WSRC-MS-2001-00072

# High Level Waste FLYGT Mixer
# A Case History for Modal Analysis (U)

Ricky Lee Badger

Westinghouse Savannah River Company
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Prepared for the U.S. Department of Energy under Contract No. DE-AC09-96SR18500

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## DISCLAIMER

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FLYGT Mixer
Model Analysis
Vibration Analysis
Natural Frequency Testing
Predictive Maintenance

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## Abstract

There are many tools available to help diagnose equipment vibration problems around the Savannah River Site. With the advancement of technology surrounding vibration analysis, modal analysis, an old, proven engineering modeling technique, can now be performed using the multi-channel machinery analyzer found in most predictive maintenance programs. The use of modal analysis can help eliminate problems with plant equipment that include failure to maintain tolerances, noisy equipment operation, material failure, premature fatigue, and shorten equipment life.

Mark H. Richardson of Vibrant Technology Inc., the creator of the MeScope Modal Analysis software program, defined modal analysis as the process of characterizing the dynamics of a structure in terms of its modes of vibration. Knowing the modes of vibration of a structure is useful information in itself, for it tells at what frequencies the structure can be excited into resonant motion, and the predominant wave-like motion it will assume at a resonant frequency.[1]

## Introduction

The High Level Waste (HLW) Predictive Maintenance (PdM) group was asked to help trouble-shoot high vibration levels on the FLYGT Mixer Pump during its third test run. This pump was designed to mix the remaining five-foot bottoms of the million gallon waste tanks located on each of the HLW tank farms. The mixer pump operates in a horizontal position just inches from the bottom of the waste tank and uses its discharge as the driving force to mix the tank bottoms. The mixer was designed to operate at 860 RPM with a flow-rate of 9000 GPM.

During the initial run-in test, the FLYGT Mixer pump sheared off one of the three propeller blades in the first hour of the test. Examination of the sheared propeller blade showed that it failed along the fillet weld that held the blade to the propeller shaft. Engineering requested a new cast propeller design to replace the existing design, eliminating the propeller blade welds.

The second run-in test lasted twelve hours and ended when the FLYGT Mixer Shroud failed. The shroud ruptured near the inlet region where the mixer motor is housed. At this time the HLW PdM group was asked to review and analyze the existing run-in data and perform a resonant frequency test and a modal analysis on the mixer pump to help determine possible causes of the failures.

## Existing Test Data

The existing vibration data collected during each run-in was collected on a Bentley-Nevada Adre On-Line Monitoring System (see Figure 1). The test data from May 2, 2000 showed a high 3x and 6x RPM of the mixer pump at 861 RPM. Review of the existing data showed an indication of a blade pass problem because of the mixer pump's three-blade propeller. The mixer pump has a natural resonance frequency at 85.9 Hz (6x RPM), which is two times the blade pass frequency of the mixer pump, running at 861 RPM. This natural resonance frequency was being excited by two times the blade pass frequency of the propeller. Using the variable frequency drive unit at the test facility, the mixer pump was slowed to 158 RPM and vibration data was collected. The 6x RPM vibration did not appear until the mixer pump reached 700 RPM, and both the 3x and 6x appeared at 800 RPM.

Bentley-Nevada Adre Data

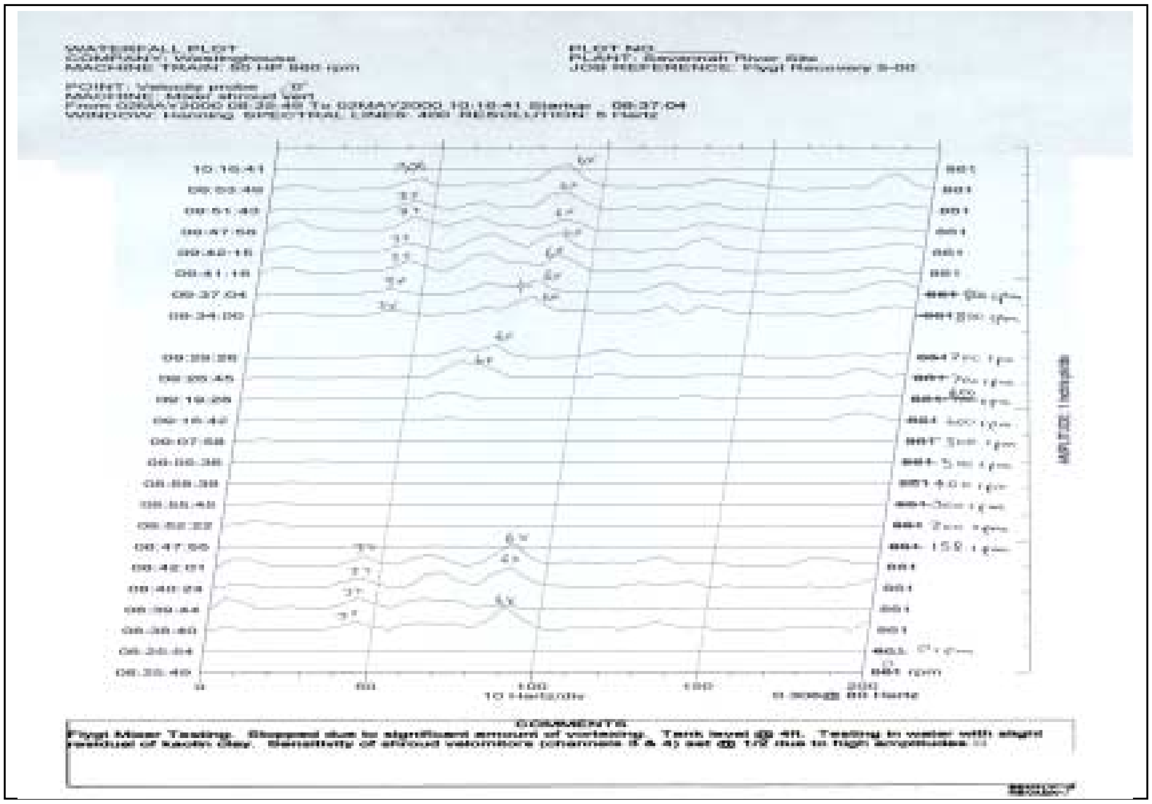


Figure 1

# Model Description

A natural frequency test and modal analysis was done using the MeScope Visual Engineering Series (VES) software and a Computational Systems Incorporated (CSI) multi-channel machinery analyzer. The MeScopeVES software program utilized multi-channel time and frequency domain data acquired during the natural frequency test to analyze the FLYGT Mixer Pump vibration problems. The CSI multi-channel analyzer computed a Fast Fourier Transform (FFT) or Discrete Fourier Transform (DFT) spectrum by performing tri-spectrum averaging on each measurement point on the FLYGT Mixer Pump.

Tri-spectrum averaging was done on two signals that were simultaneously sampled during the natural frequency test on the FLYGT Mixer Pump. In this averaging process, three or more spectrum estimates were computed from the following signals: the Auto Power Spectrum (APS) of each signal, and the Cross-Power Spectrum (XPS) between each pair of signals. This was done in the machinery analyzer using a spectrum-averaging loop as shown in Figure 2.[2]

