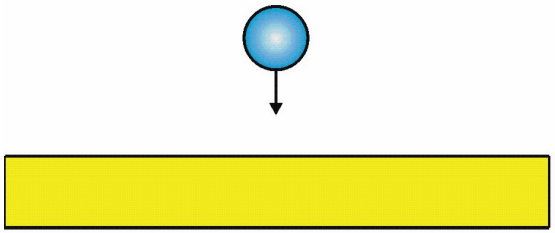
Monitoring Gear Boxes with PeakVue

Presentation at Niagara Falls Vibration Institute Chapter

January 20, 2005

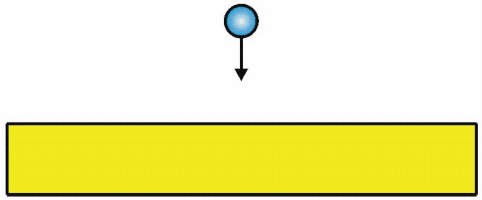
WHAT IS A STRESS WAVE?

Figure 1A



Undeflected Plate

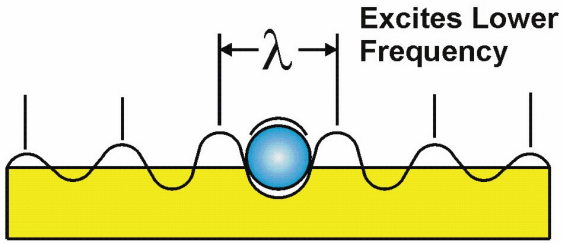
Figure 1B



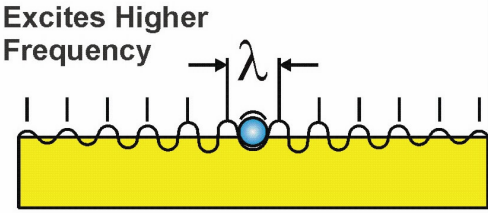
Undeflected Plate

$$\lambda = \frac{C}{F} \text{ ,Thus } F = \frac{C}{\lambda}$$

F = Predominant Stress Wave ("PeakVue") Frequency Excited by Impact
C = Speed of sound in the Component which is Impacted
λ = Wavelength of Stress wave Generated by Impact

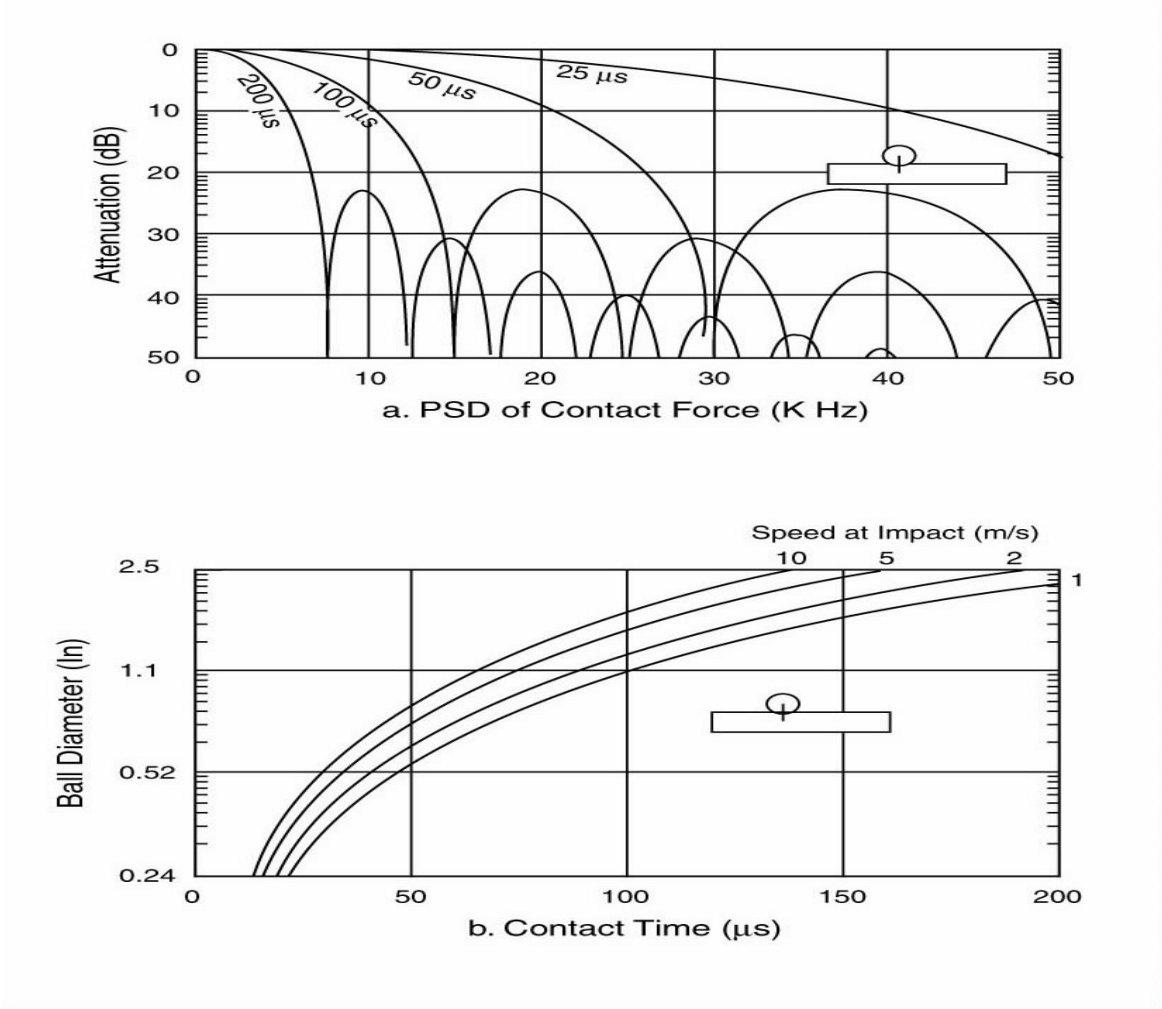


Deflected Plate

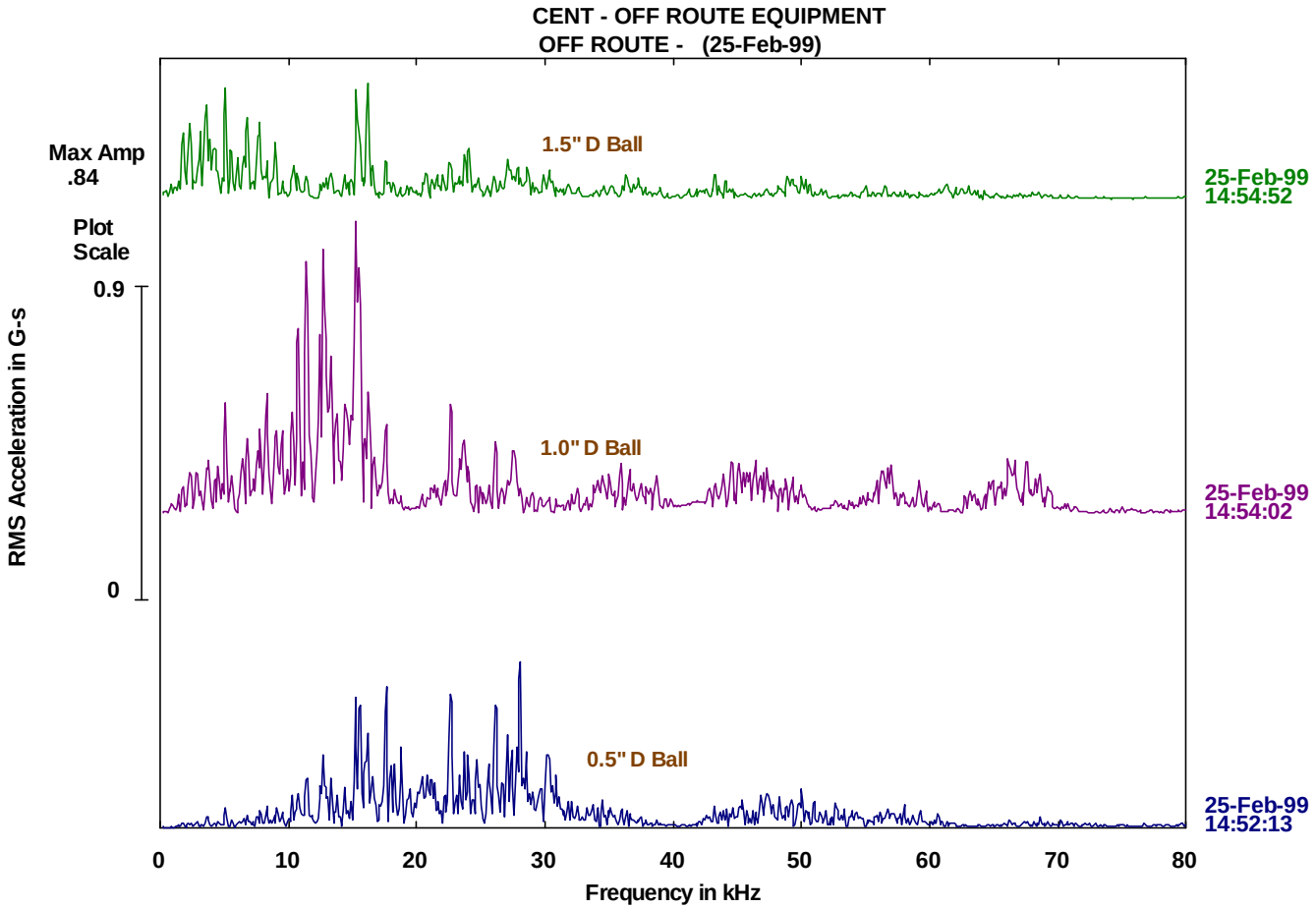


Deflected Plate

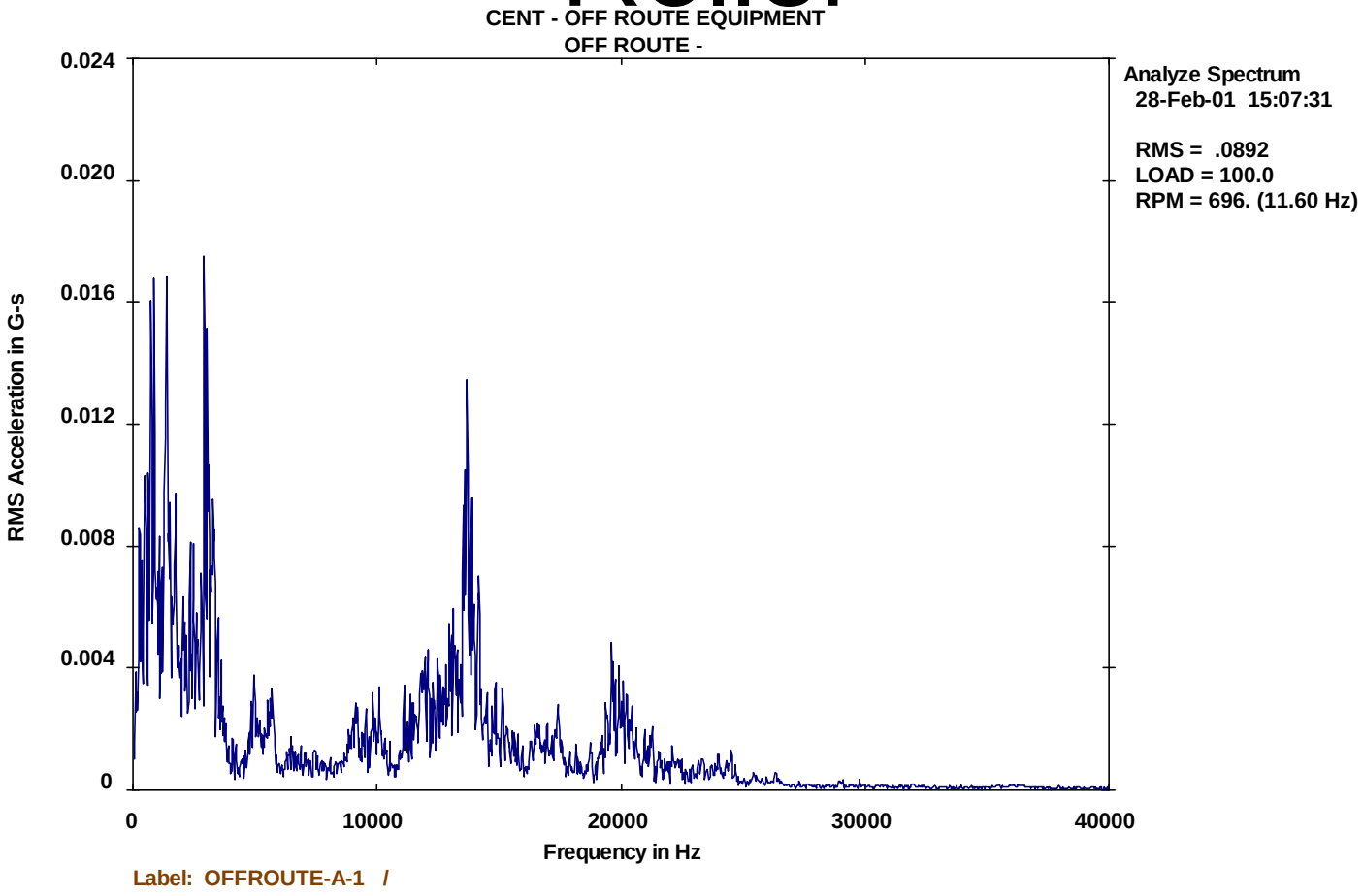
Hertz Theory Prediction for Various Size Metal Balls



Frequencies Excited by 0.5”, 1.0”. And 1.5” D Balls Impacting



Impacting and Friction: 1.0 +” D Roller



Analysis of Stress Waves

- Capture with accelerometer
- High-pass filter
- Capture time block of data (peak values)

a) Spectral Analysis

b) Autocorrelation analysis

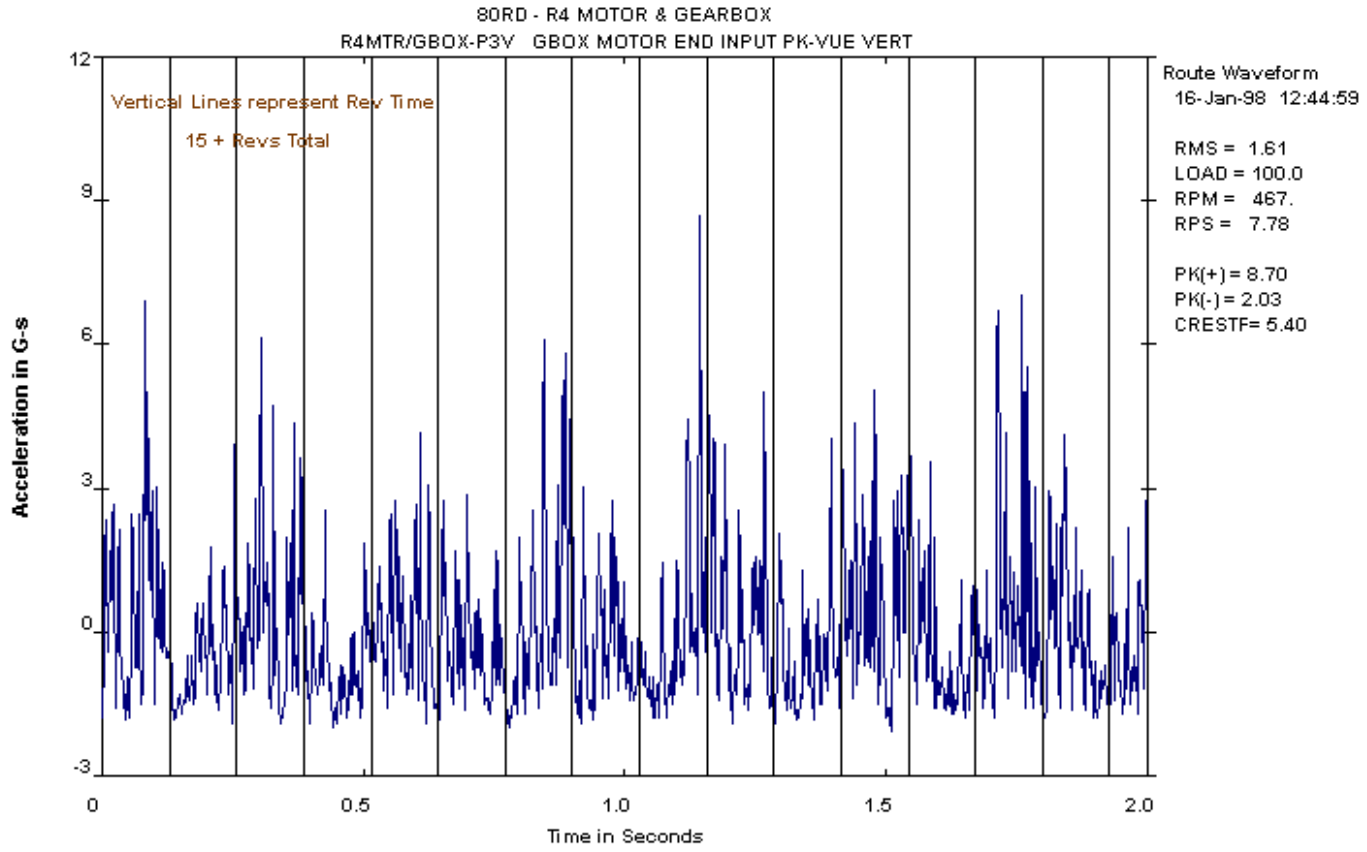
Example Time Waveform

Select F_{max}

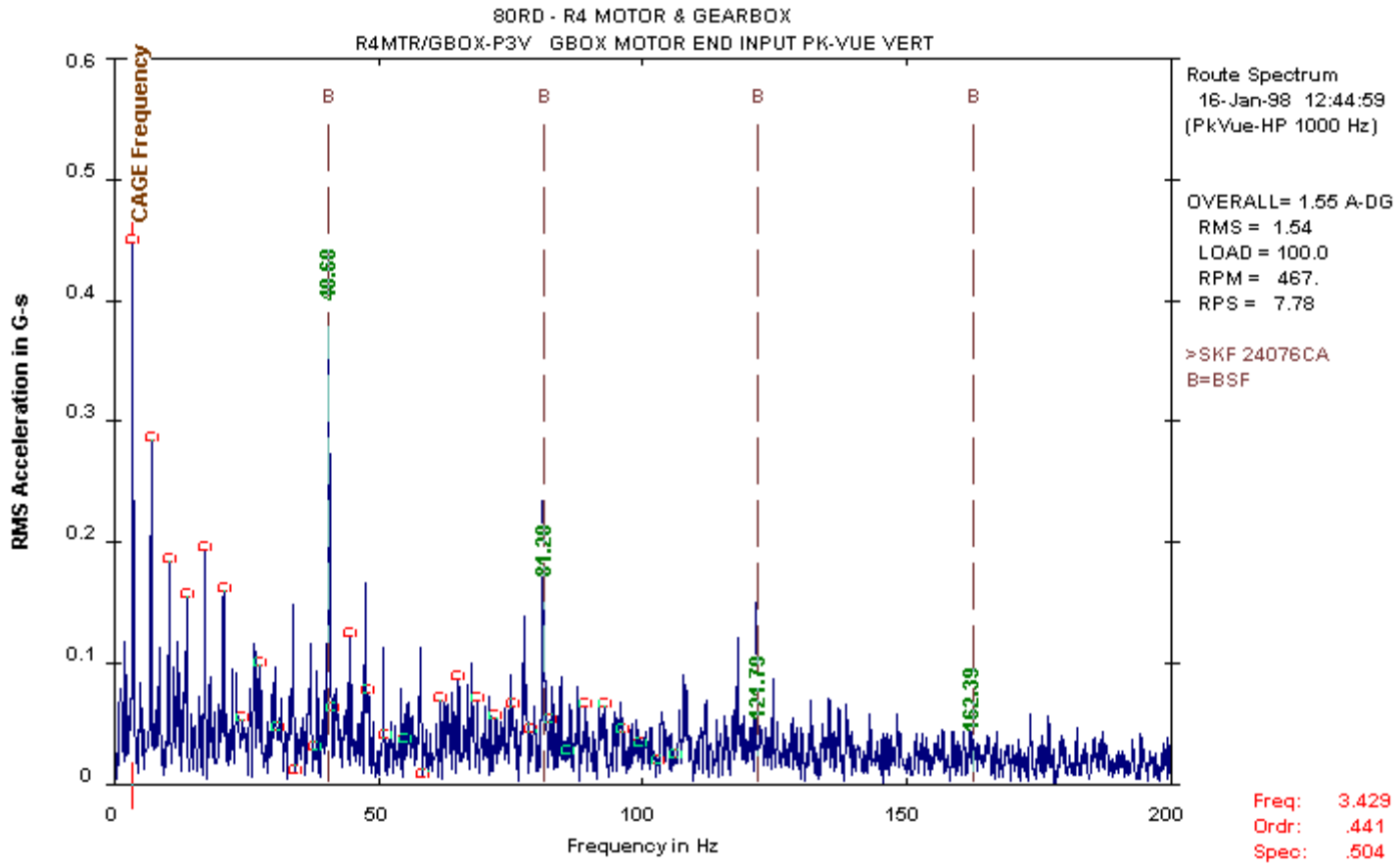
Delta t = 1/(2.56 ò F_{max})

