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VFD Fundamentals & Troubleshooting

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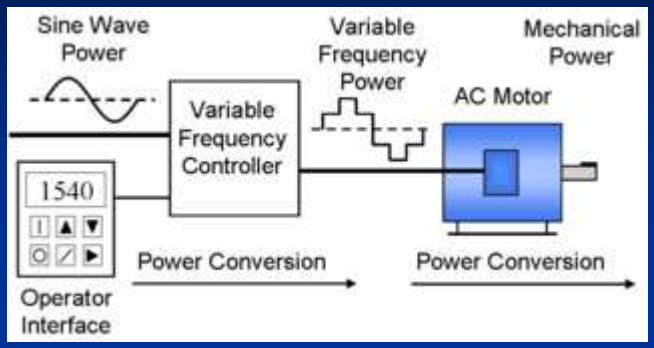
Overview

Today we will discuss some of the fundamentals of a Variable Frequency Drive (VFD) system for AC motors and general troubleshooting:

- VFD Fundamentals
- VFD Installation Considerations
- VFD Troubleshooting
- VFD Data Examples

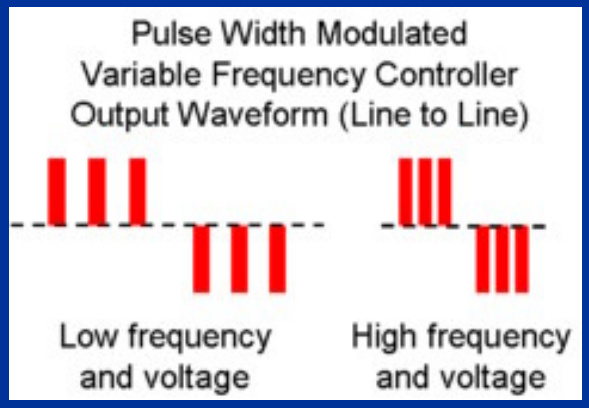
VFD Fundamentals



Courtesy: Wikipedia

Typically, the power supply to the variable frequency controller will start out as 3-phase AC power. The AC signal will be rectified and converted to a DC signal.

The DC signal is then pulse width modulated (PWM) and filtered to feed a clean power signal to the motor.



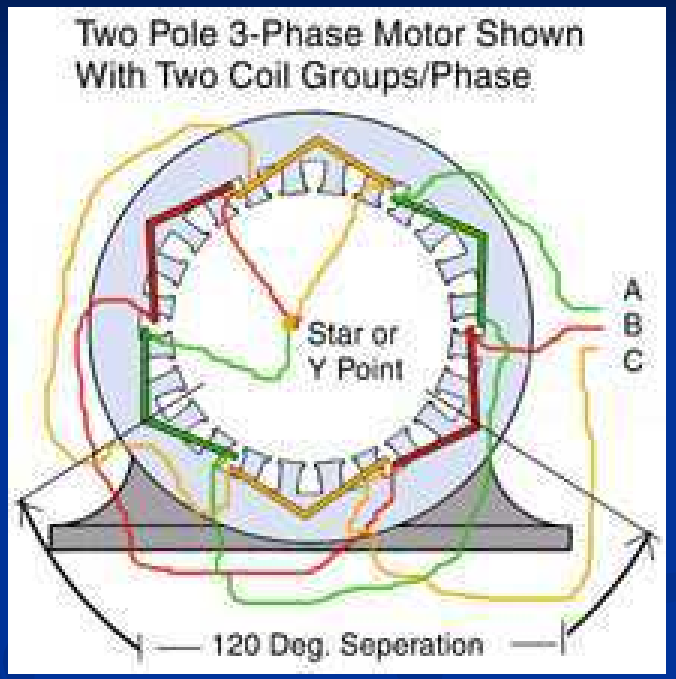
Courtesy: Wikipedia

The PWM signal is then controlled to control the speed (i.e. the output) of the motor.

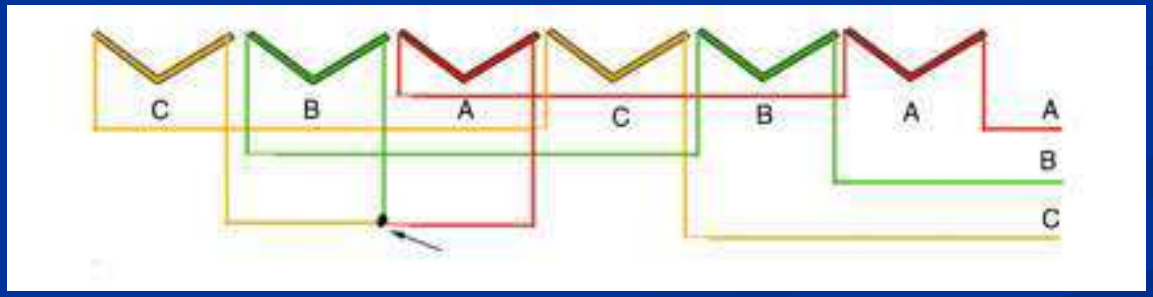
VFD Fundamentals

All Three Phases of a 2-Pole Motor
The image to the right shows all three phases wound into a 2-pole motor.

Note how the end connections of each phase are connected together at the "Y" point. This allows for three lead wires to be brought out of the terminal box to be connected to a 3-phase power system.



Courtesy: Electrical Training USA



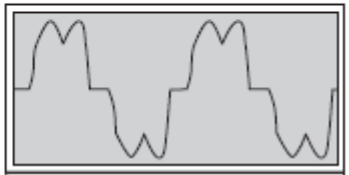
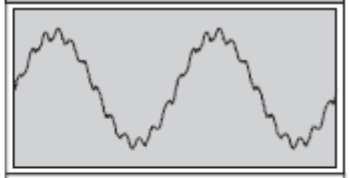
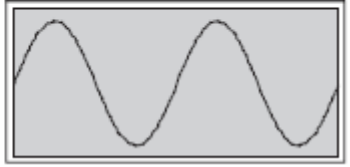
VFD Fundamentals

What's our biggest difference between a standard motor and a VFD motor operationally?

The effective difference is the feed of the power to the motor is no longer like an analog signal, but a digital signal.

It's the same difference from an 'old school' record and a 'new school' CD.

VFD Fundamentals

Supply type	Current TDH (%)	Voltage TDH (%) RSC=20	Voltage TDH (%) RSC=100	Current Waveform
6-pulse rectifier	30	10	2	
12-pulse rectifier	10	6	1.2	
IGBT Supply Unit	4	8	1.8	

Distortion is in % of RMS values

Courtesy: ABB

Development has brought the switching speeds faster and faster to try to simulate the original sine wave of the power supply.

VFD Fundamentals

There are a lot of different design options for variable frequency drive manufacturer's.

