Condition Monitoring Studies on Machinery Structures in an Oil Refinery using ODS

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***Abstract:* - In this paper an advanced condition monitoring technique called ODS or Operating Deflection Shapes is made use of to find out the vibration problems associated with the structures, on or to which a rotating machinery is connected, in an oil refinery. The vibration readings are taken before and after structural modifications such as increasing the stiffness. The operating shapes are visualized using ODS software MeScope VES-4.0 Series, which gives a clear picture of the areas of the structure which are weak and need to be stiffened. Also ODS gives information about the modal parameters such as modal frequencies, damping ratios and mode shapes which help in eliminating resonance in the structure by suitably modifying the structure to avoid catastrophic failure of the vibrating parts in a rotating machinery.**

***Keywords:* - Condition monitoring, Operating Deflection Shapes(ODS), Vibration Analysis, Rotating Equipments, Modal Analysis, Resonance, Damping.**

I. INTRODUCTION

Condition monitoring of machinery is the measurement of various parameters related to the mechanical condition of the machinery (such as vibration, bearing temperature, oil pressure, oil debris, and performance), which makes it possible to determine whether the machinery is in good or bad mechanical condition. The condition monitoring helps in identifying the mechanical condition of the machine and then makes it possible to determine the causes of the problem, if the machine is in deteriorating condition. It also helps to ascertain the condition of a good machine and thus helps in avoiding costly replacements by reducing maintenance manpower and material. [1]

Condition Monitoring is used in conjunction with predictive maintenance, i.e., a maintenance technique adopted by measuring indirect parameters like vibration, temperature etc., to ascertain maintenance requirements of rotating machinery. These changing parameters are the indication of changing machine condition. In many plants predictive maintenance is replacing run-to-breakdown maintenance and preventive maintenance, in which mechanical parts are replaced after the failure or periodically at fixed time intervals regardless of the machine's condition. [1]

Hence machine condition monitoring is an important part of condition-based maintenance (CBM), which helps in avoiding undue replacement of parts as in the case of preventive maintenance. Thus unnecessary carrying of inventory and costly maintenance jobs involving manpower and machinery can be avoided. Thus CBM is becoming recognized as the most efficient strategy for carrying out maintenance in a wide variety of industries. [2]

Even in good condition, machines generate vibrations. Many such vibrations are directly linked to periodic events in the machine's operation, such as rotating shafts, meshing gear teeth, rotating electric fields, and so on. The frequency with which such events repeat often gives a direct indication of the source and thus many powerful diagnostic techniques are based on frequency analysis. [3,4]

Some of the reasons for using Vibration Analysis as condition monitoring tool are : [5]

- All machines vibrate due to inherent forces within the machinery.
- Vibrations are easy to detect, measure and analyze.
- Vibration is the linear response of the system to input forces.
- Vibrations are highly directional.
- Vibrations are transmitted from one place to another without loss of characteristic properties.
- Vibrations are a highly localized phenomenon.

The vibrations are measured using FFT Vibration analyzer and can be interpreted using standard methods to identify the problems associated with the vibration.

The various techniques adopted for condition monitoring of rotating equipment in any industry are : Vibration amplitude trending, Spectrum Analysis, Acceleration Enveloping, Time waveform Analysis, Order Tracking, Bump Test, Temperature survey and Trending, Orbit Analysis, Transient Analysis, FRF & MODAL testing, ODS Analysis, Ultrasonics for Compressors, Lube oil Analysis, Thermography etc.,[6,7,8].

This paper discusses the use of ODS analysis in an oil refinery for condition monitoring of rotating machinery. Section I gives the introduction, section II discusses about the importance and method of ODS analysis, section III discusses application of ODS in condition monitoring of machineries in an oil refinery and section IV discusses about the conclusions of ODS studies on machineries.

II. ODS

While carrying out routine vibration analysis and root cause analysis, analysts often encounter failures that seemingly provide no clue as to the reasons of failure. In some cases the failed equipment might have exhibited no increase in vibration while in some other cases the vibration signature might have suggested a different problem altogether. Where the conventional signature (FFT and Time waveform) analysis does not help in detecting the problems the analyst needs to look for other methods of detecting problems. One such method that can be used effectively is ODS Analysis.

