Solving Sub-synchronous Vibration Problems on Butadiene Compressor with VSDS Drive

By:

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Solving Sub-synchronous Vibration Problem

- Mechanical Train consist of an axially split centrifugal compressor, a speed increasing gear box, and an induction electric motor

- Compressor
  - Back to back design having two impellers (600 mm Dia), tandem dry gas seals, tilt pad radial/thrust bearing with direct pressurized forced lubrication.
  - Rated flow 28922 Am3/h, polytropic head 2854 kg-m/kg, power 2570 kw, speed 7854 rpm
  - Operating speed 85-105% or rated, Lateral critical speed (1st 3275 rpm, 2nd 14150 rpm), torsional (1st 839 rpm, 2nd 2095 rpm, 3rd 10298 rpm)

- Gear
  - Double helical single stage increasing gear, gear ratio 5.531, service factor 1.7, integral flange at both bull gear shaft and pinion shaft

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- Electric Motor
  - 3000 kw rated at 1420 rpm, 3300V induction electrical IC611 air to air cooled
- Variable Speed Drive
  - 12 pulse converter transformer 6600 kvA to 3000 kvA, Frequency converter with integrated low pass sine filter rated for 2500 kw and 3300V. The VSD is to manage compressor capacity control where compressor suction pressure is maintained by its speed variation.
- Couplings
  - Flexible diaphragm couplings based on API 613 special purpose. Shaft end is taper fit on motor, shaft integrated hub on gearing, and taper fit on compressor.

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- Design Items
  - Torsional Vibration analysis attached
  - Unit was run at compressor manufacturer with full string test at 1 MW and speed was varied at 85%, 90%, 95%, and 100%.
  - The VSD is equipped with a sine filter. This filter is eliminating any harmonic as well as sub-harmonic components in the output voltage . Torque pulsation can assumed to be like directly connected line motors as long as the toque and speed reference do not contain any pulsations (i.e. reference is stable)

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- Design Items

  - Motor, VSD, and transformer were supplied by same vendor. Unit was tested at electrical vendor shop (see attached test set up) by connecting to a generator and then testing at 100% load and various frequencies to measure the Torque pulsations (less than 1.1%), current total harmonic distortion (less than 1.3%), and voltage total harmonic distortion (less than 1.6%) which are all less than guaranteed values of less than 2%.

  - Vibration analysis and protection – The system is provided with Bently Nevada 3500 and System 1.

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TORSIONAL CRITICAL ANALYSIS REPORT

1. Operating Speed

Motor / Bull gear speed	: 1,207 – 1,491 rpm
Compressor /Pinion speed	: 6,676 – 8,247 rpm

2. Critical Speeds :

Mode	2MCH602
First Critical	839(rpm)
Second Critical	2095(rpm)
Third Critical	10298(rpm)

3. Result of Calculation API-617 para 2.9.4

(a) First Critical

{(1207- 839) / 1207}×100 = 30.5 % > 10 %

(b) Second Critical

{(1207-2095/2) / 1207}×100 =13.2 % > 10 %

(c) Third Critical

{(6676-10298/2) / 6676}×100 =22.9 % > 10 %

4. Conclusion

(1) According to our calculation, torsional critical speed of this rotor system has sufficient margin specified in API617 para 2.9.4.2 for each case.

(2) In our own judgment, this rotor system meets the API requirement.

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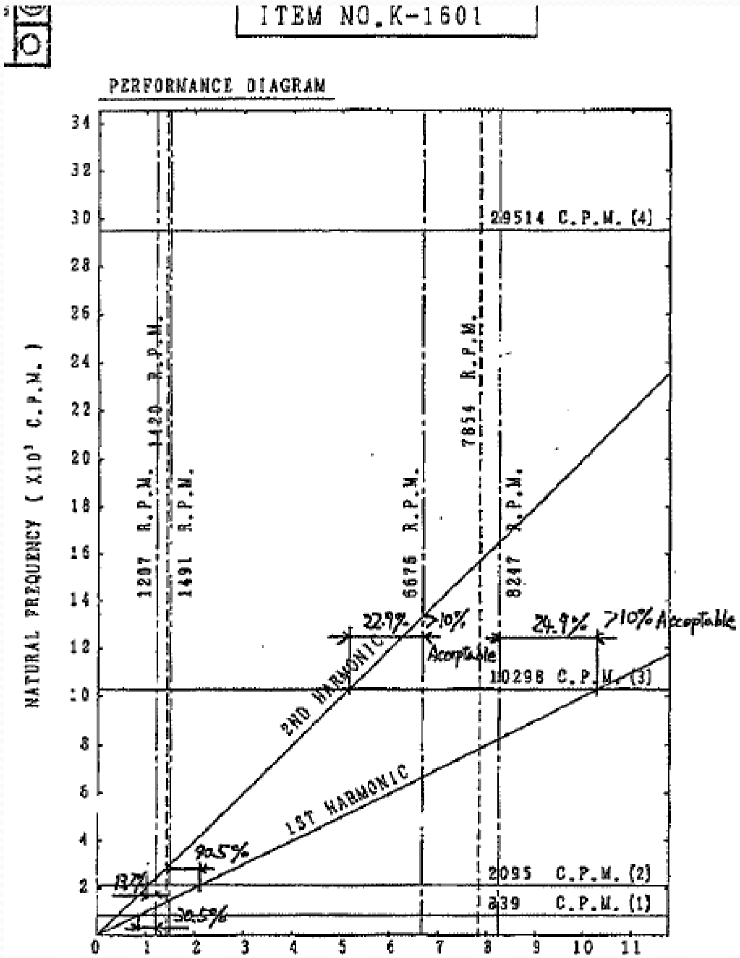

