Advanced Vibration Analysis on Gear Box Train and vibration elimination

by

Udayashankar P. Eng., MBA,CMRP
Suncor Energy

Machine Train configuration

Brief History

Problem description

Analysis

Rectification

Conclusions

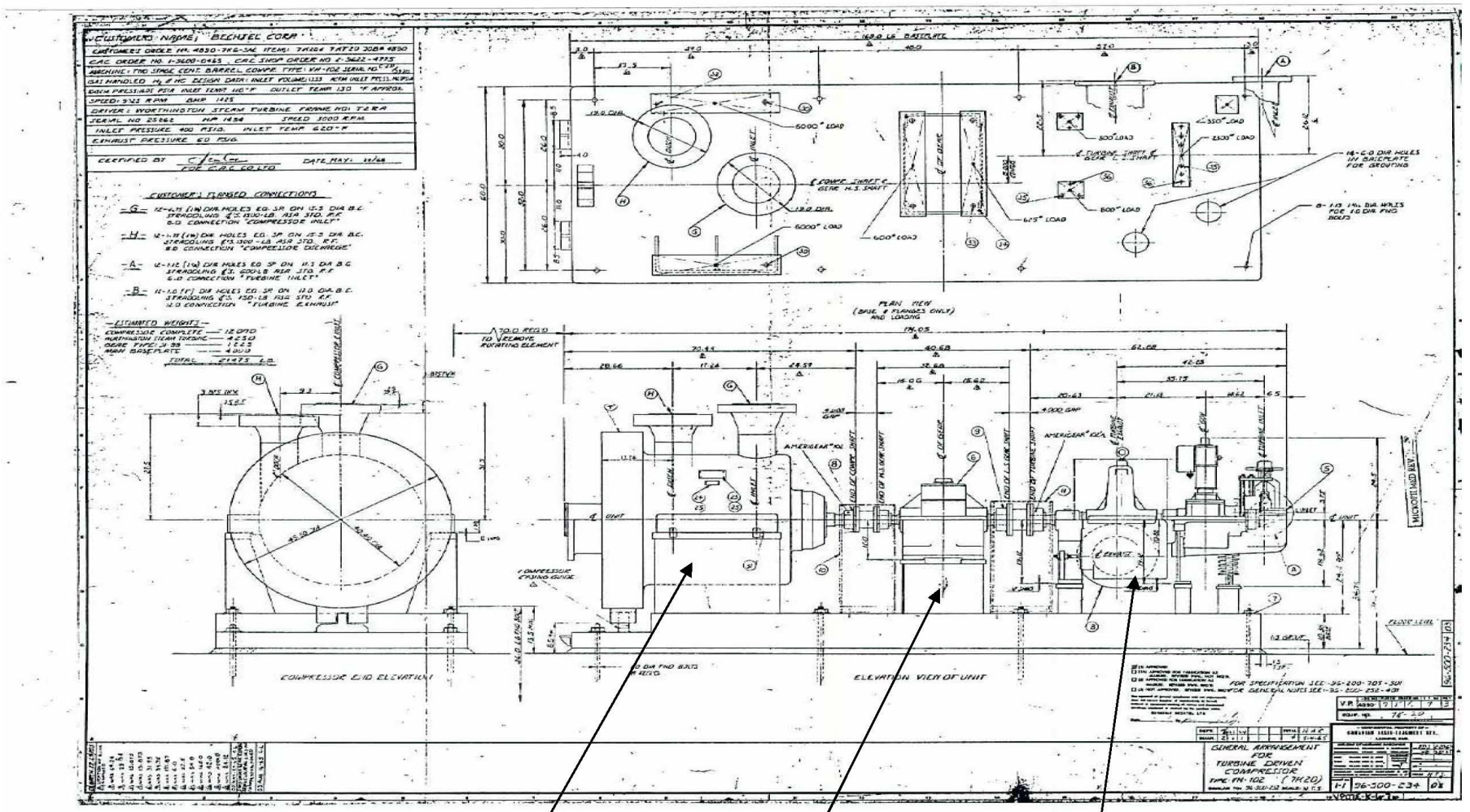
Machine Train Configuration

Compressor

Gearbox

Turbine

Machine Train Configuration GA Drawing



Unit Details

- **Service:** Gas oil Recycle Gas
- **Driver:** Steam Turbine
- **Compressor:** Centrifugal Compressor
- **Gear Box:** Double Helical Gear (109 teeth), Pinion (50 teeth)
- **Ratio:** 2.18:1
- **RPM:** Low Speed Shaft:5609 & High Speed Shaft :12228
- **Suction Pressure (Psig):** 1250
- **Discharge Pressure (Psig):** 1450-1500
- **Temperature Suction (^{0} F)** 188; **Discharge (^{0} F)** 190-220
- **Discharge Flow (MSCFH):** 4500 TO 5000 SCFM
- **Monitoring system for Gear Box:** Casing mounted accelerometers one each for Low Speed and High speed. Online monitoring system is provided for analysis, trending, etc

