uptime august/september 2013

Asset Condition Management — Vib — vibration analysis

Torsional Vibration Problem with VFD Motor/ID Fan

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An induced draft (ID) fan system at an oil refinery experienced a failure of the spool piece in the flexible disc coupling between the motor and fan shafts. The fan system is part of an atmospheric furnace that heats approximately 152,000 barrels of crude oil per day.

The ID fan is driven by a 350 HP induction motor (Figure 1). To improve efficiency, the fan speed is varied instead of using inlet dampers to control the exhaust flow from the furnace. The motor speed is controlled by a low voltage variable frequency drive (VFD) from 0 to 1200 RPM. Any unscheduled downtime would be costly and could quickly outweigh the energy savings from using the VFD instead of inlet dampers. Therefore, it is imperative that this fan system have high reliability.

FIGURE 1

Tap to get more information

The failure of the flexible disc coupling consisted of a cracked space piece, which appeared to originate at a bolt hole (Figure 2). Initially, maintenance was blamed for possibly over tightening the coupling bolts. However, the 45 degree angle of the crack through the coupling spacer (Figure 3) is typical of a failure caused by high torsional vibration.

Torsional vibration is referred to as silent because it occurs in the shaft axis of rotation where conventional vibration monitoring equipment, such as accelerometers and shaft proximity probes, would not normally detect. Coupling chatter and shim pack deformation are common indicators of a torsional vibration problem. However, problems are usually not detected until after failure occurs. Therefore, special test equipment is needed to measure torsional vibration.

Field tests were performed to diagnose the cause of the coupling failure. The transmitted torque was measured using a wireless strain gage telemetry system mounted on the motor shaft extension near the cou-

FIGURE 2

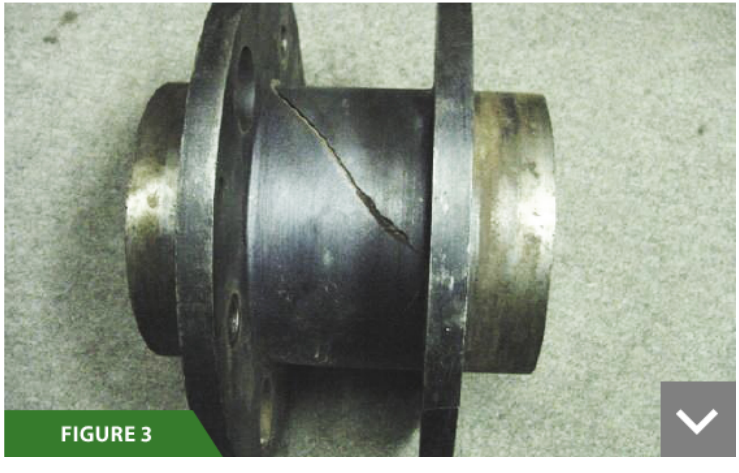

FIGURE 3

pling hub as shown in Figure 4. The waterfall plot in Figure 5 shows the measured frequency spectra of the alternating torque versus speed. The first torsional natural frequency (TNF) of the system was identified at 58 Hz.

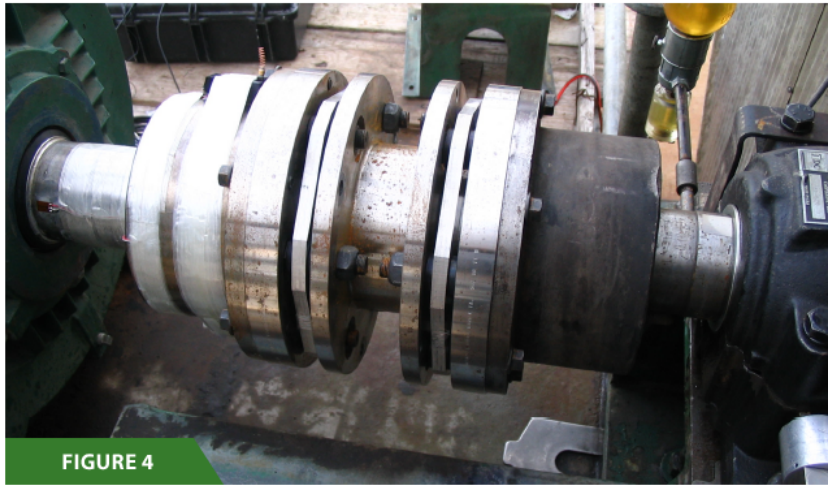

FIGURE 4

Torsional resonances occur when energy at multiples of mechanical running speed and electrical harmonics from the VFD intersect a TNF. Because the motor has six poles (three pole pairs), the mechanical frequency will be approximately 20 Hz (1200 RPM) when the fundamental VFD frequency is 60 Hz, neglecting a slip of the induction motor. High dynamic torque in the coupling was found when operating the fan in the 1000 RPM to 1200 RPM speed range due to VFD excitation, a 1× electrical frequency.