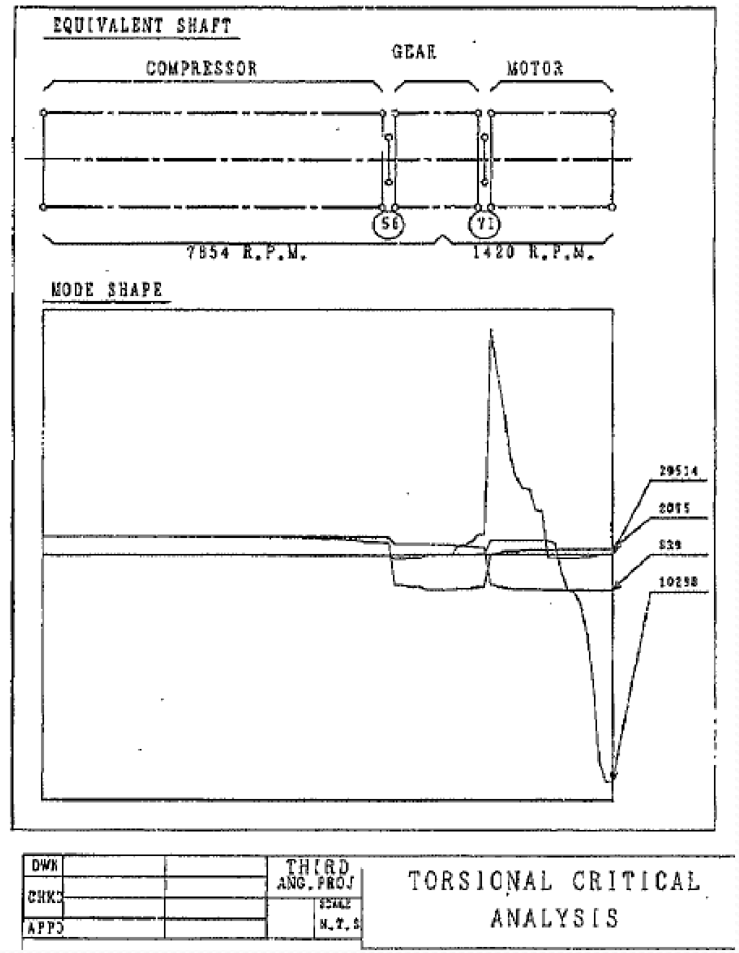

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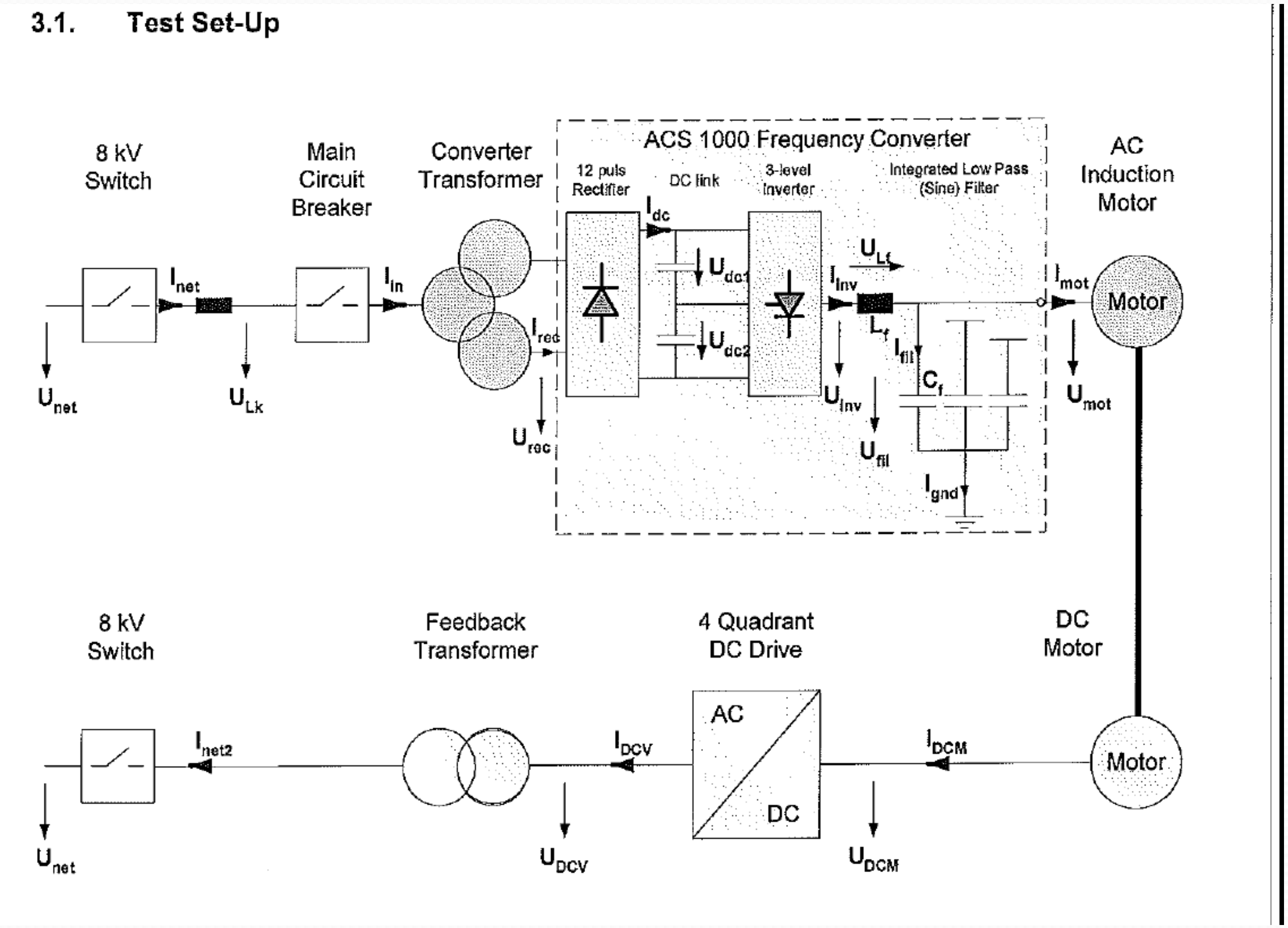