There are a lot of trade-offs in the different designs and depending on the goals and preferences of the manufacturer there will be strengths and weaknesses of each drive design style.

If you want to understand more about VFD drives there are many resources available from the different manufacturers themselves to industry trade information.

- NEMA and IEEE MG1
- NEMA Application guide for AC adjustable speed drive systems
- If you have a specific manufacturer that supplies most of your facility ask them for their technical papers

Installation Considerations

Proper motor sizing is still required for the application.

- Over speeding the motor or
- Operating the motor below 25% design speed

Are not typically recommended

Inverter duty motor

Properly chosen VFD design,
Do you need a reverse operating mode capability?

Properly designed motor leads and limited length

Final adjustment and setup by VFD technician

VFD Troubleshooting

Troubleshooting a VFD drive is similar to investigating any other electronics:

SMARTS – *Electrical Construction and Maintenance Magazine*

Safety – Understand the work scope involved
Manual –Necessary to perform any significant troubleshooting
Application – remember this is a system and the drive functions with the rest of the machine train and power supply
Readings - Taking data and checking conditions will be necessary
Talk – Talk to local operators, instrumentation, or mechanical personnel to find out what happened at the time of the failure
Symptoms – Try to separate out the symptoms from the problems (i.e. a blown fuse may be an indication of a bigger problem and not the problem itself)

VFD Motor Fault Analysis & Monitoring

Remember

We are effectively monitoring or troubleshooting a motor (with some added characteristics)

There is no reason to make it harder than it really is.

So, what we can do is take it one step at a time and eliminate potential issues one at a time

And never forget, Murphy's Laws on Technology are in full effect:

"Logic is a systematic method of coming to the wrong conclusion with confidence"

VFD Motor Fault Analysis & Monitoring

We are dealing with a variable speed machine; therefore verifying the operating speed during any data collection operations will be critical to proper diagnosis.

Depending on the application and installation use whatever tools are available and useful for your specific situation:

- On-board data
- Strobe light
- Tachometer
- Or if necessary choosing the 1X speed in the data spectrum

Order tracking tools and techniques can be very useful and efficient for analyzing a variable frequency

VFD Motor Fault Frequencies

Electric Motor Fault Conditions:

- Rolling element bearing faults
- Sleeve bearing faults
- Imbalance
- Misalignment
- Looseness
- Soft foot conditions
- Mechanical Resonances
- Rotor winding failure
- Stator winding Failure
- Air gap issues
- VFD Carrier Frequencies
- Audible Noise

Note: these are not all possible failures, but the most typical

VFD Motor Fault Frequencies

Note that when trying to evaluate the electrical fault signatures, the line frequency and 2X line frequency will not necessarily be at 60 Hz and 120 Hz.

You need to know line frequency to verify slip frequency to verify pole pass frequencies.

If the on board controls tells you what the ‘line frequency’ is then use that information. If not you may have to look for the 2X line frequency just beyond the 2X of rotor speed for an ~ 3600 rpm machine; or 4X of rotor speed for an ~ 1800 rpm machine.

If there is very little slip you may have to do a high resolution data set To separate the multiples of the rotor speed and the line frequency.

VFD Motor Fault Frequencies

After you eliminate any other 'typical' fault frequencies, we can focus on the faults associated with the VFD drive:

If you have an unidentified wide frequency band vibration fault (~ 10 Hz) it is possible that it is a VFD problem. Additional tuning of the torque profiles, carrier frequencies, or smoothing parameters may correct the issue

Various carrier frequency possibilities:

- Older SCR drives were usually 250 to 500 Hz
- BJT drives were typically 1 to 2 kHz
- IGBT drives have ranges from 3 kHz to 12 kHz and even higher with newer designs

Need to get manufacturer to tell you their design parameters

VFD Motor Fault Frequencies

What can a poorly designed or faulty drive system do to a motor?

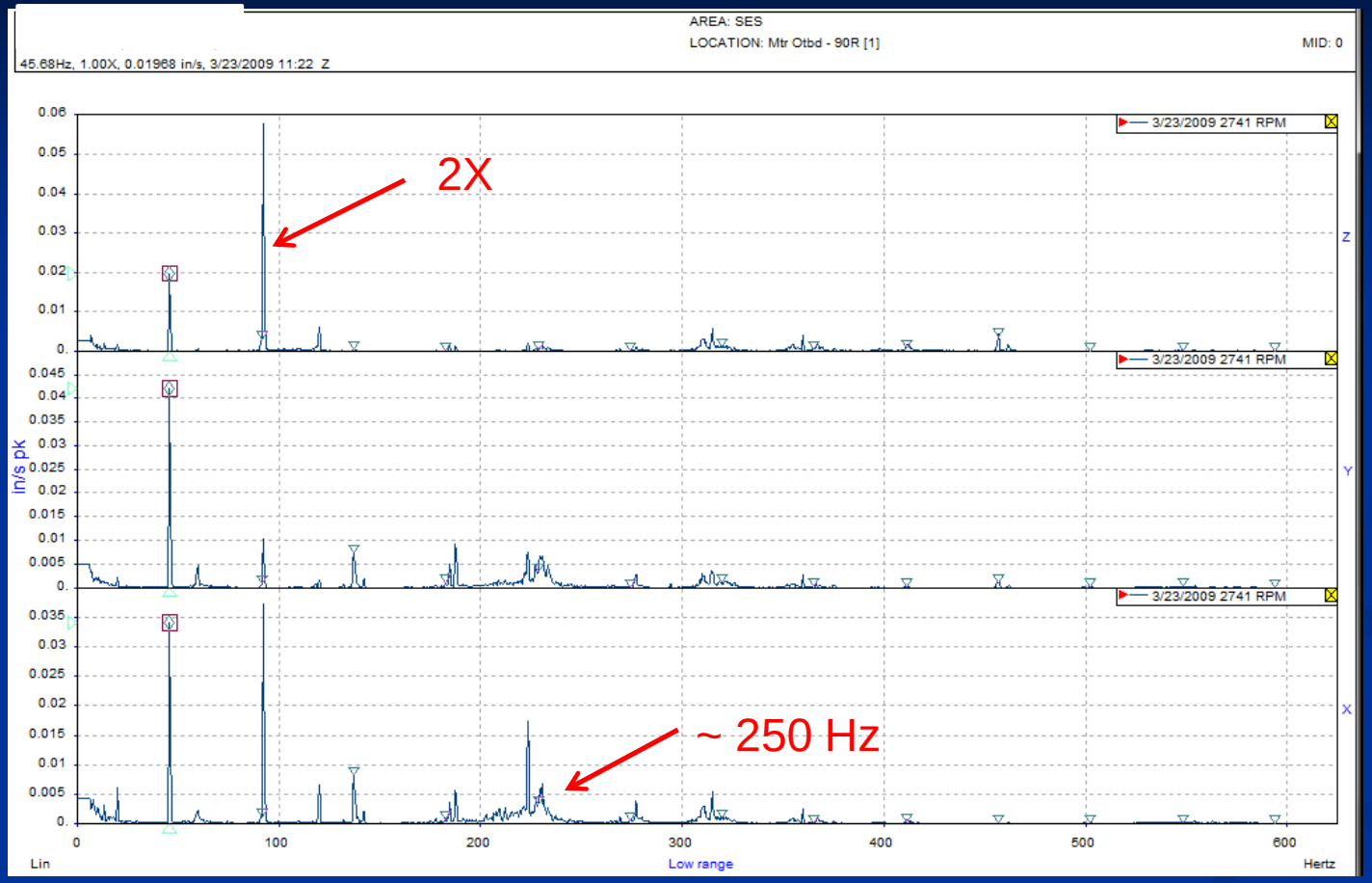
The fast voltage rise times can break down motor winding insulation that is not designed for those conditions