VFDs control motor speed by varying the electrical frequency. In the U.S., electrical power is supplied at 60 Hz. The VFD first rectifies the input AC power to the DC bus. The VFD then inverts from DC back to AC power at the required electrical frequency to drive the motor at the desired speed. The output frequency from the drive can range from 0 to 60 Hz, or even higher frequencies. Because the output waveform is no longer a pure sine wave, torque ripple can be produced. Some newer VFD technologies, such as pulse width modulation (PWM), can produce smoother waveforms and thus reduce excitation at electrical harmonics.

Because the refinery normally operates the fan from 1000 RPM to 1200 RPM, which was the speed range where excessive amount of dynamic torque was measured, this is believed to be the reason for the coupling failure. For example, the VFD excitation was approximately five percent of the full load torque (FLT) and at torsional resonance, the dynamic torque is amplified by a factor of thirty. Therefore, the maximum alternating torque was approximately 150 percent of the transmitted torque, which exceeded the rating of the coupling.

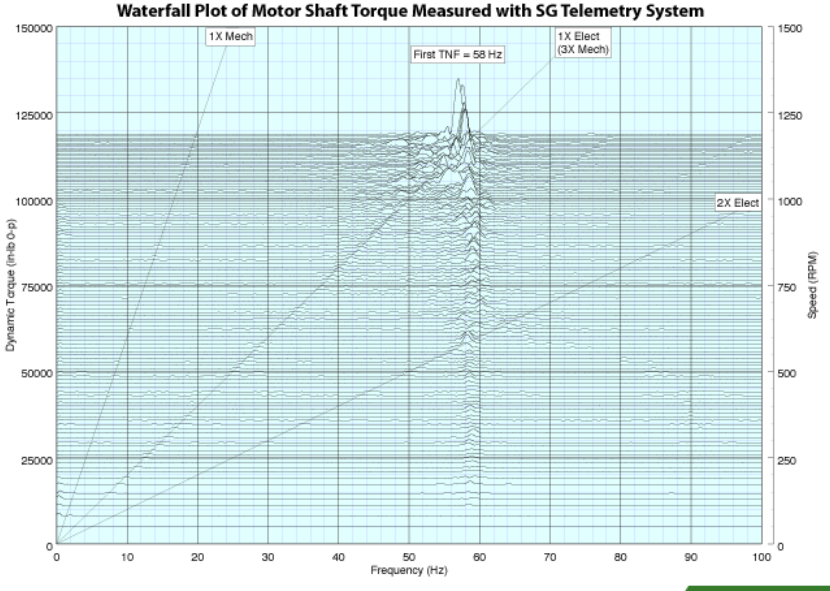

FIGURE 5

Because of the large diameter size and weight involved, the inertia of the fan is many times greater than the inertia of the motor. For the first torsional mode, the motor core is typically near an anti-node and acts like a torsional pendulum. The fan, on the other hand, is usually near the node and acts as an anchor. The drive infers load changes by monitoring motor current, which could also contain variations from the first TNF. In a torsionally stiff, lightly damped system, the first torsional mode is very sensitive to any harmonic excitation or sudden speed adjustments from the VFD motor. The references listed at the end of this article provide additional information and examples.

After further discussion with plant personnel, it was determined that the fan was originally driven by another motor from a different manufacturer. Repairs were needed on the original motor and would have taken longer than the plant could accept. Therefore, an alternate motor from a different manufacturer was installed. This new motor was similar in electrical performance, but was vastly different in physical size and inertia. Unfortunately, the electrical engineers did not communicate with the mechanical engineers that this change was being made and did not realize the effect on the mass-elastic torsional system.