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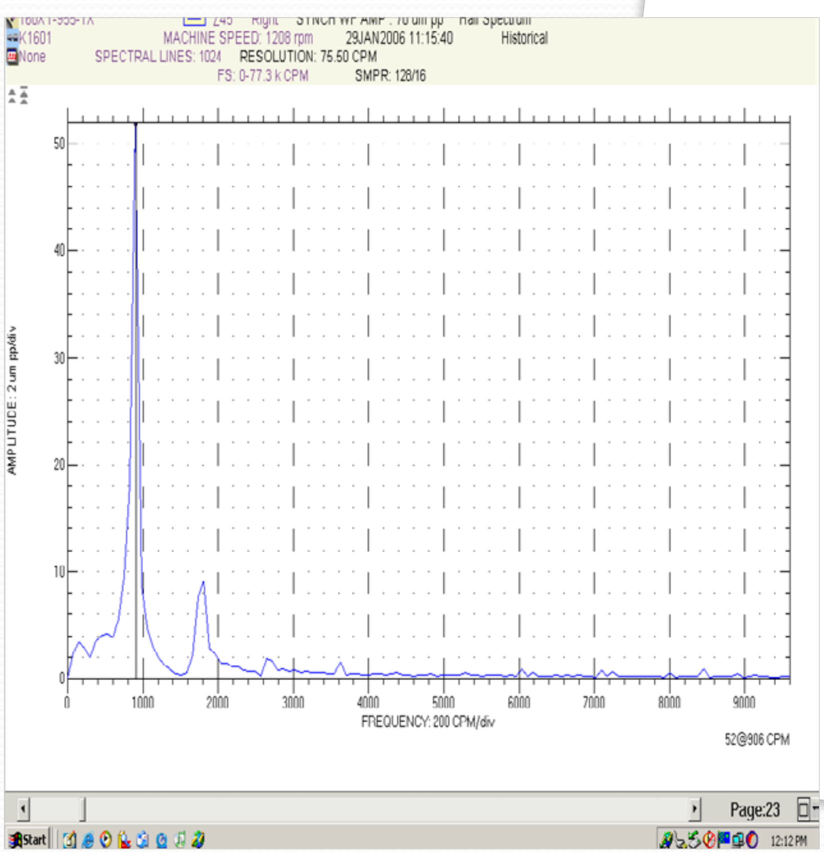
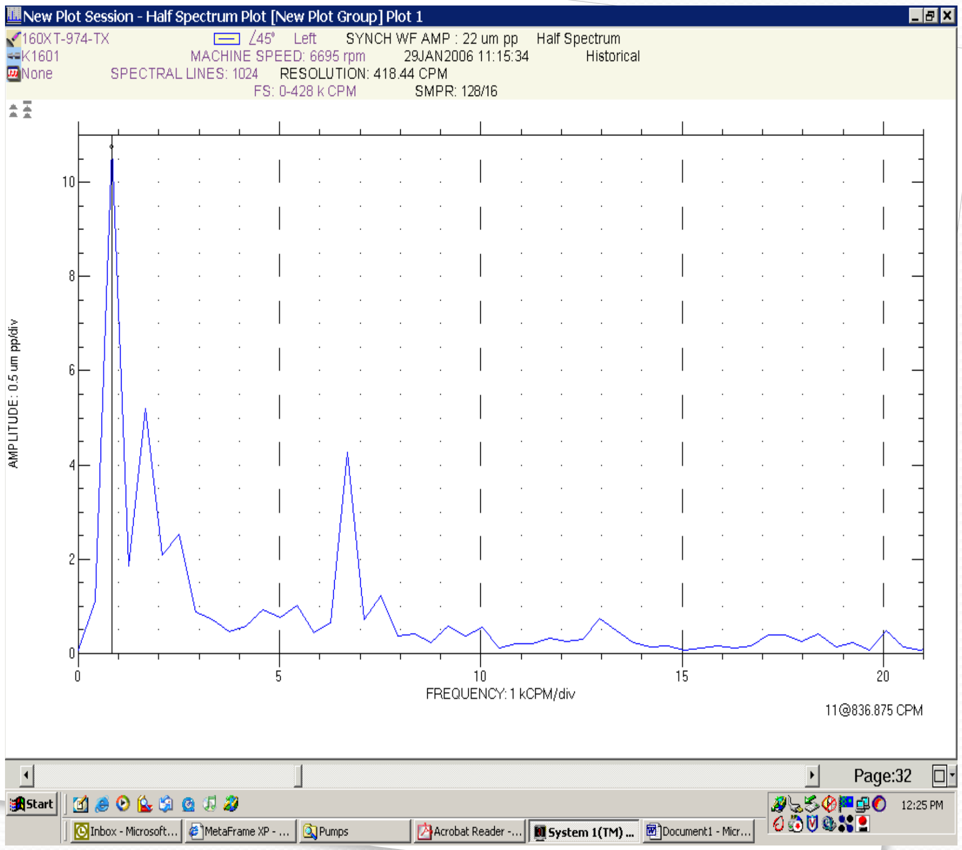
- Plant Operation
  - Compressor train was started for the first time on 1/29/2006
  - Compressor train was shutdown after less than 10 minutes of operation. Gear box was making noise due to teeth contacting as they oscillate between the backlash. High Vibration of 60-70 microns is observed on the gear box bull gear drive end.
- Troubleshooting
  - Gearbox inspected on 1/30/2006 and no problems found
  - Vibration analyzed see slides 10 to 12
  - Orbit on slide 11 shows the gear teeth contact and audible noise that was observed
  - Spectrum and waterfall plots show that the vibration frequency is sub-synchronous
  - Vibration frequency is very close to first torsional critical speed.