ODS analysis helps to determine the forced dynamic deflection shape under the steady state (operating) frequency of the system. ODS data is collected with the machine running and shows motion due to a combination of structural resonances and operational forces such as misalignment or imbalance. It can be performed with a single channel data collector using peak & phase measurements from a tachometer input to animate multiples of running speed (where many vibration problems show up).

Traditionally ODS has been defined as the deflection of a structure at a particular frequency. However, an ODS can be defined more generally as any forced motion of two or more points on a structure. Specifying the motion of two or more points defines a shape. Stated differently, a shape is the motion of one point relative to all others. Motion is a vector quantity, which means that it has both a location and a direction associated with it. Motion at a point in a direction is also called a Degree of Freedom, or DOF. [7,8] All experimental modal parameters are obtained from measured ODS's. i.e., experimental modal parameters are obtained by artificially exciting a machine or structure, measuring its operating deflection shapes (motion at two or more DOFs), and post-processing the vibration data.[9,10]

The software used in this work for ODS Analysis is ME'Scope VES-4.0 Visual Engineering Series by Vibrant Technology Inc., USA., [11,12].

The package used contains the following options.

- ✓ Signal Processing
- ✓ Basic Modal Analysis

The instrumentation used in ODS study consists of mainly a computer with ODS software for modeling & analysis, Vibration analyzer for downloading, measuring & uploading of data, stroboscope for speed & phase measurement. These instruments come with associated cables, probes, transducers etc.

III. CONDITION MONITORING STUDIES ON MACHINERIES USING ODS

The following machines in the oil refinery were identified for the purpose of ODS study which had mechanical problems

A. Case Study : Vibration Analysis of Pipeline of Naptha Stabilizer Overhead Refined LPG Product Pump Unit

1) Machinery Details :

This pump unit with pipelines is a part of the CDU (Crude Distillation Unit) used for pumping refined LPG from the overhead Naptha Stabiliser. This unit had long unsupported bent pipelines which were the cause of vibrations of the whole pump unit as shown in the Fig. 1 & Fig. 2 and table 1 gives the specifications. This machine with support structure and pipelines was analyzed using ODS and a suitable solution was suggested.

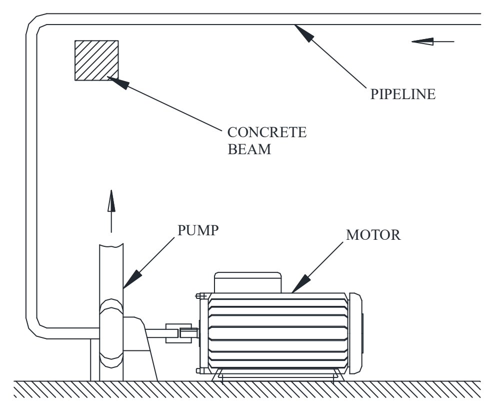

Fig. 1: Schematic of Naptha Stabilizer Overhead Refined LPG Product Pump Unit (No bracket)

TABLE I
MACHINE SPECIFICATIONS

Naptha Stabilizer Overhead Refined LPG Product Pump Unit Details		
Sl. No	**Description**	**Specifications**
1	Motor	Make- NGEF, Power-160kW, 50Hz, 415V, 257A, 2985 RPM, Model No.-EXET3, Frame-315L, Horizontal Mounting, Insulation Class-F, Cable 351 Sq.mm, Contactor Rating-25A
2	Pump	Make-KSB Pumps, Type-Centrifugal, Model No.-150/400 RPKEM, Class-16, Capacity-91.7/146 m^3/Hr, Diff. Hd.-204/200m, Discharge Pressure- 20.05/23.55kg/m^2, NPSH-3.95m, Speed-2900 RPM, Imp. Dia-385mm, Discharge Size-6"x300RF, Efficiency-58%.

