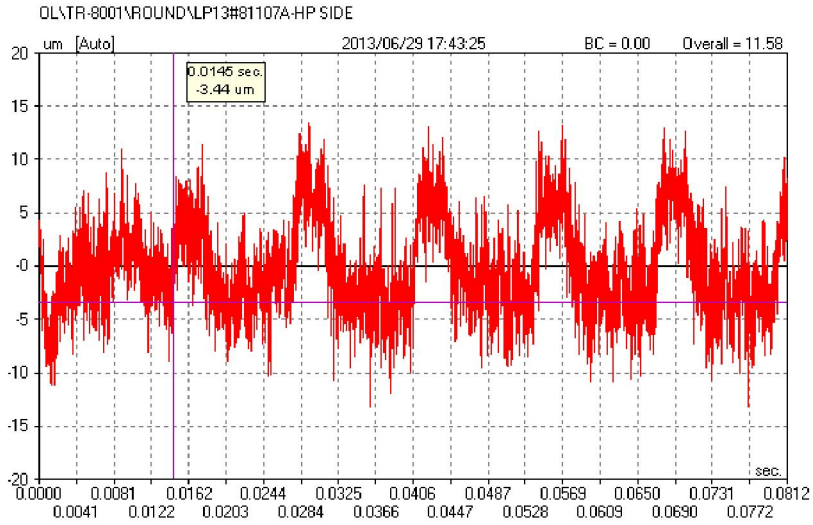


Figure 12. TWF point 3 vertical direction

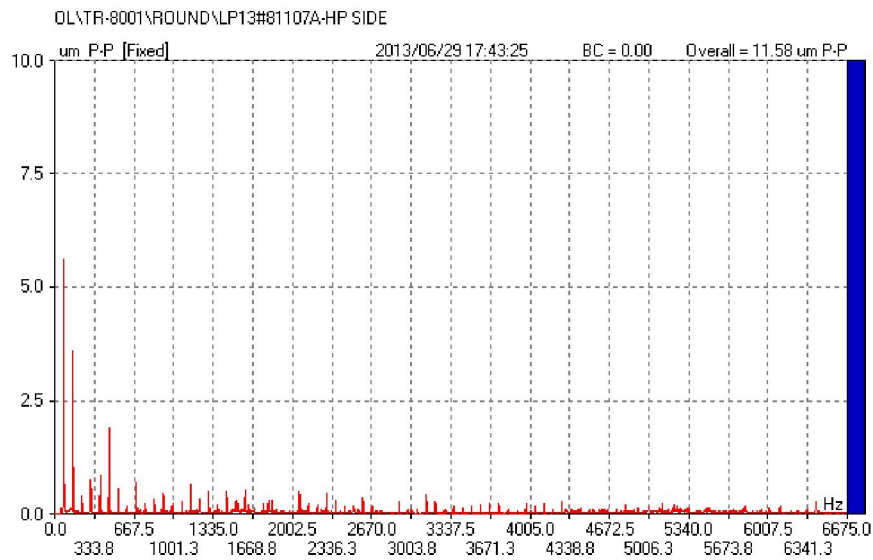


Figure 13. FFT point 3 vertical direction.

Due to performing all analysis and also PM report and maintenance history of this main compressor CM group decided to perform shaft center line analysis in point 3 for further vibration analysis.

4. Result and discussion

The process condition of both turbine and compressor such as suction and discharge pressure and also inlet and outlet temperature was constant and in the range of turbine and compressor technical documents due to the trend data of operation system in

main board of olefin plant. also the quality of steam was acceptable and in range of turbine documentation. therefore the problem of abnormal noise in point 3 should be mechanical rather than something related to the process problems. the gap voltage data monitored and trend from bently Nevada board in substation. also by using these data and the methodology that I explained before we draw the allowable circle and calculated the centerline shaft position as following in last 34 days. the shaft position data calculated as following table:

Table 2. shaft center line position data in final allowable circle.

date	27/05/2013	28/05/2013	29/05/2013	30/05/2013	31/05/2013
Y	0.9	1.2	1.2	1.4	1.8
X	-1.2	-1.2	-0.8	-0.6	-0.6
date	01/06/2013	02/06/2013	03/06/2013	04/06/2013	05/06/2013
Y	2.2	2	1.8	1.5	1.8
X	-0.4	-1	-2.2	-1.5	-1.6
date	06/06/2013	07/06/2013	08/06/2013	09/06/2013	10/06/2013
Y	1.9	1.9	1.7	2.4	1.6
X	-1.8	-2	-2.2	-2.4	-2.8
date	11/06/2013	12/06/2013	13/06/2013	14/06/2013	15/06/2013
Y	0.9	0.6	0.4	0.2	0.1
X	-3	-3.2	-3.6	-3.6	-3.5
date	16/06/2013	17/06/2013	18/06/2013	19/06/2013	20/06/2013
Y	-0.1	-0.6	-1	-1.2	-1.2
X	-3.6	-3	-2.9	-3.5	-3.6
date	21/06/2013	22/06/2013	23/06/2013	24/06/2013	25/06/2013
Y	-1.4	-1.7	-1.9	-2	-2.2
X	-3.8	-3.9	-4.2	-4.2	-3.5
date	26/06/2013	27/06/2013	28/06/2013	29/06/2013	
Y	-2.5	-3.2	-4	-4.2	
X	-2.5	-2.3	-2.5	-3	