Sequentially insert in each Delta t the Peak Value observed over that time increment

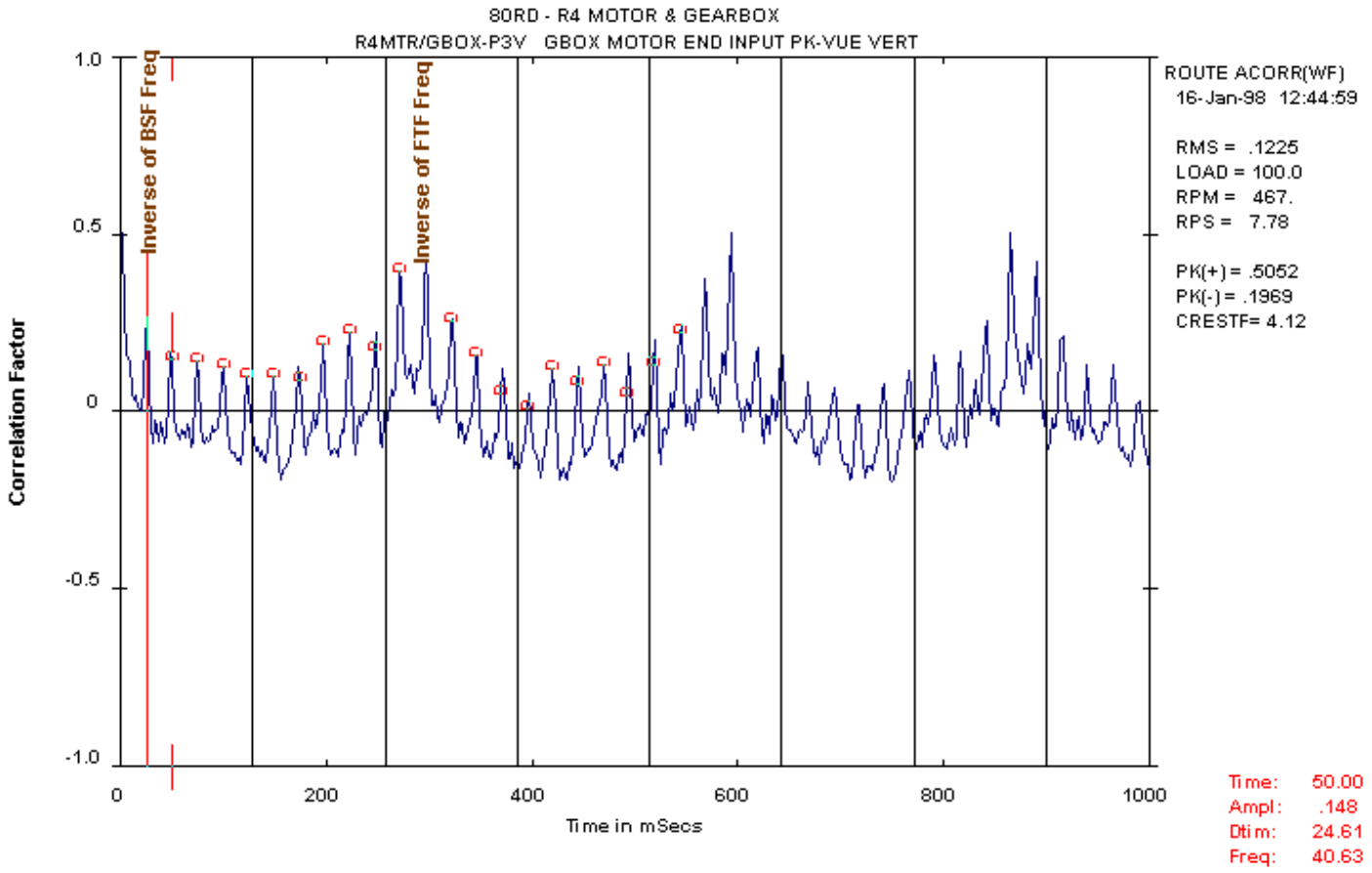
PeakVue Waveform Indicates Defective Rolling Elements
(Rollers pass in and out of load zone at rate of Cage Freq.)



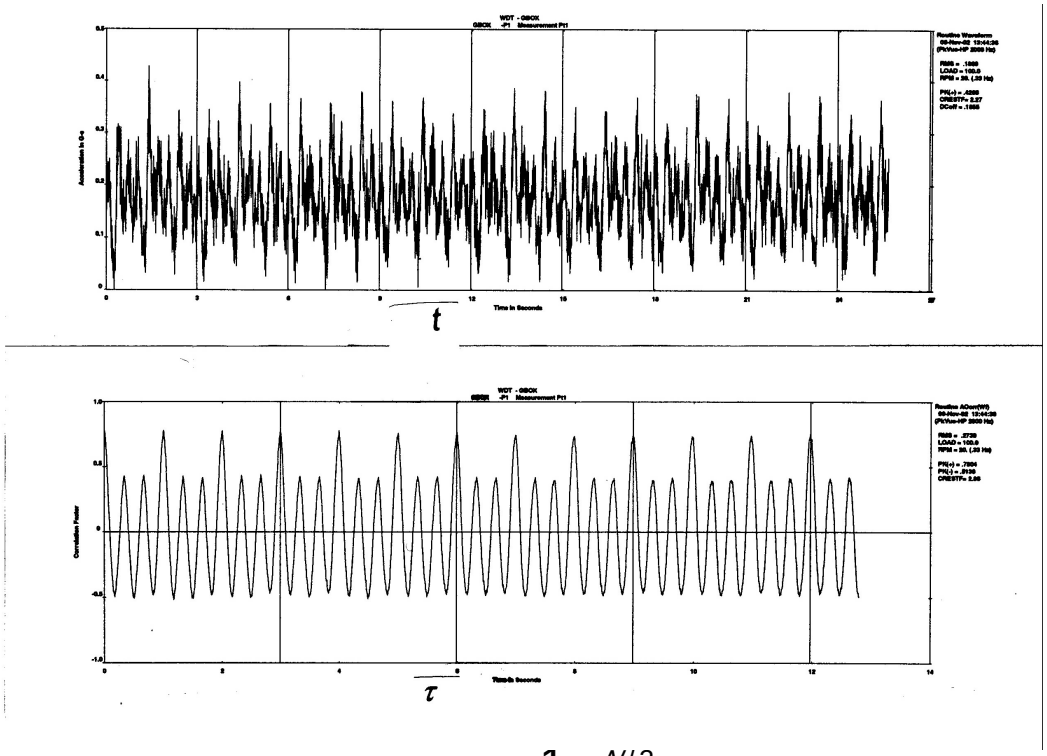
PeakVue Spectrum Derived from PeakVue Waveform (Cage Freq. = 3.43 Hz; BSF = 40.6 Hz)



Autocorrelation Coefficient Function Identifies Dominant Impact Sources in PeakVue Data



Computation of Autocorrelation



$$A(\tau_j) = \frac{1}{A(0)} \sum_{i=1}^{N/2} x(t_i)\, x(t_i + \tau_j)$$

$$t_i = i\Delta t\,;\; i = 1, N$$

$$\tau_j = j\Delta t\,;\; j = 1, N/2$$

Measurement Setup Parameters

$F_{HP} \geq F_{max}$

- Select F_{max} Based on Fault Frequencies

  Bearings: $F_{max} > 4 \times BPFI$

  Gearing: $F_{max} > 2 \times GMF$

- Select Resolution (# Lines) Based on Lowest Fault Frequency

  Bearings: Cage

  Gearing: Slowest shaft for gear pair in Mesh

Measurement Setup Parameters (cont.)

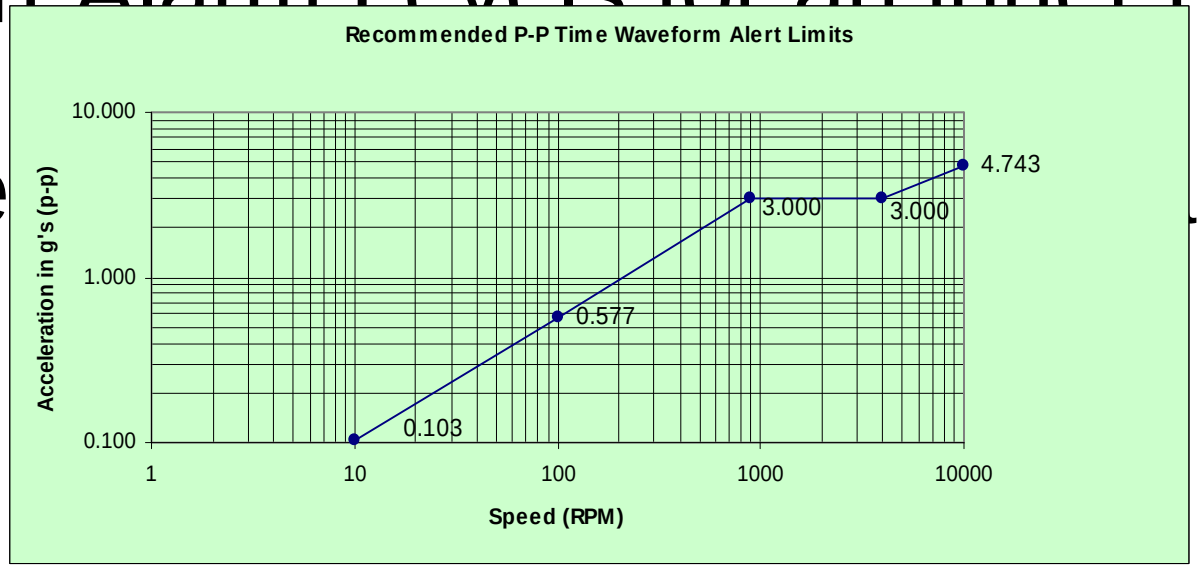
- Cage - requires 12+ shaft revs

$$\#\,\text{Revs} = \frac{\#\,\text{lines}}{F_m \text{ in orders}}$$

- Shaft - Requires 5+ shaft revs
- F_{HP} (High-Pass Filter)
  - Same (highest) over a machine (structure with continuous housing).
  - F_{HP} greatest for bearings or gears on machine
  - F_{max} can be varied, but same F_{HP} must be used on all points on component (i.e., throughout Gearbox)

Guidelines for setting Pk-Pk PeakVue Time Waveform Alert Alarm Levels for an inner race

(Se rm)



$$g's = \left(\frac{\text{RPM}}{900}\right)^{0.75} \times 3 \qquad \text{for RPM} < 900$$

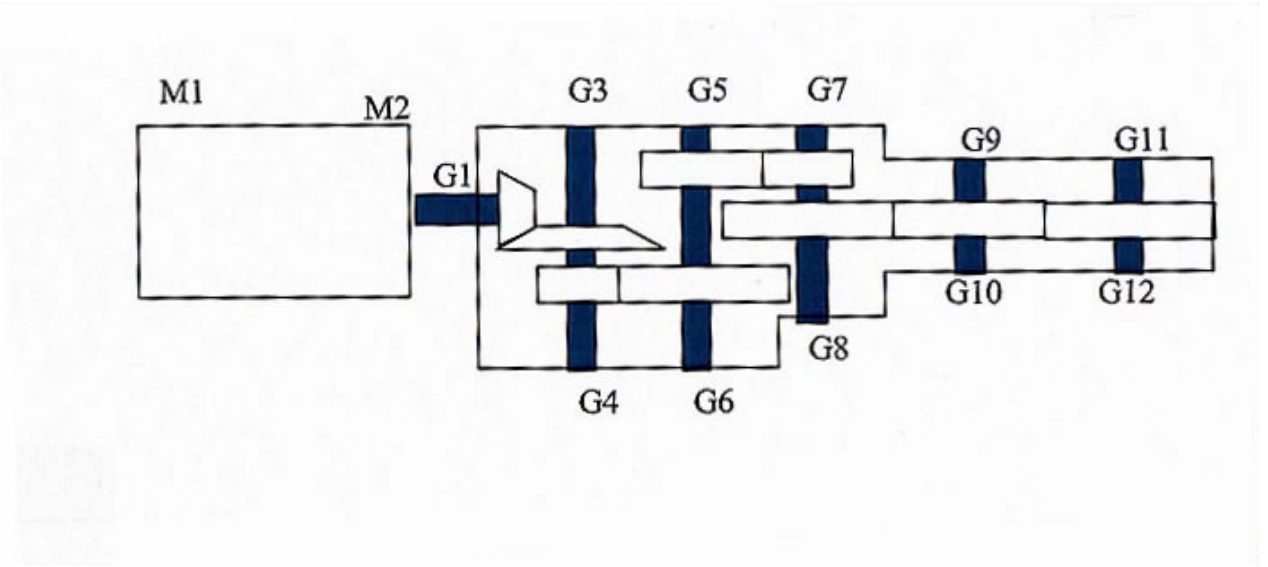
$$g's = 3\ , \qquad \text{for } 900 < \text{RPM} \le 4000\ ,$$

$$g's = \left(\frac{\text{RPM}}{4000}\right)^{0.5} \times 3 \qquad \text{for } 4000 < \text{RPM} \le 10000\ ,$$

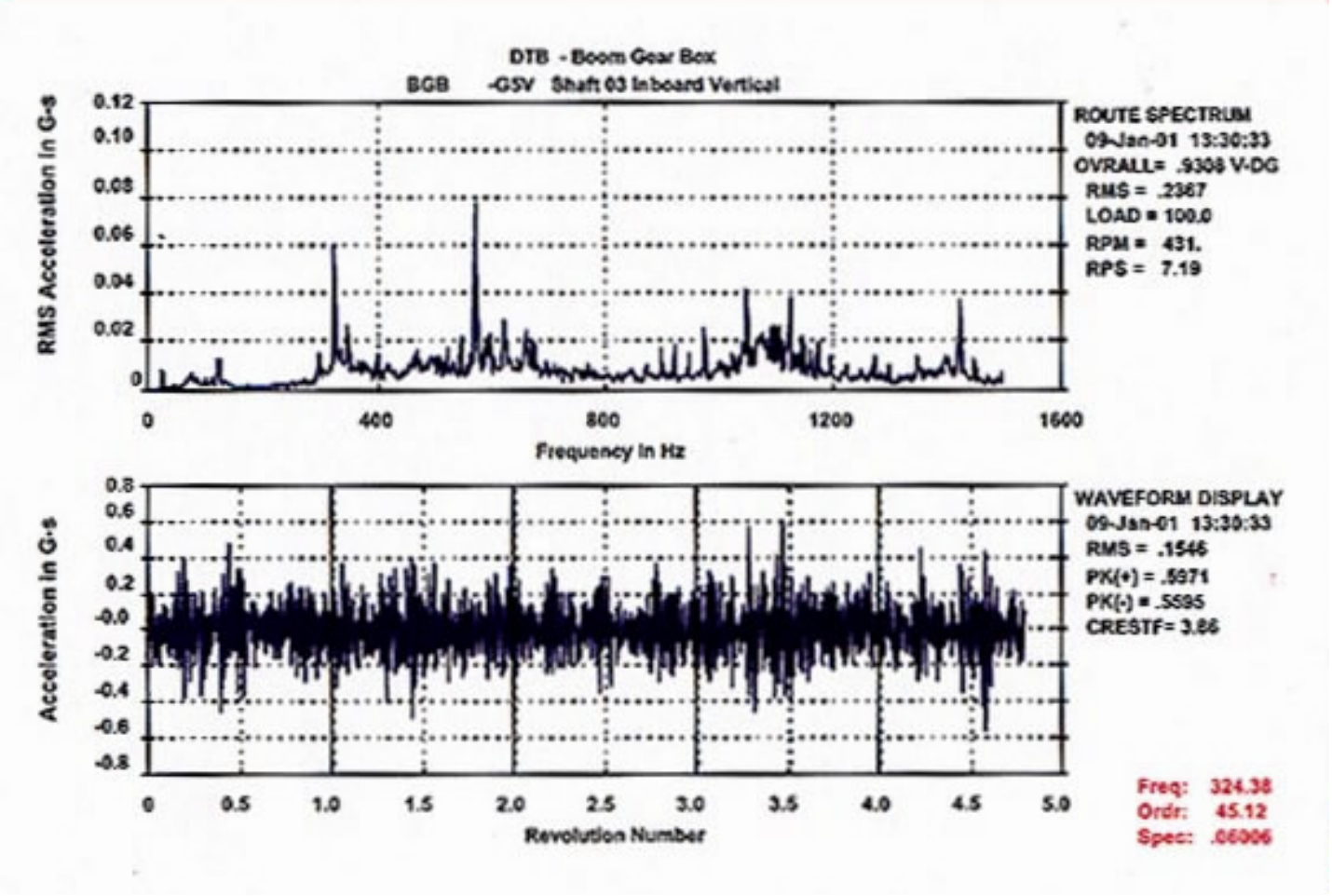
$$g's = 5\ , \qquad \text{for RPM} > 10000\ ,$$