Fig. 2: Photograph of Naptha Stabilizer Overhead Refined LPG Product Pump Unit

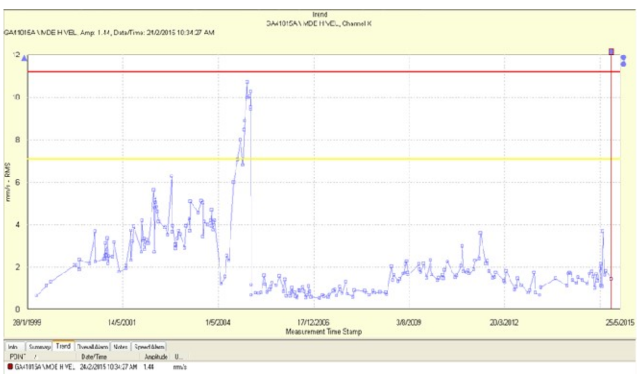

Fig. 3: Trend plots for Naptha Stabilizer Overhead Refined LPG Product Pump Unit showing motor drive end horizontal velocity peaks.

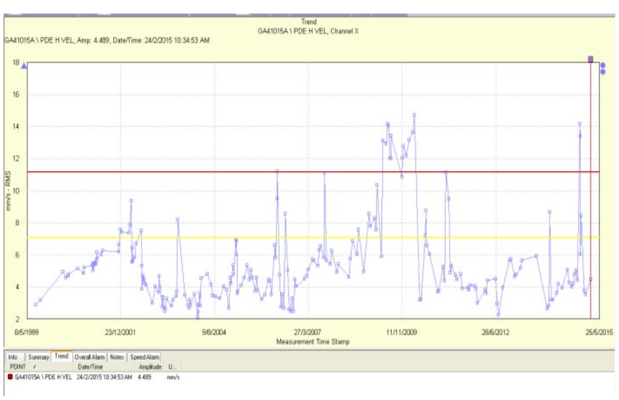

Fig. 4: Trend plots for Naptha Stabilizer Overhead Refined LPG Product Pump Unit showing pump drive end horizontal velocity peaks.

2) ODS Vibration Analysis :

The various steps in the ODS analysis are explained with illustrations in the next section. The steps mentioned below must be carried out before and after modifications to ascertain whether the vibrations have come down or not.

Steps in ODS analysis:

To start with a representative model is built in *Mescope* VES-4.0 series software and various test points are identified for measurements. These test points numbered and direction of measurement is fixed. (Route Definition). That is at each numbered points indicated on fig. 5, the possible directions of measurements along any of the X,Y,Z axes) is marked. Each measurement is also called the degrees of freedom or DOF. This is shown in Fig. 6.

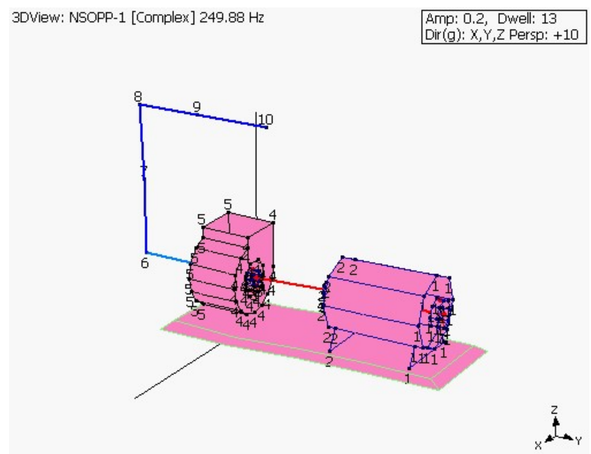

Fig. 5: ODS Model of Naptha Stabilizer Overhead Refined LPG Product Pump Unit with points numbered.