Tri-Spectrum Averaging

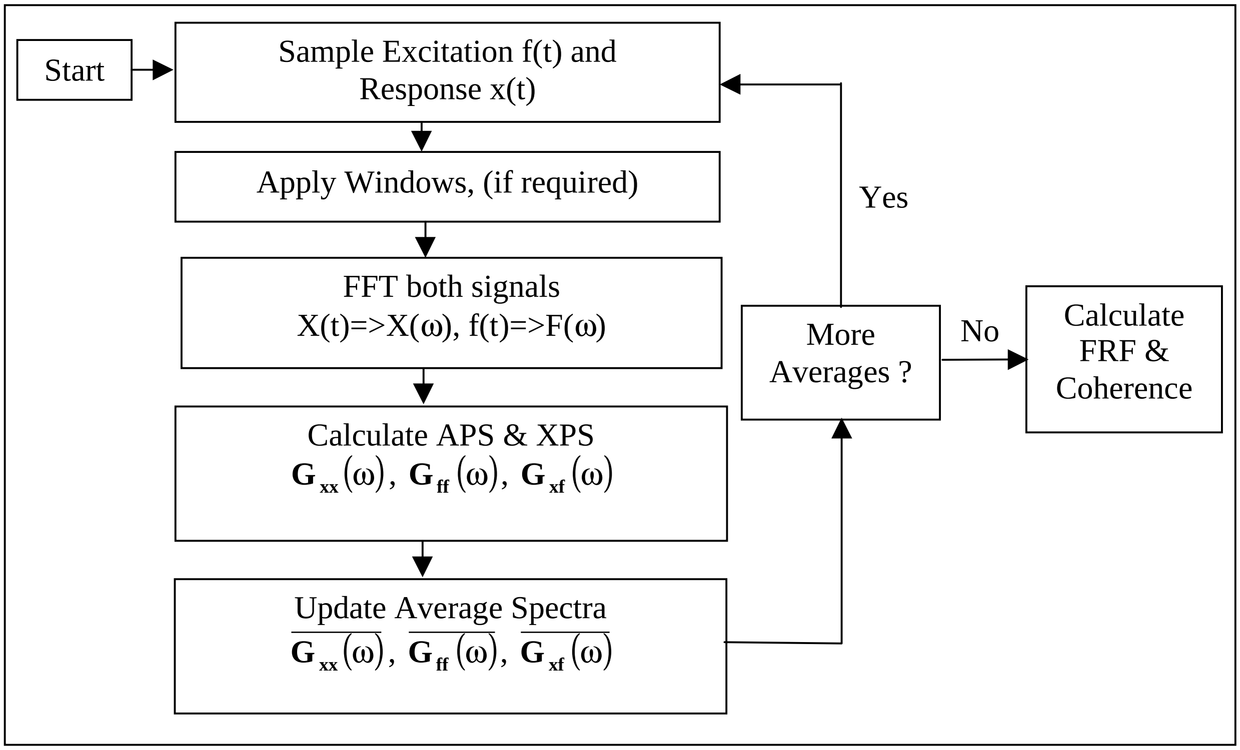



Figure 2

The Fourier Transform was calculated as,[3]

$$\mathbf{X}(\mathbf{f}) = \int_{-\infty}^{\infty} \mathbf{x}(\mathbf{t})\mathbf{e}^{-j2\pi ft}\mathbf{dt} \qquad (1)$$

where: f = frequency in Hz
t = time in seconds

The Inverse Fourier Transform was calculated as,[3]

$$\mathbf{x}(\mathbf{t}) = \int_{-\infty}^{\infty} \mathbf{X}(\mathbf{f})\mathbf{e}^{j2\pi ft}\mathbf{df} \qquad (2)$$

The Auto Power Spectrum was calculated as,[3]

$$\mathbf{G}_{xx}(\mathbf{f}) = \mathbf{X}(\mathbf{f})\mathbf{X}^*(\mathbf{f}) \qquad (3)$$

$\mathbf{G}_{xx}(\mathbf{f})$ is a spectrum obtained by multiplying X(f) by its own conjugate X*.

The Cross-Power Spectrum was calculated as,[3]

$$\mathbf{G}_{yx}(\mathbf{f}) = \mathbf{Y}(\mathbf{f})\mathbf{X}^*(\mathbf{f}) \qquad (4)$$

The Discrete Fourier Transform was calculated as,[3]

$$\mathbf{x}(\mathbf{n}\Delta\mathbf{t}) = \Delta\mathbf{f}\sum_{\mathbf{m}=0}^{\mathbf{N}-1}\mathbf{X}(\mathbf{m}\Delta\mathbf{f})\mathbf{e}^{-\mathbf{j}2\pi\mathbf{mn}/\mathbf{N}} \qquad (5)$$

m = 0…, N-1

The Inverse Discrete Fourier Transform was calculated as,[3]

$$\mathbf{x}(\mathbf{n}\Delta\mathbf{t}) = \Delta\mathbf{f}\sum_{\mathbf{m}=0}^{\mathbf{N}-1}\mathbf{X}(\mathbf{m}\Delta\mathbf{f})\mathbf{e}^{\mathbf{j}2\pi\mathbf{mn}/\mathbf{N}} \qquad (6)$$

n = 0…, N-1

The Frequency Response Function (FRF) was calculated from the tri-spectrum averaging. The FRF showed the input-output relationship between two points on the mixer pump as a function of frequency. The input force was measured with a load cell at the input (driving) point. The output motion was measured with an accelerometer at all the desired measurement points. In other words, the calculated FRF showed how much displacement, velocity, or acceleration response the mixer pump had at a measurement point, per unit of excitation force at the input point.

The FRF was computed by dividing the cross channel spectrum estimate between input and output by the input auto power spectrum estimate,[3]

$$\mathbf{H}(\mathbf{f}) = \frac{\mathbf{G}_{\mathbf{yx}}(\mathbf{f})}{\mathbf{G}_{\mathbf{xx}}(\mathbf{f})} \qquad (7)$$

The MeScopeVES software then placed each FRF into a matrix model as a frequency domain representation of a structure’s linear dynamics, where linear spectra (FFTs) of multiple inputs are multiplied by elements of the FRF matrix to yield linear spectra of multiple outputs.

The FRF matrix model was calculated as,[2]

$$\{\mathbf{X}(\omega)\} = [\mathbf{H}(\omega)]\{\mathbf{F}(\omega)\} \qquad (8)$$

where:

$\{\mathbf{X}(\omega)\}$= Linear spectra of output motions … (n vector)

$[\mathbf{H}(\omega)]$= FRF matrix … (n by m)

$\{\mathbf{F}(\omega)\}$= Linear spectra of input forces … (m vector)

m = number of inputs

n = number of outputs

ω = frequency variable

The mixer pump was excited for each measurement point, using a broad band signal at the input (driving) point. In this case, the broad band signal was the hard plastic tip of the modally tuned force hammer used to impact the mixer pump during the test. A PCB Piezotronics, INC. model 086C41 medium sledgehammer was used to impact the mixer unit. The hammer weighed 3.0

pounds, had a 2-inch aluminum head with a hard plastic tip, and a handle length of 13 inches. Its upper frequency limit was 2000 Hz (see Figure 3).[4]

Functional Transfer vs. Frequency

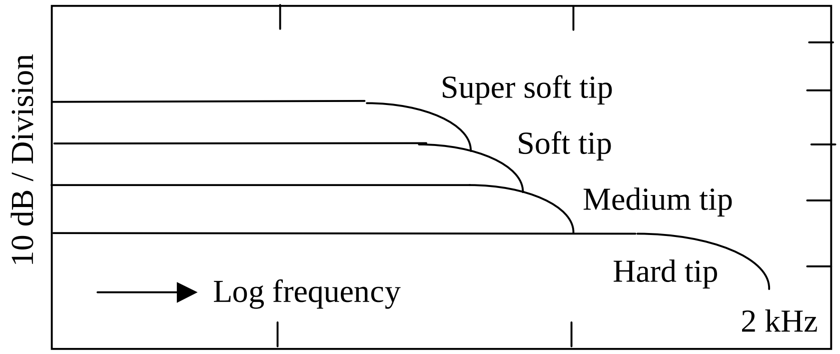



Figure 3

An Industrial Monitoring Instrumentation (IMI) accelerometer model number 621B41 was used for the response accelerometer. This accelerometer had a sensitivity of 100 mV/g, a 10- 32- microdot connector, and weighed only 4.8 grams. This low weight factor allowed the accelerometer to be attached to each measurement point during the test with bee's wax.

The hammer (input) and the accelerometer (output) were connected to the multi-channel analyzer as shown in Figure 4. Channel A was used for the input signal and Channel B was used for the response signal. Measurement point 3z was used as the fixed excitation point during the test. The force hammer was used to strike 3z (in the same direction) while the response accelerometer was moved to each new measurement point and direction.