Reflected wave over voltage condition can also break down motor winding insulation

Shaft currents that ground through the bearings;
If you have a problem motor that is failing bearings, be sure that you inspect them for fluting or electrical damage

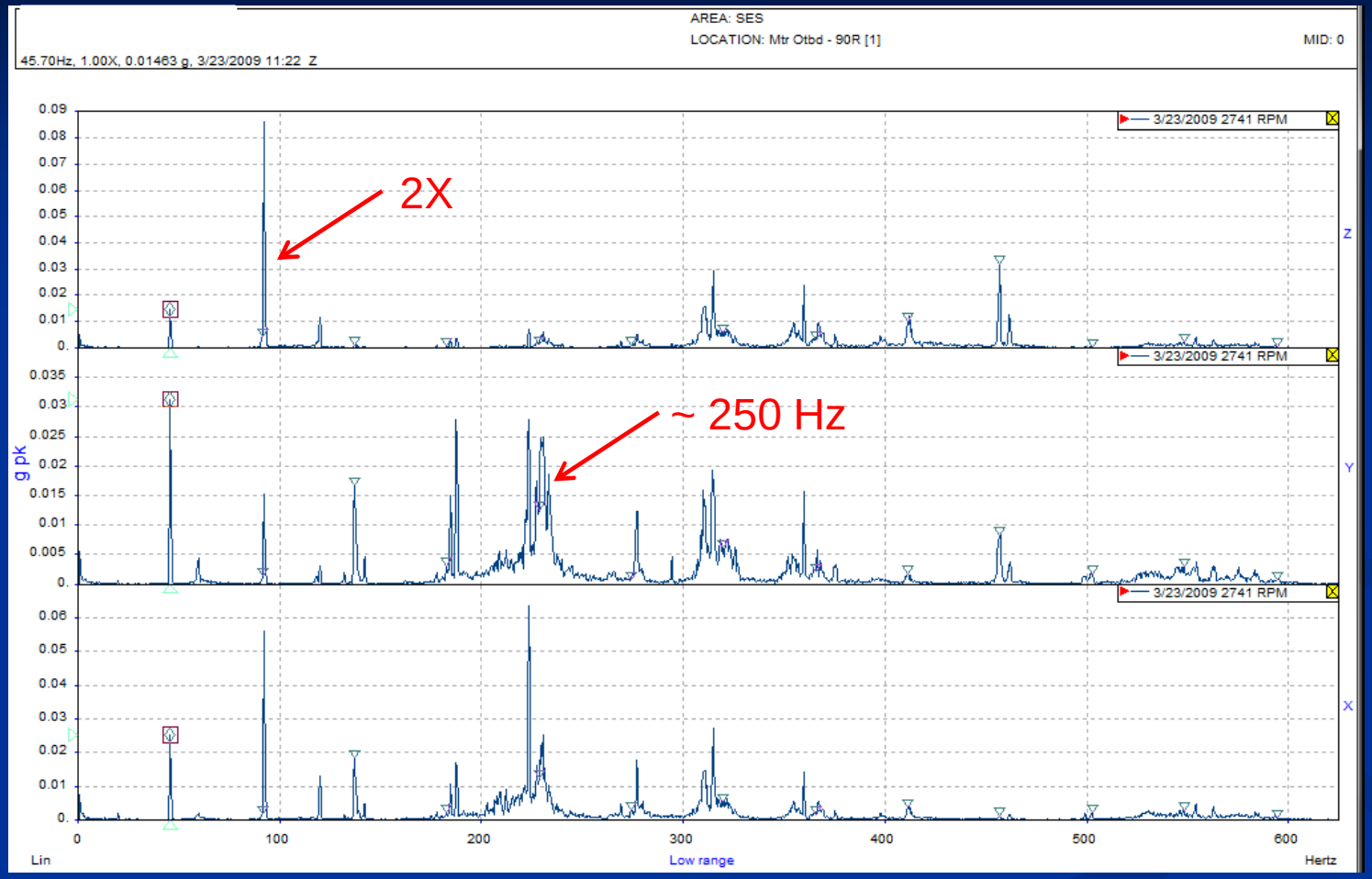
If you find electrical damage in the bearing, then there is additional testing and analysis that can be done to evaluate the condition for the best corrective actions.