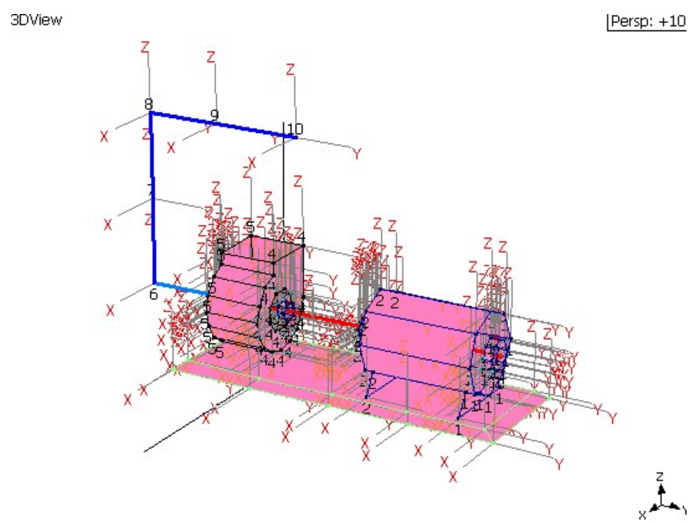

Fig. 6: ODS Model of Naptha Stabilizer Overhead Refined LPG Product Pump Unit with measurement no.s or DOF

Once the model is complete the root information including phase is downloaded into the analyzer software. Then the machine is excited & run at constant speed. Amplitude and Phase readings are recorded at the test points. After the measurements the data is uploaded into software and spectrums are assigned to each point. The measurement process is shown in Fig..7.

Fig. 7 : Downloading, Measuring & Uploading of data for measurement points into & from SKF Microlog Vibration analyzer

Once the measurements are uploaded into the MEScope VES-4.0 software, the vibration data is analysed and data file & shape files are created by the software. Using these data files and shape files the vibrations can be visualized. Animation of the shape with measured data as shown in Fig..8.

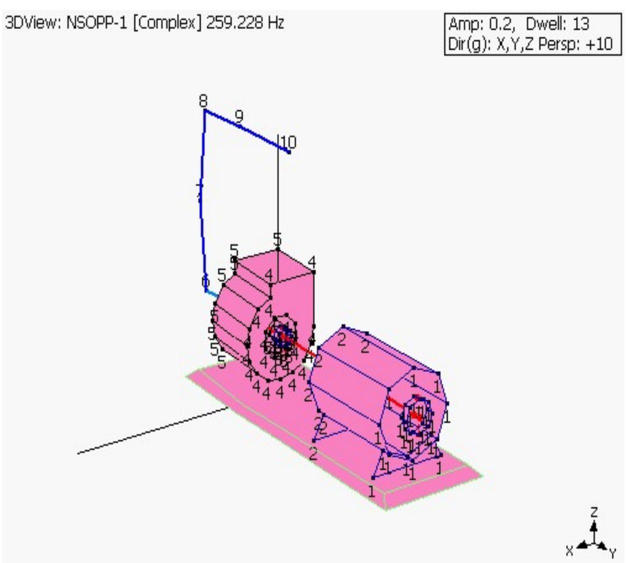

Fig. 8: O.D.S. animation showing different points with deflection under vibration

The various basic signal processing outputs can be obtained using the software as shown in Fig..9.

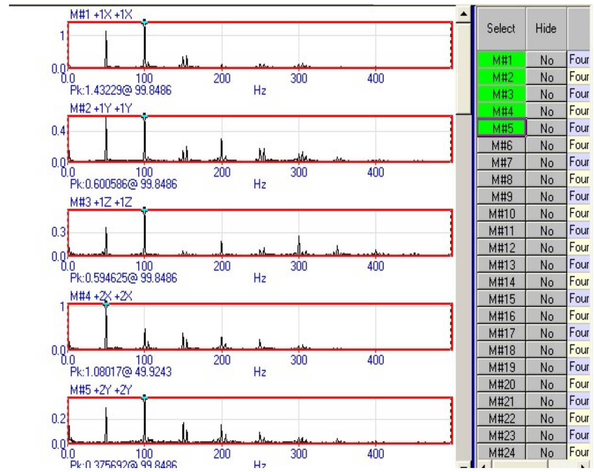

Fig. 9 : The basic signal processing outputs obtained from ODS Software.