Test Diagram

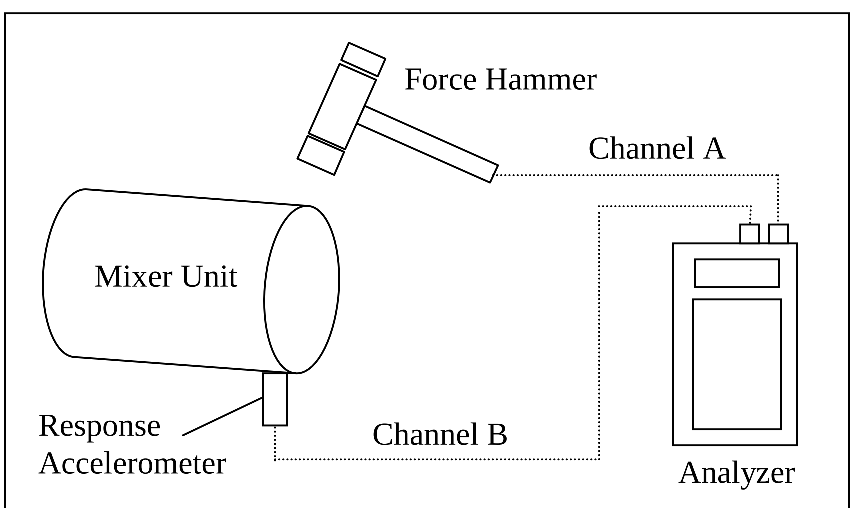



Figure 4

# Data Test Points

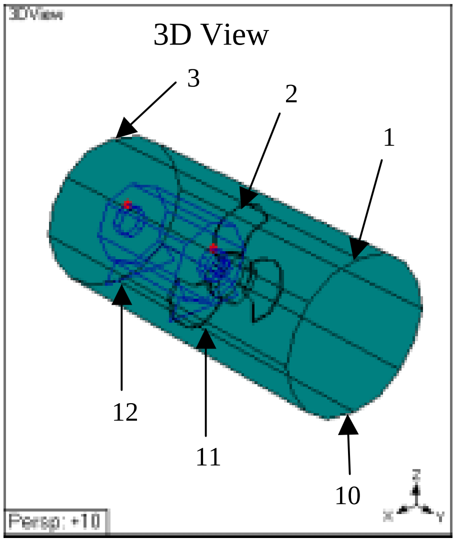



Figure 5

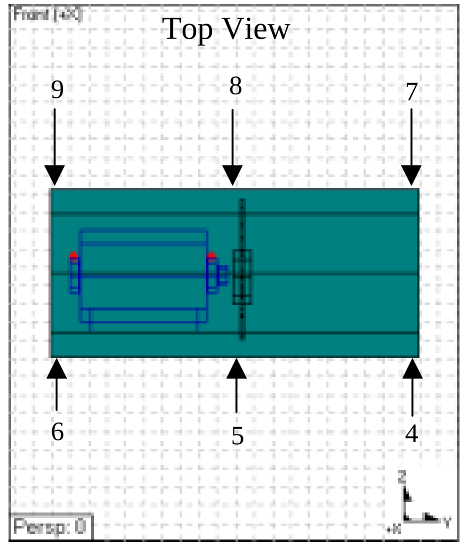



Figure 6

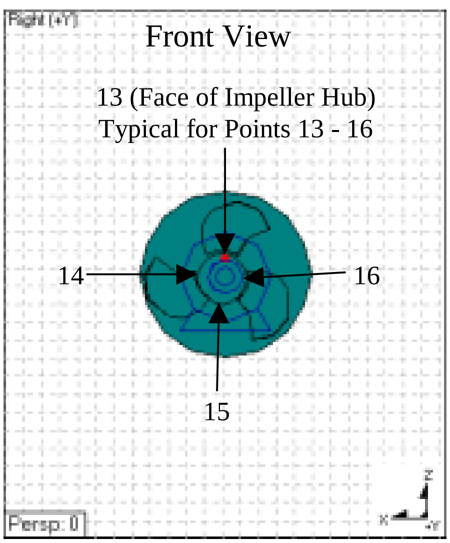



Figure 7

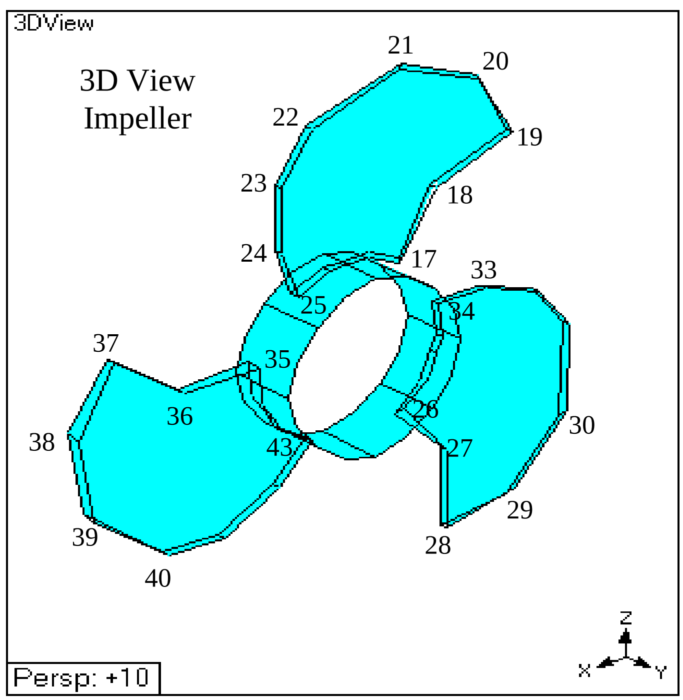
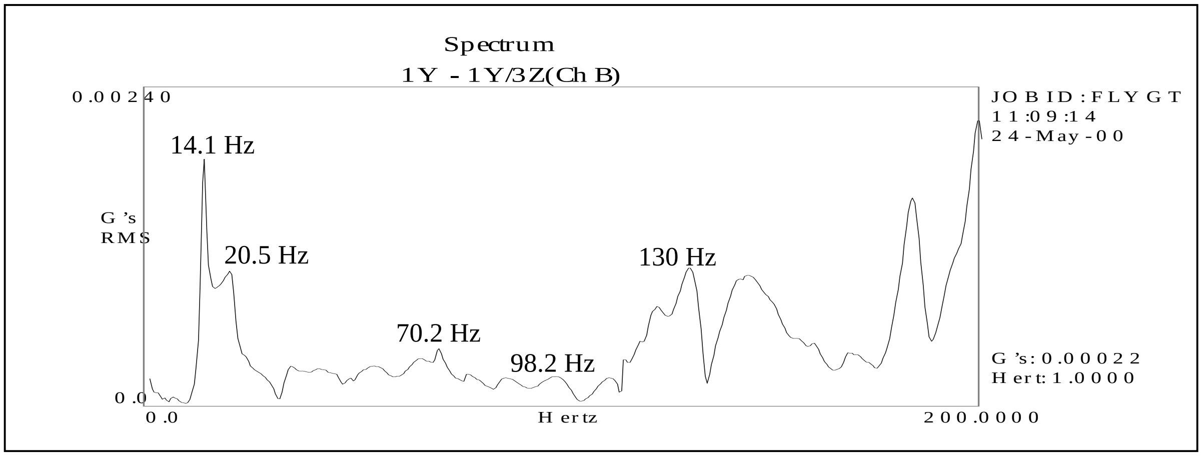