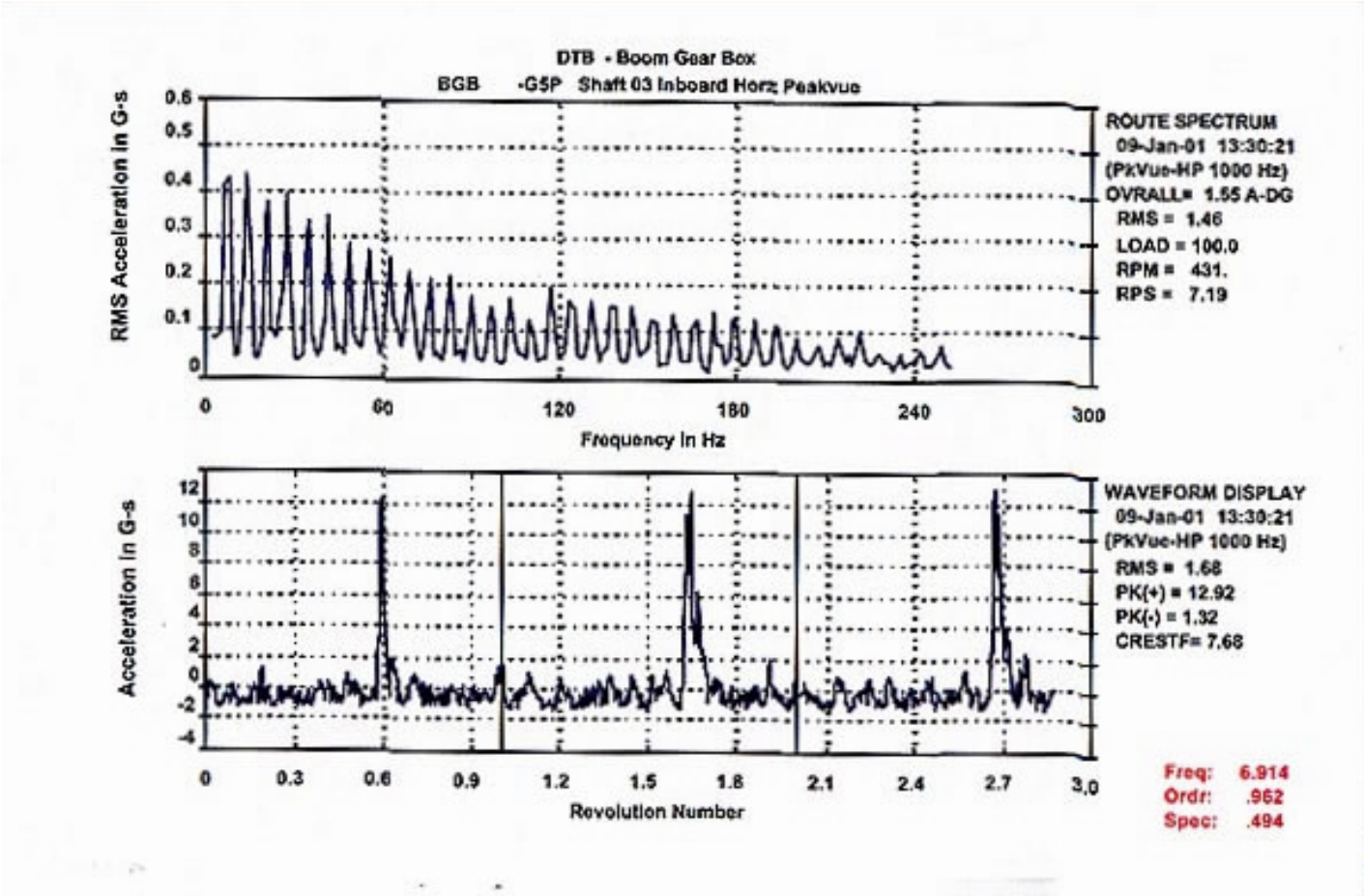
Gear Box

- Case Study # 1
  - A) Cracked Tooth on post rebuild gear box
  - B) Cracked Tooth on Precision Tension Bridle

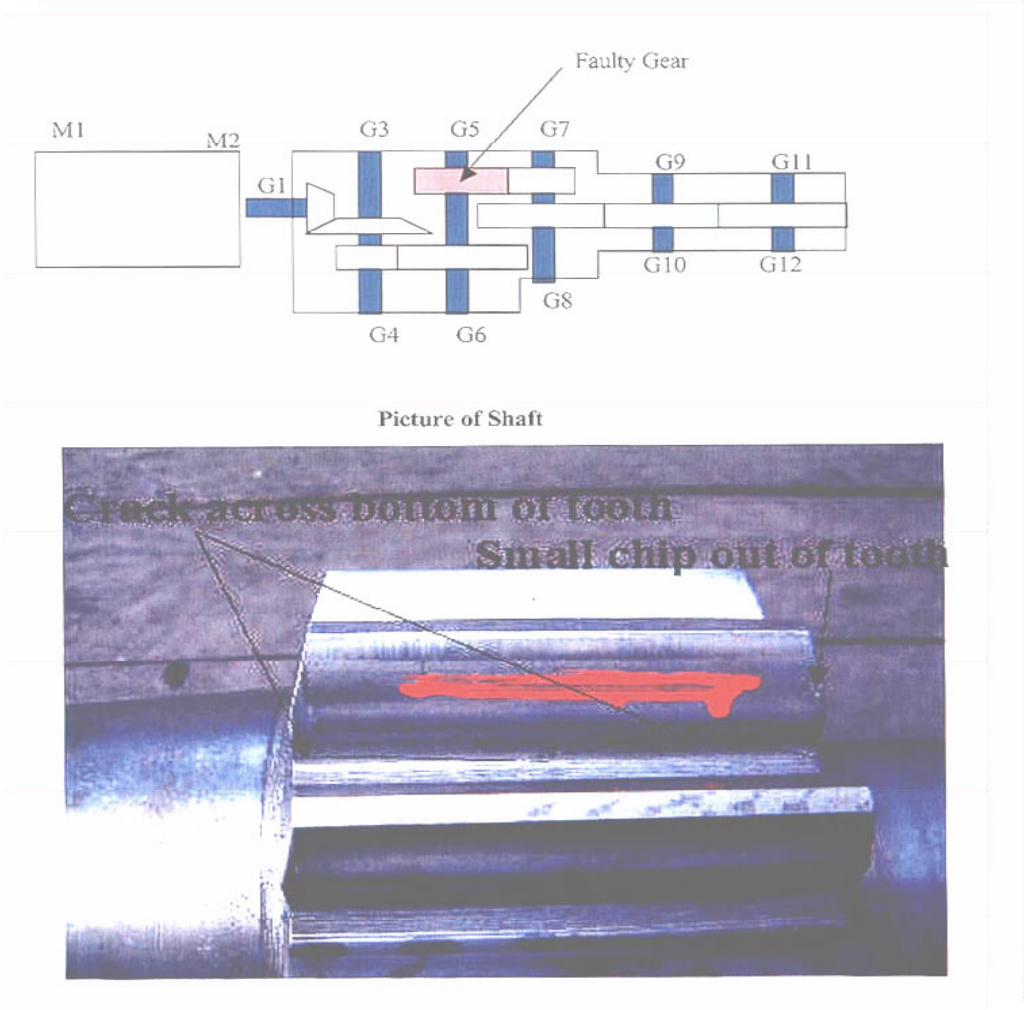

M1
M2
G1
G3
G5
G7
G9
G11
G10
G12
G8
G4
G6

Fault under Meas Point G5




DTB - Boom Gear Box
BGB -G5P Shaft 03 Inboard Horz Peakvue
RMS Acceleration in G-s
0.6
0.5
0.4
0.3
0.2
0.1
0
0
60
120
180
240
300
Frequency in Hz
ROUTE SPECTRUM
09-Jan-01 13:30:21
(PkVue-HP 1000 Hz)
OVRALL= 1.55 A-DG
RMS = 1.46
LOAD = 100.0
RPM = 431.
RPS = 7.19
Acceleration in G-s
12
10
8
6
4
2
0
-2
-4
0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
2.7
3.0
Revolution Number
WAVEFORM DISPLAY
09-Jan-01 13:30:21
(PkVue-HP 1000 Hz)
RMS = 1.68
PK(+) = 12.92
PK(-) = 1.32
CRESTF= 7.68
Freq: 6.914
Ordr: .962
Spec: .494

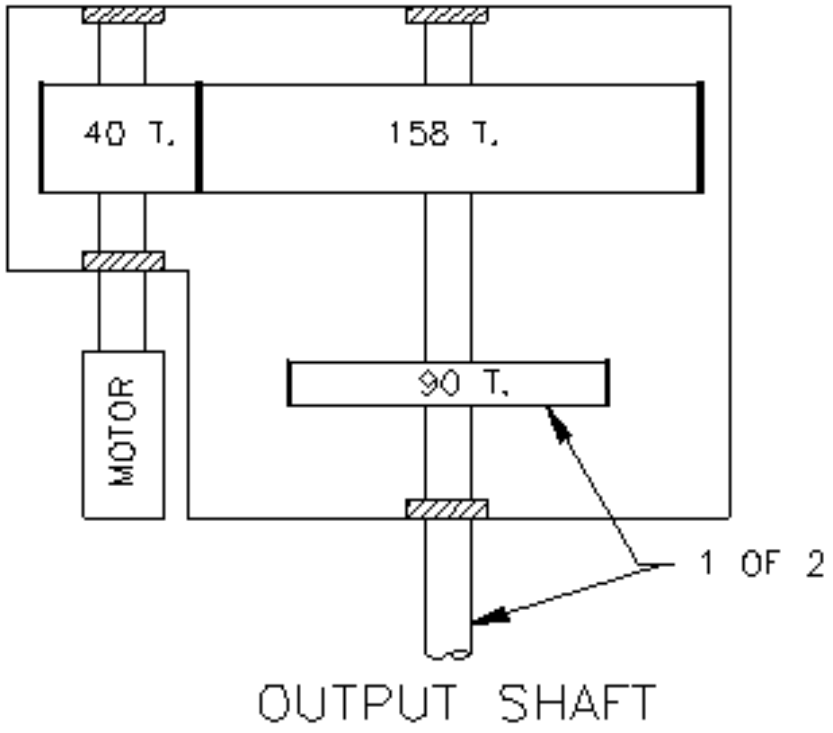
Cracked Tooth Highlighted



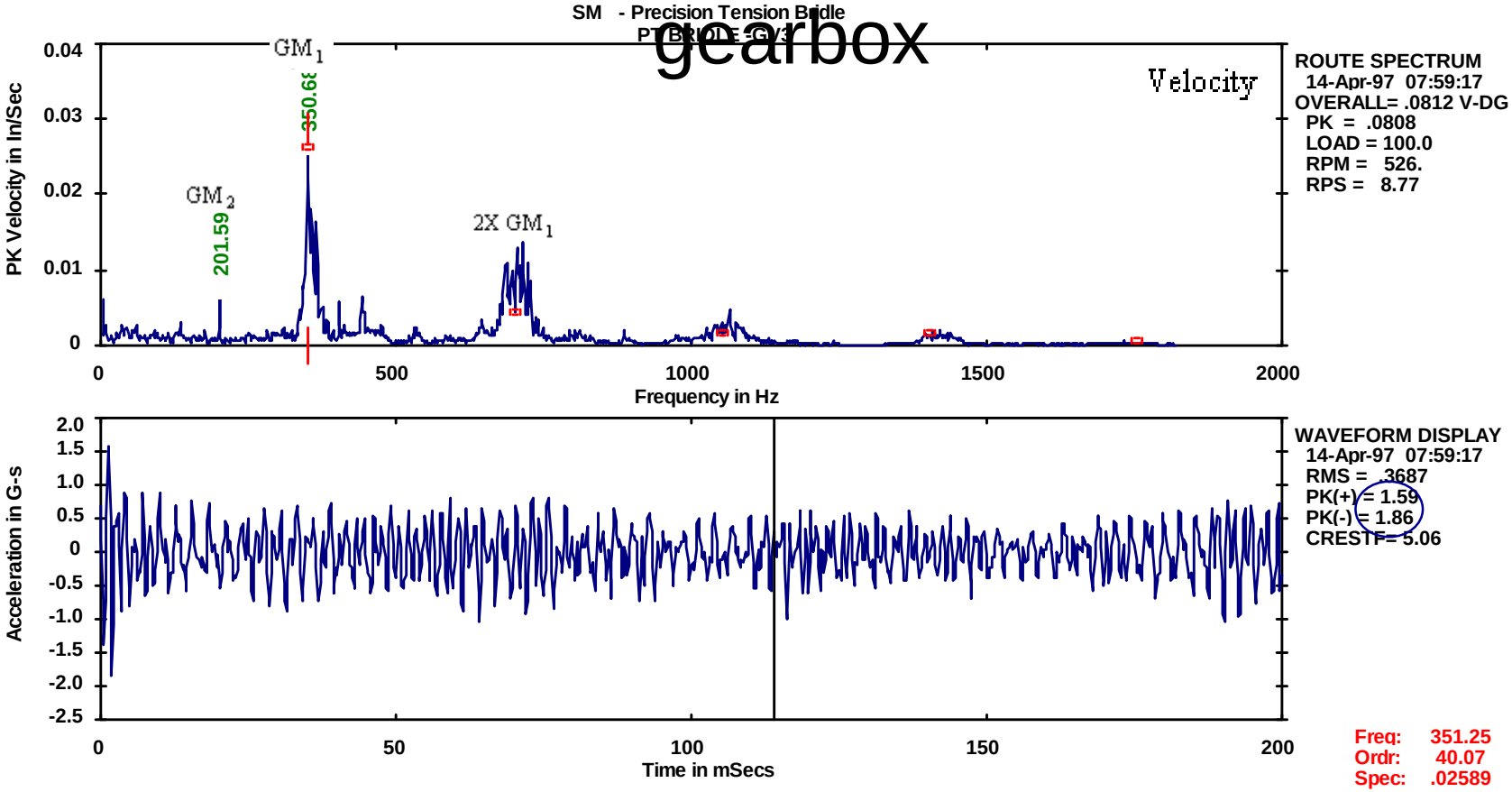
Cracked Teeth in Precision Tension Bridle GearBox

- Based on Pk-Pk Level of 41 g's in TWF
- Pronounced Impact Pulses in TWF (2/Rev)
- No Real Indication of Problem in Vibration Data

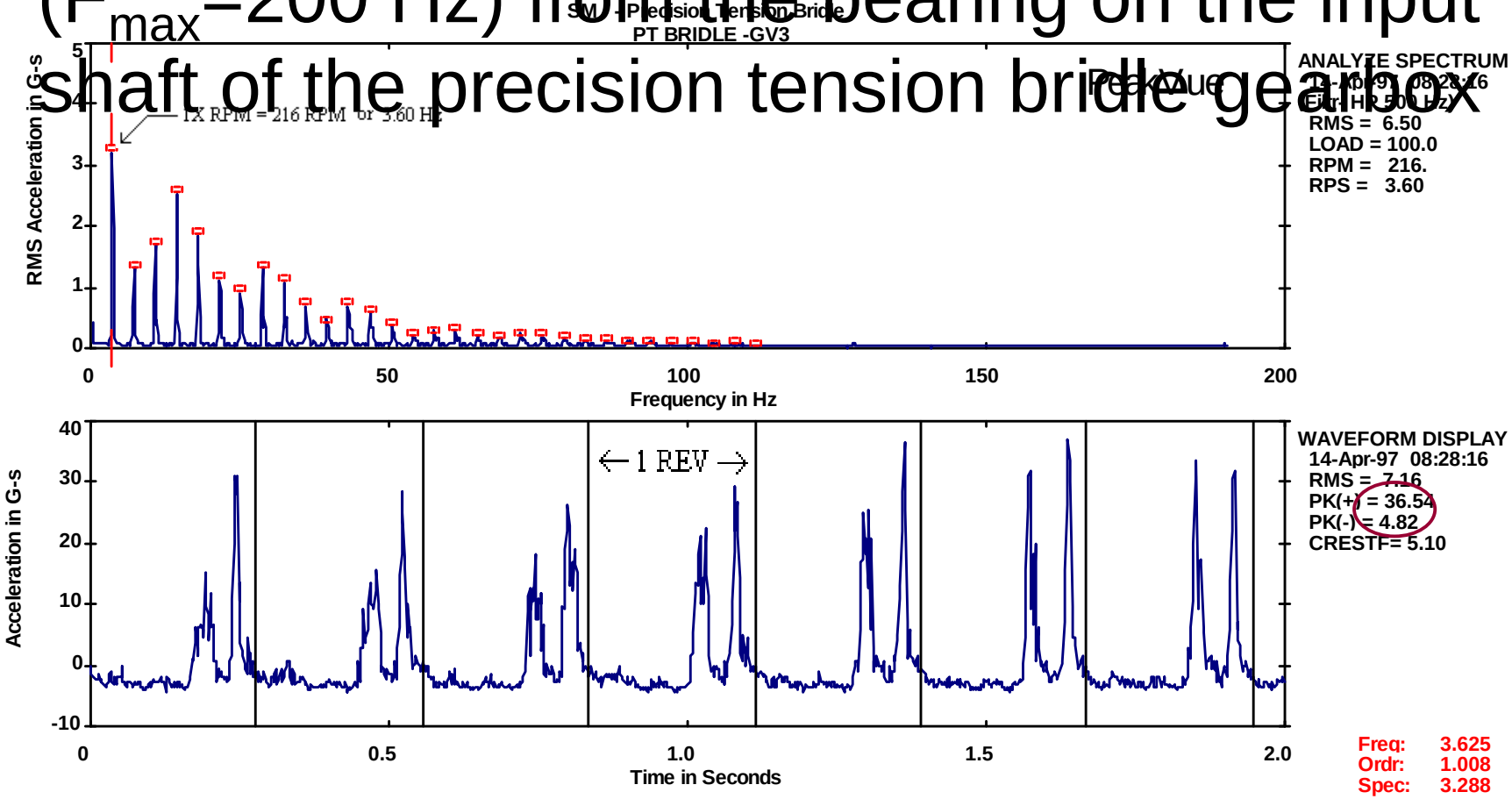
Plan view of precision tension bridle gearbox (single speed reduction with two output shafts)



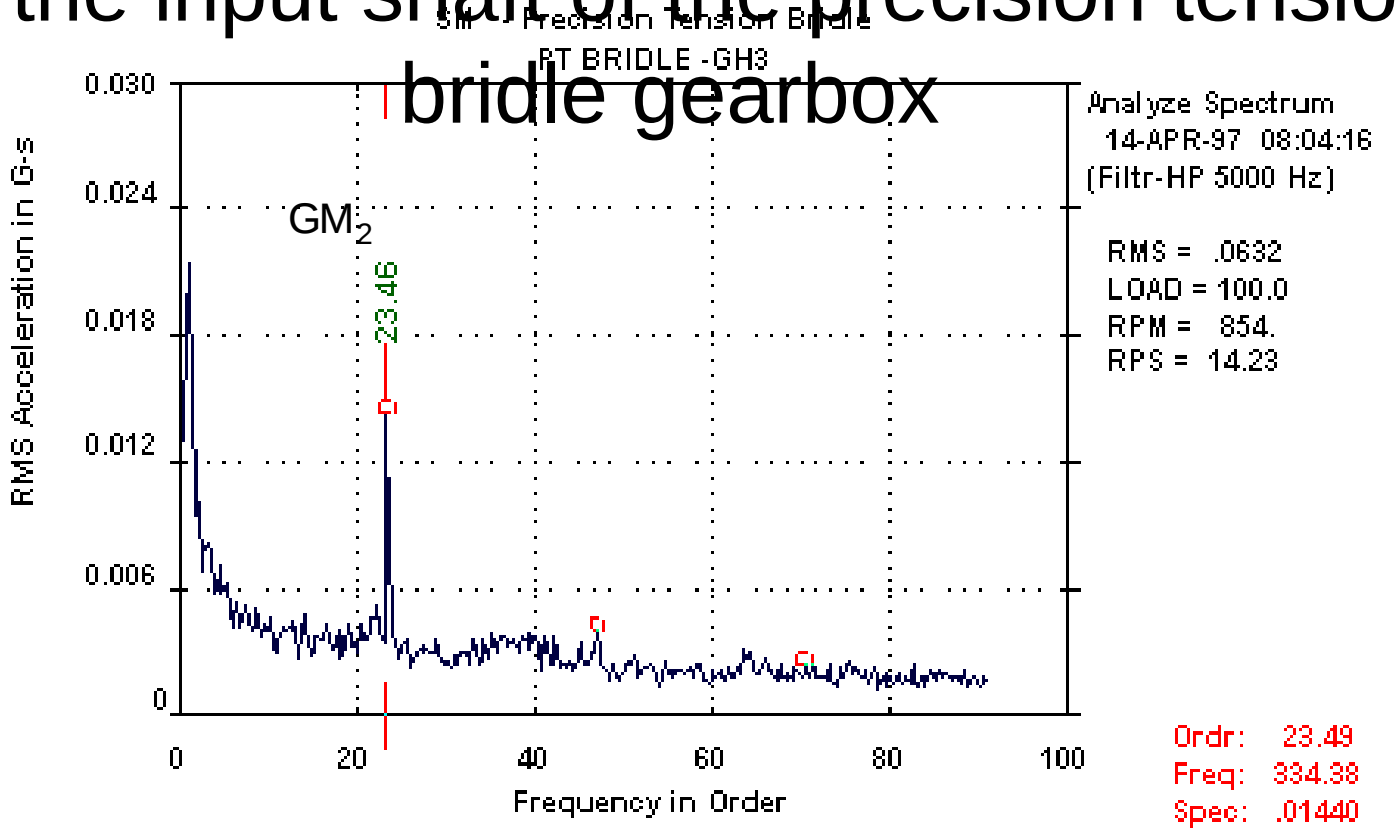
Velocity spectral and acceleration waveform data (Fmax=2000 Hz) from the bearing on the input shaft of the precision tension bridle gearbox