Brief History-7K-20 Gear box

- **Gear Box was overhauled in1999, 2003,2005, 2006, 2008.**
- **The gears were not changed from 1999 onwards as per the records available.**
- **In general contact pattern of the gears was good; Dimensional, run out & clearance checks within specs**
- **Bearings on the high-speed shaft were in poor condition. Some damage and overheating of the Babbitt was evident in the top halves. Low speed shaft bearings did not have any major damage.**
- **2005 Inspection did reveal some deposit and discoloration due to overheating on the GB Bearings. However the Bearings were replaced.**
- **GB vibration acceleration was trending high from the start up on April 15 th 2005 though the vibration velocity did not trend that high. Vibration alarms occurred on this gear box & alarm levels were re-adjusted up to an overall level of 18 g's on low speed shaft.**
- **April 2006 Specialised Machinery Consultant deployed to conduct a vibration & operating deflecting shape analysis (ODS).**
- **Dominant frequency at 15 times the running speed of the pinion. There was no abnormal gear mesh vibration.**

Brief History (Continued)

- **Engineering evaluation at that time in 2003-2005 recommended that:**
- **Frequency of 5 years between major inspections for the gearbox is considered too long***
- **Evidence of overheating at the bearing as indicated by:**
  1) melting of white metal
  2) by the evidence of varnish deposition on the bearing top half.
- **The overheating is considered to be caused by the effect of the following:**
  - **Use of higher viscosity oil. (ISO 46 grade instead of the original ISO 32)**
  - **Increase in speed ratio and higher output speed for the pinion shaft.**
- **Increase the alarm limits from 10g-12g-14g-18g-22g. No real effort done to address root cause..... The high vibes resulted in frequent failure of Compressor also.**

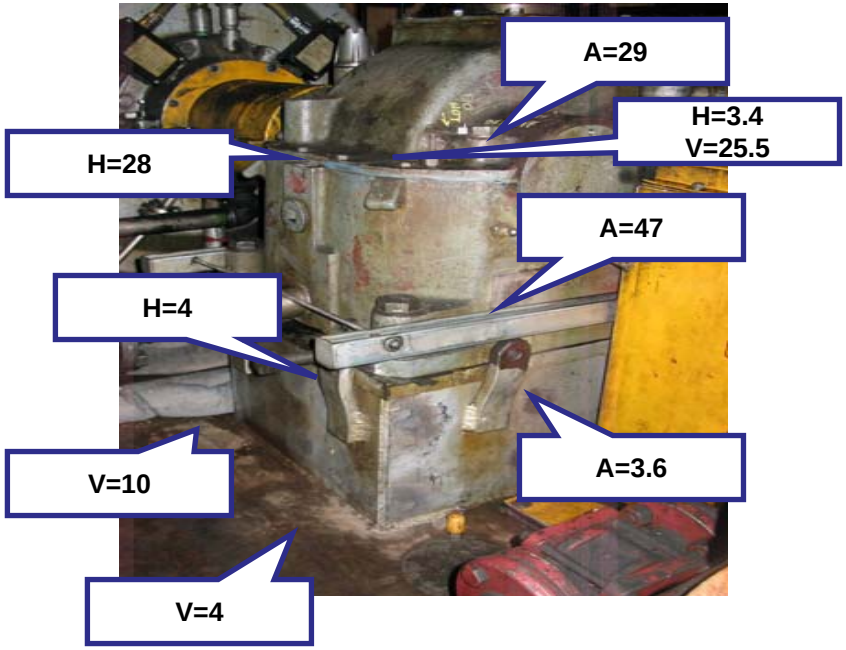
We were trusting the Experts.....