VFD Data Examples



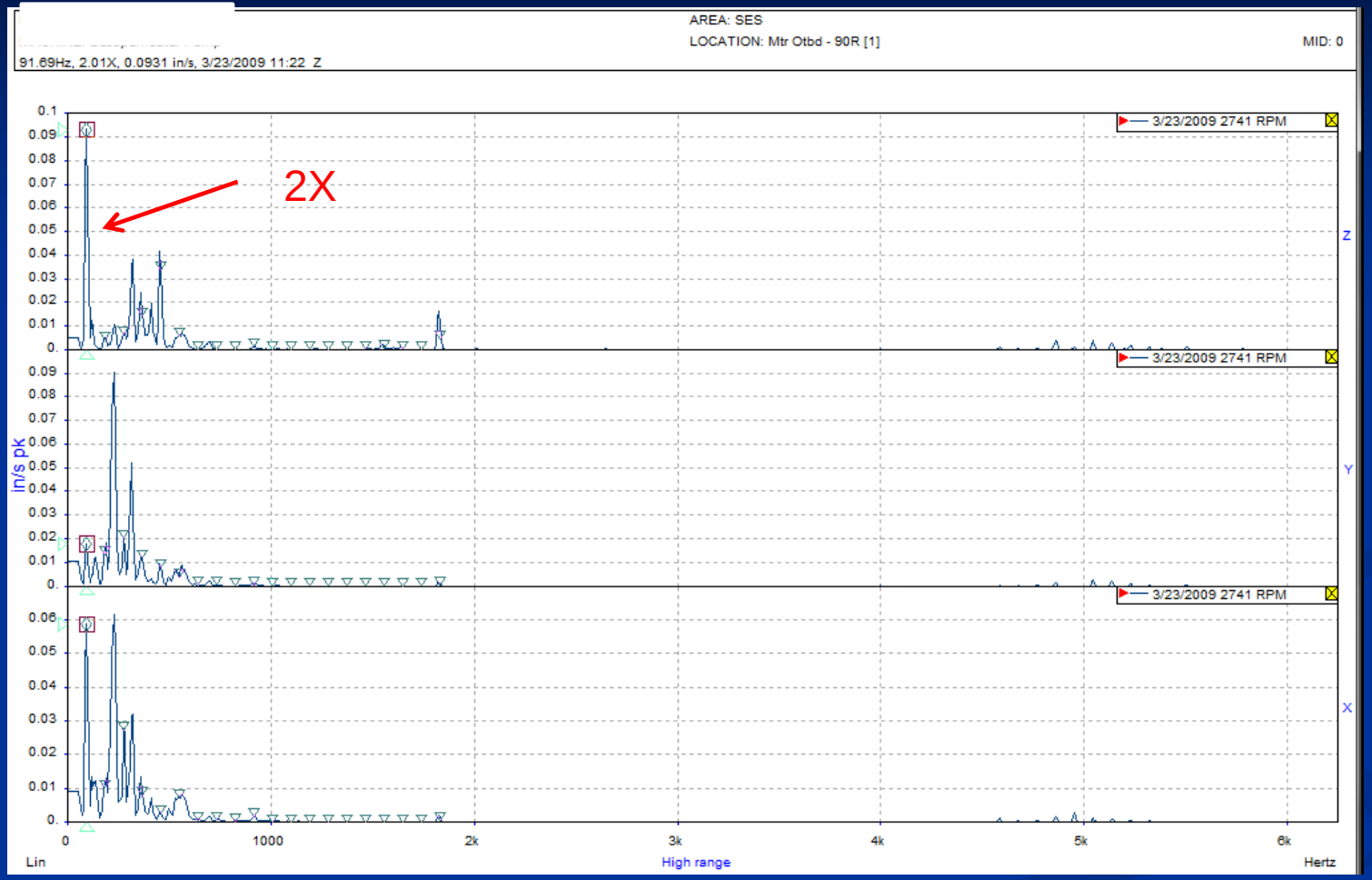
This is a data set from a VFD motor that has not had any routine problems just for review. Here is a low frequency span using velocity

VFD Data Examples



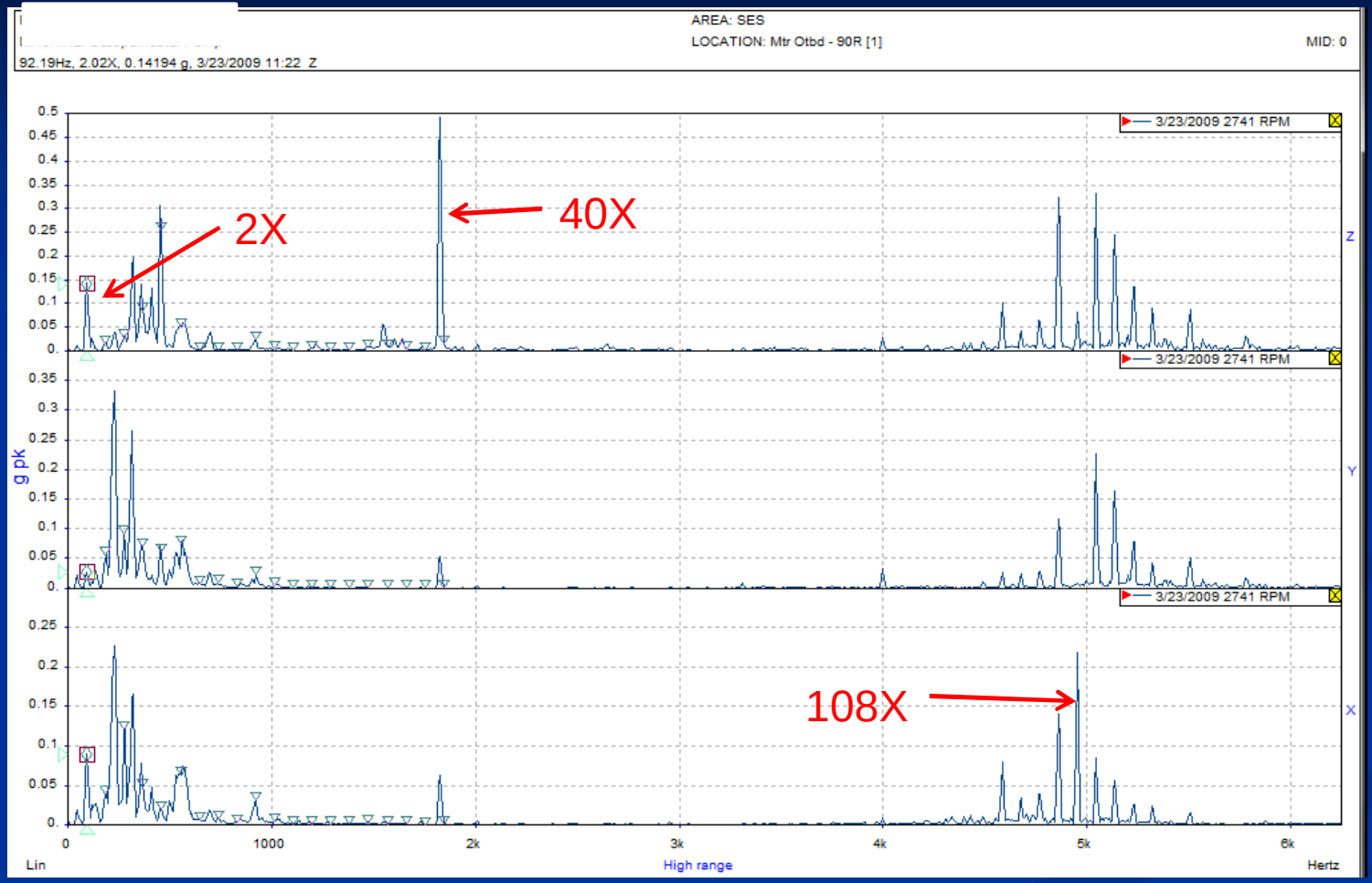
Here is the same data set with a low frequency span in acceleration