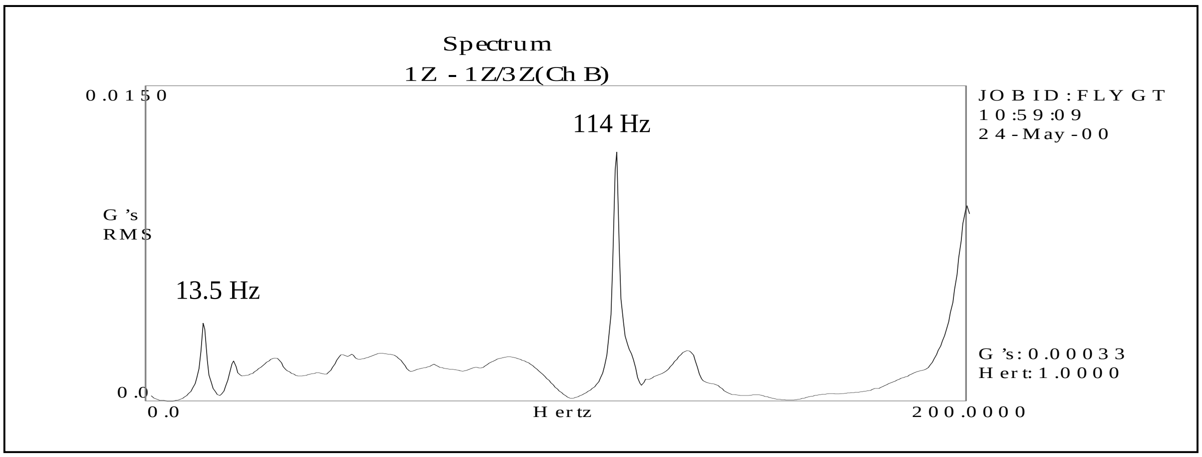

Figure 8

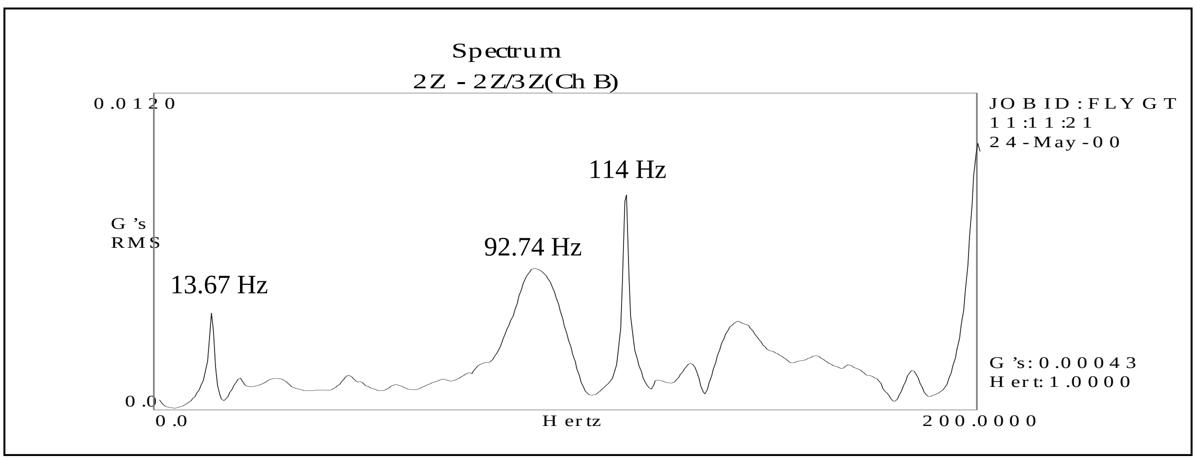
Measurement Point Description Table

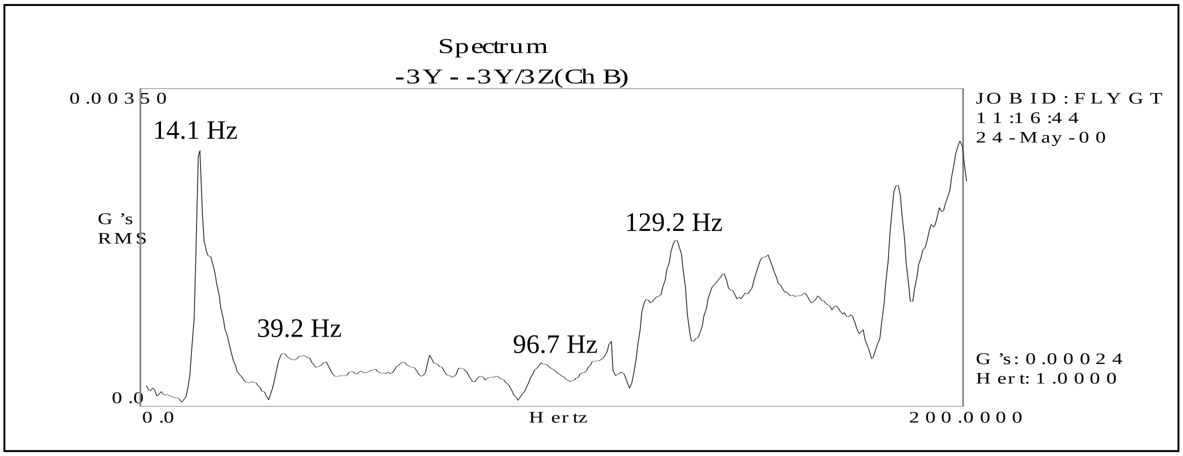
| Measurement Point | Input | Output | | Measurement Point | Input | Output |
|---|---|---|---|---|---|---|
| 1Z / 1Z/3Z | 3Z | 1Z | | 21Y / 21Y/3Z | 3Z | 21Y |
| 1Y / 1Y/3Z | 3Z | 1Y | | 22X / 22X/3Z | 3Z | 22X |
| 2Z / 2Z/3Z | 3Z | 2Z | | 22Y / 22Y/3Z | 3Z | 22Y |
| 3Z / 3Z/3Z | 3Z | 3Z | | 23X / 23X/3Z | 3Z | 23X |
| -3Y / -3Y/3Z | 3Z | -3Y | | 23Y / 23Y/3Z | 3Z | 23Y |
| 4X / 4X/3Z | 3Z | 4X | | 24Y / 24Y/3Z | 3Z | 24Y |
| 4Y / 4Y/3Z | 3Z | 4Y | | 25Y / 25Y/3Z | 3Z | 25Y |
| 5X / 5X/3Z | 3Z | 5X | | 26Y / 26Y/3Z | 3Z | 26Y |
| 6X / 6X/3Z | 3Z | 6X | | 27Y / 27Y/3Z | 3Z | 27Y |
| -6Y / -6Y/3Z | 3Z | -6Y | | 28Y / 28Y/3Z | 3Z | 28Y |
| -7X / -7X/3Z | 3Z | -7X | | 29Y / 29Y/3Z | 3Z | 29Y |
| 7Y / 7Y/3Z | 3Z | 7Y | | 30Y / 30Y/3Z | 3Z | 30Y |
| -8X / -8X/3Z | 3Z | -8X | | 31Y / 31Y/3Z | 3Z | 31Y |
| -9X / -9X/3Z | 3Z | -9X | | 32Y / 32Y/3Z | 3Z | 32Y |
| 10Y / 10Y/3Z | 3Z | 10Y | | -33X / -33X/3Z | 3Z | -33X |
| -10Z / -10Z/3Z | 3Z | -10Z | | 33Y / 33Y/3Z | 3Z | 33Y |
| -11Z / -11Z/3Z | 3Z | -11Z | | 34Y / 34Y/3Z | 3Z | 34Y |
| -12Z / -12Z/3Z | 3Z | -12Z | | 35Y / 35Y/3Z | 3Z | 35Y |
| 13Y / 13Y/3Z | 3Z | 13Y | | 36X / 36X/3Z | 3Z | 36X |
| 13Z / 13Z/3Z | 3Z | 13Z | | 36Y / 36Y/3Z | 3Z | 36Y |
| 14X / 14X/3Z | 3Z | 14X | | 37X / 37X/3Z | 3Z | 37X |
| 14Y / 14Y/3Z | 3Z | 14Y | | 37Y / 37Y/3Z | 3Z | 37Y |
| 15Y / 15Y/3Z | 3Z | 15Y | | 38Y / 38Y/3Z | 3Z | 38Y |
| -15Z / -15Z/3Z | 3Z | -15Z | | 39Y / 39Y/3Z | 3Z | 39Y |
| -16X / -16X/3Z | 3Z | -16X | | 40Y / 40Y/3Z | 3Z | 40Y |
| 16Y / 16Y/3Z | 3Z | 16Y | | 41Y / 41Y/3Z | 3Z | 41Y |
| -17X / -17X/3Z | 3Z | -17X | | 42Y / 42Y/3Z | 3Z | 42Y |
| 17Y / 17Y/3Z | 3Z | 17Y | | 43X / 43X/3Z | 3Z | 43X |
| -18X / -18X/3Z | 3Z | -18X | | 43Y / 43Y/3Z | 3Z | 43Y |
| 18Y / 18Y/3Z | 3Z | 18Y | | -12Y / -12Y/3Z | 3Z | -12Y |
| -19X / -19X/3Z | 3Z | -19X | | 42X / 42X/3Z | 3Z | 42X |
| 19Y / 19Y/3Z | 3Z | 19Y | | | | |
| 20Z / 20Z/3Z | 3Z | 20Z | | | | |