PeakVue spectral and waveform data (F_{max}=200 Hz) from the bearing on the input shaft of the precision tension bridle gearbox

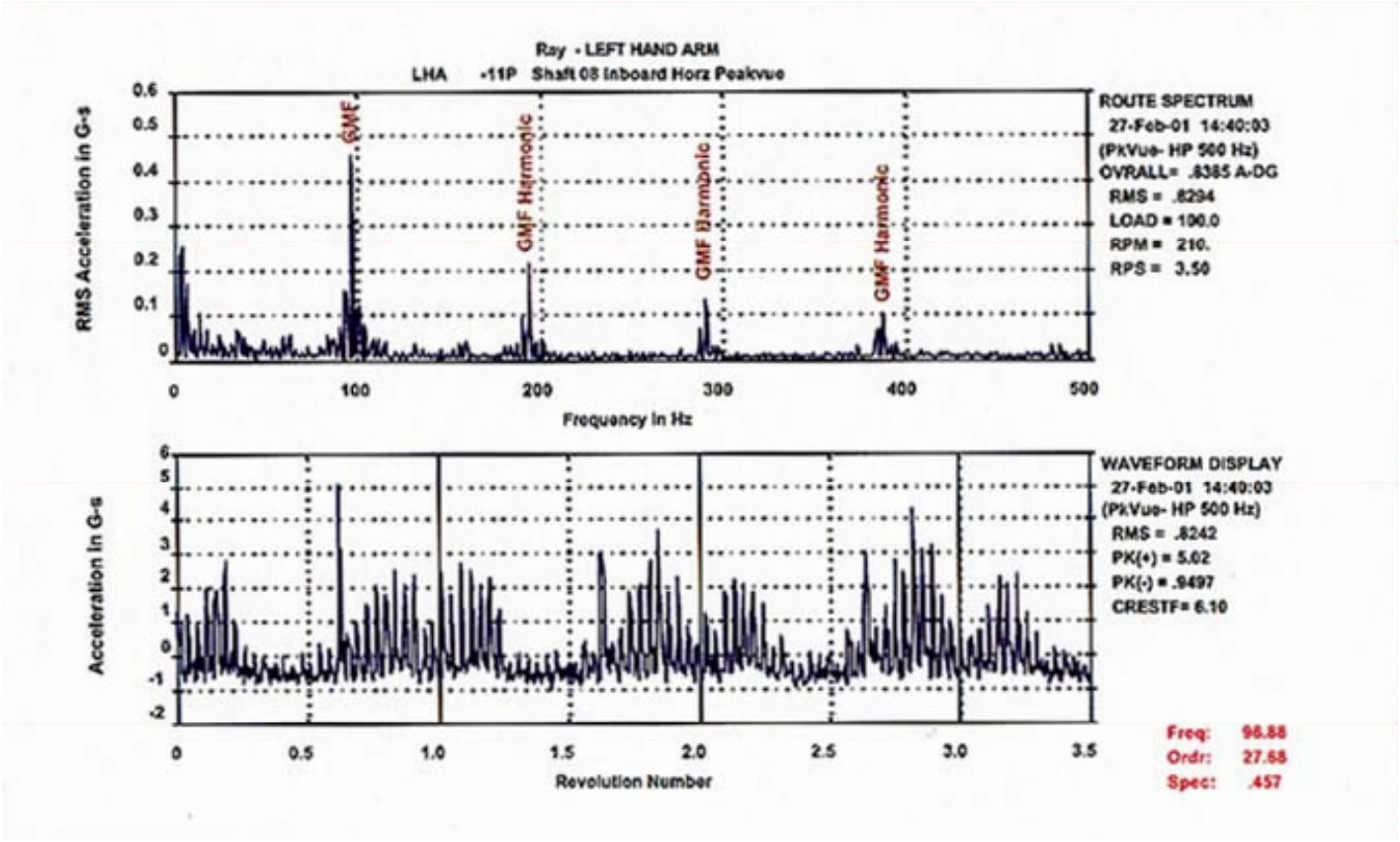


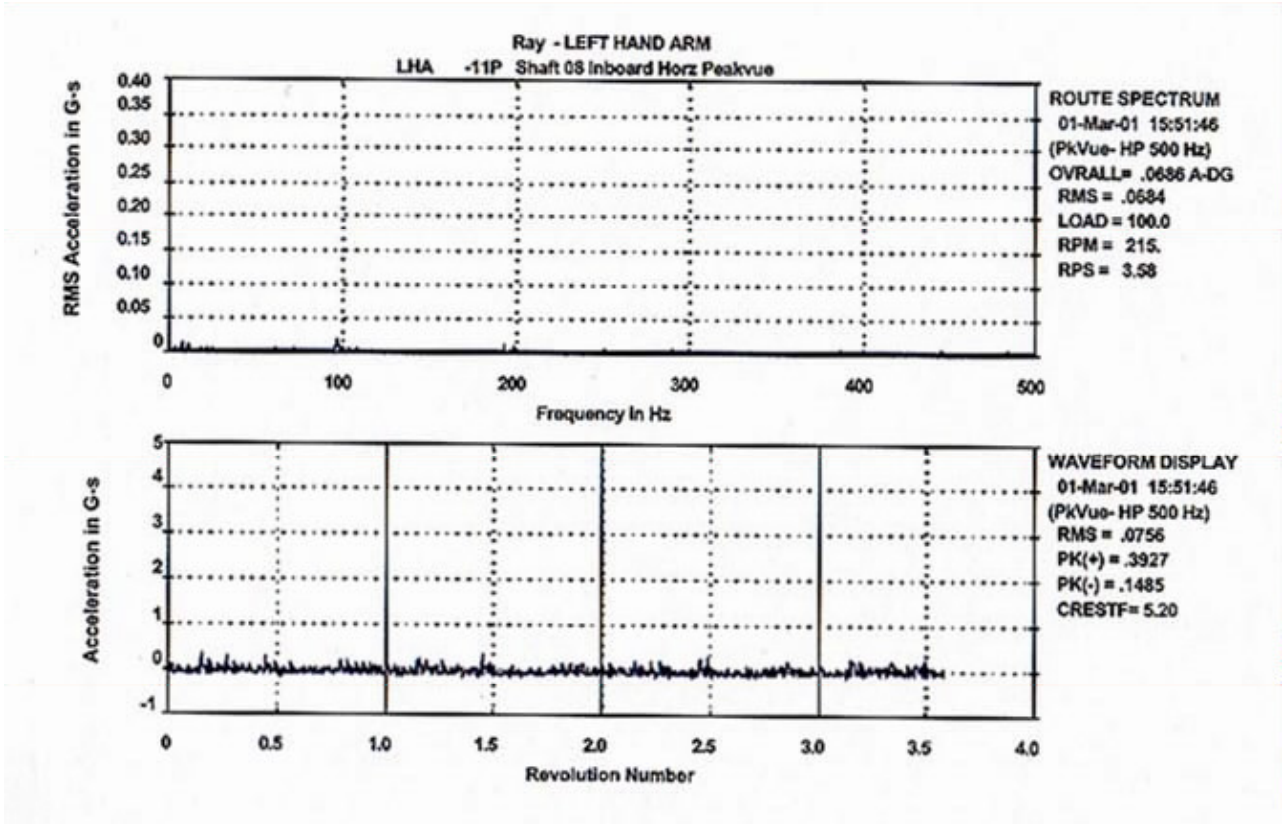
PeakVue spectral and (Fmax=100 Hz but with a 5000 Hz HP filter) from the bearing on the input shaft of the precision tension bridle gearbox



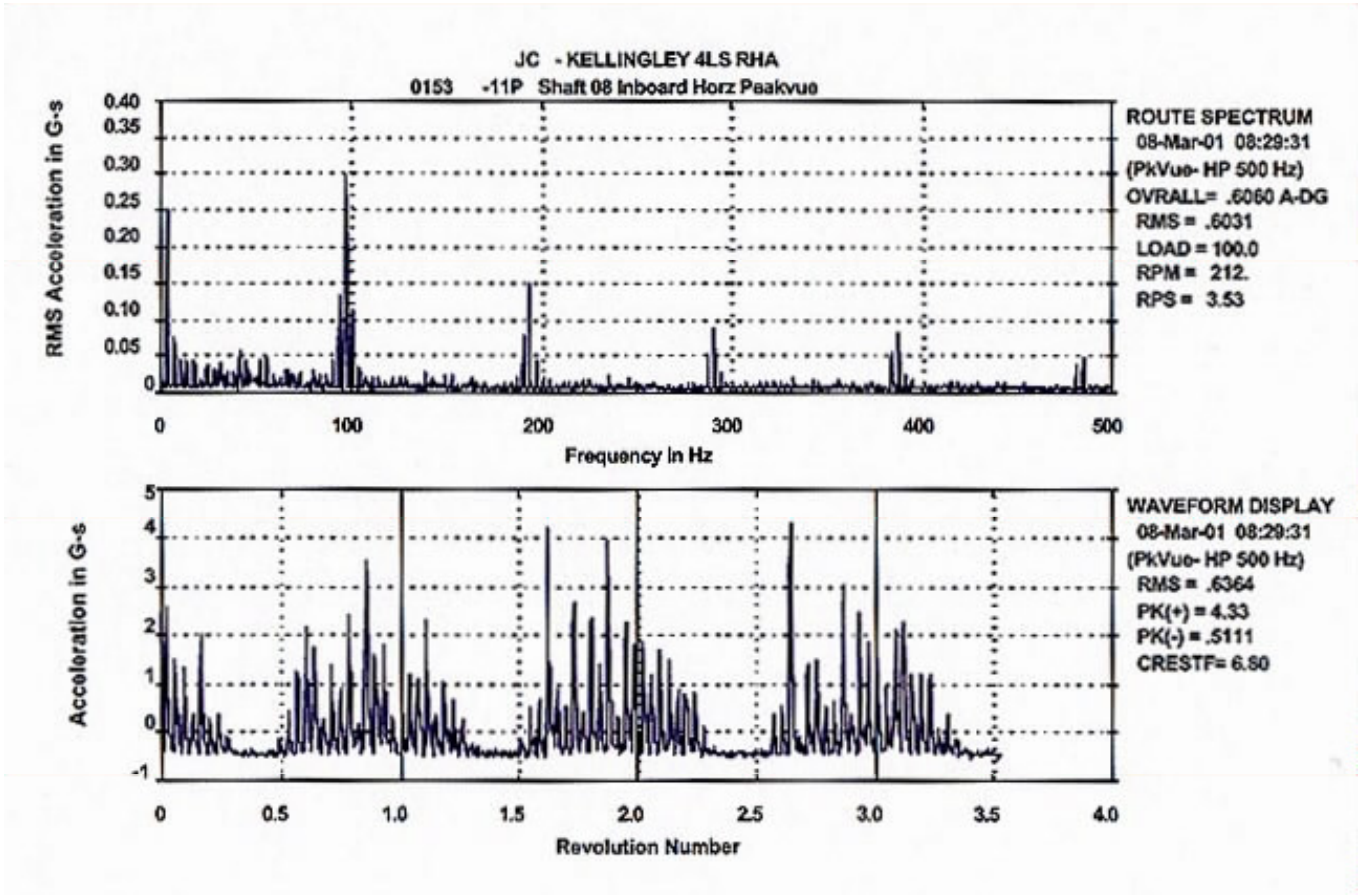
Gearbox

- Case Study # 2
  - Eccentric gear on post rebuild gear box


Ray - LEFT HAND ARM
LHA -11P Shaft 08 Inboard Horz Peakvue
RMS Acceleration in G-s
0.6
0.5
0.4
0.3
0.2
0.1
0
GMF
GMF Harmonic
GMF Harmonic
GMF Harmonic
0
100
200
300
400
500
Frequency in Hz
ROUTE SPECTRUM
27-Feb-01 14:40:03
(PkVue- HP 500 Hz)
OVRALL= .8385 A-DG
RMS = .8294
LOAD = 100.0
RPM = 210.
RPS = 3.50
Acceleration in G-s
6
5
4
3
2
1
0
-1
-2
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Revolution Number
WAVEFORM DISPLAY
27-Feb-01 14:40:03
(PkVue- HP 500 Hz)
RMS = .8242
PK(+) = 5.02
PK(-) = .9497
CRESTF= 6.10
Freq: 96.88
Ordr: 27.68
Spec: .457

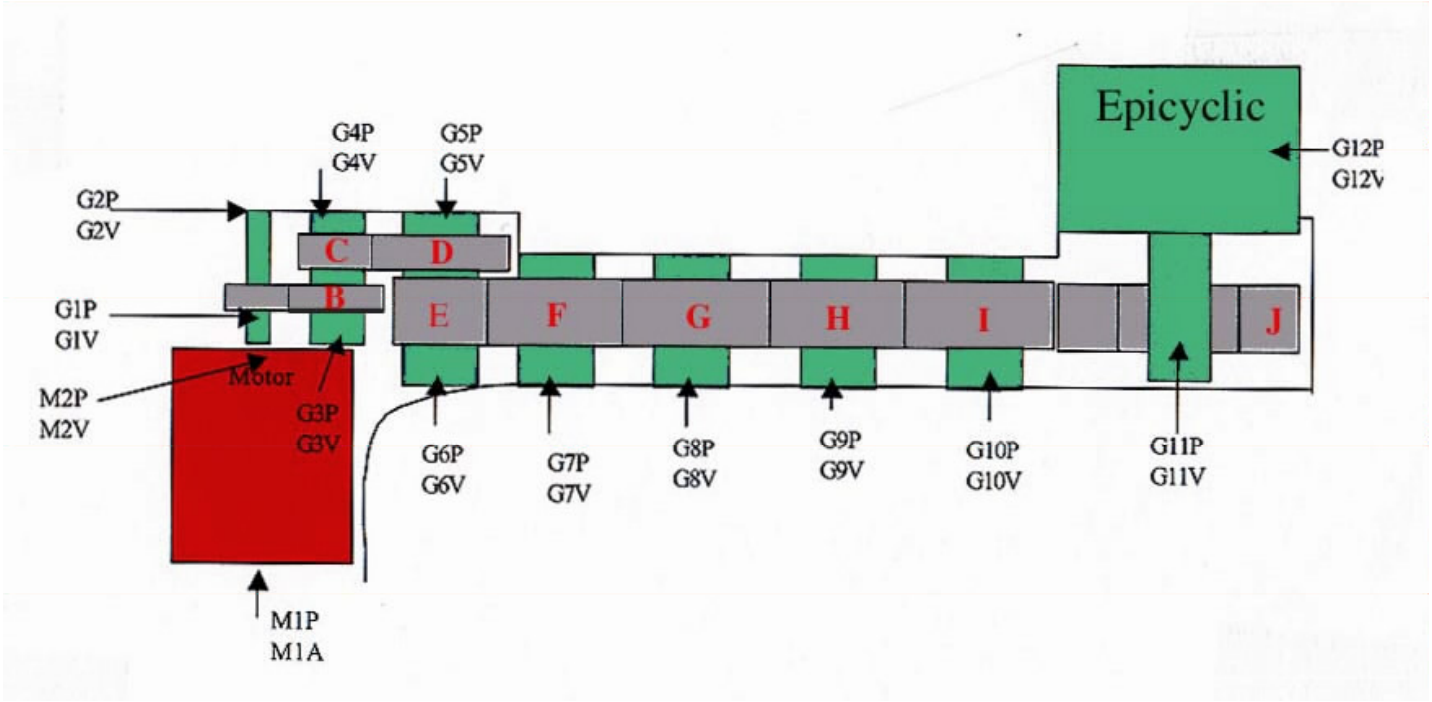

Ray - LEFT HAND ARM
LHA -11P Shaft 08 Inboard Horz Peakvue
RMS Acceleration in G-s
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
0
100
200
300
400
500
Frequency In Hz
ROUTE SPECTRUM
01-Mar-01 15:51:46
(PkVue- HP 500 Hz)
OVRALL= .0686 A-DG
RMS = .0684
LOAD = 100.0
RPM = 215.
RPS = 3.58
Acceleration in G-s
5
4
3
2
1
0
-1
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Revolution Number
WAVEFORM DISPLAY
01-Mar-01 15:51:46
(PkVue- HP 500 Hz)
RMS = .0756
PK(+) = .3927
PK(-) = .1485
CRESTF= 5.20

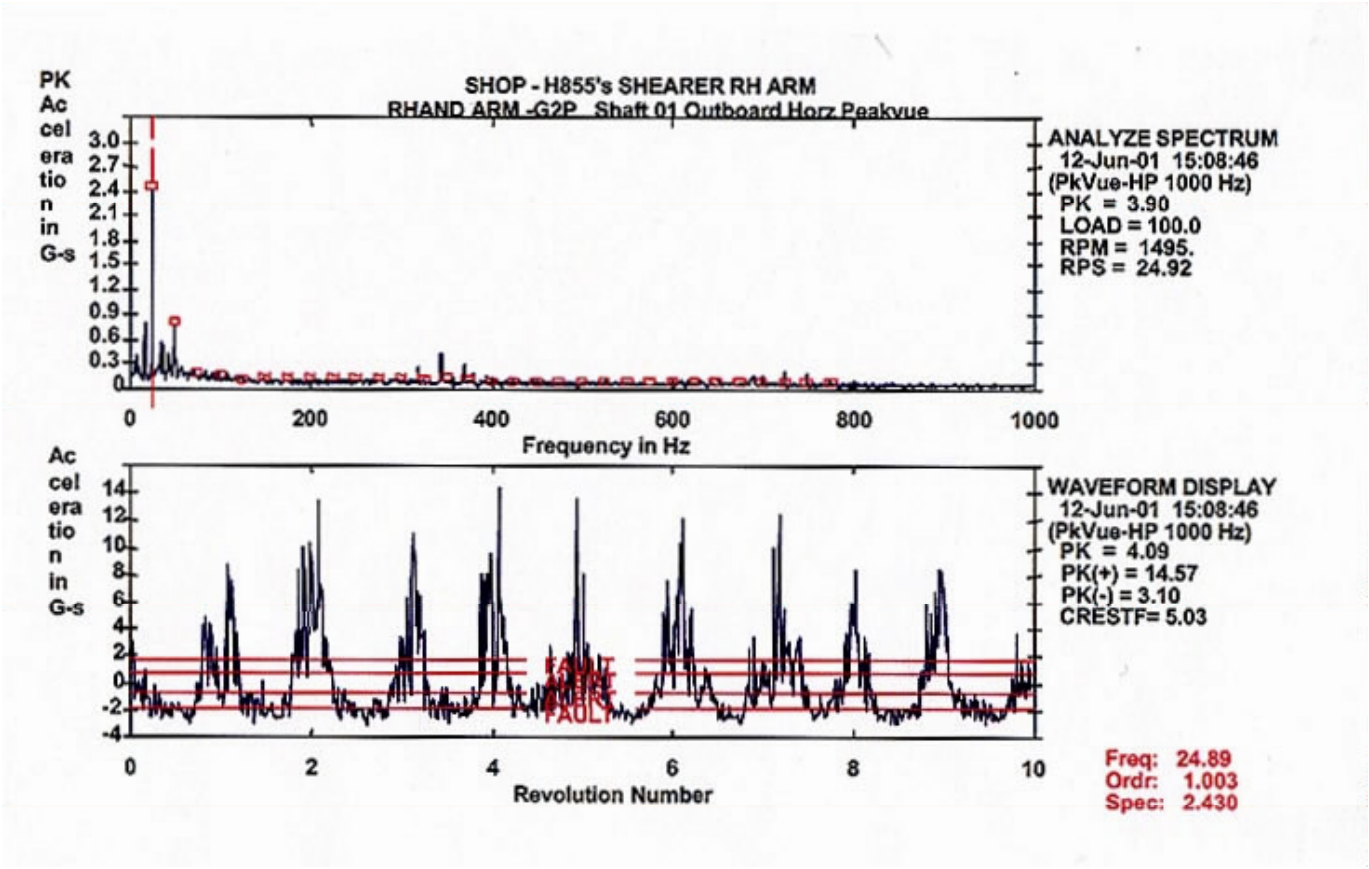
Defective Gear Placed in Separate Gear Box