VFD Data Examples



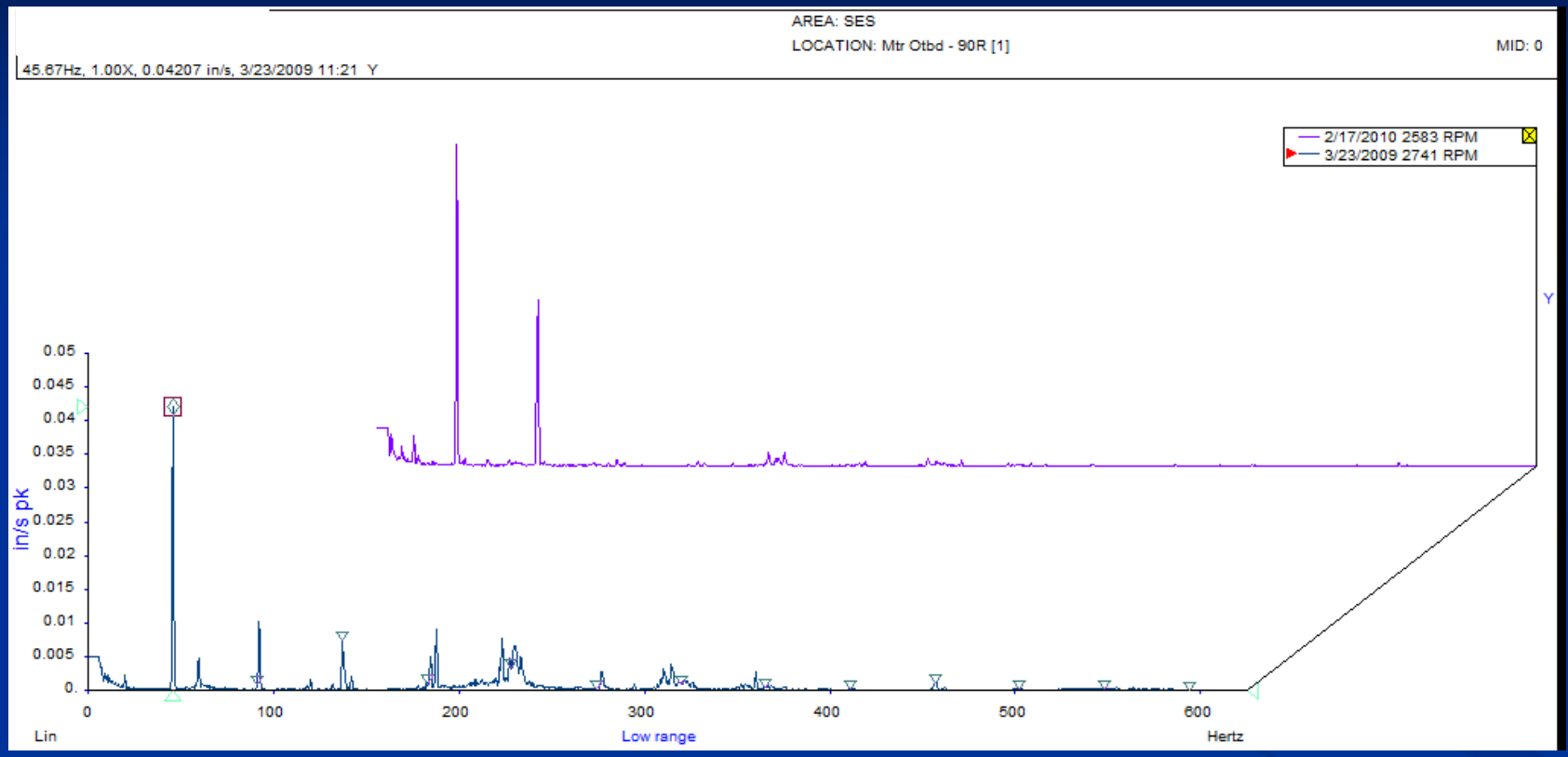
Here is a high frequency span in velocity

VFD Data Examples



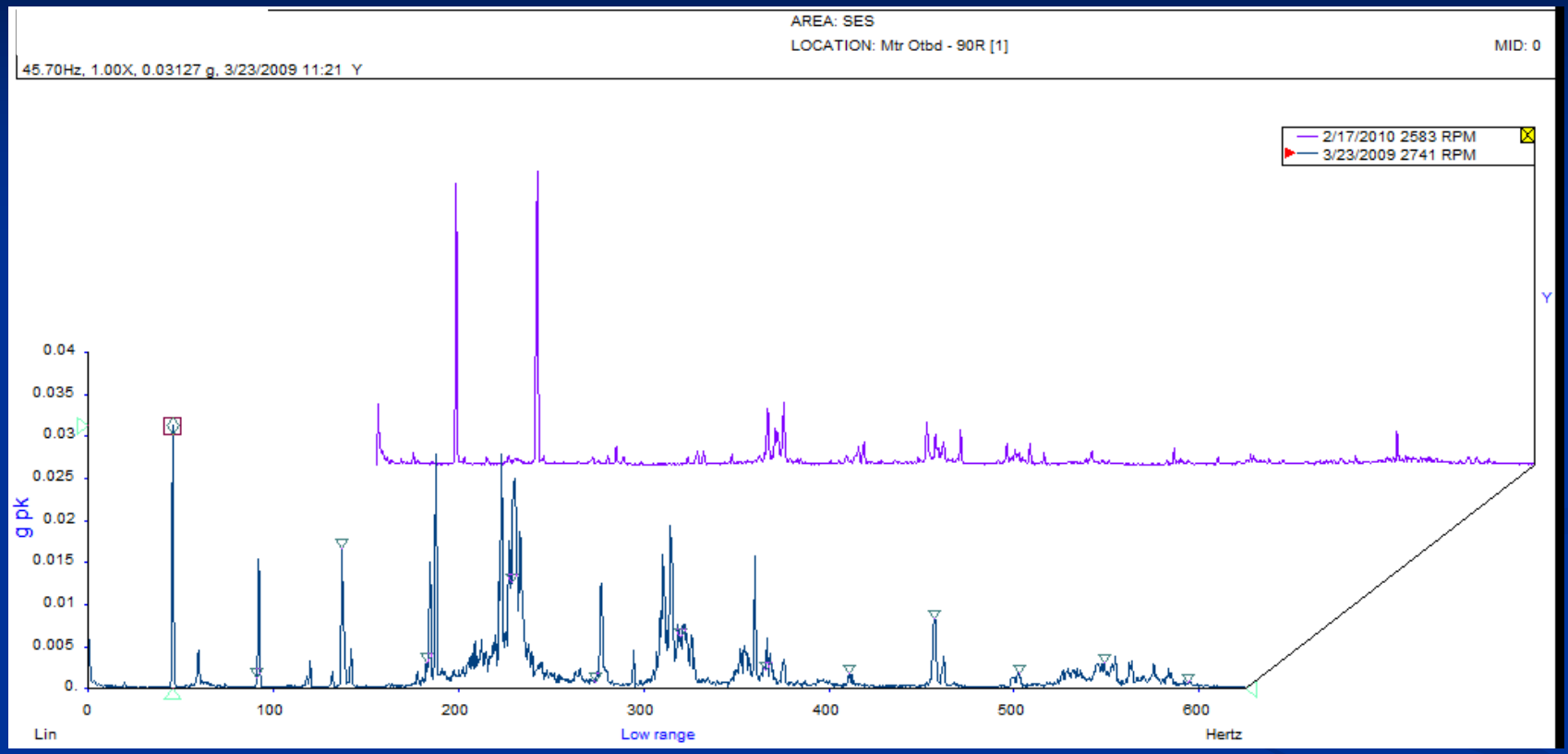
Here is the same high frequency data set in acceleration
108 side banded with 2X of running speed (i.e.) 2 x line frequency