Also the mode shapes with measured data can be obtained. Modal parameters are also obtained from the analysis as shown in Fig..10.

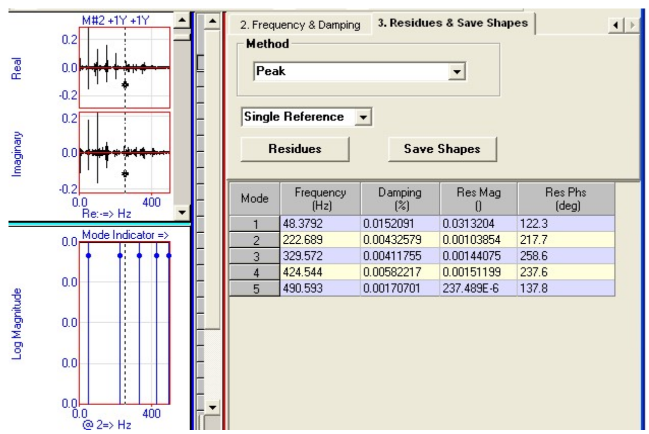

Fig. 10: Mode & Modal parameters obtained from ODS Software.

The results of signal analysis and modal analysis can be summarized as follows.

A peak RMS Velocity value of 5.81855 mm/s was noted at point 6 in X direction at a frequency of 1.24811Hz. Comparing this with the vibration severity chart ISO-10816 a maximum limit of 4.5 mm/s RMS velocity for motors with power > 75kW on rigid foundations is exceeded. Hence this indicates that the structure needs to be stiffened to bring down the vibrations.

Also from the modal frequencies obtained by curve fitting ODS data indicates that there is operating frequency approaching modal frequency which has to be avoided by suitably stiffening the vibrating structure. From the animation of the structure using ODS Data it can be seen that some areas far away from the motor and pump are weak and hence need support.

Hence a new fabricated bracket was provided as shown in the Fig. 11 between the pipe and concrete beam and the whole exercise was repeated. A new set of ODS readings were taken and compared with the Vibration severity chart. A maximum RMS velocity value of 2.77116 at 49.8515Hz was noted which is much below the limits for allowable values. And hence the stiffness of the structure was assumed to be enough.

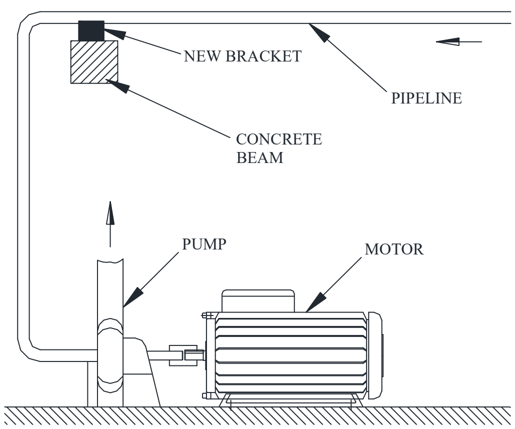

Fig. 11: Schematic of Naptha Stabilizer Overhead Refined LPG Product Pump Unit (With new bracket)

B. Case Study : Vibration Analysis of the Base Structure of Scanner Fan for Boiler

1) Machinery Details :

The scanner fan for Boiler inside CPP (Captive Power Plant) which is used for supplying air to the control cabinet of boiler is used for ODS study. The motor was coupled to the scanner fan using intermediate bearing supports. The whole assembly was mounted on two separate structures as shown Fig.12. Due to the inherent problems with the foundation and stiffness of the base, unusually high vibrations in the unit were identified. These vibrations used to present itself at 1X and was not responsive to balancing. Hence the whole unit was subjected to ODS analysis and the reason for vibration was found out and a corrective action was suggested to bring down the vibrations.