Problem Description

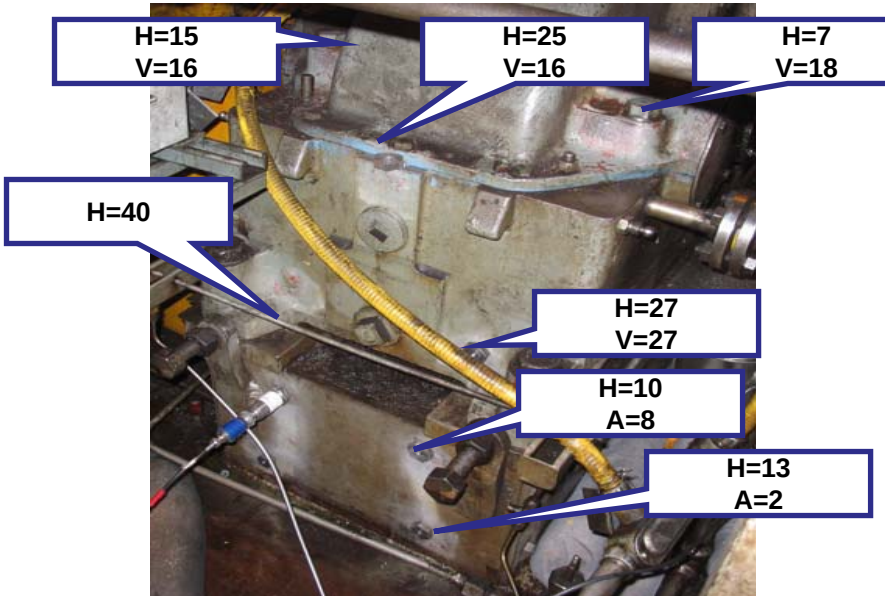
- **High Vibration acceleration of Low and High Speed shafts**
- **Both the speed and the compressor flow rate have a significant effect on the gear box vibration.**
- **Vibration levels are at the worst in the speed range of 5420 to 5620 rpm of the low speed shaft i.e. 11,815 to 12,252 rpm of the high speed shaft. If we do not operate in this range catalyst life will be affected. Catalysts change: $5M**
- **Spectrum showed high vibration at a single frequency that is 15X Compressor speed.**

Observations

The vibration amplitude (units in g – peak) with stud mounted accelerometers at 3.056 KHz frequency i.e. 15 times run speed frequency of the high speed shaft at 12,224 rpm:



Gear Box Front Right Side



Gear Box Left Side

G measured before correction were in the range of 40 g

Analysis

- **The casing vibration velocities on the GB were comparable to sister compressors 7K-10 and &7K-01.**
- **The acceleration trend was increasing slowly on both the LS and HS side of the gears.**
- **Had there been a defect in the gears the GB would not have sustained that long service in spite of indications of High Vibes.**
- **The predominant frequency was 15 times the high speed shaft frequency which again did not seem to correlate to any mechanical components of the assembly train.**
- **It was suspected that this is also due to possible excitations. Can only be confirmed if a natural frequency test of the gears or a hammer test is done.**
- **New instrumentation specific for capturing high frequency vibration data- the 2^{nd} and 3^{rd} harmonic associated with this 15X fundamental frequency was captured.**

Analysis

- **As per API guidelines the acceleration is a parameter for assessing the condition only but not for Machinery Protection.**
- **From the machinery protection point of view, velocity is the more appropriate value to be monitored which is already being done using portable data collectors.**
- **Further from Vibration perspective it is the TREND that counts most rather than the absolute values.**
- **For the gearbox in question the casing vibration velocities have not changed significantly in spite of an increase in the acceleration.**

Analysis

Following types of Vibration data were collected :

- **Time waveforms from the Online system and field data using stud mounted accelerometers.**

- **Frequency averaging from Bently panel and field data using stud mounted accelerometers.**

- **Peak hold vibration data from Bently panel and field data using stud mounted accelerometers.**

- **Operating deflecting shape data of the gear box, its pedestal, grout and foundation.**

Analysis

- **GB Pedestal is made of two metal plates & two C-Channels welded together**
- **No anchor bolts used to anchor these plates to the concrete**
- **Anchor bolts can also get loose with time**
- **Unit is running over 30 years and Oil spills observed all over the area including foundation, base plate & pedestal**
- **Chances of weak bond between pedestal & concrete, base plate and grout are high**
- **Vibrations at all the test points had a dominant peak at 3.056 KHz. i.e. 15 times running speed of high speed shaft at 12 224 rpm. The gear mesh frequency at 12224 rpm of high speed shaft was 10.187 KHz.**
- **Compressor impeller has 18 vanes and diffuser has 14 vanes.**