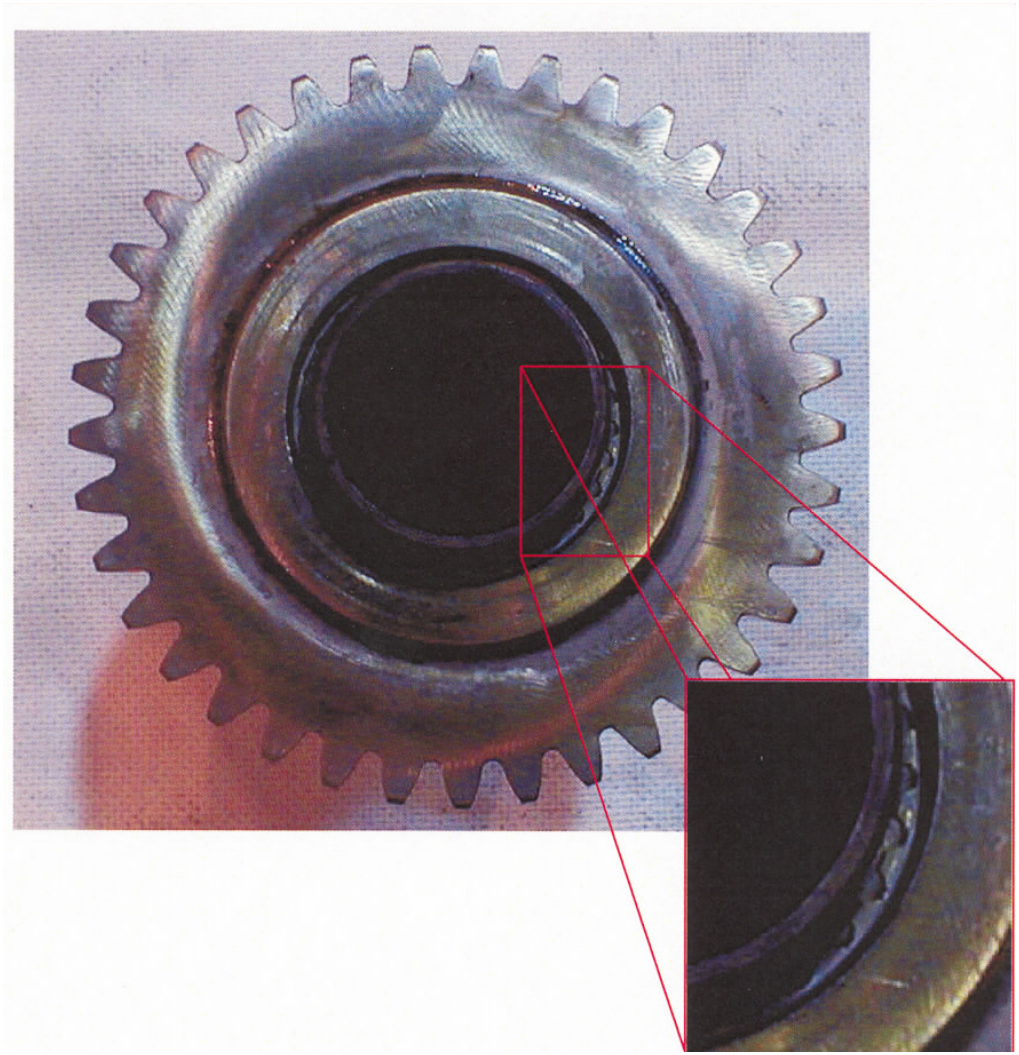


Gear Box

- Case study #3
  - Worn spline on post rebuild gear box


Epicyclic
G12P
G12V
G4P
G4V
G5P
G5V
G2P
G2V
C
D
B
E
F
G
H
I
J
G1P
G1V
M2P
M2V
Motor
G3P
G3V
G6P
G6V
G7P
G7V
G8P
G8V
G9P
G9V
G10P
G10V
G11P
G11V
M1P
M1A

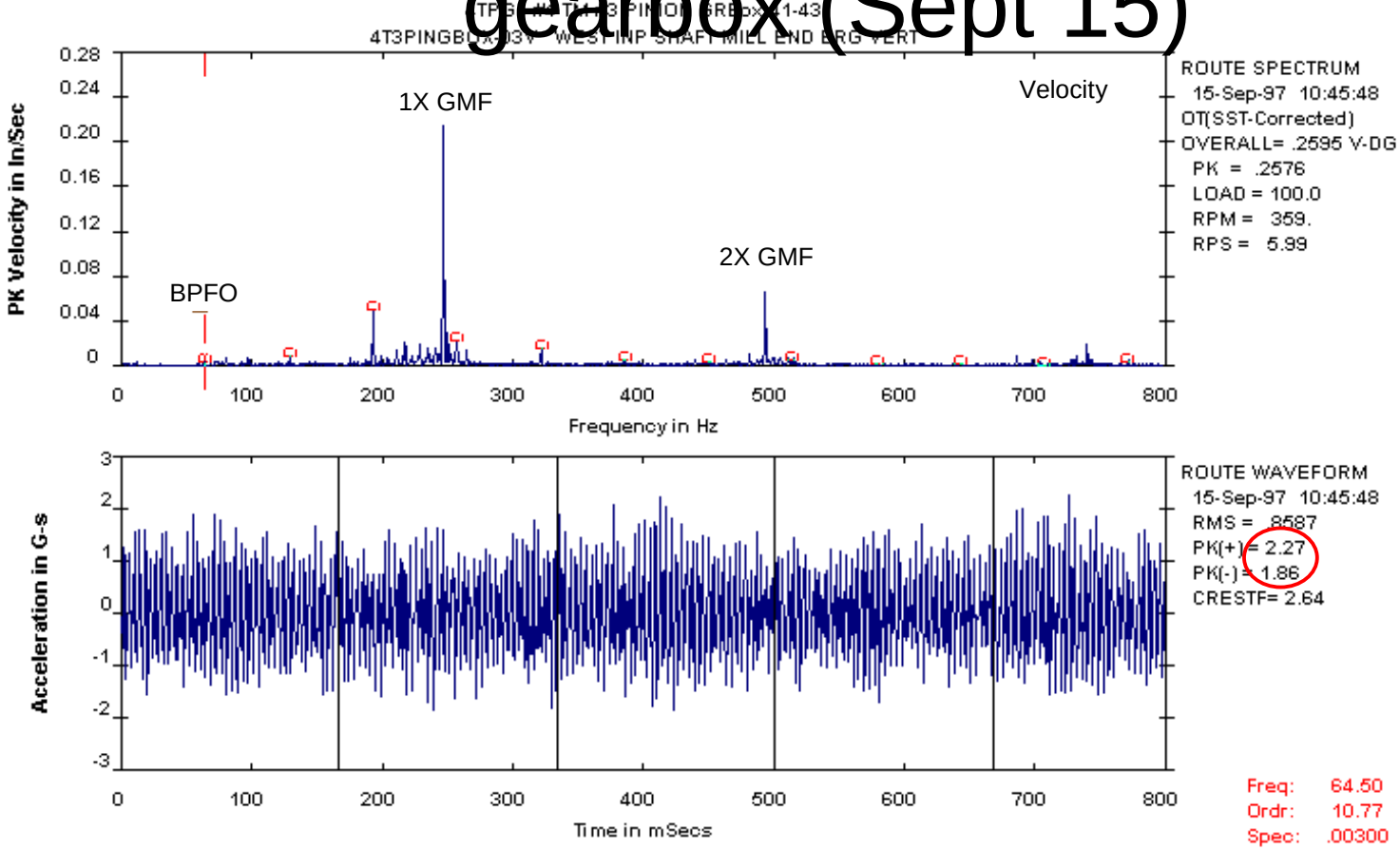

SHOP - H855's SHEARER RH ARM
RHAND ARM -G2P Shaft 01 Outboard Horz Peakvue
PK Acceleration in G-s
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
0
200
400
600
800
1000
Frequency in Hz
ANALYZE SPECTRUM
12-Jun-01 15:08:46
(PkVue-HP 1000 Hz)
PK = 3.90
LOAD = 100.0
RPM = 1495.
RPS = 24.92
Acceleration in G-s
14
12
10
8
6
4
2
0
-2
-4
FAULT
FAULT
FAULT
0
2
4
6
8
10
Revolution Number
WAVEFORM DISPLAY
12-Jun-01 15:08:46
(PkVue-HP 1000 Hz)
PK = 4.09
PK(+) = 14.57
PK(-) = 3.10
CRESTF= 5.03
Freq: 24.89
Ordr: 1.003
Spec: 2.430



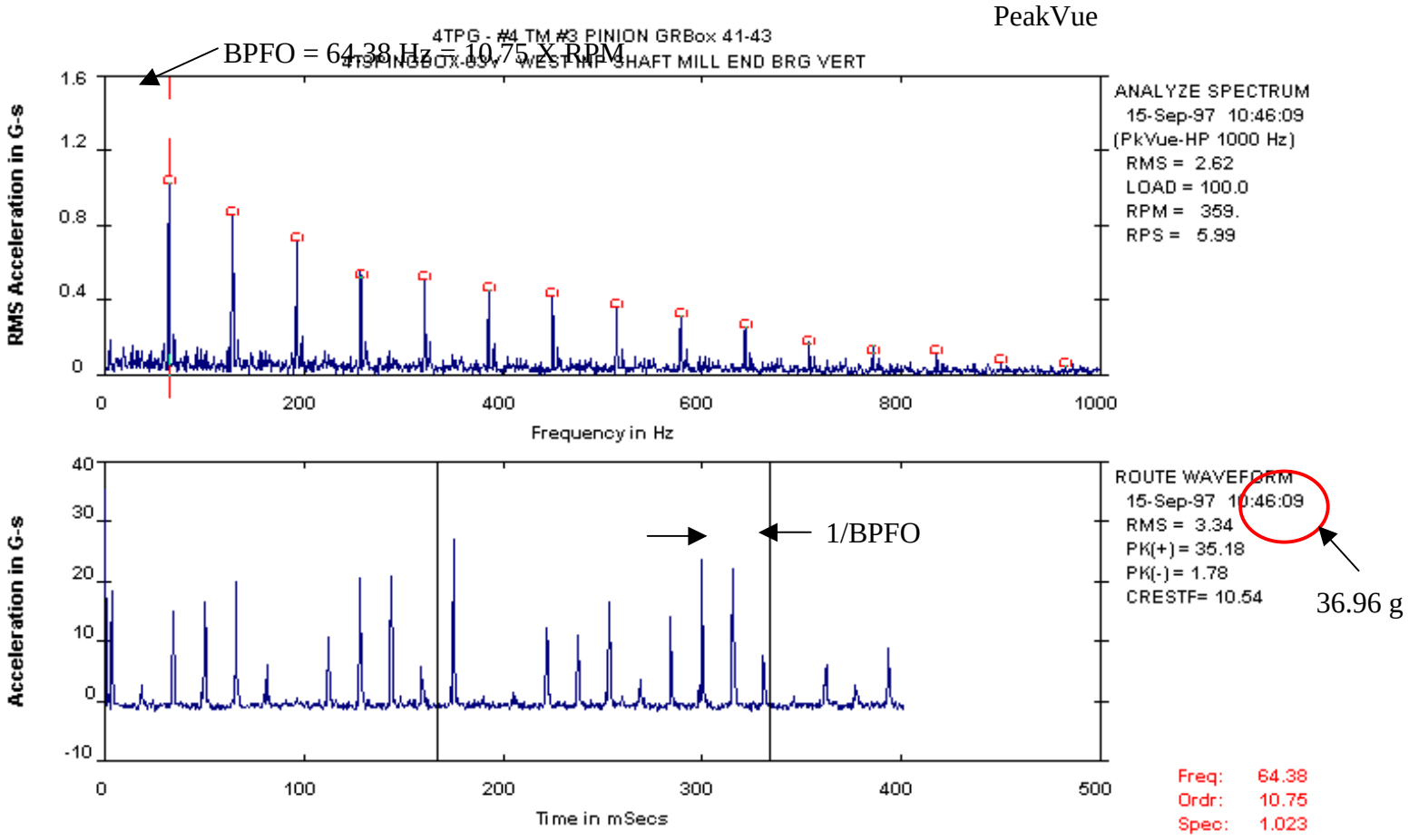
Bearing-Outer Race

- Case Study #4
- BPFO in Pinion Stand Gearbox
  - Speed of shaft=360 RPM
  - Peak g-level=37 g’s
  - Fault=6.3 g’s

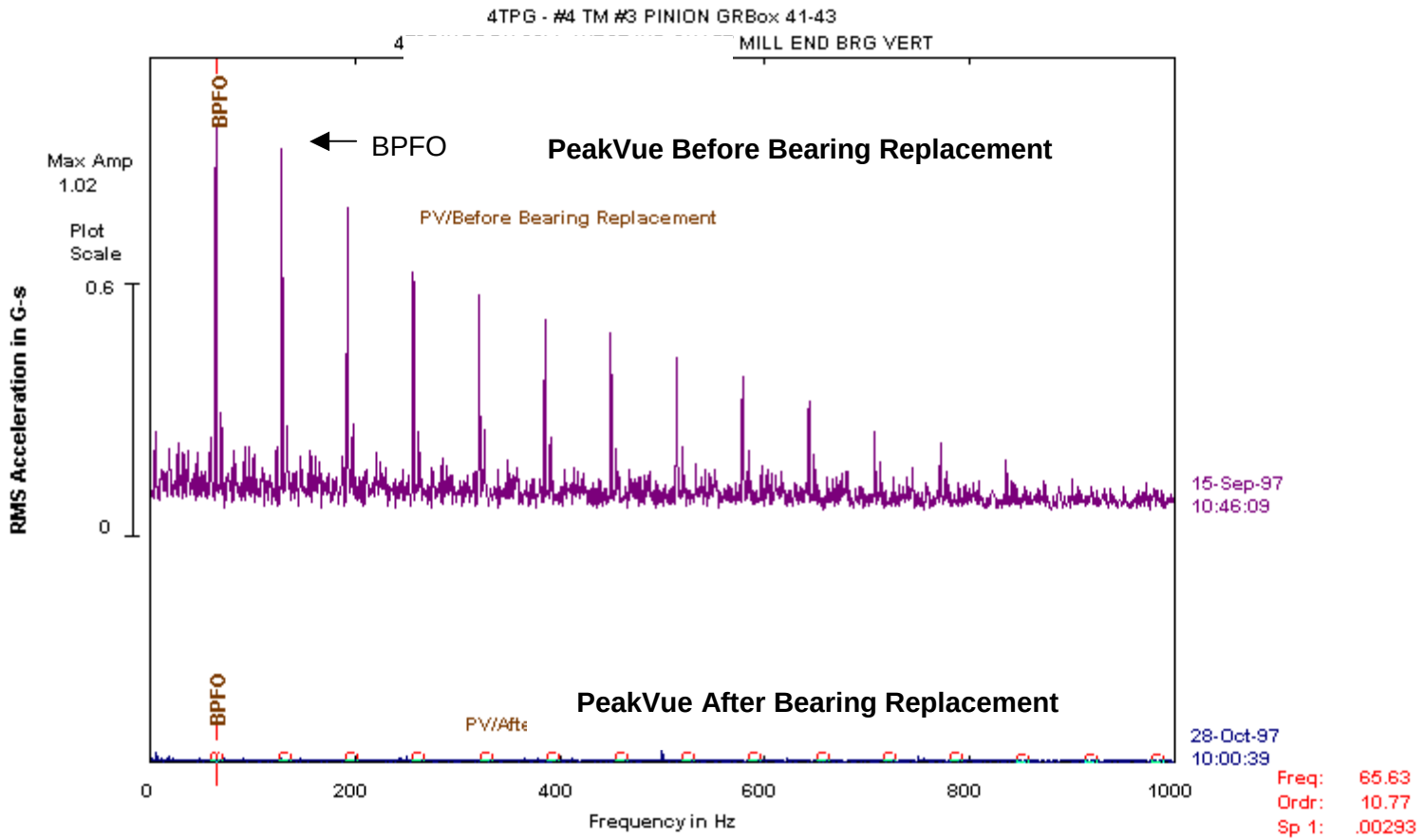
Velocity spectral and acceleration waveform data (Fmax=800 Hz) from the bearing on the input shaft of the gearbox (Sept 15)



Peakvue spectral and waveform data (Fmax=1000 Hz) from the bearing on the input shaft of the gearbox (Sept 15)



Peakvue spectral and waveform data (Fmax=1000 Hz) from the bearing on the input shaft of the gearbox before and after bearing replacement

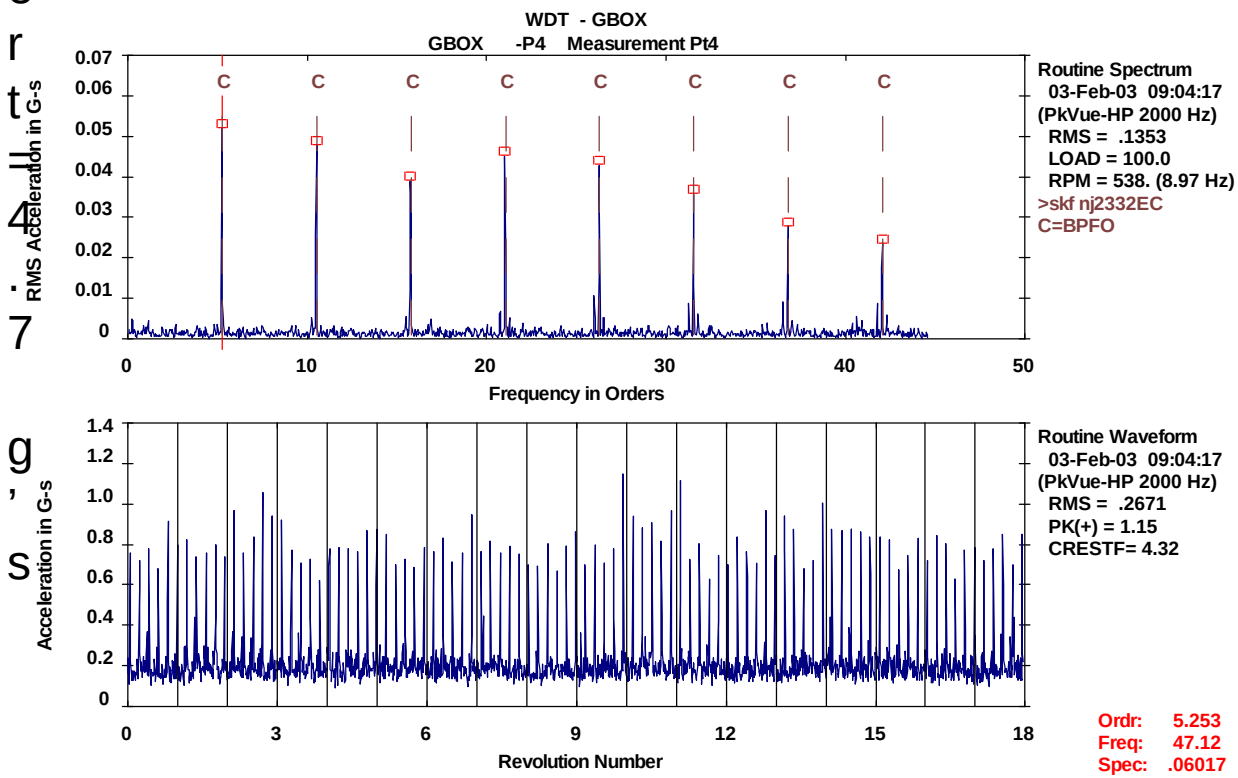


Closeup picture of the outer race of the defective bearing showing significant spalling over an area of 5 in. x 5 in.