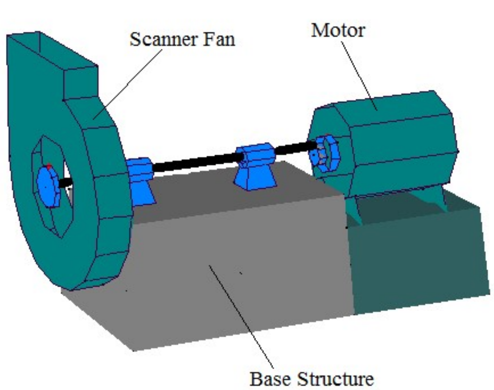

Fig. 12: Schematic of Scanner Fan Unit for Blower

The Table II gives the details of specifications of the scanner and fan Fig.13 shows the photograph of the scanner fan unit.

TABLE II
MACHINE SPECIFICATIONS

Scanner Fan Details		
Sl. No	**Description**	**Specifications**
1	Motor	Make-ABB, Power-11kW, 50Hz, 415V, FLC-19.5A, 2920 RPM, Model No.-K5419570, Frame-160M, Insulation Class-F, Fuse 63A, Cable 351 Sq.mm, Contactor Rating-25A
2	Fan	Make-ABB, Fan Speed-2920 RPM, Flow-300m^3/min, No. of Fans-4, Outlet Pressure-900 kg/m^2, Speed Ratio- 1:1

Fig. 13: Photograph of Scanner Fan Unit for Boiler

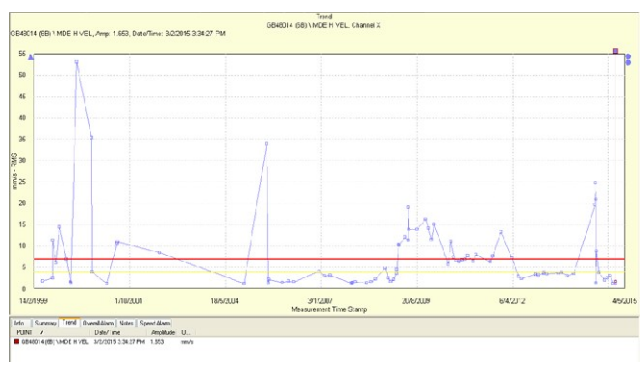

Fig. 14: Trend plots for Scanner Fan for Boiler showing motor drive end horizontal velocity peaks.

2) ODS Vibration Analysis :-

The high vibrations in the Fan/Motor and base structure were noticed. The motor operation was noisy. Motor base bolts were getting cut several times due to high vibration.

The vibrations were of low amplitude in the solo run of the motor. It was high with a value of 53 mm/sec in coupled run in spite of balancing the rotor. The vibrations were predominantly at 1X speed of 2248 RPM. There were unsteady phase readings on motor and base frame which indicated structural resonance. The graphs in Fig.15 indicate the peak vibration readings.

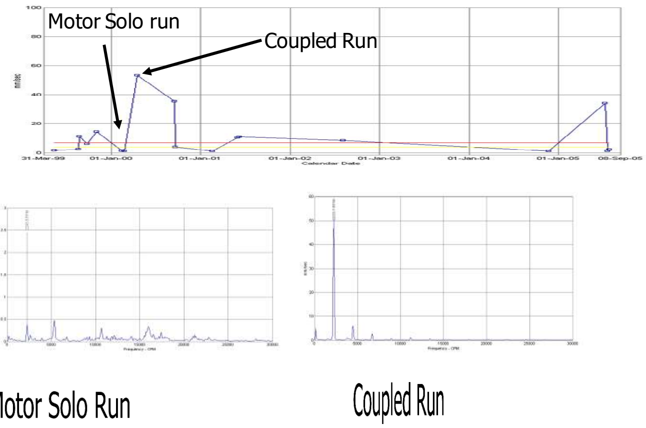

Fig. 15: Vibration graphs for motor(Solo/Coupled)

To avoid the frequency of motor rotation approaching natural frequency of the base structure, the speed was increased to 2850 rpm. The noise level reduced and vibrations came down from 50mm/sec to 9mm/sec RMS. Still the vibrations were high as per vibration standards and were not acceptable.