Rectification- Action Plan

- **GB Inspected in 2005**
- **Continuously Monitored**
- **Correlation between Vibes & Process identified. Marginal reduction in RPM to keep vibe levels recommended**
- **ODS done using External Expertise.**
- **Based on this it was decided to rectify the foundation & fill up the voids during an Opportunity**
- **GB vendor (OEM) was consulted**
- **Vibes alarm levels adjusted safely (twice)**
- **Circuits checked for integrity of the readings.**

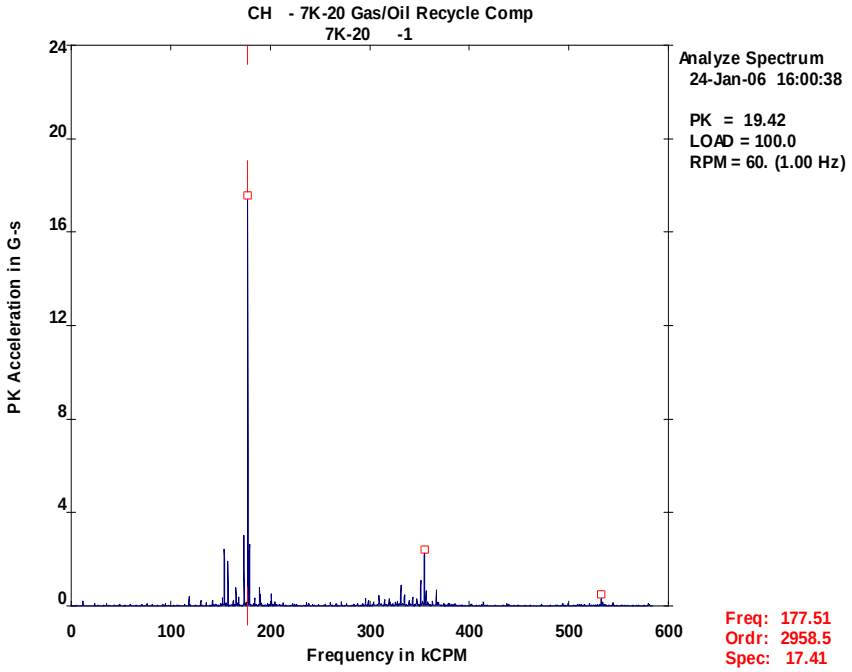
Efforts Made

Stiffen the steel pedestal and attempt to repair the bond to the concrete.

Ensure that the gear box is properly anchored to the pedestal

If we do nothing, the vibration levels will likely worsen. As the vibrations increase the Gear Box deflections will increase to the point the failure will occur

Before rectification- Vibration Spectra



Spectrum on gearbox with high frequency accelerometer showing 2nd & 3rd harmonic of the fundamental frequency- Aug 2005

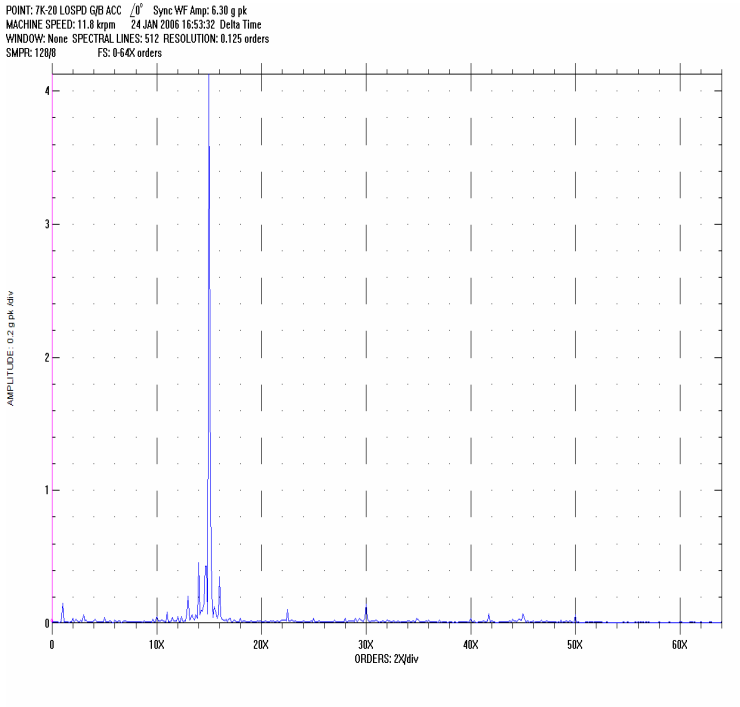


Figure - Spectrum from Data Manager - Spectrum does not show 2nd or 3rd harmonic of frequency- August 2005