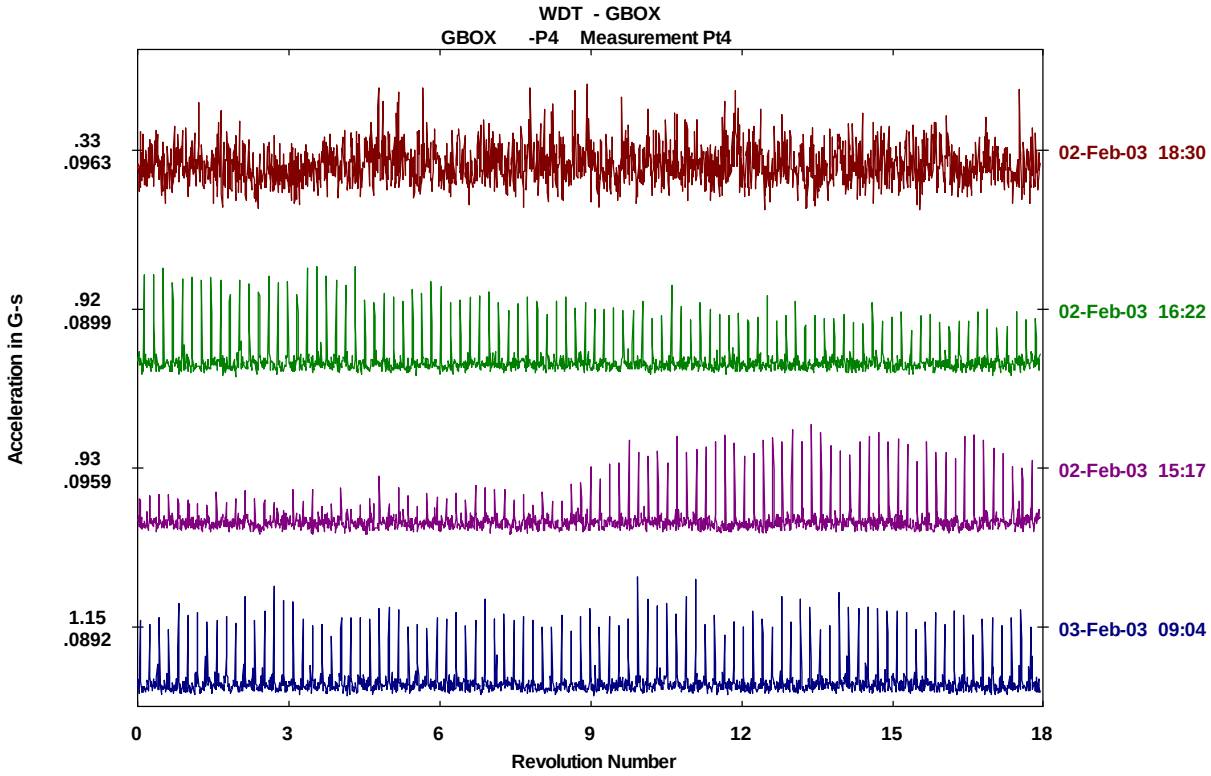
Bearing Outer Race

- Case Study #5 BPFO
  - **Early stage fatiguing**
  - **Shaft speed=650 RPM**
  - **Alert=4.7 g's**

Alert=4.7 g's


WDT - GBOX
GBOX -P4 Measurement Pt4
RMS Acceleration in G-s
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C C C C C C C C
0 10 20 30 40 50
Frequency in Orders
Routine Spectrum
03-Feb-03 09:04:17
(PkVue-HP 2000 Hz)
RMS = .1353
LOAD = 100.0
RPM = 538. (8.97 Hz)
>skf nj2332EC
C=BPFO
Acceleration in G-s
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0 3 6 9 12 15 18
Revolution Number
Routine Waveform
03-Feb-03 09:04:17
(PkVue-HP 2000 Hz)
RMS = .2671
PK(+) = 1.15
CRESTF= 4.32
Ordr: 5.253
Freq: 47.12
Spec: .06017

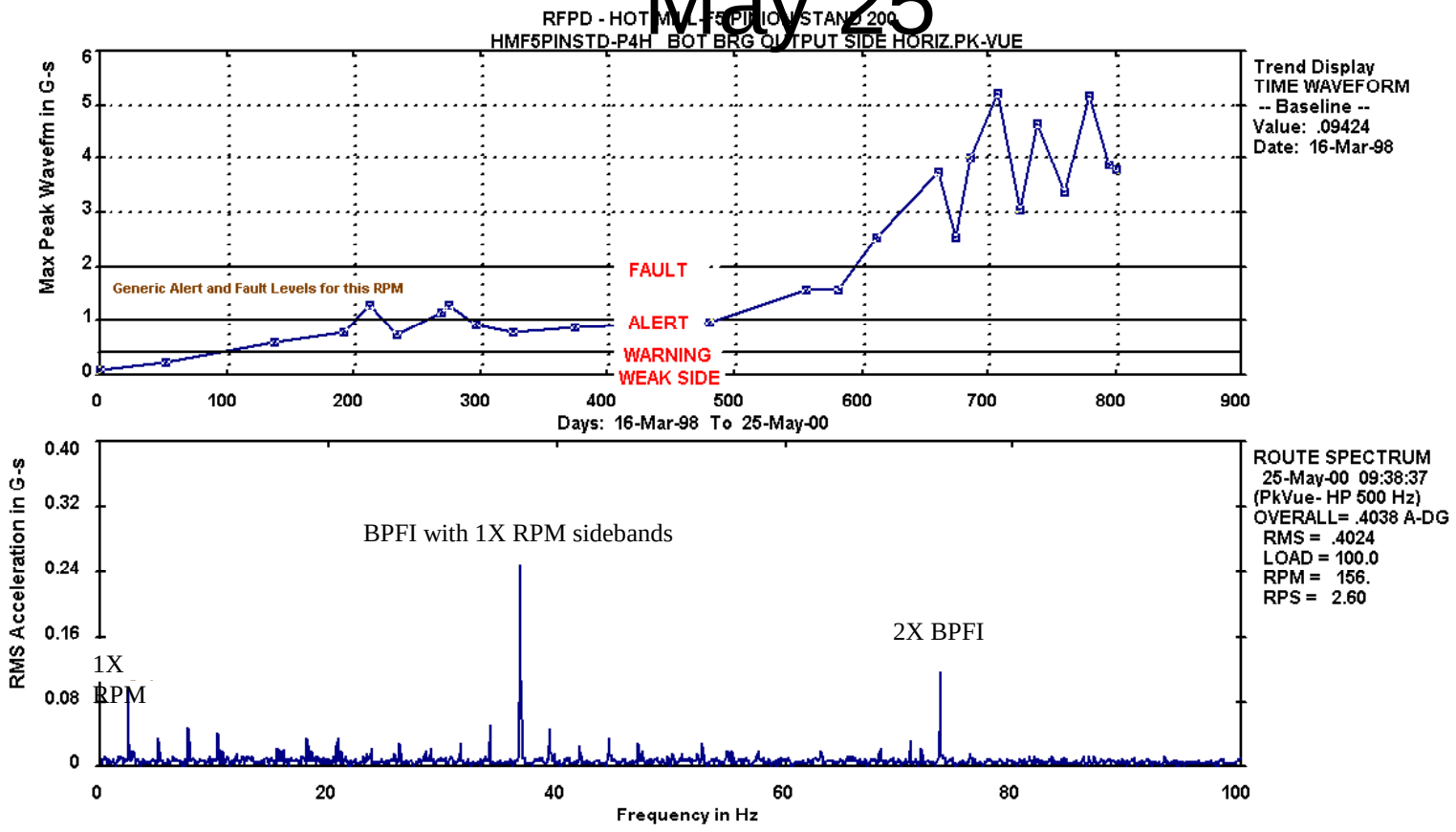
Impacting Sporadic



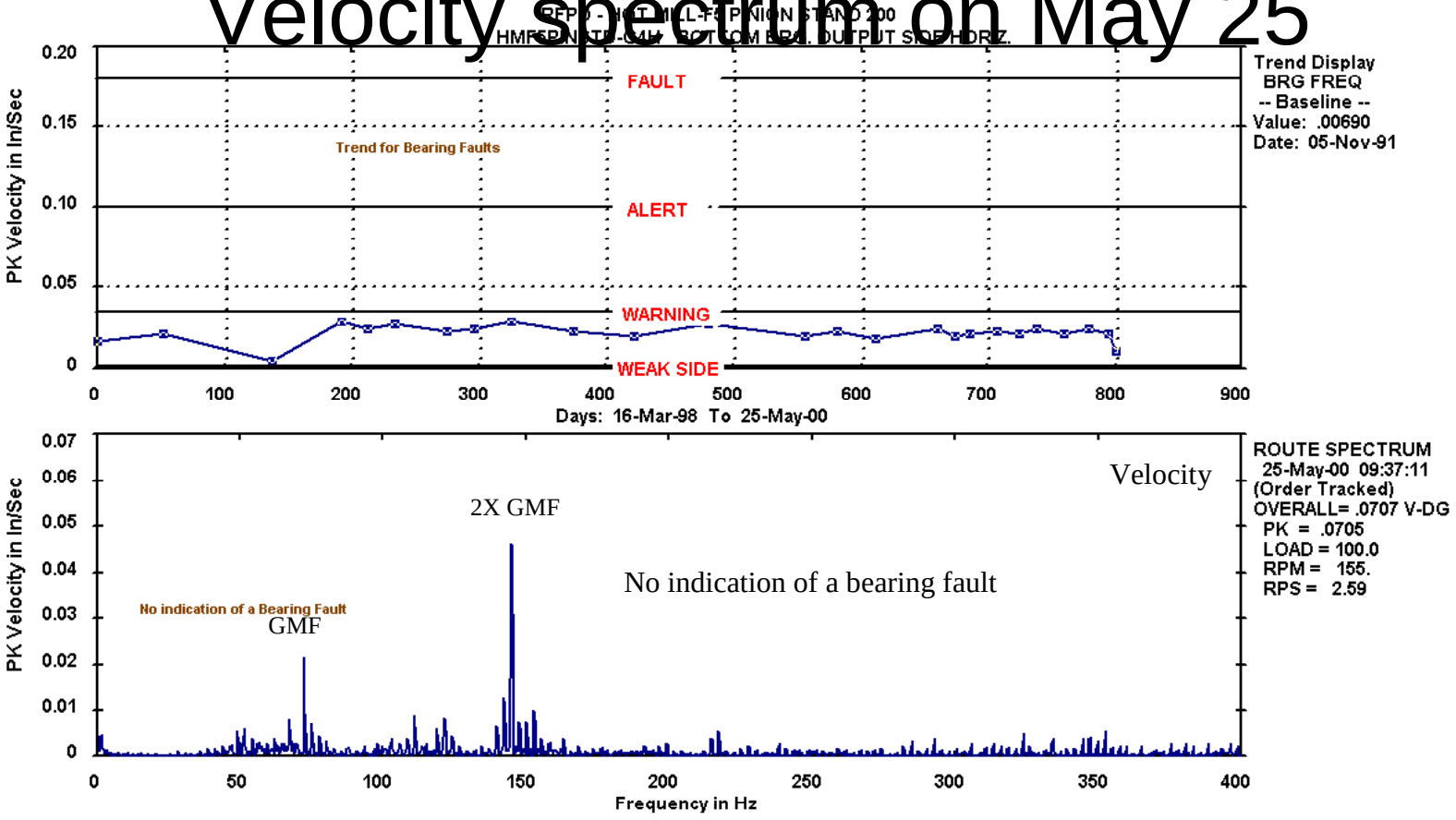
Bearing (Inner Race)

- Case Study #6
  - **BPFI on bearing on output shaft**
  - **Severity ascertained from trending**

Trend (2 years) of the maximum peak amplitude (g's) from the Peakvue waveform and a Peakvue spectrum on May 25



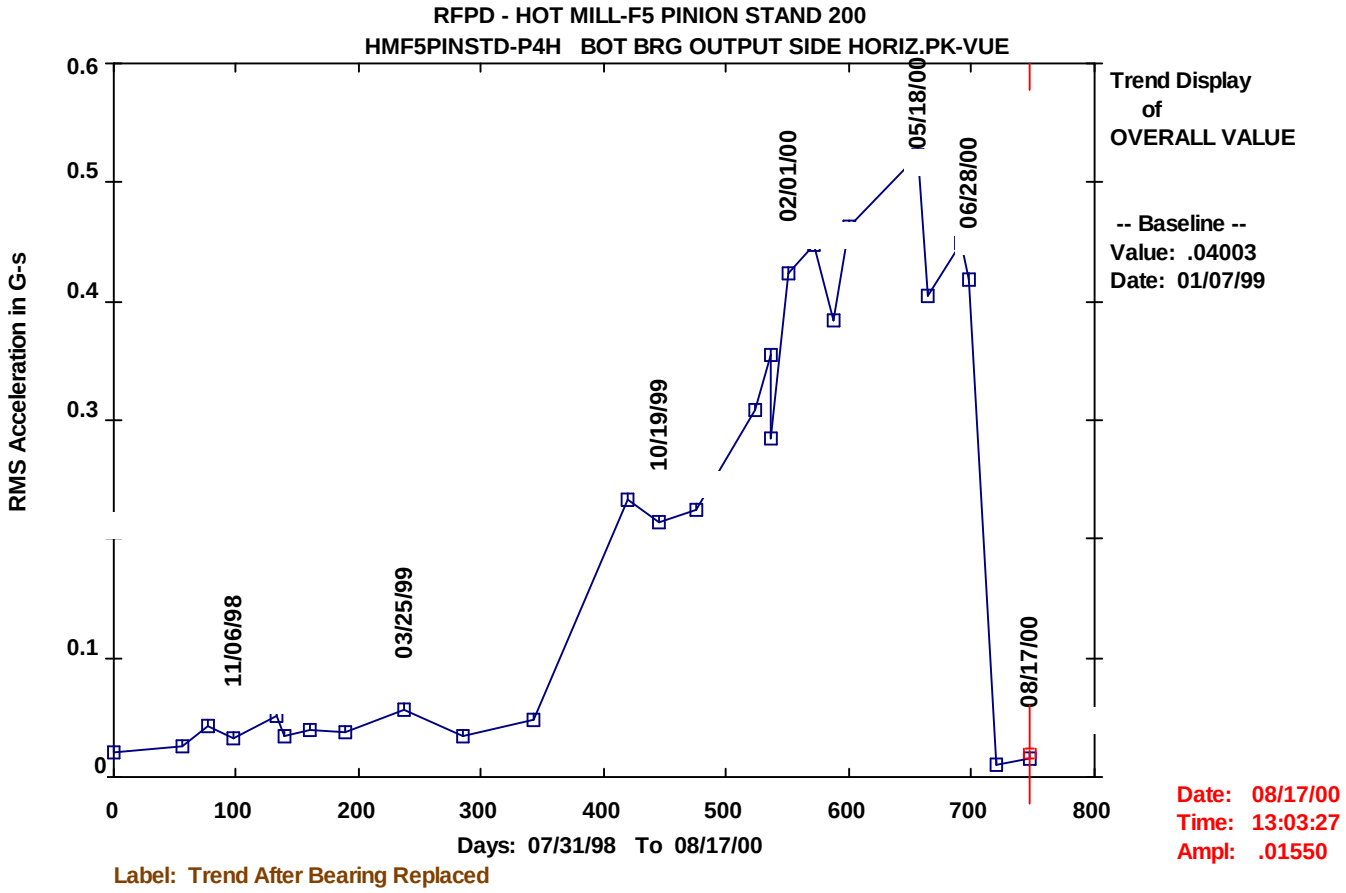
Trend (2 years) of the bearing frequency band from the velocity spectrum and a Velocity spectrum on May 25



Picture of the defective bearing with a significant inner race defect identified by Peakvue trends

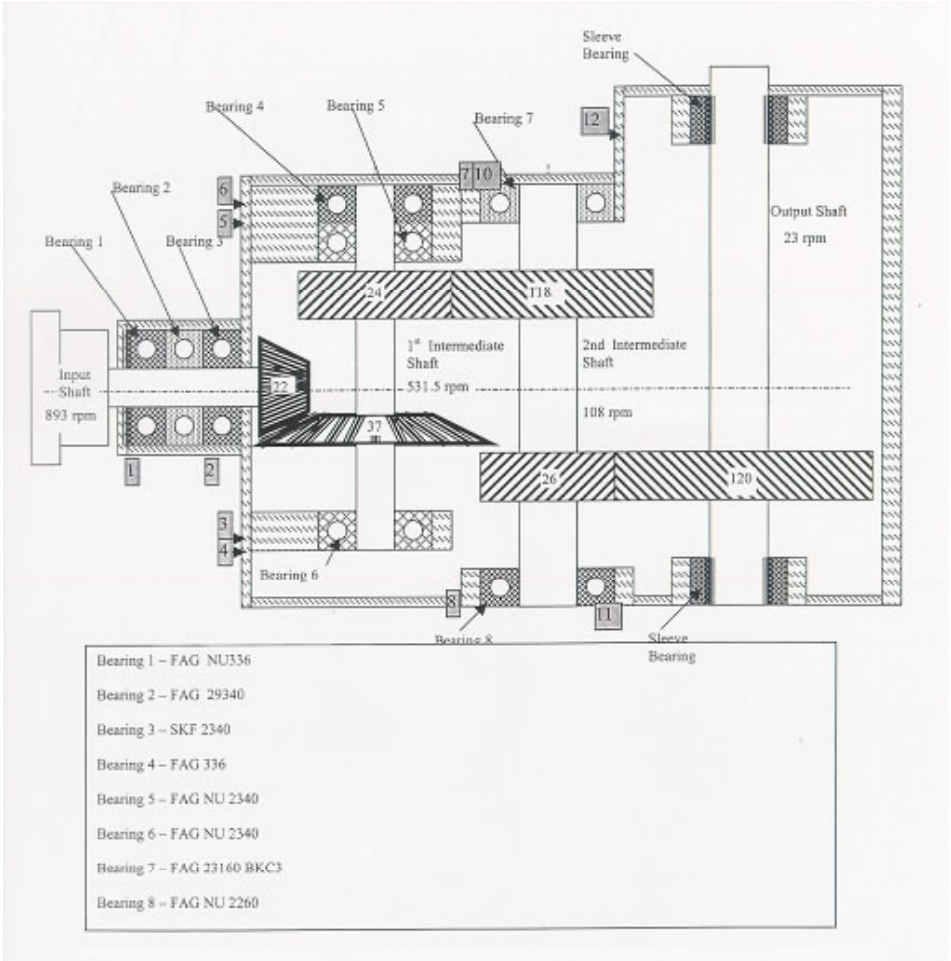
PeakVue Trend Before & After Bearing was Replaced