# RBMware / VIBpro Data

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G's
RMS
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39.2 Hz
96.7 Hz
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Hertz
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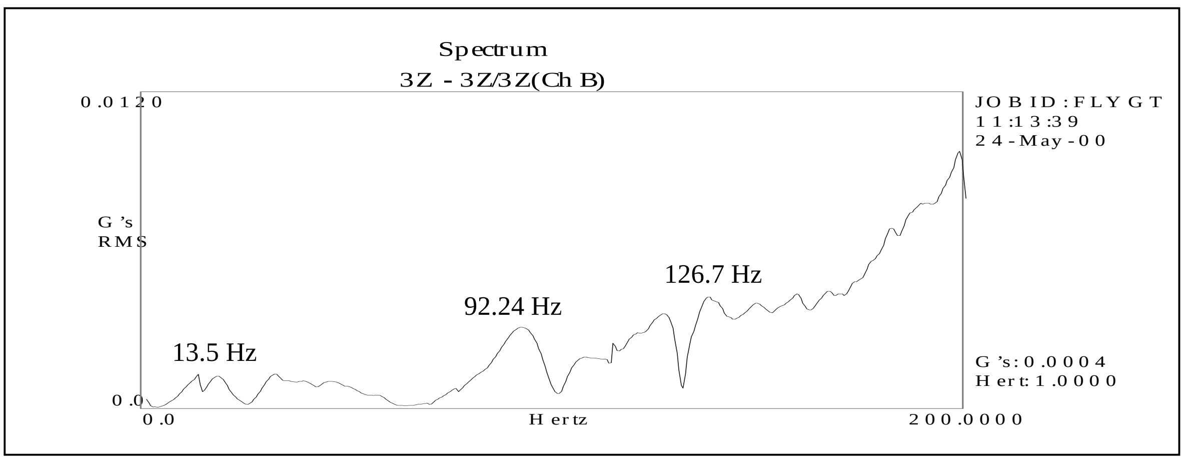
24-May-00
G's: 0.00024
Hert: 1.0000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Hertz
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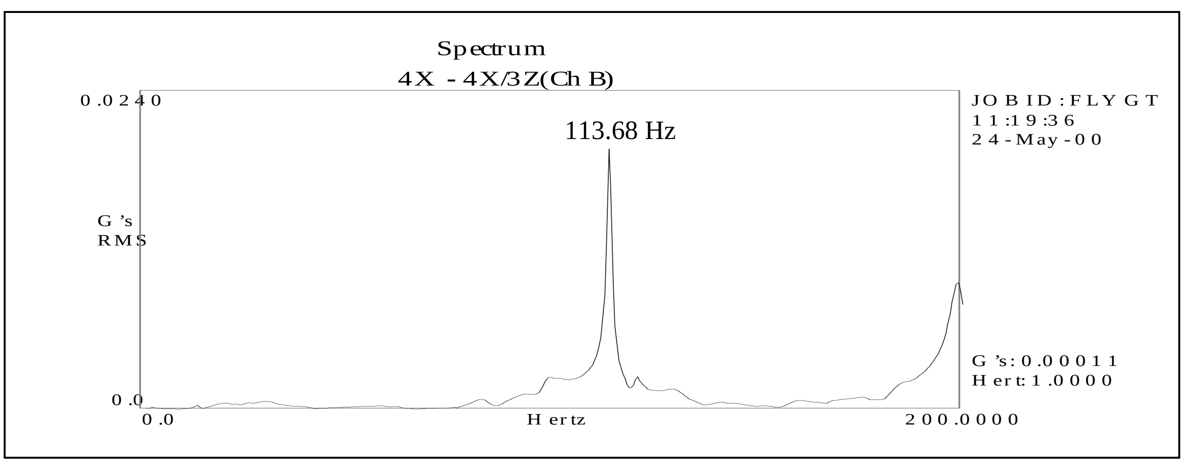
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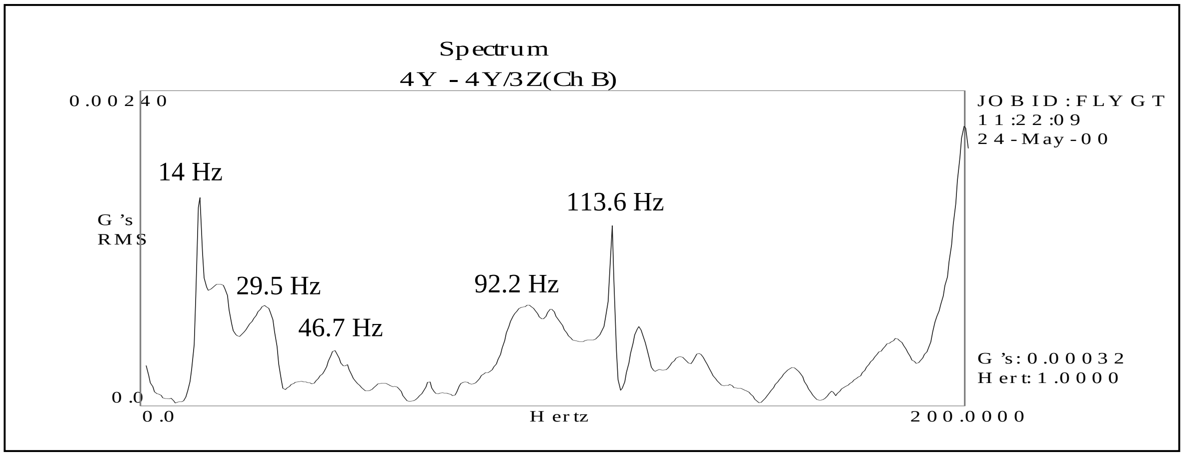
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0.0
Hertz
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24-May-00
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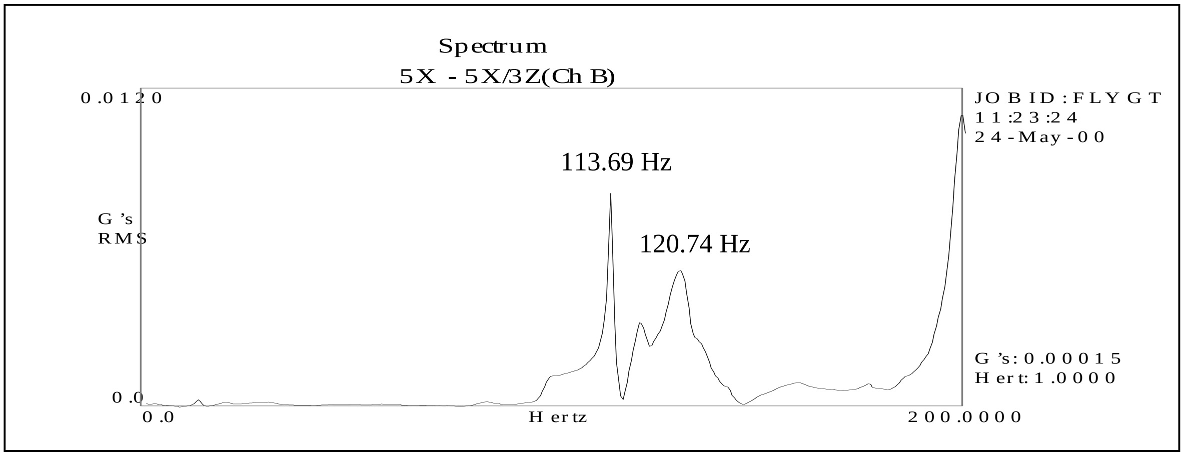
Hert: 1.0000
14 Hz
29.5 Hz
46.7 Hz
92.2 Hz