Solving Sub-synchronous Vibration Problem





Bull Gear spectrum and Pinion spectrum

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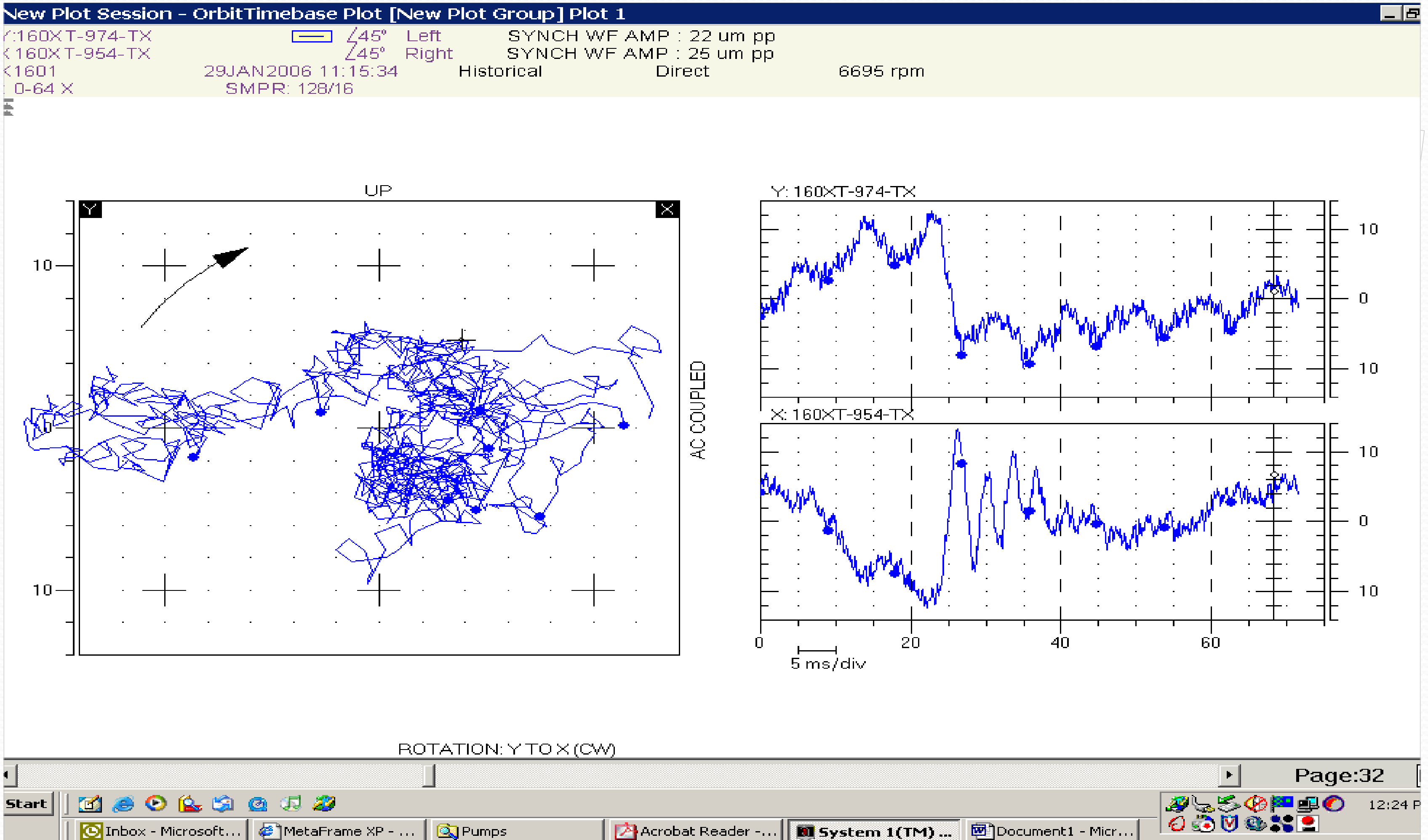
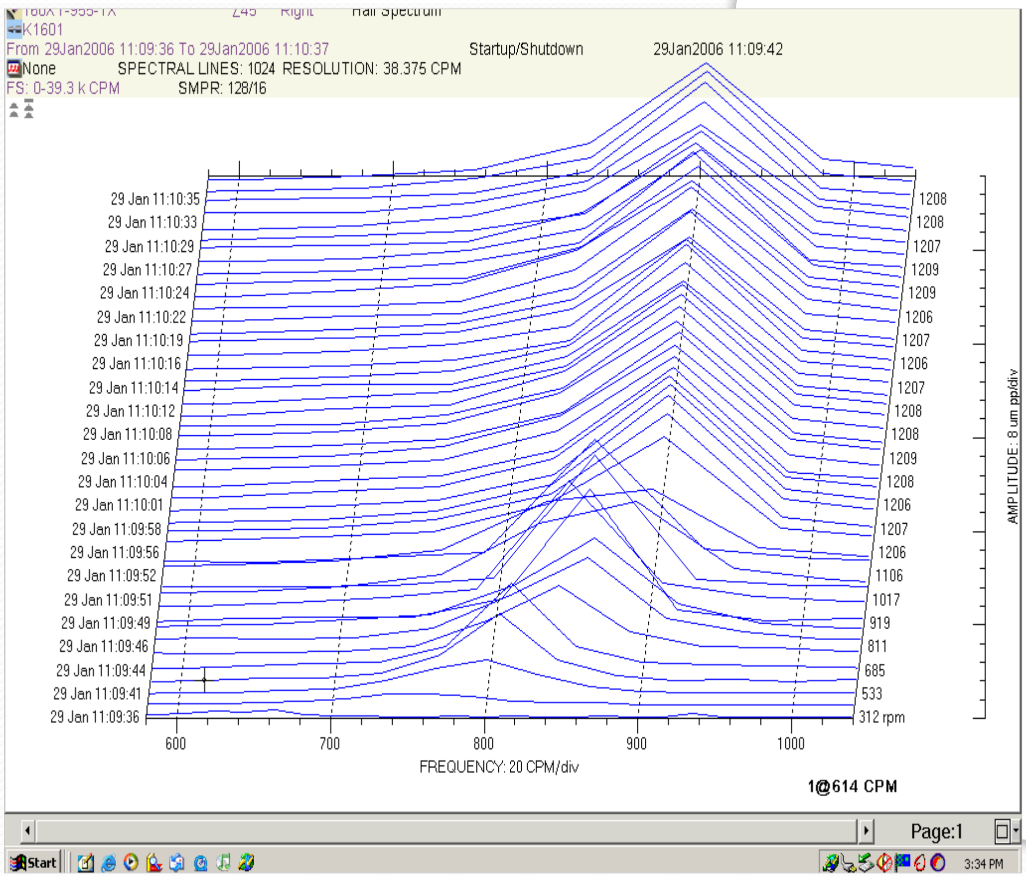
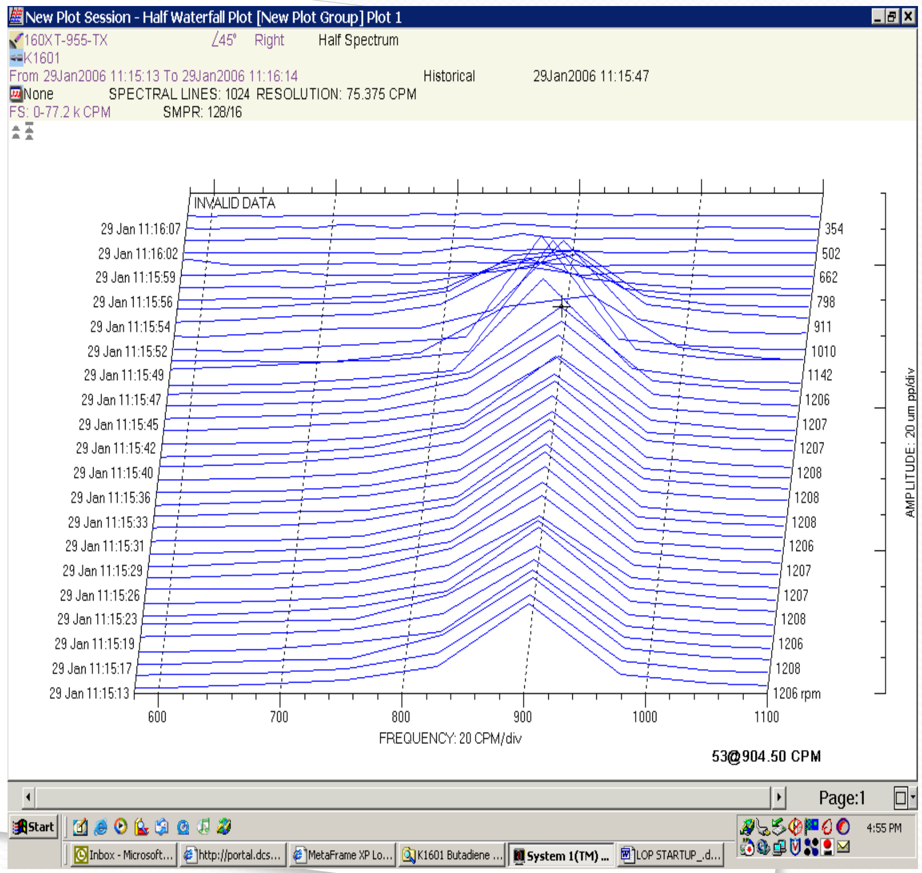