(Trend of Digital Overall)

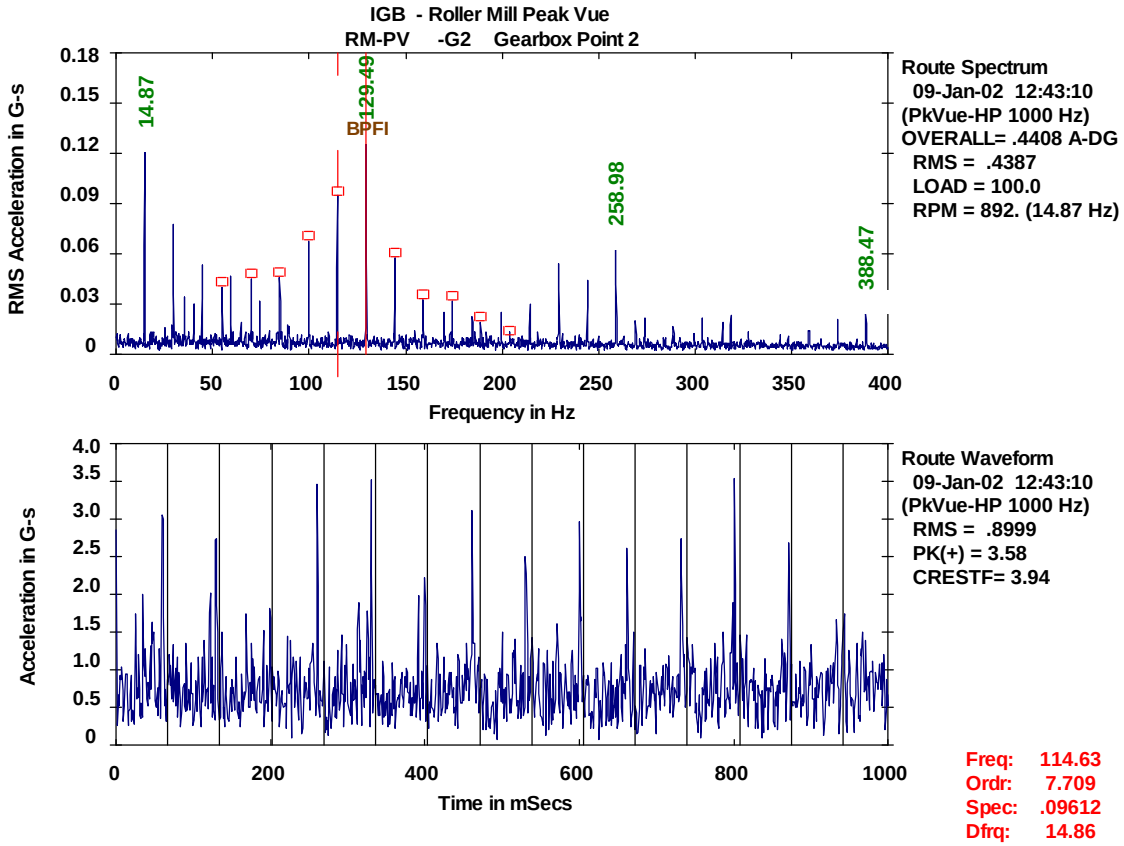


Bearing Inner Race

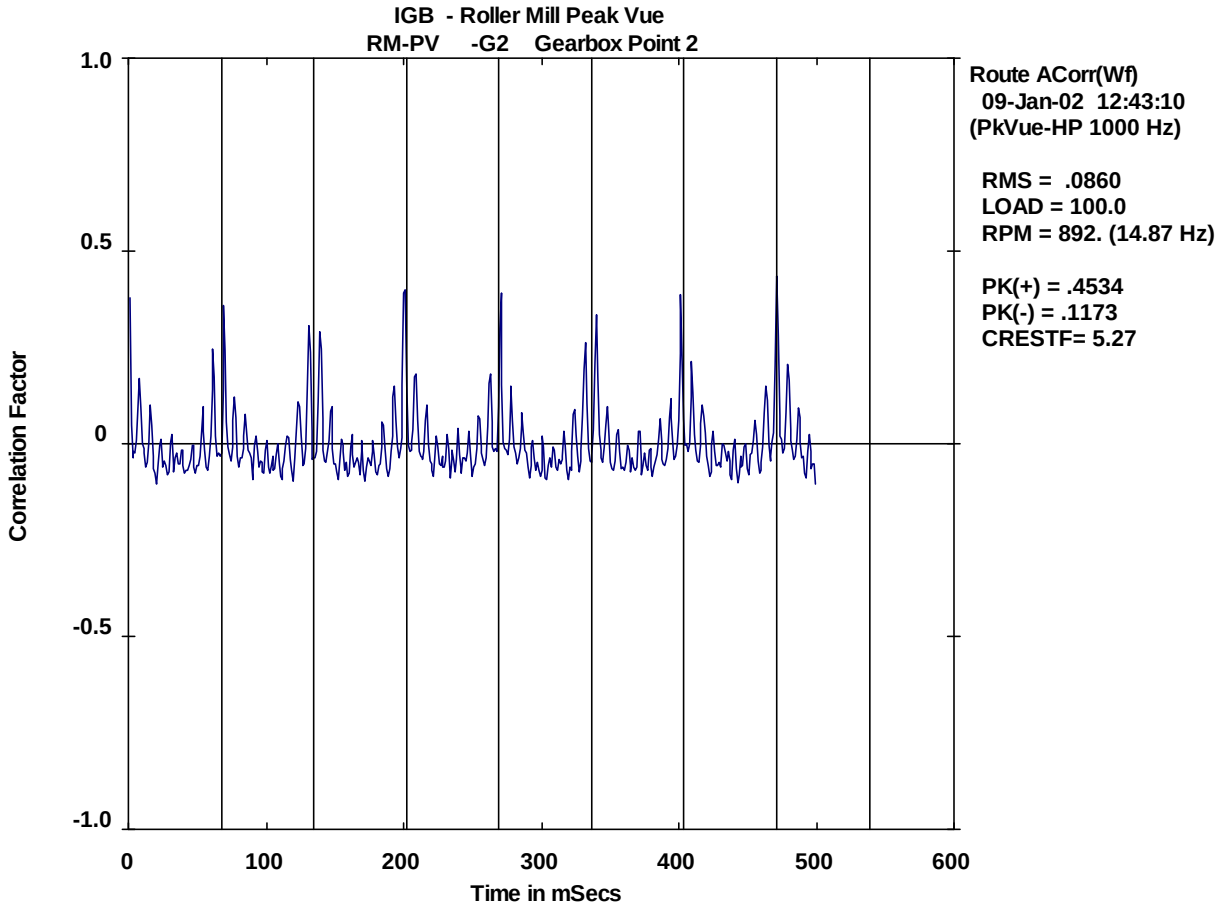
- Case Study # 7
  - **BPFI (mechanical plus lubrication)**


Sleeve Bearing
Bearing 4
Bearing 5
Bearing 7
12
7
10
Bearing 2
6
5
Bearing 1
Bearing 3
Output Shaft
23 rpm
24
118
1st Intermediate Shaft
2nd Intermediate Shaft
Input Shaft
893 rpm
22
531.5 rpm
108 rpm
37
1
2
26
120
3
4
Bearing 6
9
11
Bearing 8
Sleeve Bearing
Bearing 1 – FAG NU336
Bearing 2 – FAG 29340
Bearing 3 – SKF 2340
Bearing 4 – FAG 336
Bearing 5 – FAG NU 2340
Bearing 6 – FAG NU 2340
Bearing 7 – FAG 23160 BKC3
Bearing 8 – FAG NU 2260

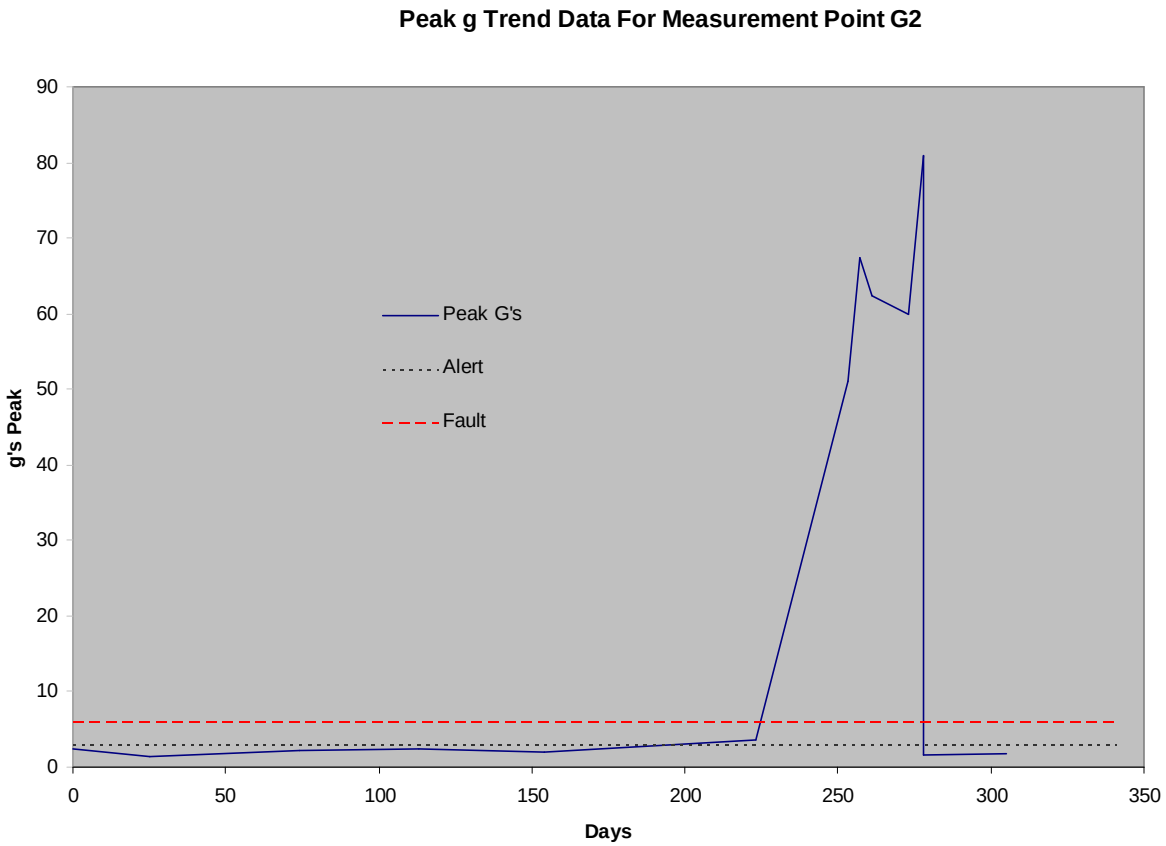
Data acquired outer bearing re input



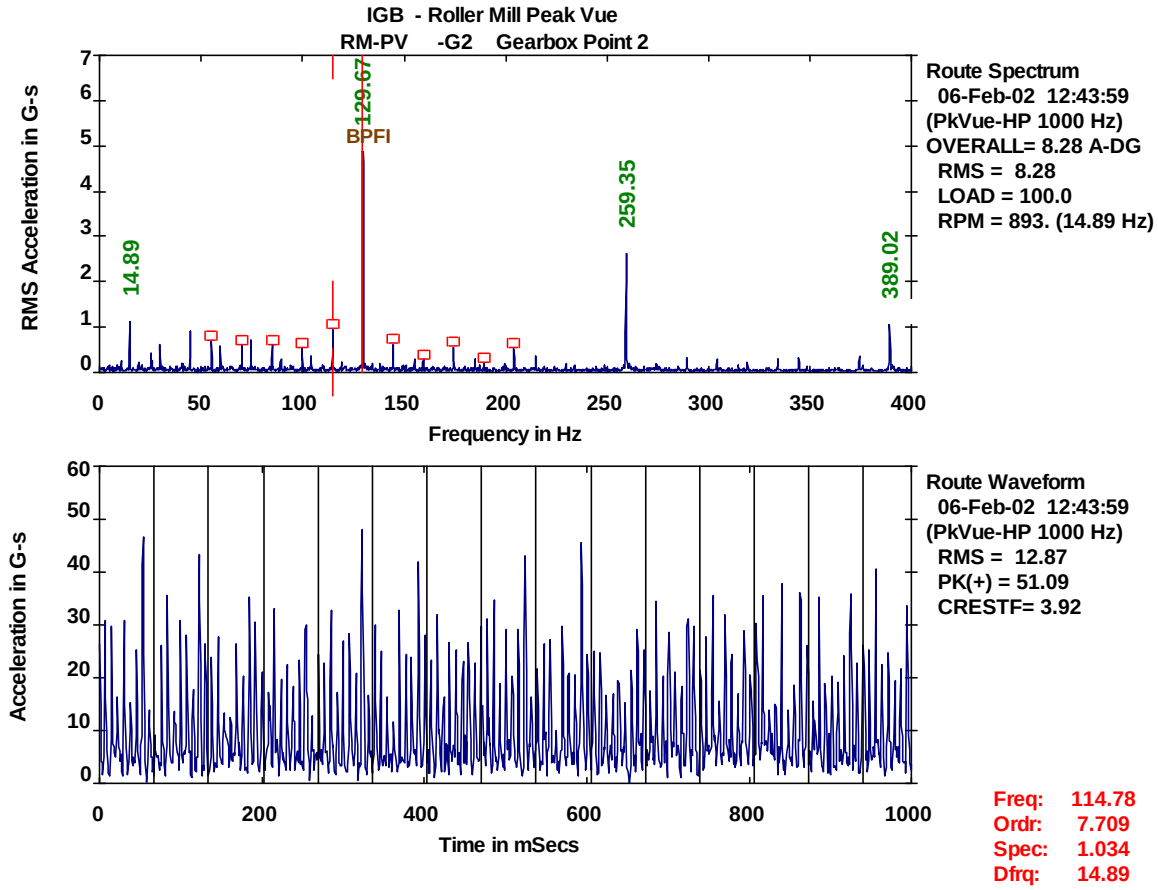
Typical BPFI pattern in Autocorrelation



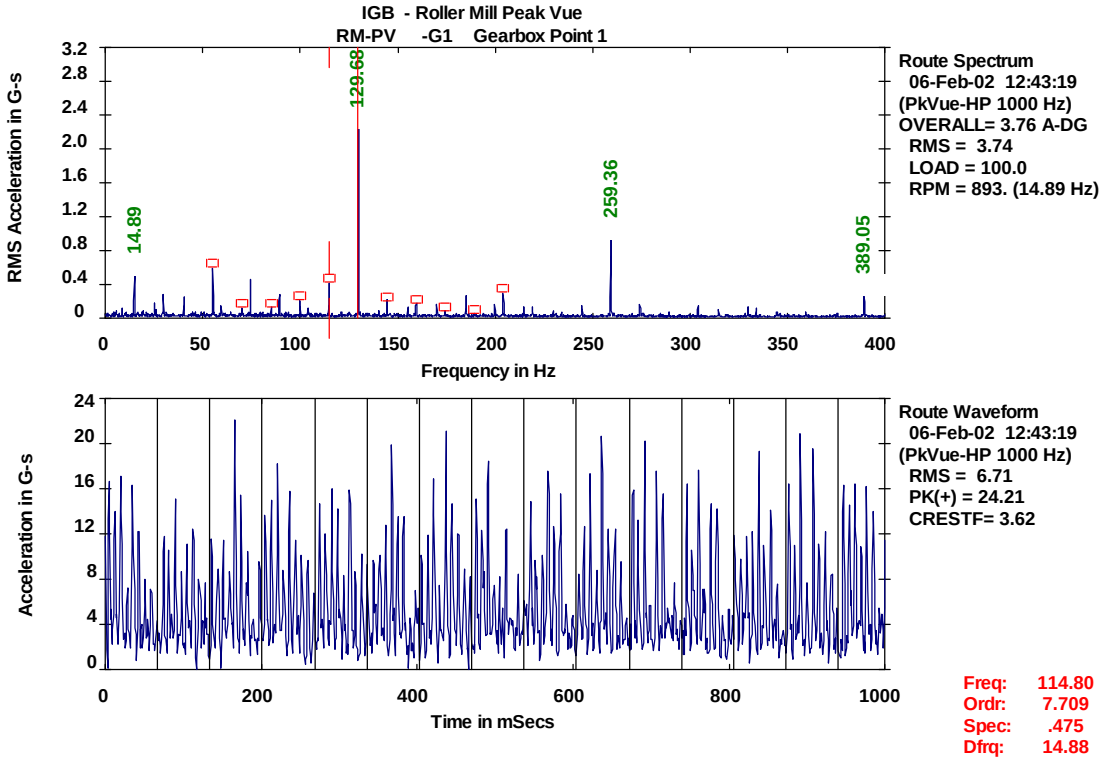
Trended Peak g-level from G2



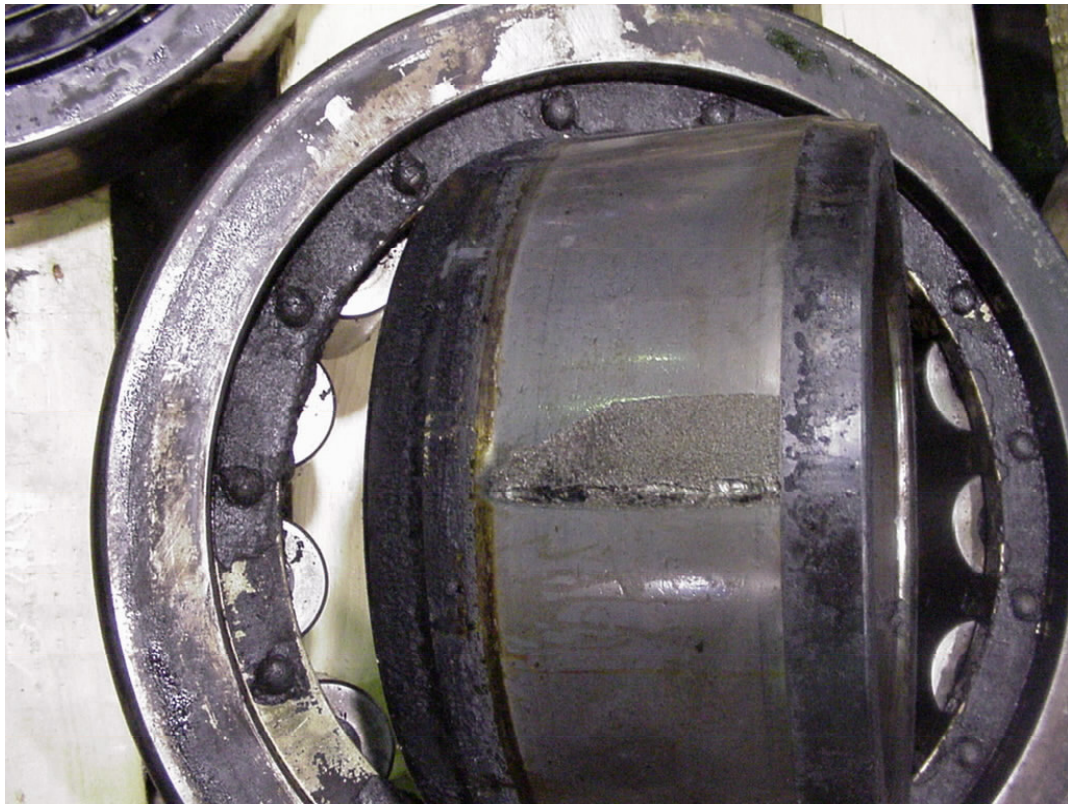
51 g's on Point G2 on February 6, 2002



25 g's on Point G1 on February 6, 2002.