Animation- ODS of the Gear Box

Rectification Plan

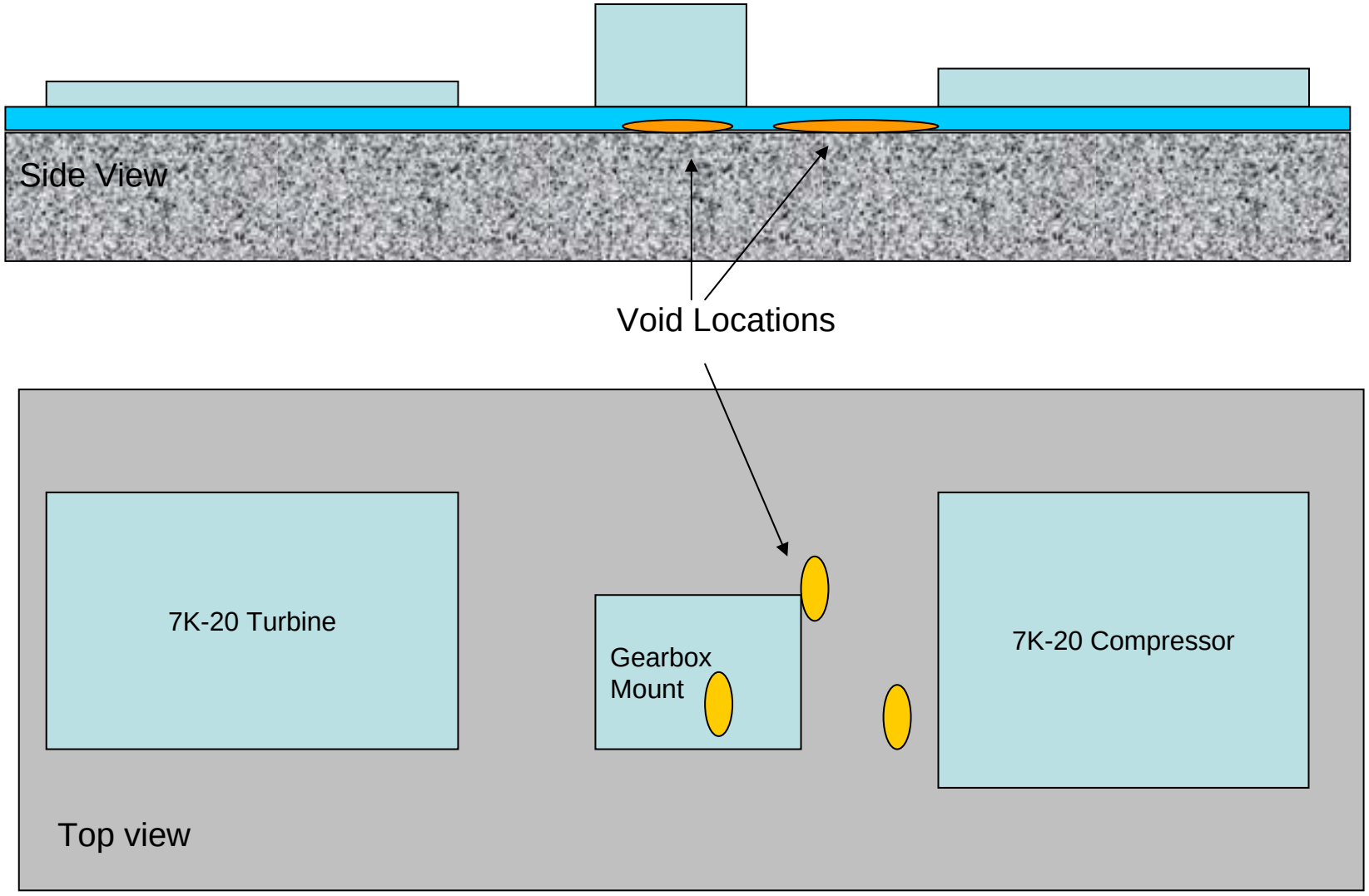
- Gear box was removed & sent to a specialized Gear Box facility
- Adhesive anchors were installed
- Pressure grouting was done to fill the voids
- Additional reinforcement plates installed
- Old grouting was removed & refilled with fresh grout
-
- In situ machining of the base done to level the base
- All base bolts replaced
- The Machinery train realigned and running ever since.
- Compressor overhaul extended to at least 2 to 4 years.