VFD Data Examples



Two samples – same data point – different loads
2578 rpm vs. 2742

VFD Data Examples



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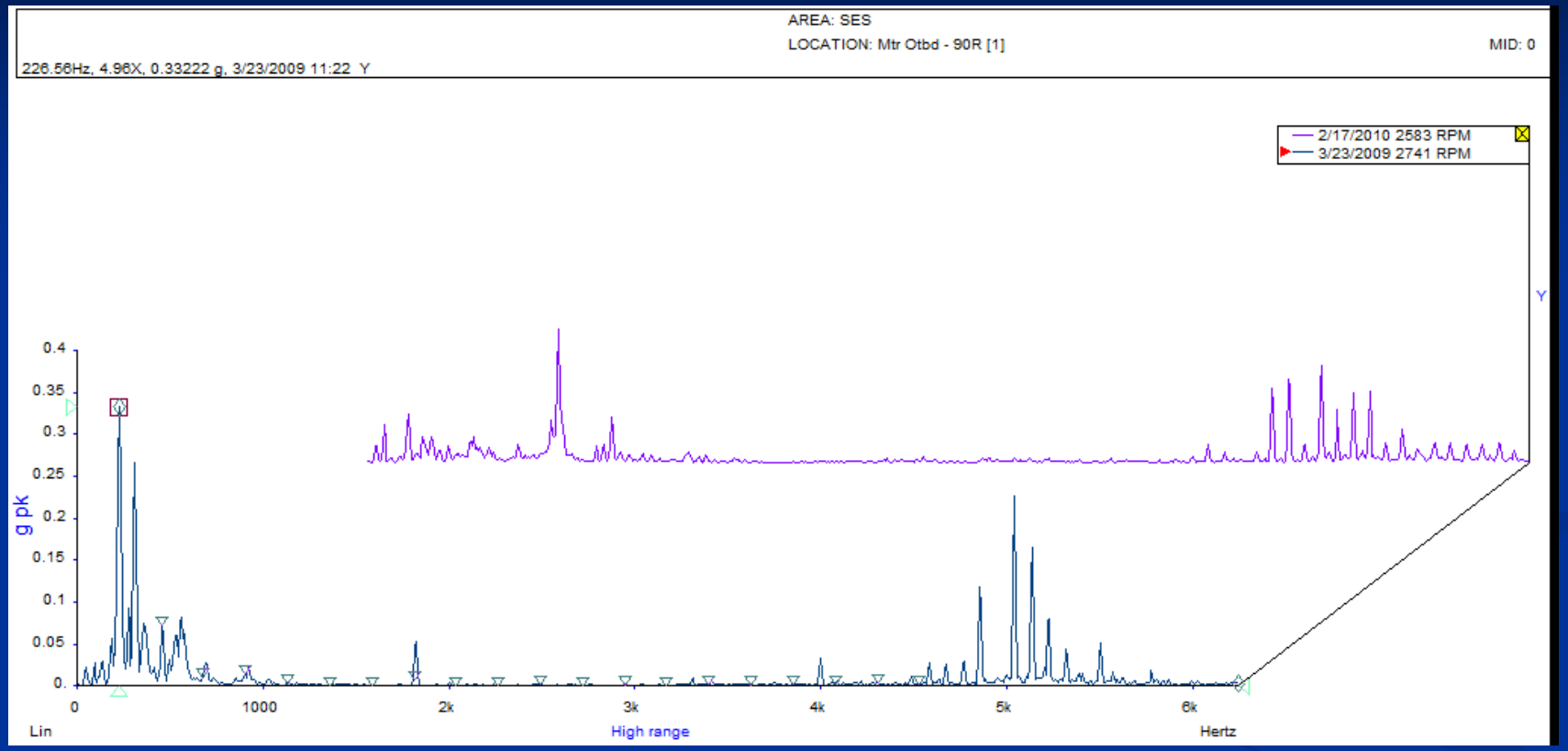
VFD Data Examples