Pinion Orbit

Solving Sub-synchronous Vibration Problem

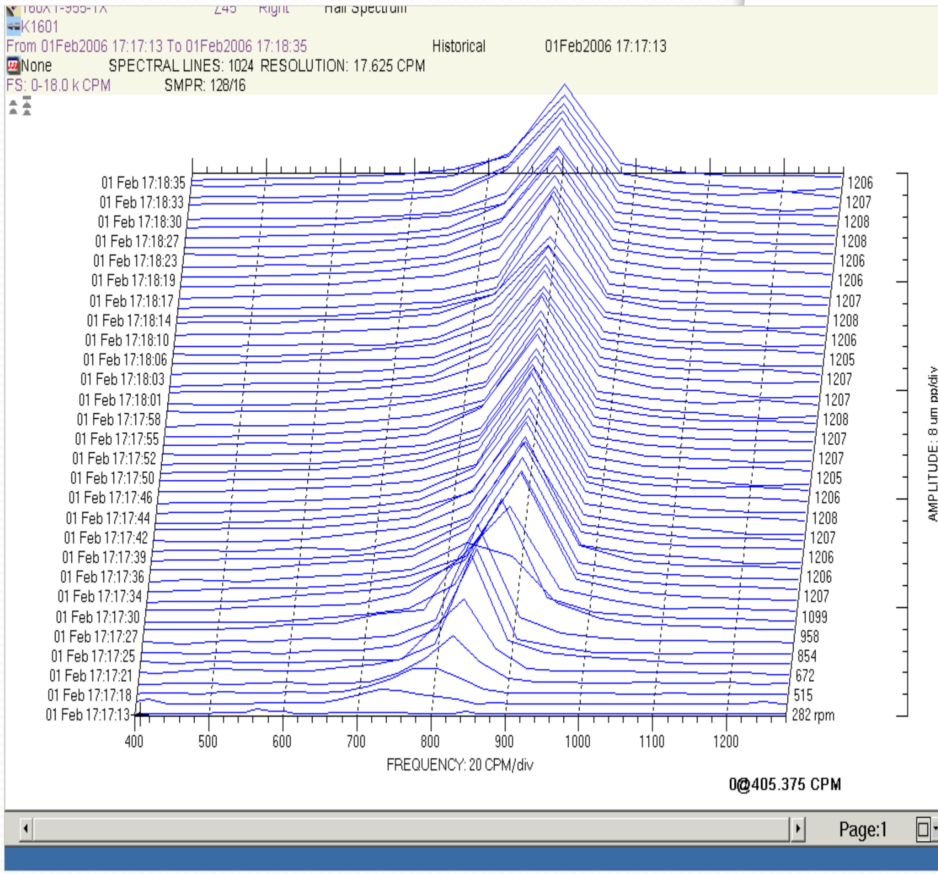


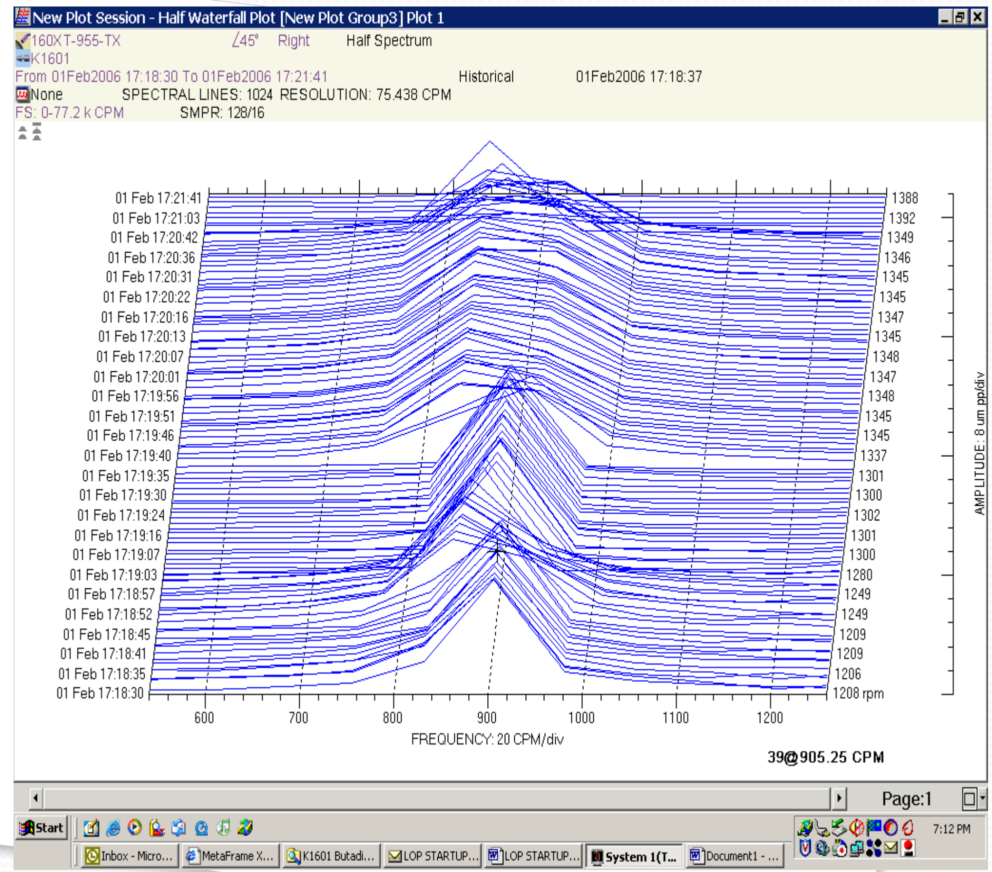


Solving Sub-synchronous Vibration Problem

- Troubleshooting
  - What is exciting the first torsional critical? Is it a mechanical problem or electrical problem?
  - Electrical vendor is contacted and specialist arrived at site in several days
  - It is decided to start the train again on 2/1/2006 and collect more data. See vibration plots on slides 14 and 15.