Alternate options like replacing the DC motor with AC motor and mounting the fan impeller directly on motor shaft were suggested as shown in the Fig. 16.

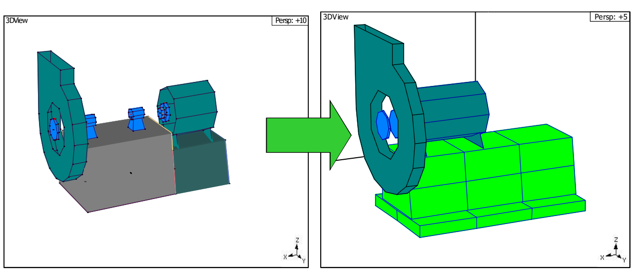

Fig.16 Fan impeller to be mounted directly on motor shaft.

Still the fan vibrations were in the range of 30mm/sec RMS when the unit was run and the whole structure started vibrating at 1X frequency as indicated in the trend plot shown in Fig. 17.

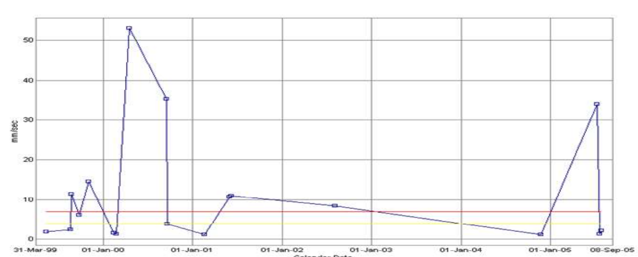

Fig.17 Motor Drive End Vibration Trend

Since the vibrations were still high, the cause for vibrations was not clear from the simple vibration analysis and hence it was decided to do ODS on the fan base structure.

The various steps in the ODS analysis of the base structure for scanner fan for boiler are similar to the previous case study. Fig. 18 shows the fan base model.

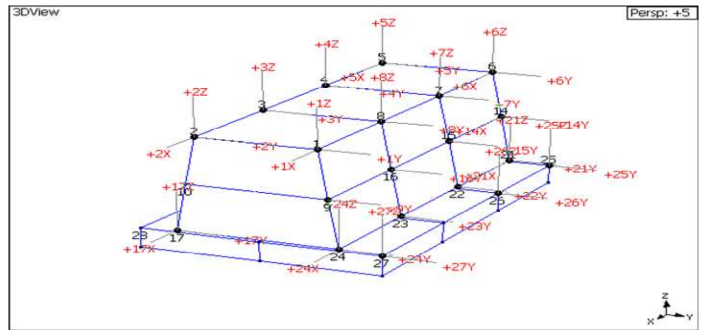

Fig.18 Fan base model for ODS analysis

The ODS or Operating Deflection Shapes were obtained from the analysis as shown in Fig. 19.

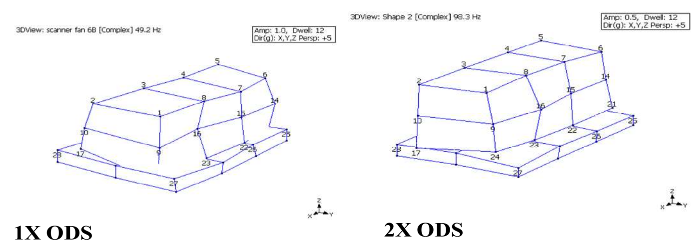

Fig.19 ODS animations

The animations of the base structure indicated the looseness in the mounting and pivoting action of the base.

The ODS spectrums in the order of their measurement numbers with amplitude and phase information were obtained as shown in Fig. 20.