Also the shaft centerline position with allowable circle drew as following:

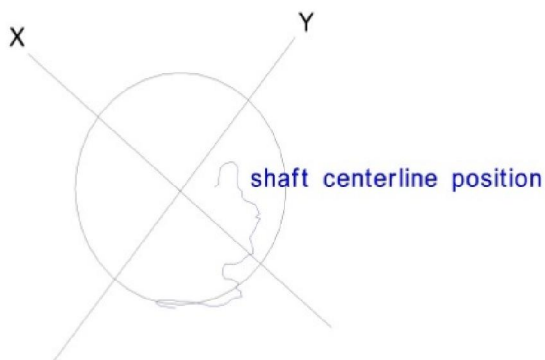


Figure 14. shaft center line position MPC-C-8001.

As we can see in this circle the shaft touch the bearing in the down half of the bearing and the bearing may damage in this condition now we have enough evidence to predict this phenomena and it is mandatory to recommend the operation process department and management to turn of the machine and change the process role of this compressor to the spare compressor simultaneously to continuing the olefin production during maintenance of this compressor. The bearing housing in point 3 consist of a journal and a thrust bearing. the journal is sleeve type and the thrust is tilting pad. after checking the bearings system in point 3. the upper half was ok but the down half was touch and damage seriously. Also the main shaft touch and should be send to metal spray. the bearing should change and reinstall. The down half of bearing shown in these figures:



Figure 15. down half of the bearing point 3.

The up half of the bearing as following:



Figure 16. up half of the bearing point 3.

The rotor and main shaft condition as following:

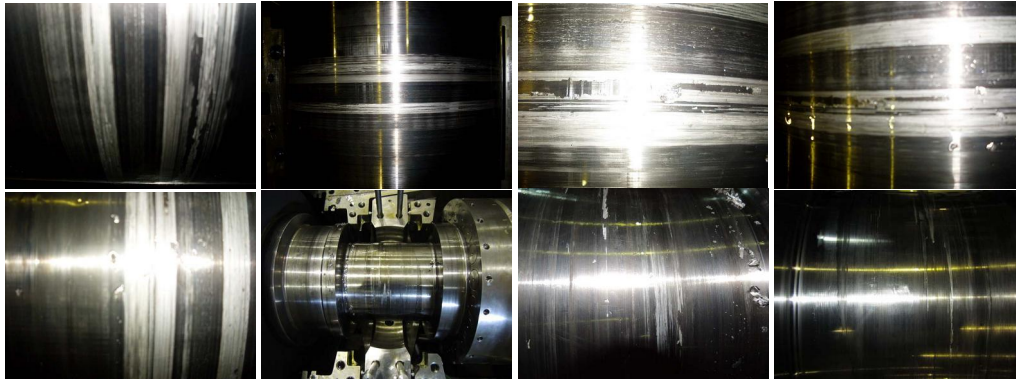


figure 17. rotor and main shaft condition MPC-C-8001.

As it is clear from the above photos the bearing condition was very bad and it was in the condition that all traditional signals like overall vibration BNC and TWF, FFT, phase trend, gap voltage trend show nothing abnormal or any dramatic increase but the shaft centerline monitoring provide evidence for recommendation and cause successful predictive recommendation. if CM group did not perform this method the alignment will face problem in next step. the valuable turbine blades may have some touch or damage or some damage will accrue in multi stage compressor parts and pose high economical costing to the factory. also the plant will face an unexpected shut down for several hours. the process may have 4 to 5 hours high pressure work to start up the spare compressor also there are thousands of dollars waste

in these kind of shut downs because of quit of olefin production. also olefin is the base material for tens of other petrochemical companies in the pet zone and they will face a serious problems in production and petrochemical companies should pay fine to the export ships that coming from far countries every hours. all in all this 4 to 5 hours may cost thousands of dollars waste in production. beside this we have considerable mechanical part damage like turbine parts. and all these evidence show us the effectiveness of shaft centerline method for future application in any most critical equipment in any factories.

5. Conclusion

the shaft centerline analysis perform successfully for main stem turbine multistage compressor MPC-C-

8001 olefin plant in point 3-compressor drive end bearing. the traditional methods like overall trend of vibration displacement micrometer peak to peak (p-p) by Bently Nevada board in substation and also phase trend, TWF, FFT, monitoring did not show any dramatic change and enough evidence to any machinery maintenance recommendation for checking the bearings but by shaft center line analysis we predict the strong touch in down half of bearing that was true. after maintenance action the bearing changed and reinstalled and the shaft send to metal spray. this successful analysis cause protect potential unexpected shutdown that may pose huge mechanical and production cost on the factory. therefore shaft centerline analysis could be effective if perform accurately and correctly on the most critical equipment. and consider as one of the effective tools in predictive maintenance and condition monitoring systems. also low vibration do not always indicate a healthy machine.

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