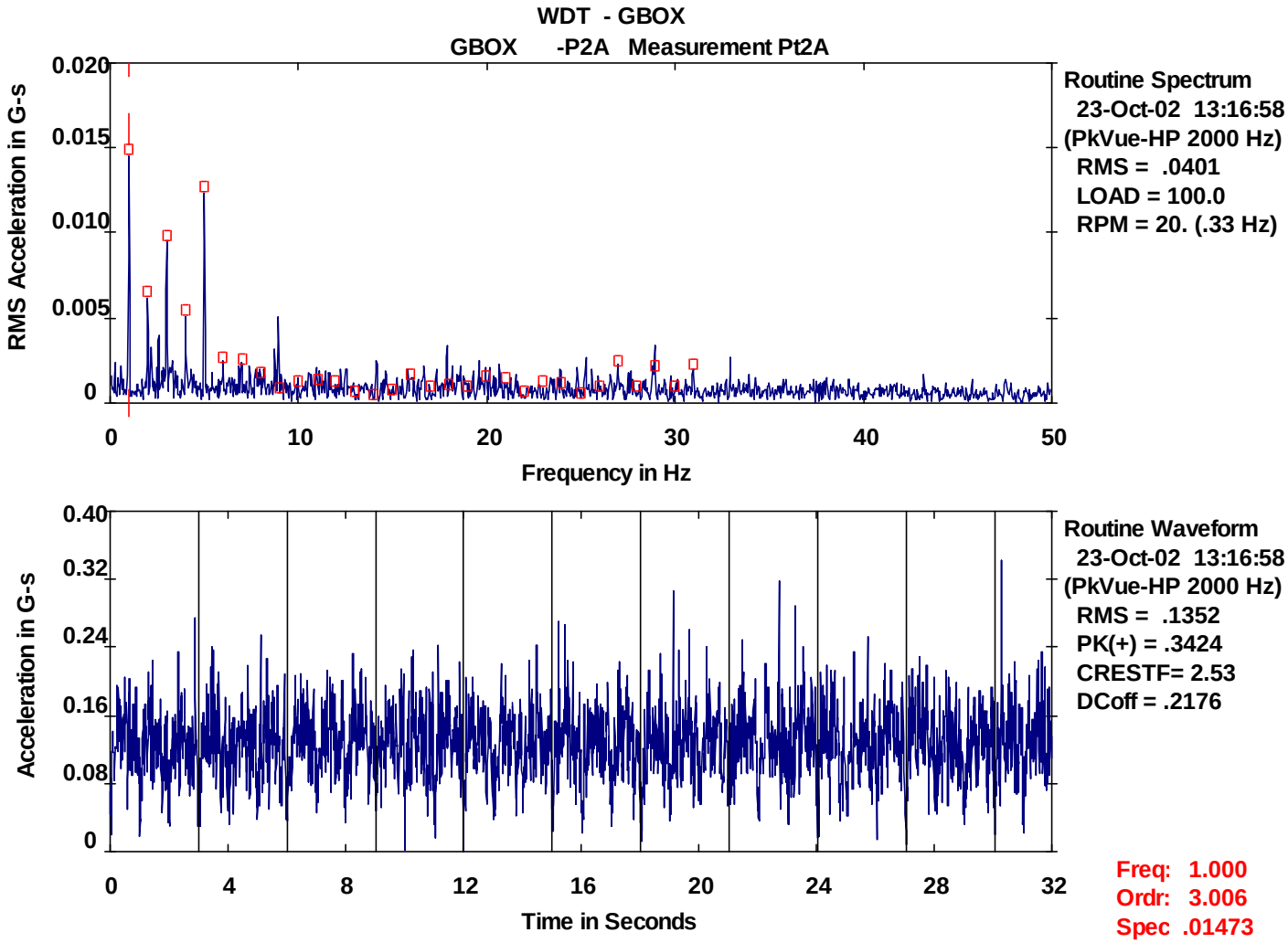
Note metal removal on inner race downstream of fault



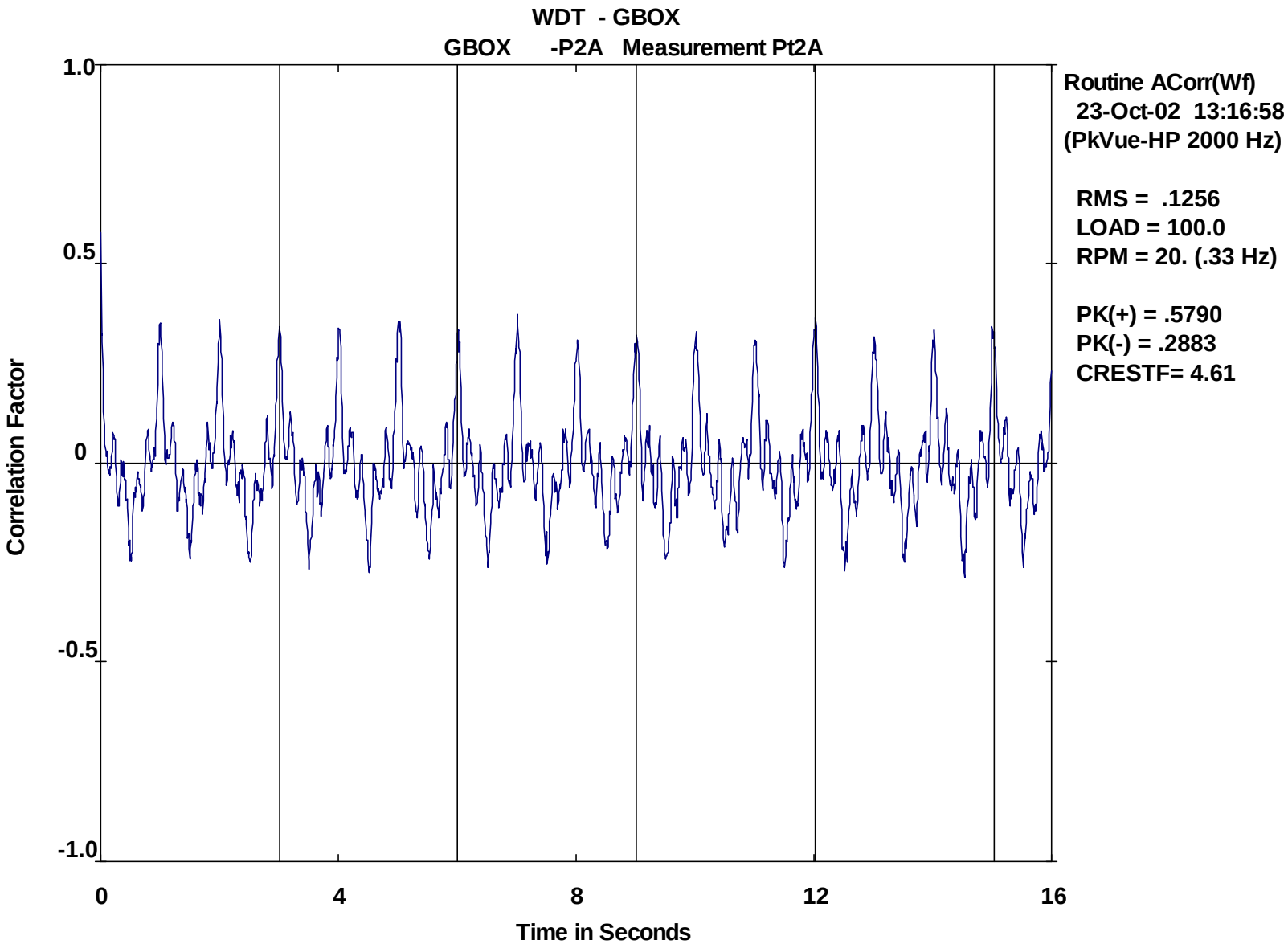
Gear Fault in Planetary Gear

- Planetary Gearbox
- Carrier turning at approximately 20 RPM

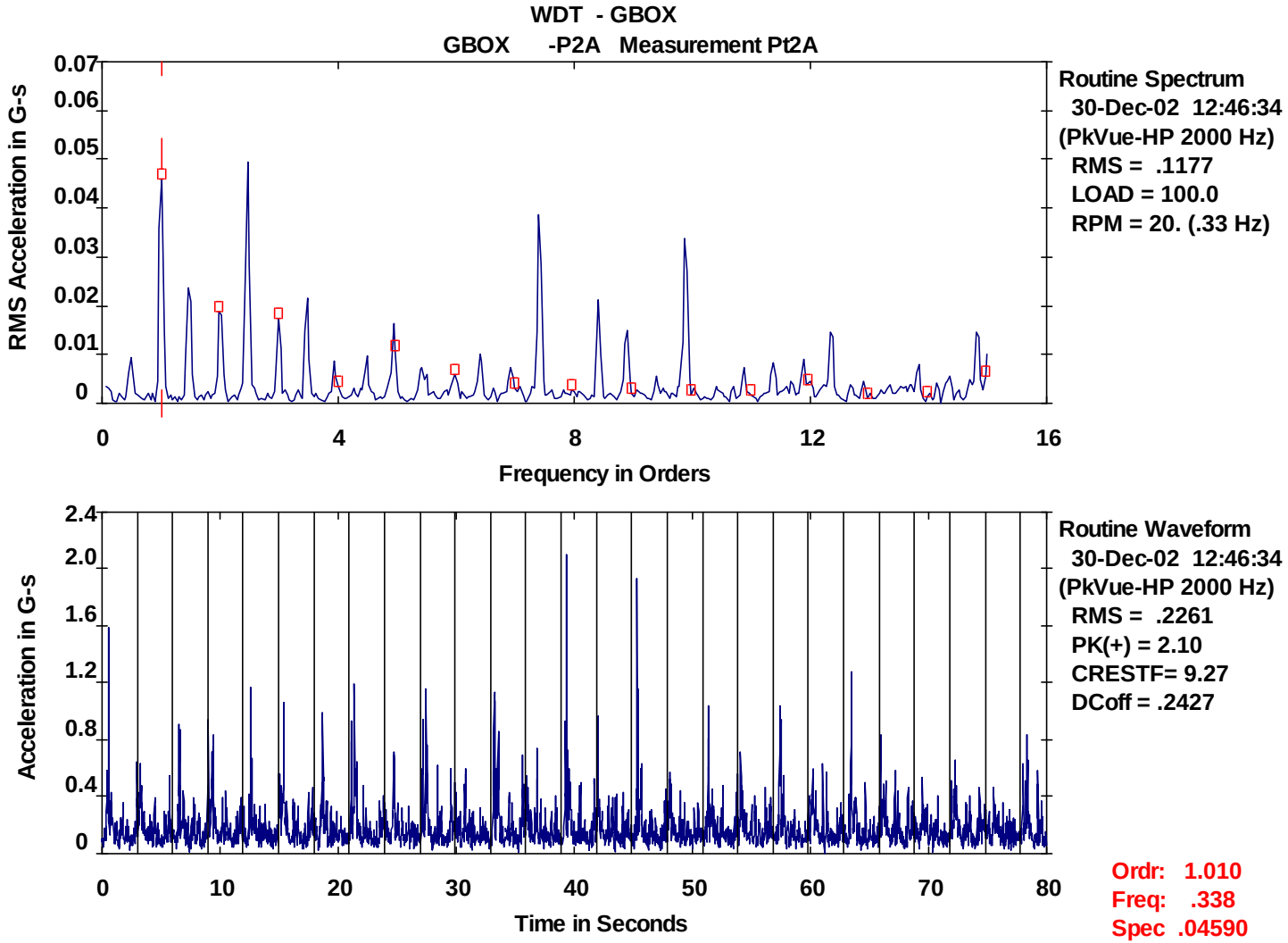
Dominant activity at 3x: 0.34 g's on October 23, 2002



Autocorrelation on October 23, 2002

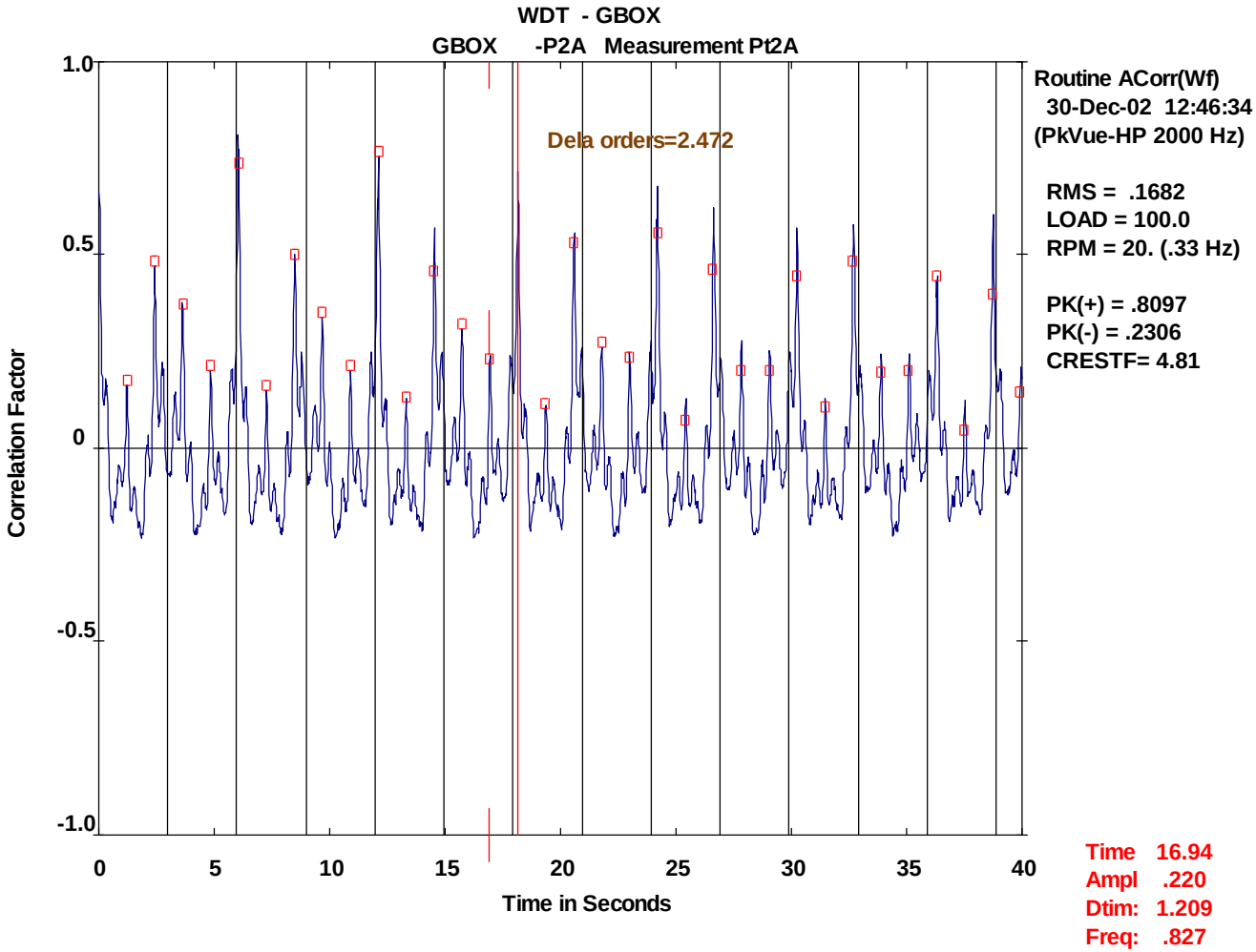


Dominate activity at 1x: 2.1 g's on December 30, 2002

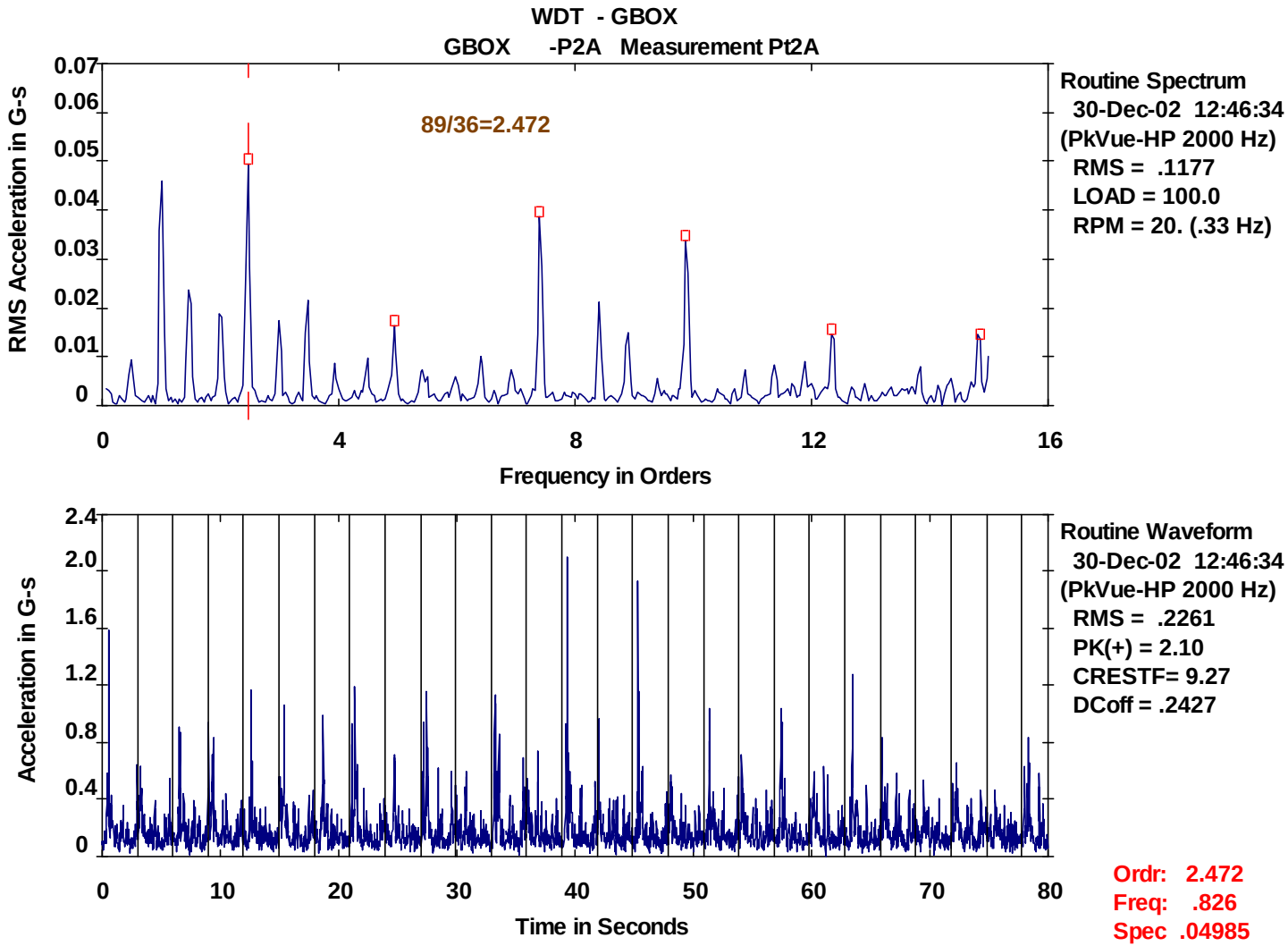


Autocorrelation on December 30, 2002

Dominate activity at 2.47 orders



Activity Highlighted at 2.47 Orders



2.47 activity gone on February 3, 2003

Dominate activity at 3x: 0.75 g's