Rectification Plan- Adhesive anchors

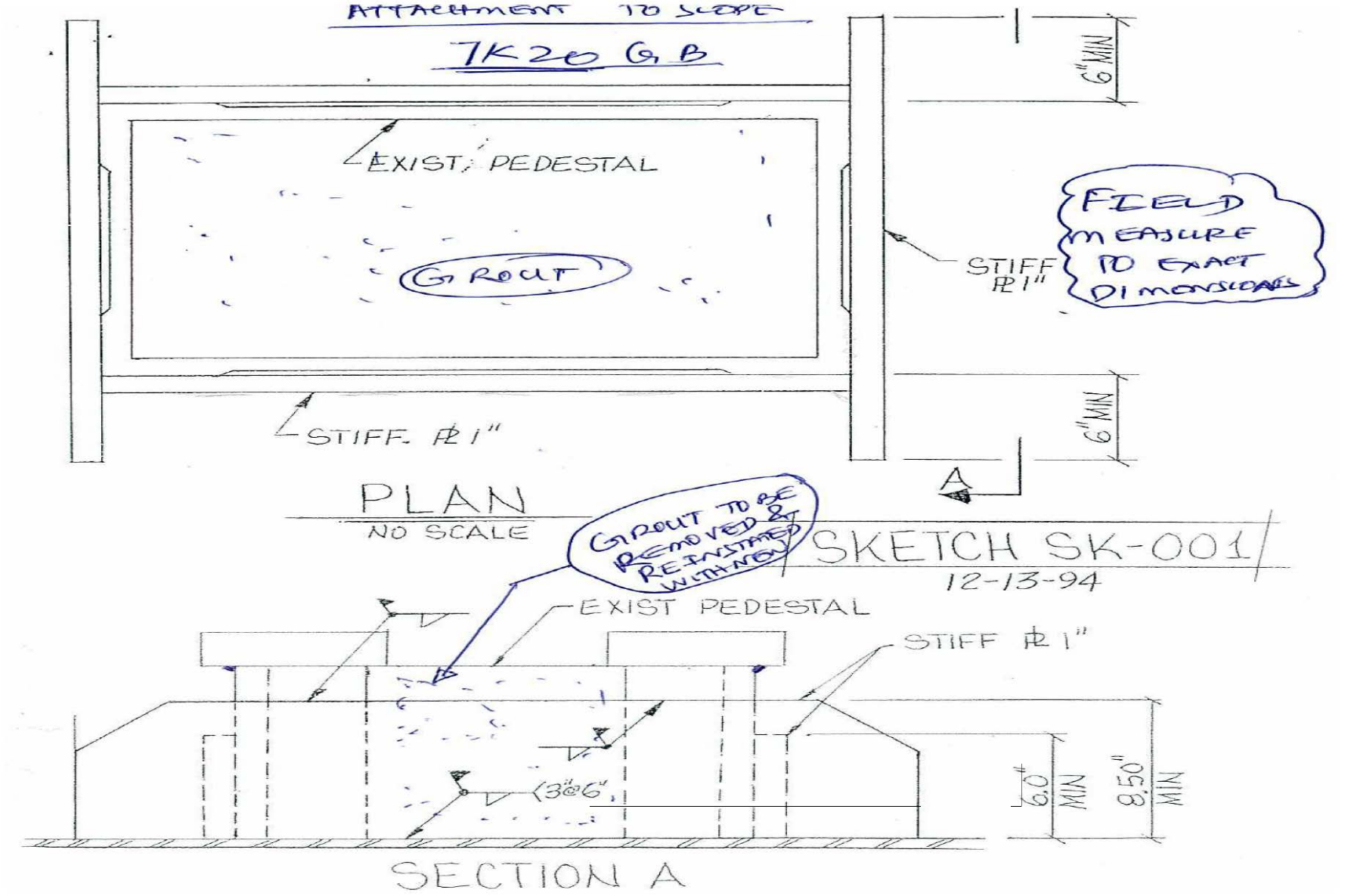
Installed ½” Adhesive anchor bolts at approx. 4” apart