113.6 Hz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G's RMS
0.0
0.0
Hertz
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24-May-00
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Hert: 1.0000
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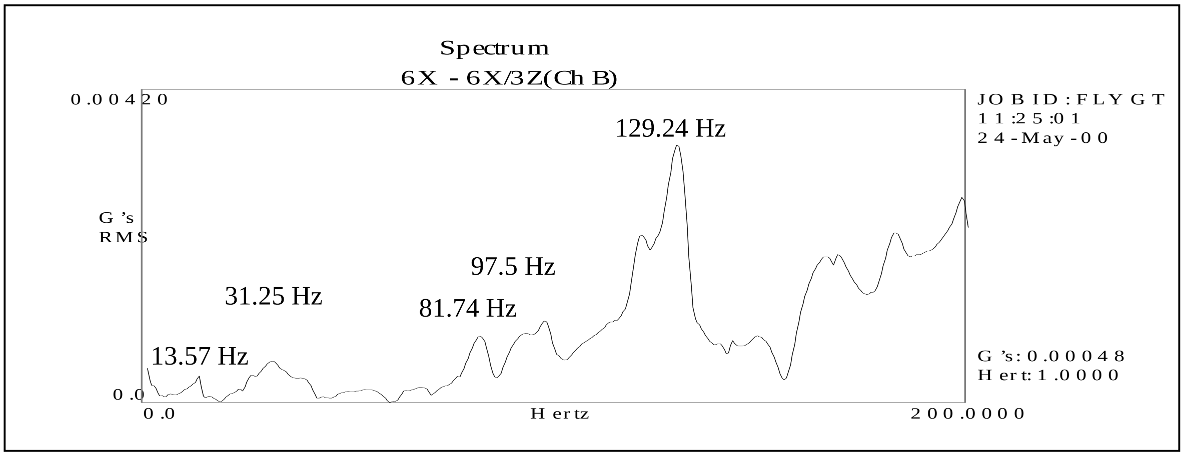
120.74 Hz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G's RMS
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0.0
Hertz
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Hert: 1.0000
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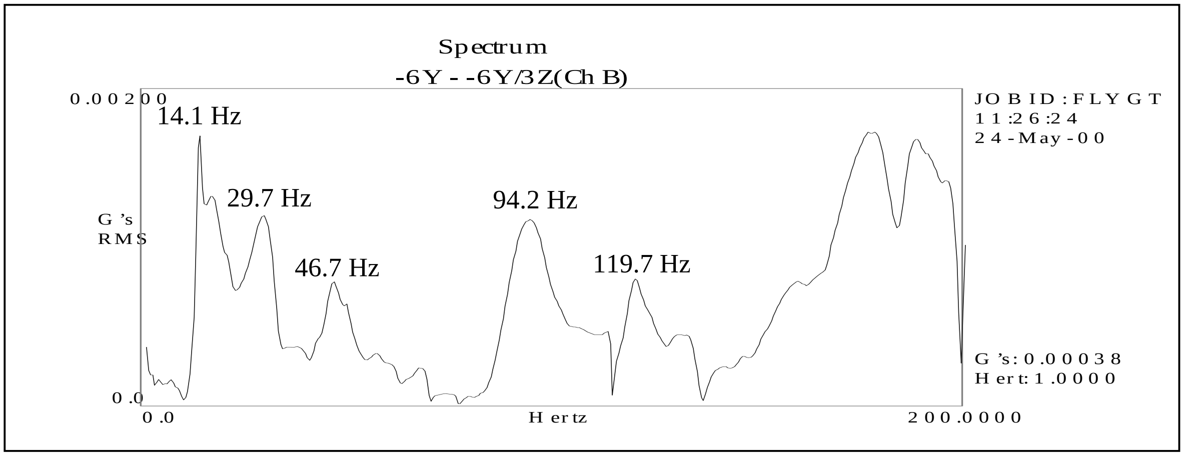
97.5 Hz
31.25 Hz
81.74 Hz
13.57 Hz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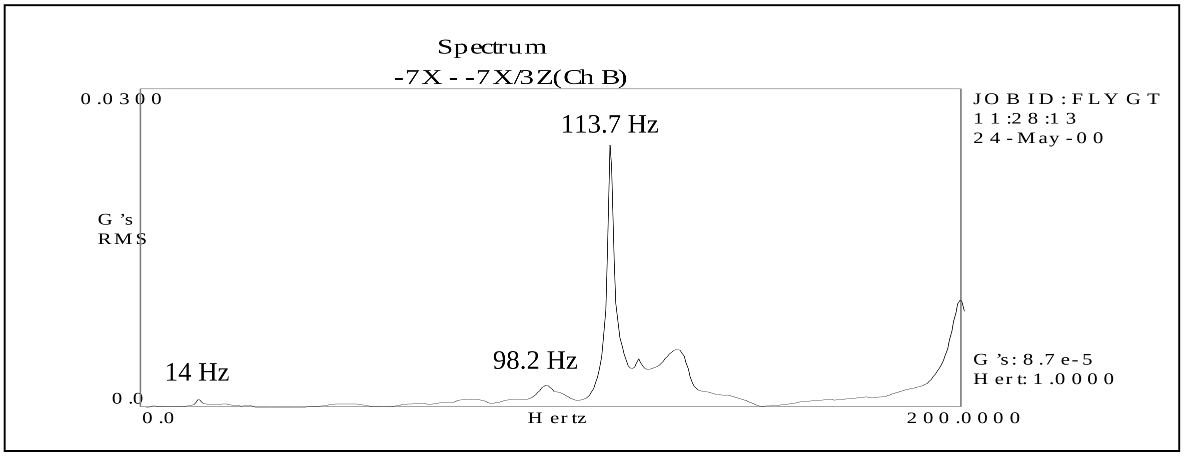
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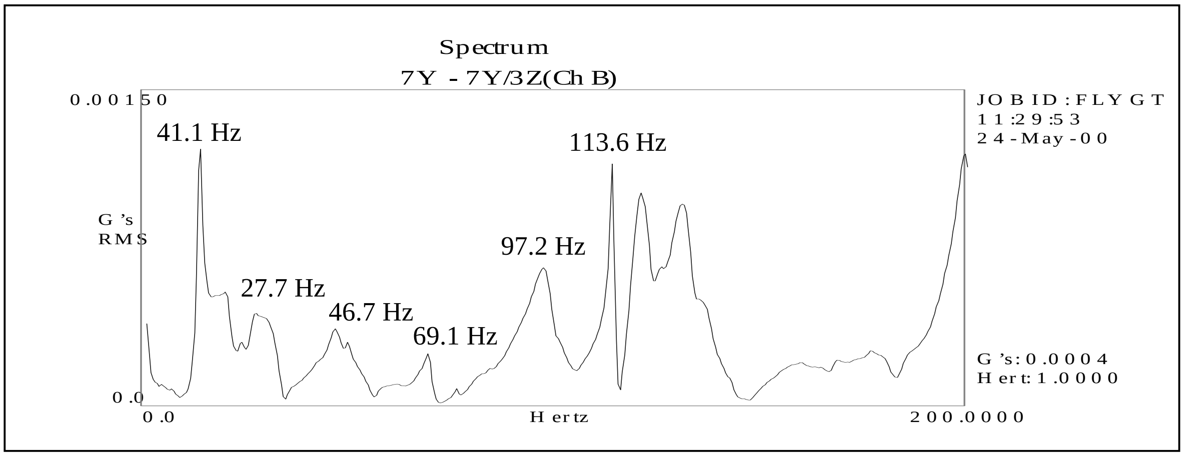
Hert: 1.0000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27.7 Hz