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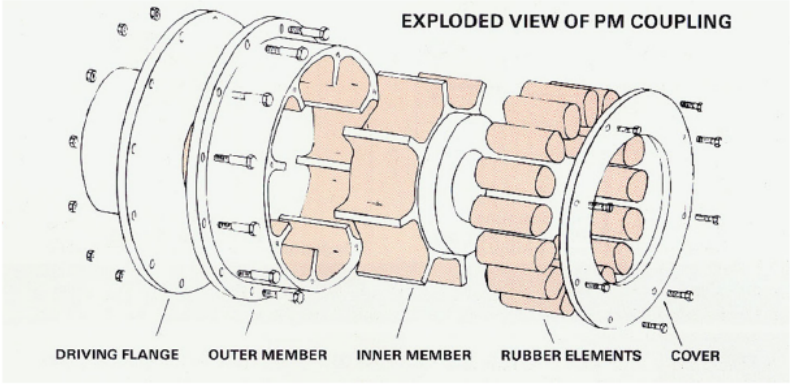
American Petroleum Institute (API) recommends that a torsional analysis be performed in the design stage to prevent failures. A separation margin (SM) of at least 10 percent between the torsional natural frequencies and the excitation frequencies is recommended to avoid running at a torsional resonance. This is required unless safe operation can be demonstrated at resonance. Often times, satisfying the 10 percent SM is impractical for VFD motor systems, which typically operate over a large speed range.

Unfortunately, a torsional analysis of the fan system was not performed with either motor. Therefore, the location of the first torsional natural frequency was unknown and could not be avoided. After the coupling failure, the inertia values of the two motors were compared. It was found that the replacement motor had a much lower inertia (WR2) value than the original motor. Reducing the motor inertia caused the first TNF of the system, which was originally below the minimum speed, to increase into the normal operating speed range of the fan.

Since it was not possible to switch back to the original motor, a temporary solution was recommended where the running speed would be limited to a maximum motor speed of 1000 RPM (VFD frequency of 50 Hz) to avoid exciting the first TNF at 58 Hz. This provided a SM of approximately 13 percent between the VFD excitation frequency and the first TNF of the system. The plant was able to run the fan in a safe condition until a long-term solution could be developed.



(Illustration courtesy of Holset Coupling Catalog)

FIGURE 6

A torsional analysis of the system was performed and normalized to match the measured field data. Based on the results of the computer analysis, an alternate coupling was selected to detune the TNF away from the 1× electrical frequency of the VFD. A coupling with rubber blocks in compression (Figure 6) generally has a lower torsional stiffness than a steel flexible disc coupling and provides additional damping. The damping limits the dynamic torque when operating near resonance. Rubber couplings in compression are commonly found on large VFD motor/fan systems at power plants.

The torsional stiffness of the coupling is non-linear and sensitive to shore durometer (hardness) of the rubber blocks. Therefore, when using this type of coupling, it is important to compute the TNFs using various rubber durometers (SM60, SM70, SM80) over the entire operating range. The interference or Campbell diagram shown in Figure 7 illustrates how the first TNF varies with speed/load for various rubber durometers. With SM60 blocks, the torsional resonance was predicted well below

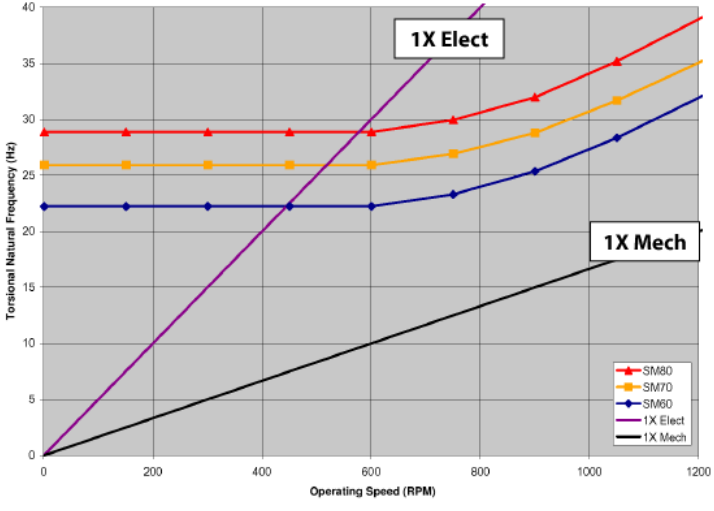
the normal operating speed range. Fortunately, a suitable coupling with proper size and durometer blocks was located within a short delivery time.

The new coupling was installed and the fan system has been operating satisfactorily for five years. This case study shows the importance of performing a torsional analysis on a new system in the design stage and whenever the system is modified. Variables in the system include motor inertia and coupling torsional stiffness. The inertia was significantly different between the old and new motor models.

It is interesting to note that the VFD excitation was higher than reported by the manufacturer. For a smoother VFD producing only one percent torque ripple, the rubber coupling may not have been required. To achieve a reliable design, adequate safety factors must be considered to account for possible variation in the supplied information.

Renold Hi-Tec PM 8 Coupling with Various Durometer Blocks
Interference Diagram - First Torsional Natural Frequency

FIGURE 7



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