Installed 3/4” Adhesive anchor bolts at approx. 12” apart on the base plate

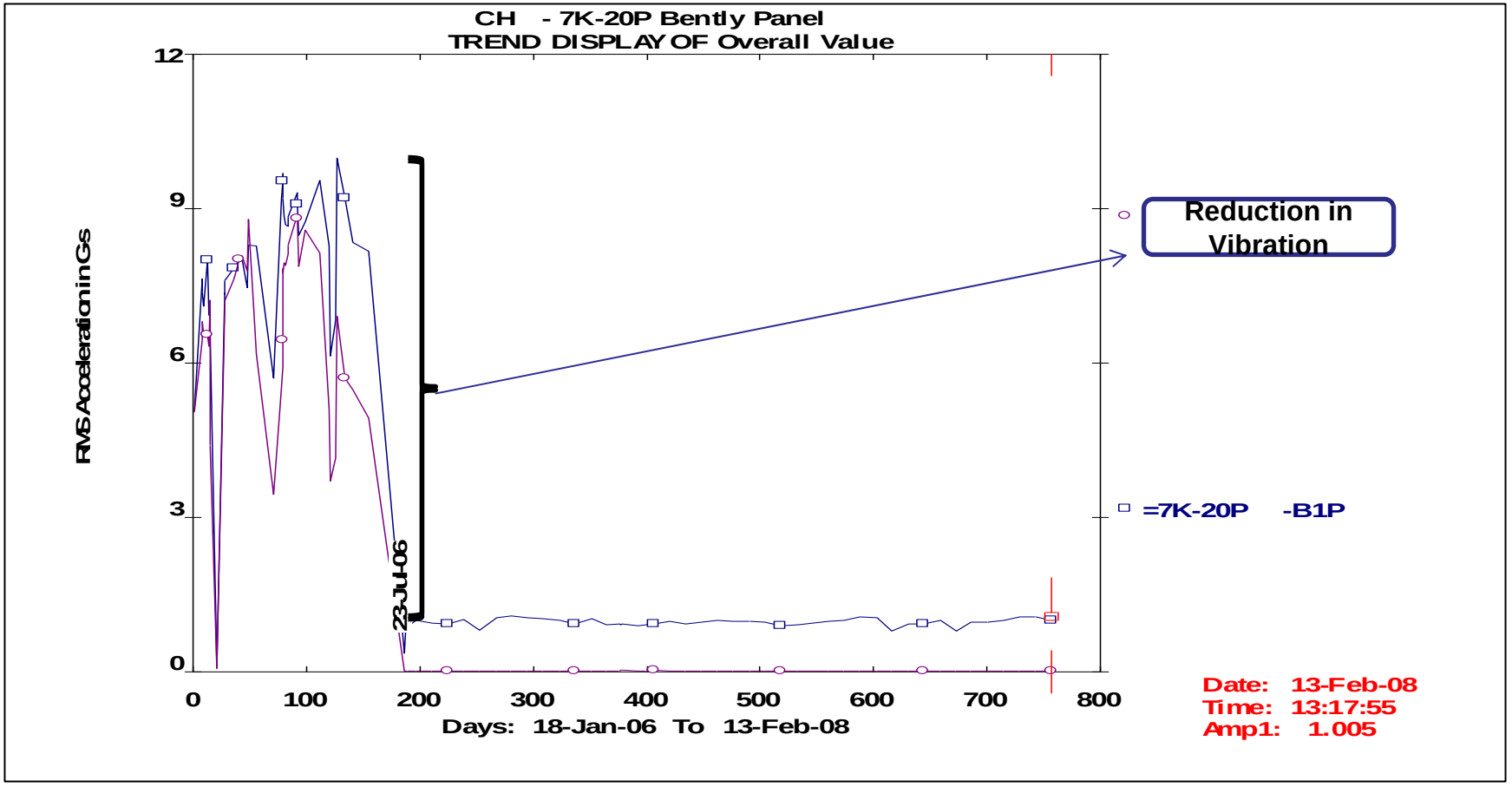
7K-20 Voids In the Gear Box Foundation



Rectification Plan-Reinforcement



Vibration Trend- Pre and Post Correction cases



Post Rectification- Spectrum

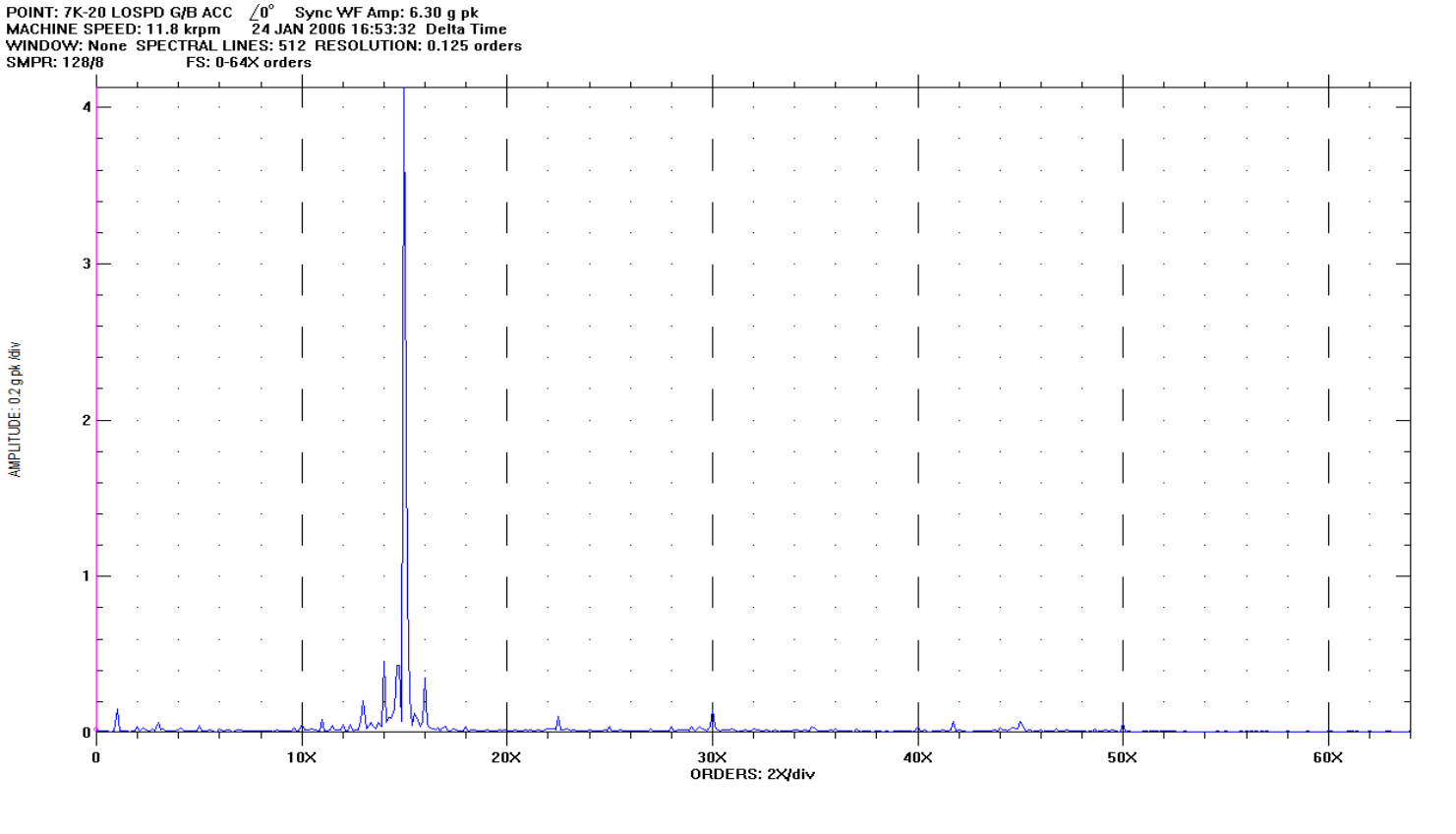


Figure - Spectrum from Data Manager - Spectrum does not show 2nd or 3rd harmonic of frequency- August 2005

Gear Box Vibration Before/ After correction

- Before: 18g to 22g for 20 years approximately
- Predominant: 15 times RPM
- RPM restricted to Max 5000
- **After: 3 to 3.5g**
- Predominant: 1 x RPM
- RPM: 5650
- Result: Catalyst life increase due to increased run time & higher pressure
- Estimated Annual Benefit: at least $1 million & one extra outage avoided

Conclusions

- **Highest amplitude vibrations on the gearbox are not frequencies that would be normally associated with a gearbox mechanical issue.**
- **It was challenging to absolutely identify the source without doing a speed sweep and mechanical impact tests (with the machine shutdown).**
- **The increased levels were well above any industry guidelines for long-term reliability.**
- **The ODS showed significant motion of the gearbox pedestal at those frequencies.**
- **The pedestal is concrete filled and the bond between the steel pedestal and the concrete must have failed. ODS showed that at, at least on one anchor bolt foot, the gearbox is not well attached to the pedestal.**
- **The pedestal and concrete were contaminated with oil. Oil and ANY relative motion at micro-cracks in the concrete or between the concrete and bonded steel will cause the cracks to grow or the bond to fail.**