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97.2 Hz
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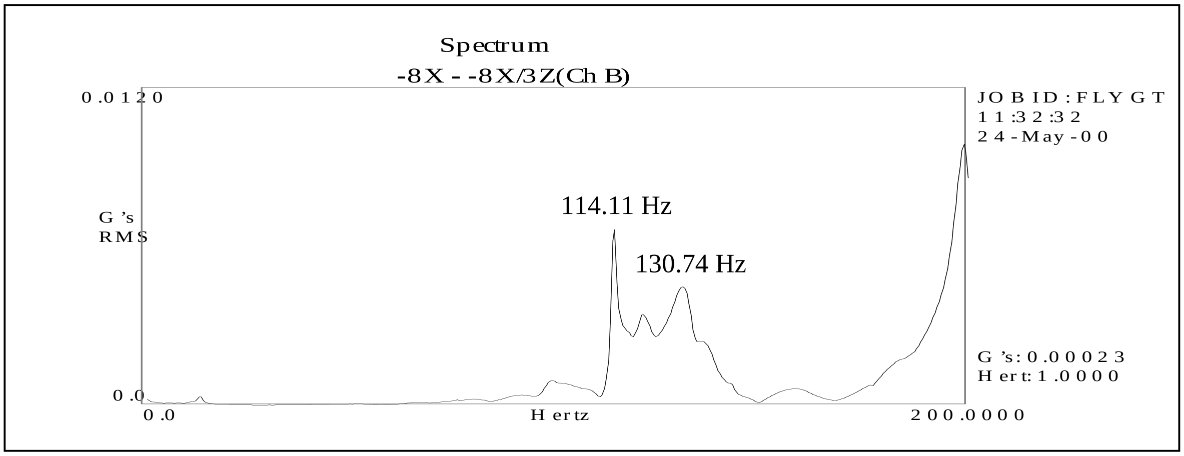
Hert: 1.0000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G's
RMS
0.0
0.0
Hertz
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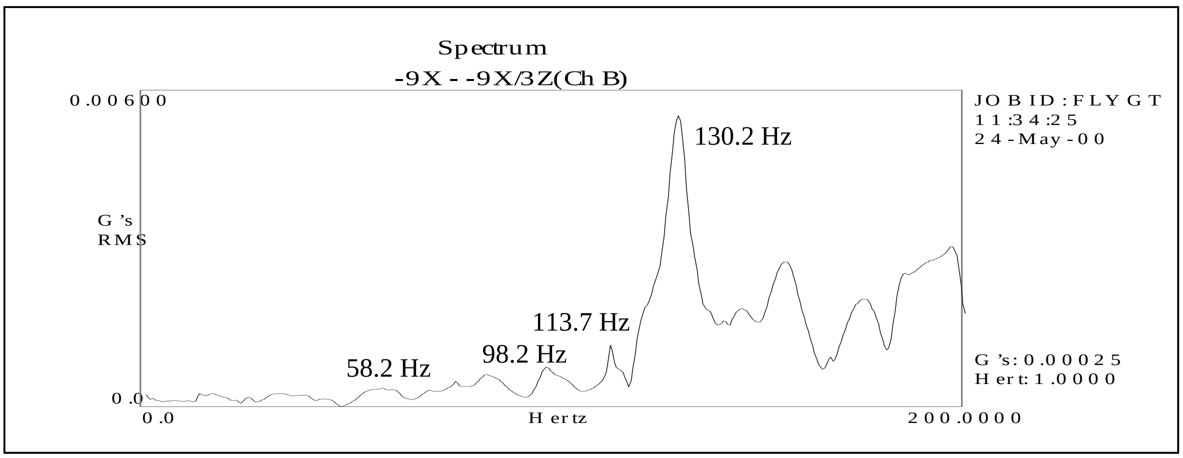
Hert: 1.0000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RMS
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98.2 Hz
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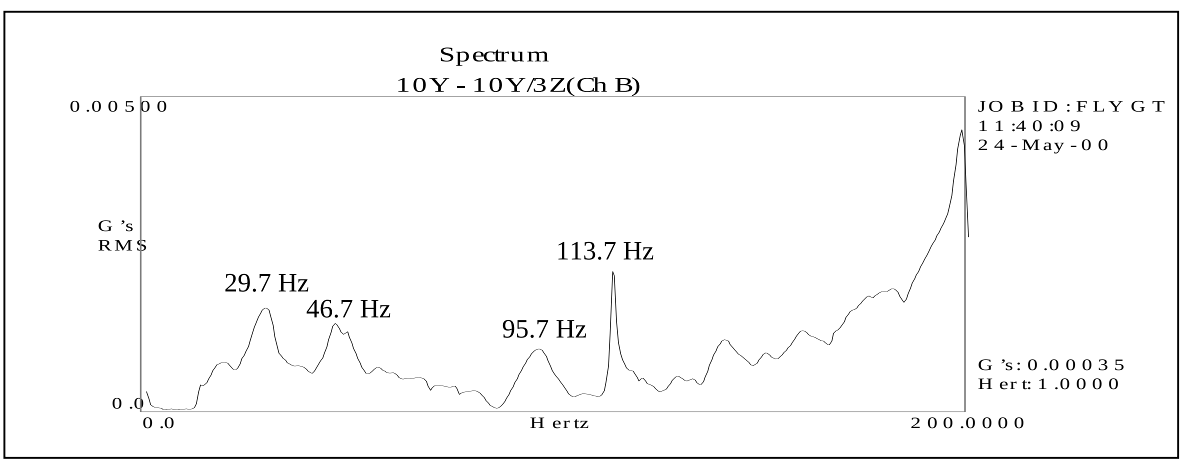
Hert: 1.0000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RMS
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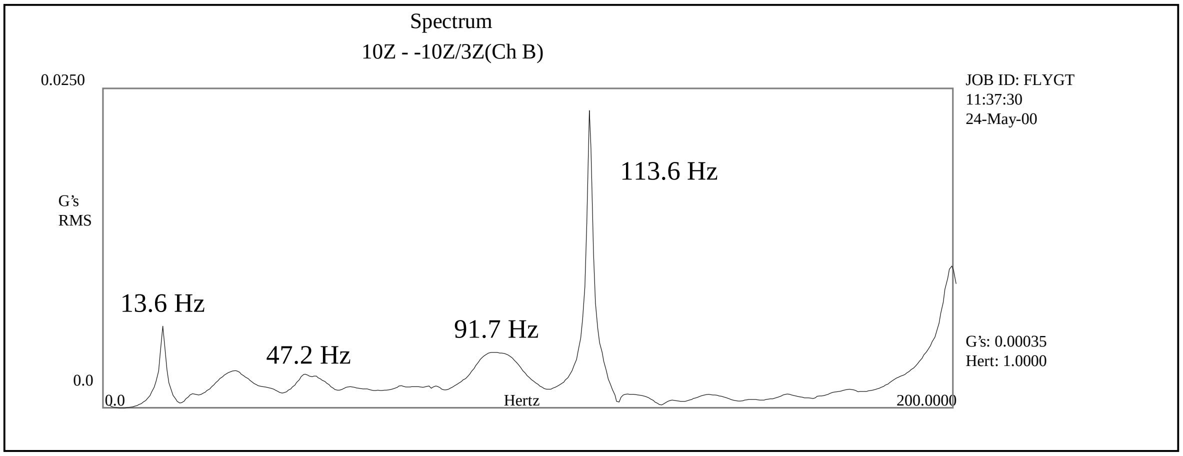
Hert: 1.0000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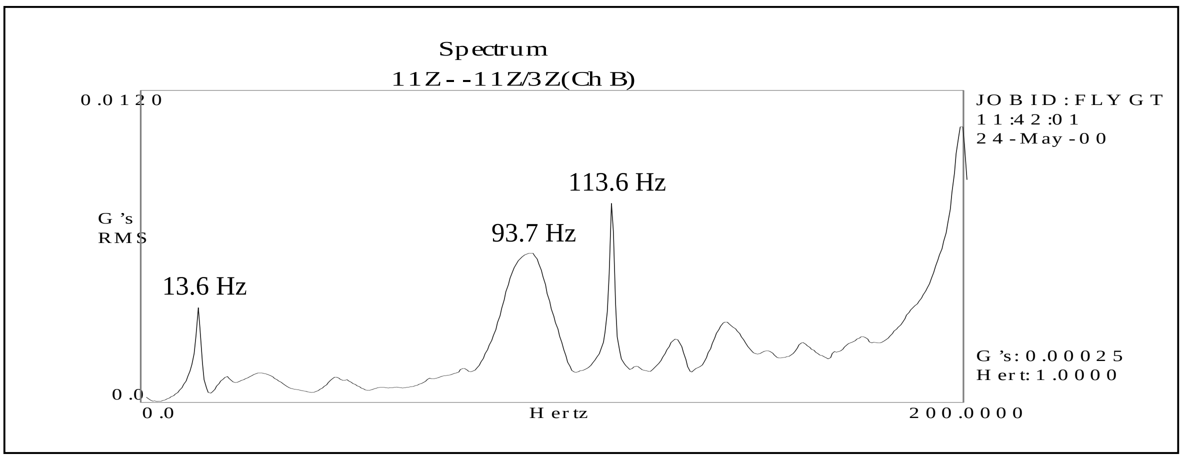
0.0
Hertz
200.0000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JOB ID:FLYGT