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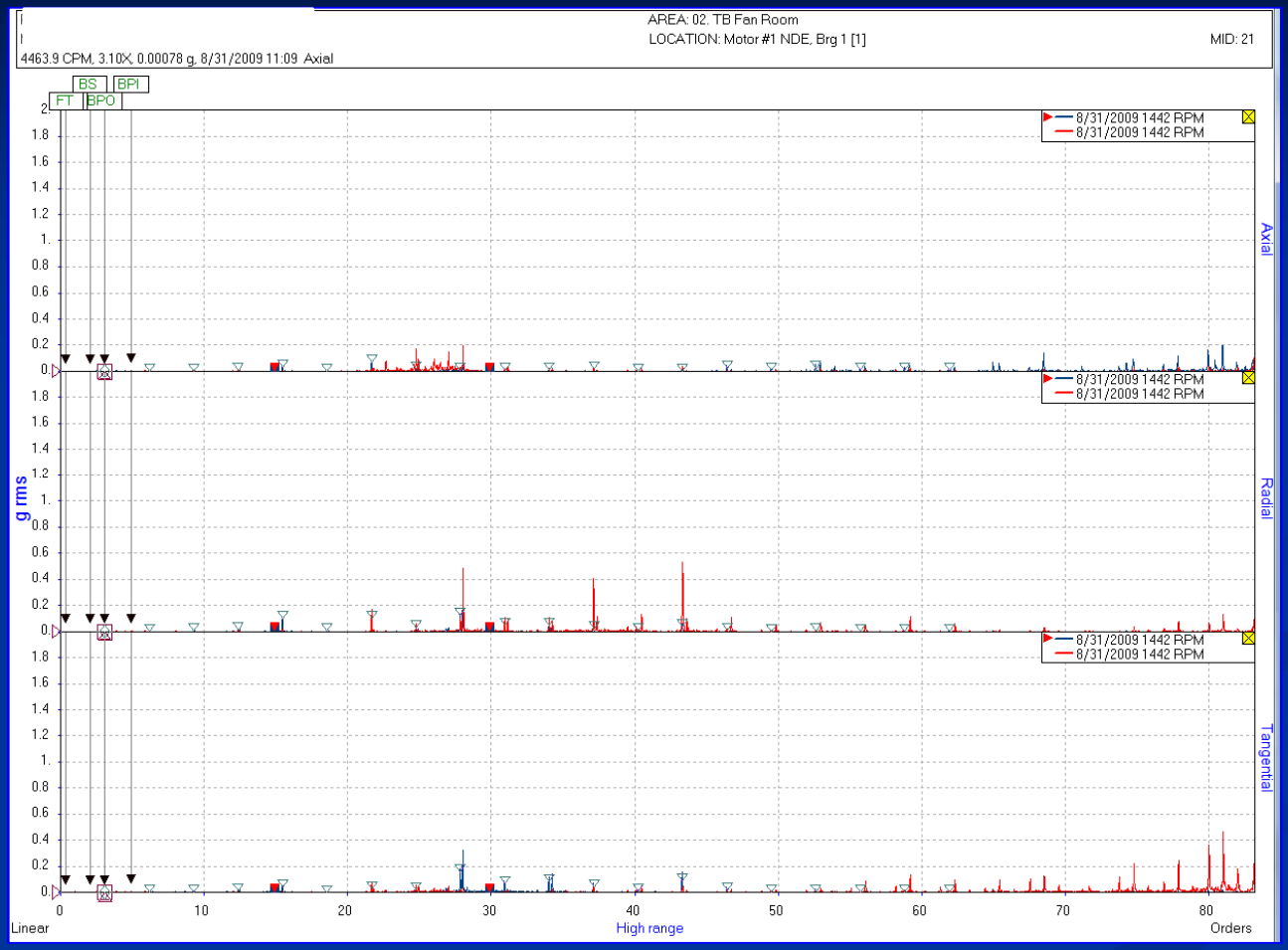
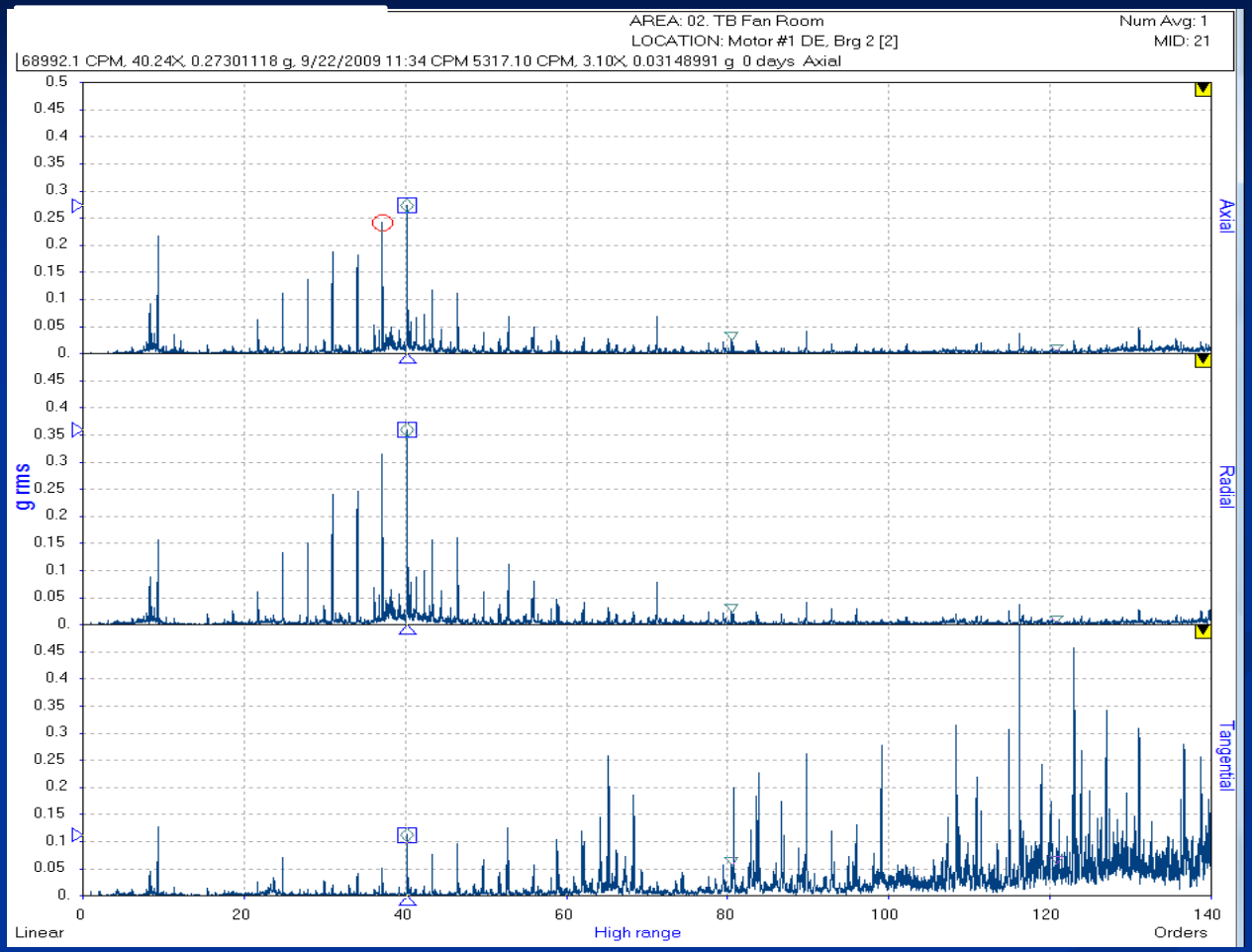