  - One test is to perform a hard stop and see if vibration reduces as soon as the electrical source is shot down.
- Observations
  - Vibration amplitude drops off on shut down. Problem is now believed to be caused by an electrical excitation.
  - Vibration drops to normal levels near 100% speed
  - Vibration frequency shifts from 905 CPM to 840 CPM with increasing train speed

Solving Sub-synchronous Vibration Problem





Start up waterfall and increasing speed to 100% waterfall

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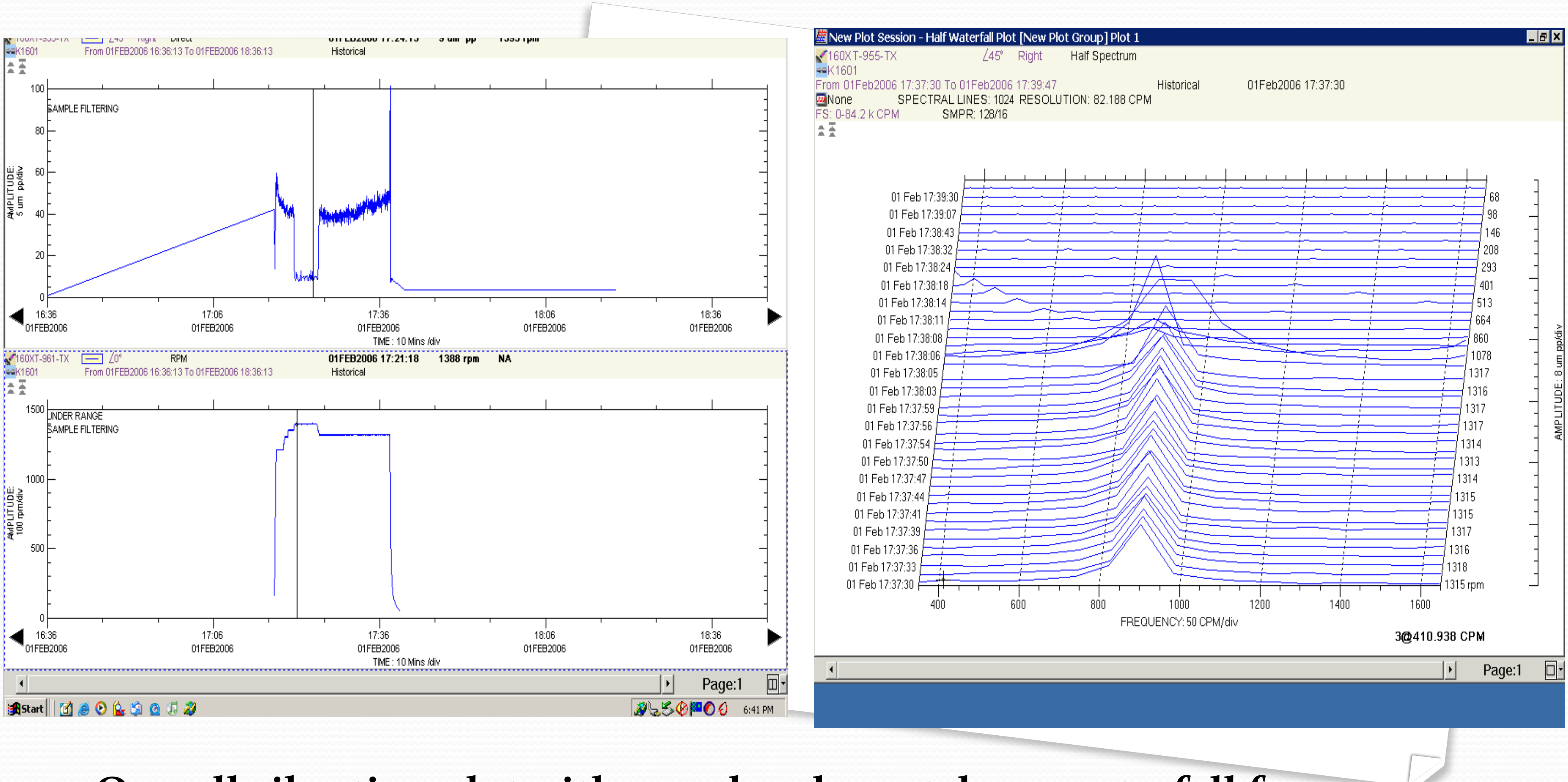