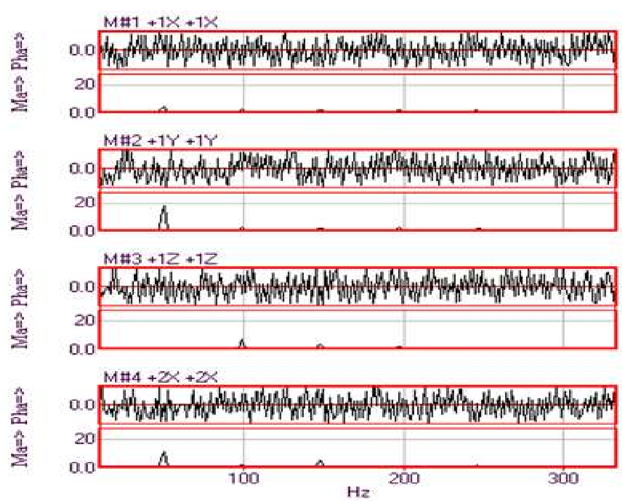

Fig.20 ODS time domain & frequency domain spectrums

The following conclusions were drawn from the ODS analysis as the reasons for high vibrations.

- Low damping of the base frame.
- Low Stiffness on fan base structure.
- High spots on base frame - Lack of flatness.
- Motor to base – lack of flatness.

The following recommendations and corrections were suggested to reduce the high vibrations.

- Base frame was filled with concrete - increase damping.
- Stiffeners were welded to increase rigidity/stiffness.
- Leveling of base frame – flat plates.
- Motor base plate – replaced by flat thicker plate.
- The above modifications are shown in fig.21

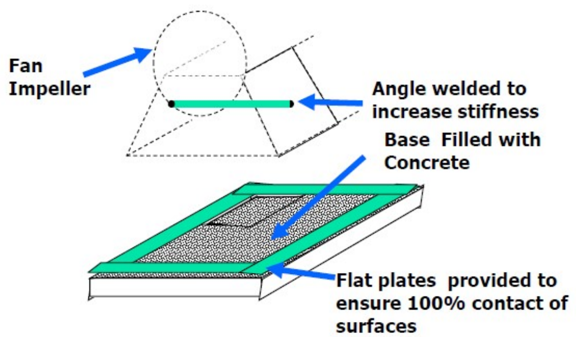

Fig.21 Modifications to the base structure

The following were the results of modifications on the base structure.

- Vibration in Horizontal directions reduced drastically from 30 to 2 mm/sec RMS.
- Base frame vibrations - as low as 0.3 mm/sec RMS.

The severity of vibrations was visualized by animating the ODS data as shown in the Fig. 22. The figure clearly shows the magnitude of vibrations reduced after modifications on the structure as explained previously.

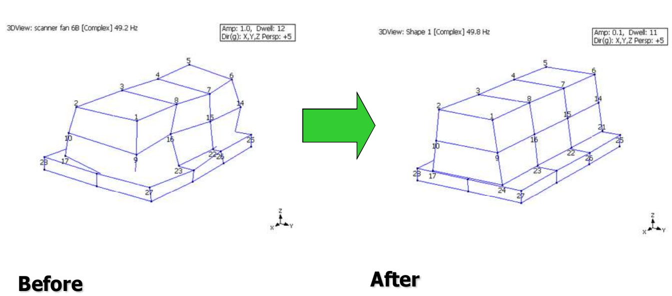

Fig.22 ODS animations of base structure before and after modifications

Thus it can be summarized that the reasons for high vibrations are unbalance coupled with mechanical looseness in the base structure, low damping and lack of stiffness. By addressing these problems the vibration levels can be reduced.

IV. CONCLUSIONS

The two case studies presented here discuss the effectiveness of ODS analysis in an oil refinery to reduce the vibrations. The case studies also show that the ODS analysis is used mainly for structural vibration related problems and when the conventional vibration analysis techniques like time domain and frequency domain analyses using FFT analyzers do not give clear information about the source of vibrations.

The animation of ODS model clearly indicates the areas on the structure which are weak and have more deflections. It also gives the idea where the part has to be stiffened. The modal ODS analysis shows nodes in a mode shape, giving idea about the location where stiffeners have to be provided.

ODS analysis also gives indication of other causes of vibrations such as mechanical looseness in the structure like in clamps or anchor bolts. ODS also shows if the damping provided by the structure is adequate or not in absorbing the vibrations. Based on these outcomes from ODS it can be accordingly decided to modify the structural parts.

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