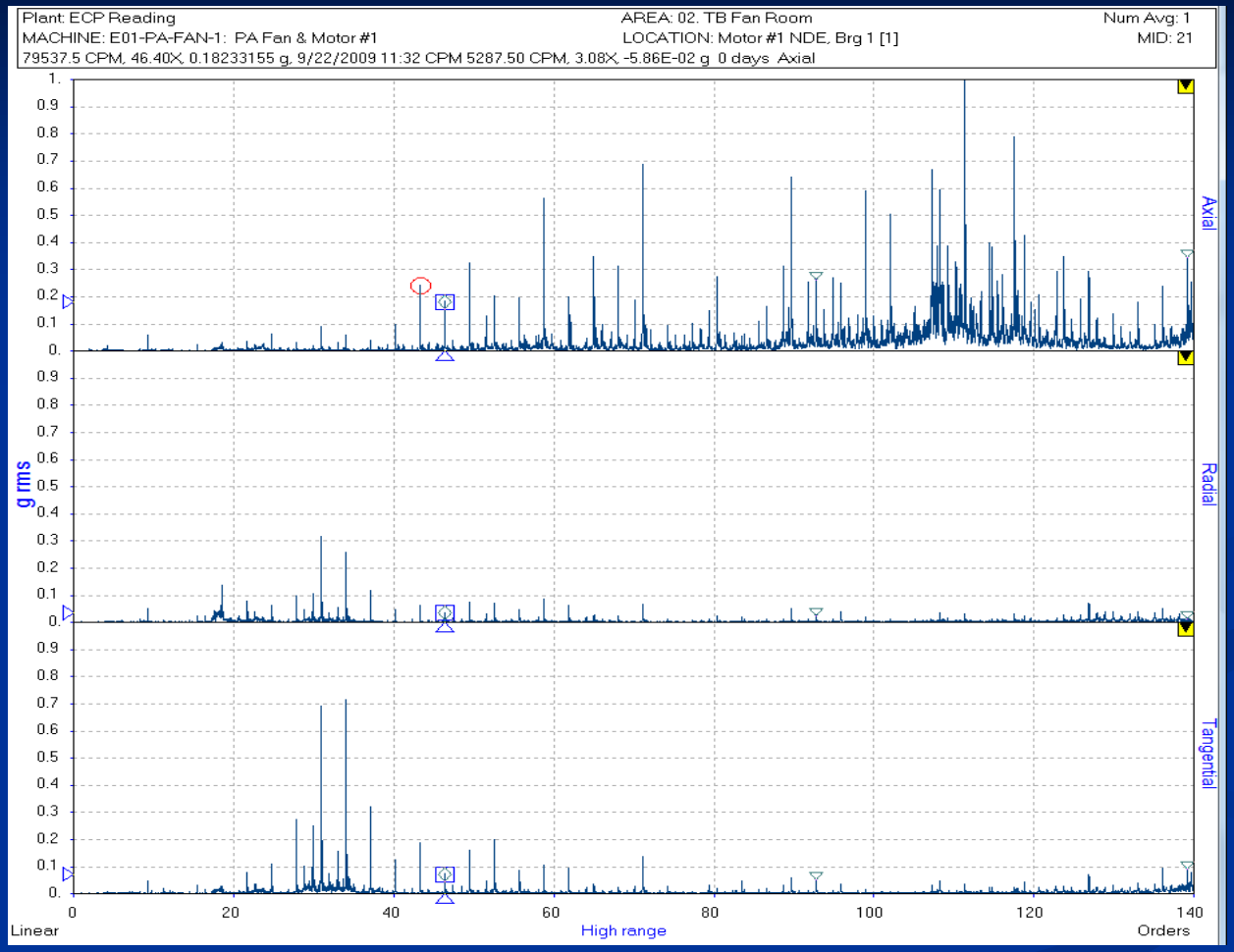
Here is a motor with what initially looked like a lack of lubrication during the initial data set. 8/31/09 – Low – high freq range

VFD Data Examples



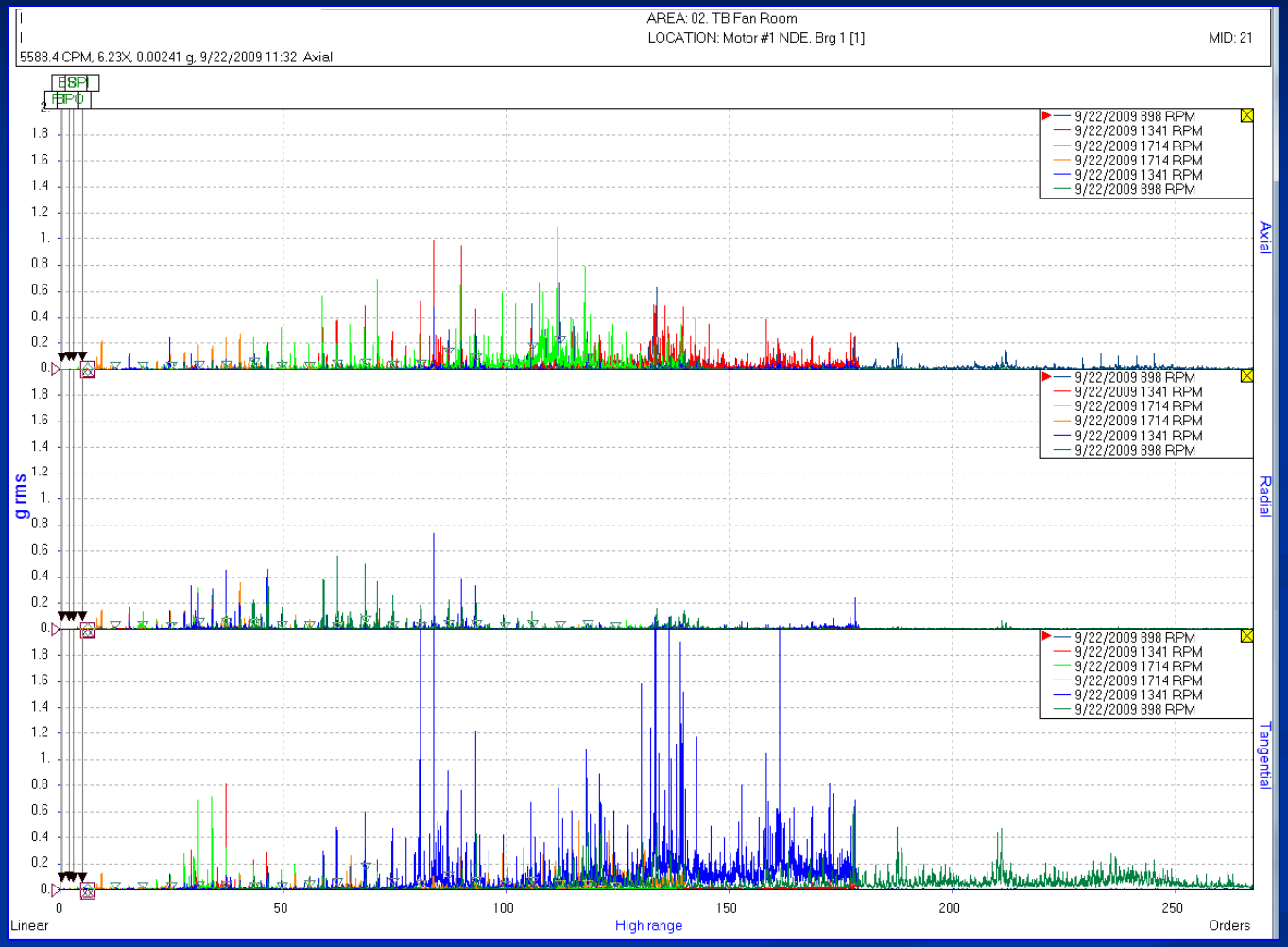
22 days later severe fluting in the bearing outer race.
09/22/09 – high freq - Driven End bearing

VFD Data Examples



22 days later severe fluting in the bearing outer race.
09/22/09 – high freq - Non-Driven End bearing

VFD Data Examples



VFD Data Examples

Thank You – Any Questions?