Overall vibration plot with speed and coast down waterfall from hard stop

Solving Sub-synchronous Vibration Problem

- Troubleshooting
  - Electrical vendor specialist arrives on 2/8/2006
  - Specialist finds that the speed reference is oscillating and causing a variation in the motor torque.
  - Specialist tunes the VSD and brings the speed error and motor torque within acceptable levels. See slide 17. (Changed proportional gain ½ value to obtain slower response)
  - Result is that the sub-synchronous vibration is reduced to acceptable levels allowing the compressor train to run continuously. See Slide 18.

Solving Sub-synchronous Vibration Problem

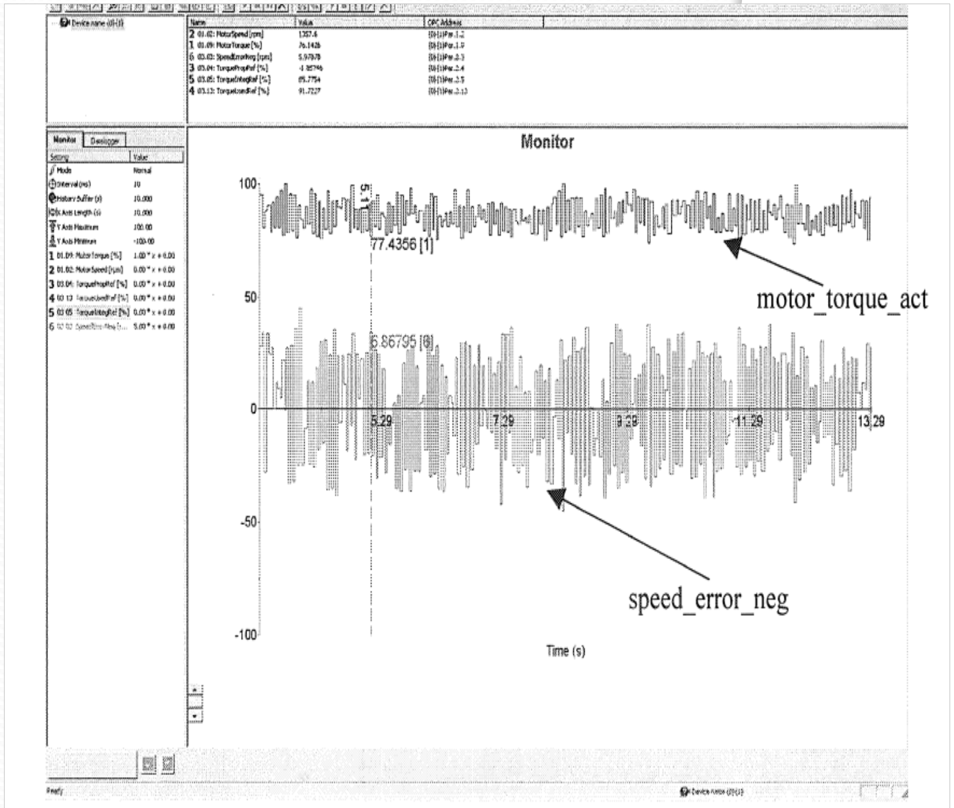


Fig1 before tunning

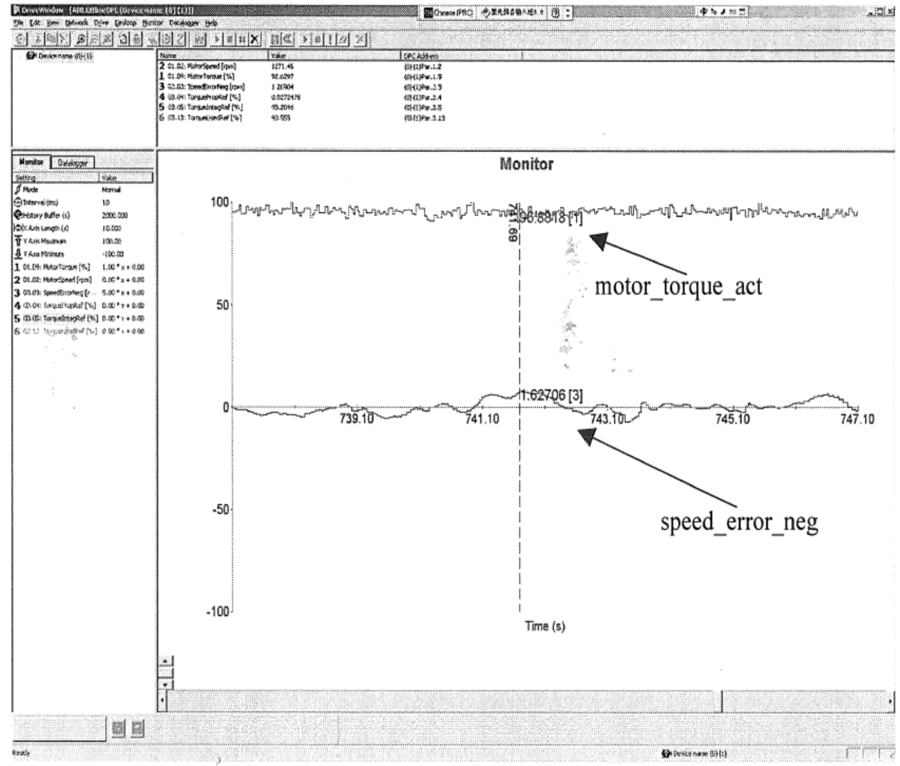
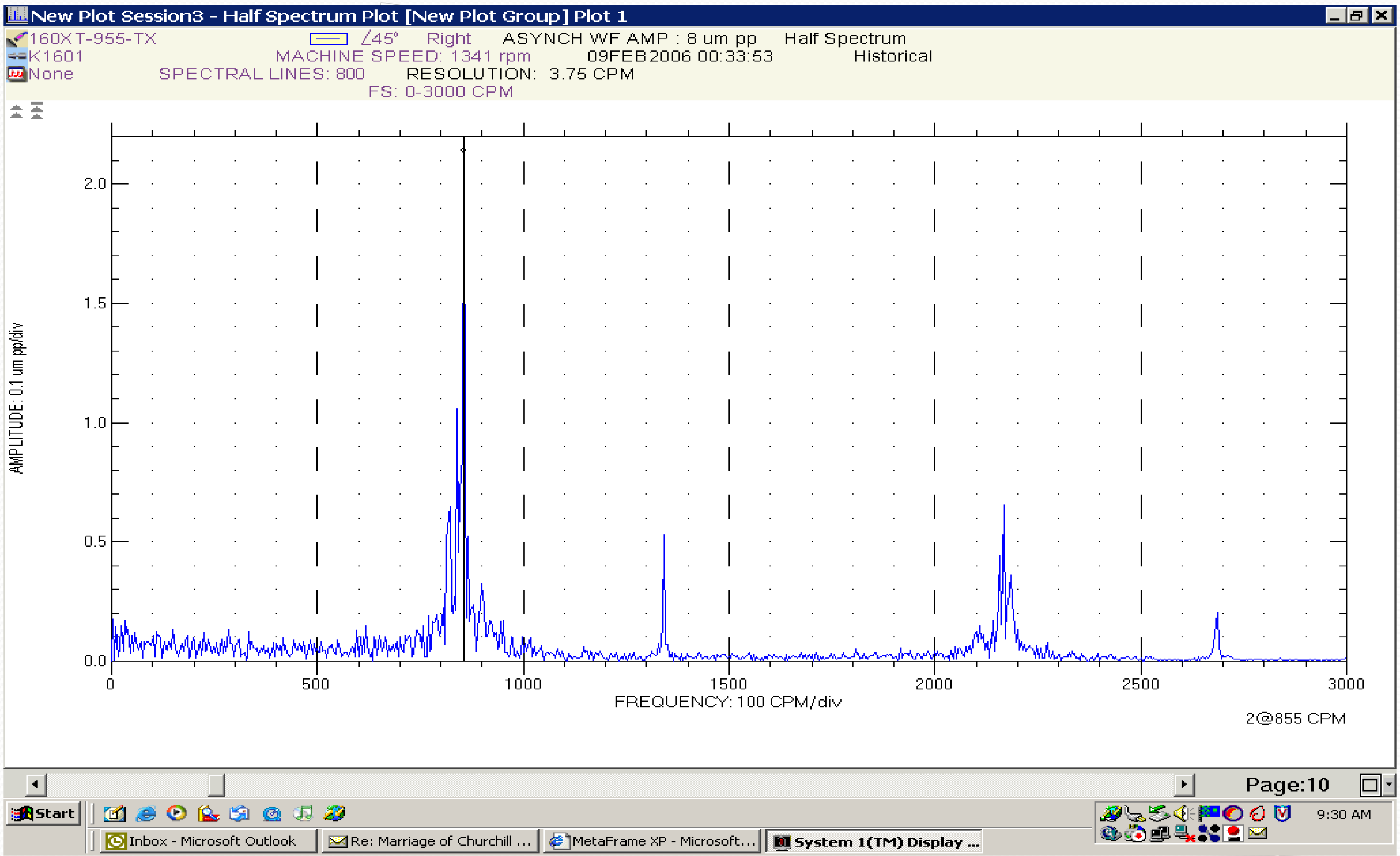


fig 2 after tunning

Motor torque and speed error before and after tuning

Solving Sub-synchronous Vibration Problem



Vibration spectrum on bull gear after tuning the VSD

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- Additional Findings and Outstanding Issues
  - High vibration suddenly has been back in two years later where coupling bolt failure was observed.
  - The high vibration appeared at particularly higher rotating speed than the previous occurrence.
  - The initial VSD tuning did work on reducing vibration amplitude but did not completely kill the component of 1st torsional frequency.
  - The issue existing on this mechanical string might be a combination of self-excited vibration by VSD feedback control and forced vibration by VSD harmonics.

Solving Sub-synchronous Vibration Problem

- Conclusions
  - Vibration problems are complex and require elimination of probable causes to solve the problem. In this case, the vibration data and rotor dynamics (torsional) identified the problem as exciting the first torsional critical. Probable causes were eliminated one by one until the solution was found.
  - VSD drives have a history of exciting torsional resonance frequencies resulting in vibration problems. Manufacturers have installed filters to eliminate the traditional torque ripples that were present and excited torsional natural frequencies.
  - Speed feedback control within a VSD can also be a culprit of torque ripple as is the case for this compressor train. Speed feedback control provides very quick response, but can produce toque ripples.

Solving Sub-synchronous Vibration Problem

- Conclusions
  - It may be recommendable upon adopting electrical VSD that key parameters available in VSD controller such as current, torque, speed error are to be hard-wired to plant monitoring system in order for operator to ease analysis.
  - VSD manufacturer and its OEM (driven equipment manufacturer) desire to discuss whether or not the excitation caused by VSD can be predictable during design stage and/or shop running test, and establish a appropriate design process that can satisfy the customer.
  - Owner should consider if a very quick response in the process is required. Open loop control is slower, but reduces the torque ripple.
  - Require in the purchase order for the manufacturer to build a simulation model that predicts the torsional response for different control functionality.

Solving Sub-synchronous Vibration Problem

- Conclusions
  - Complete root cause analysis may need several field exercises. This can usually disturb plant commercial operation once oil & gas/petrochemical plant starts up, and sufficient RCA is not achievable. Appropriate ways to predict those issues during engineering stage is required.