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24-May-00
G's
RMS
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13.6 Hz
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Hertz
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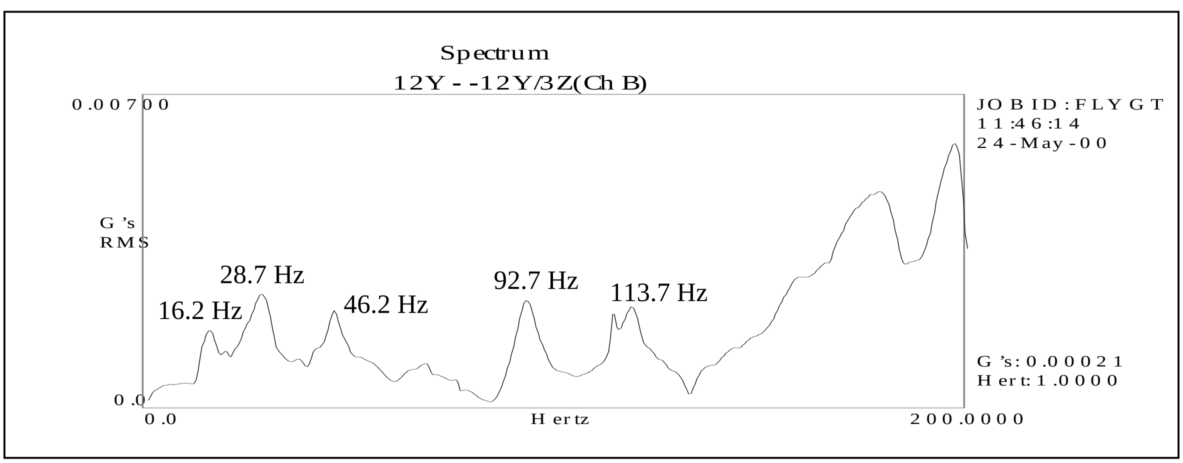
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24-May-00
G's
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16.2 Hz
46.2 Hz
92.7 Hz
113.7 Hz
G's:0.00021
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0.0
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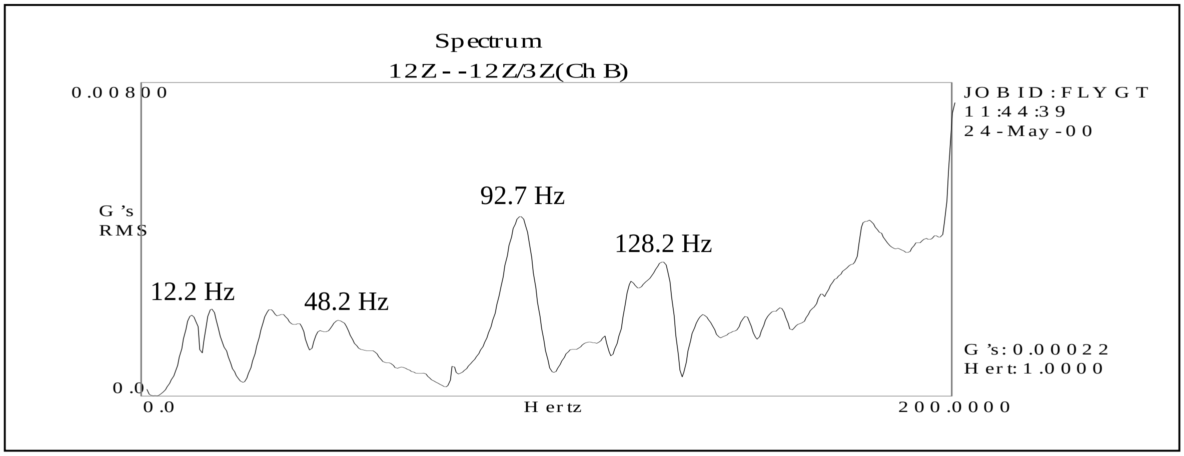
200.0000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11:44:39
24-May-00
G's
RMS
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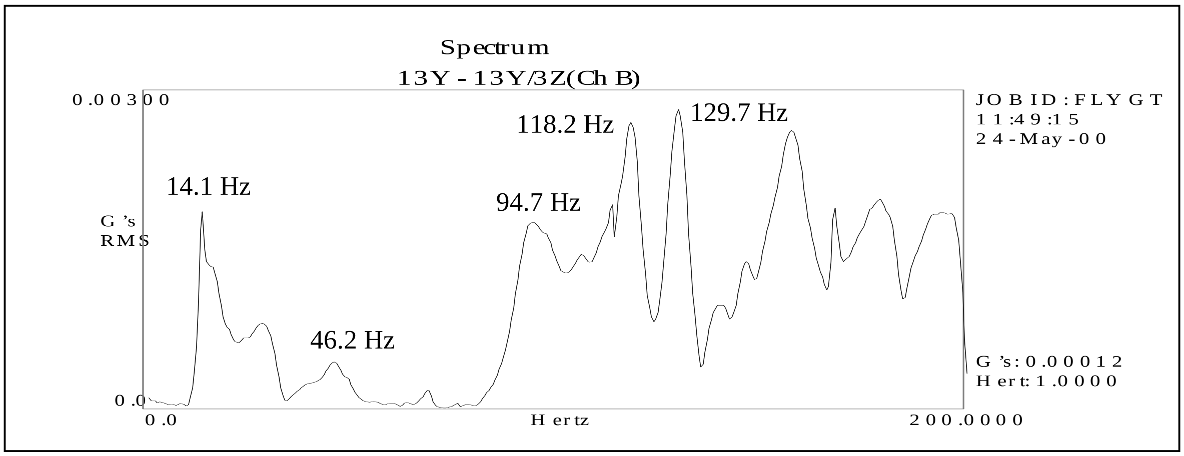
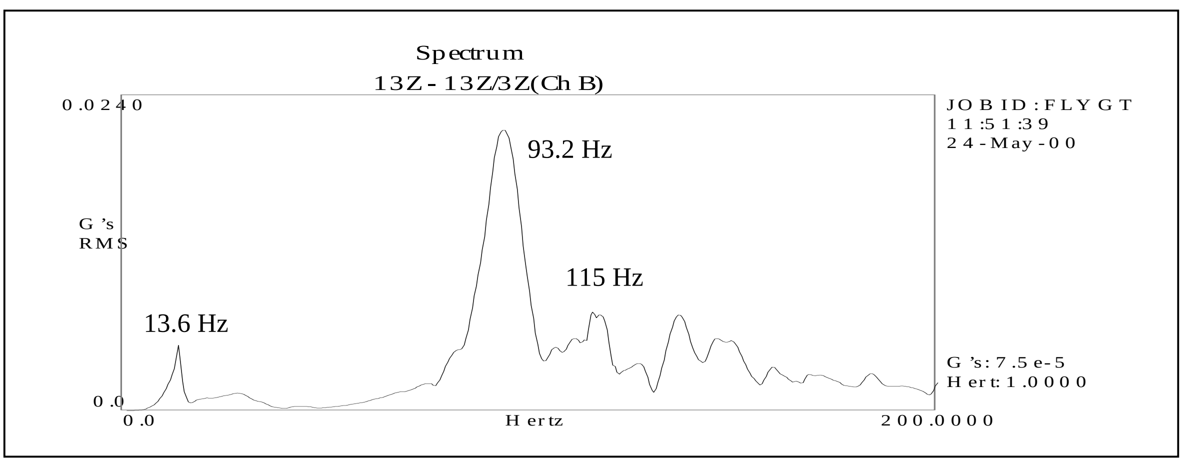
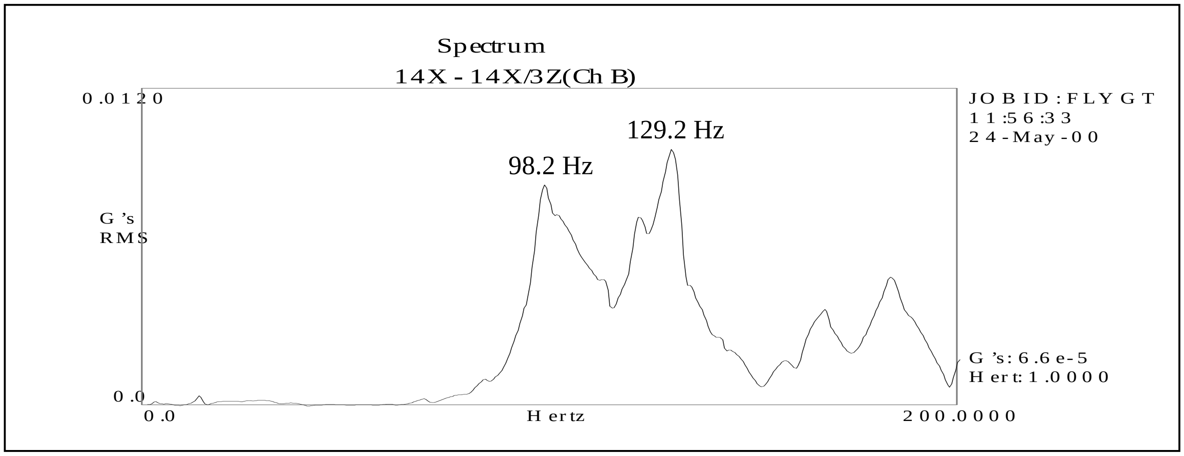
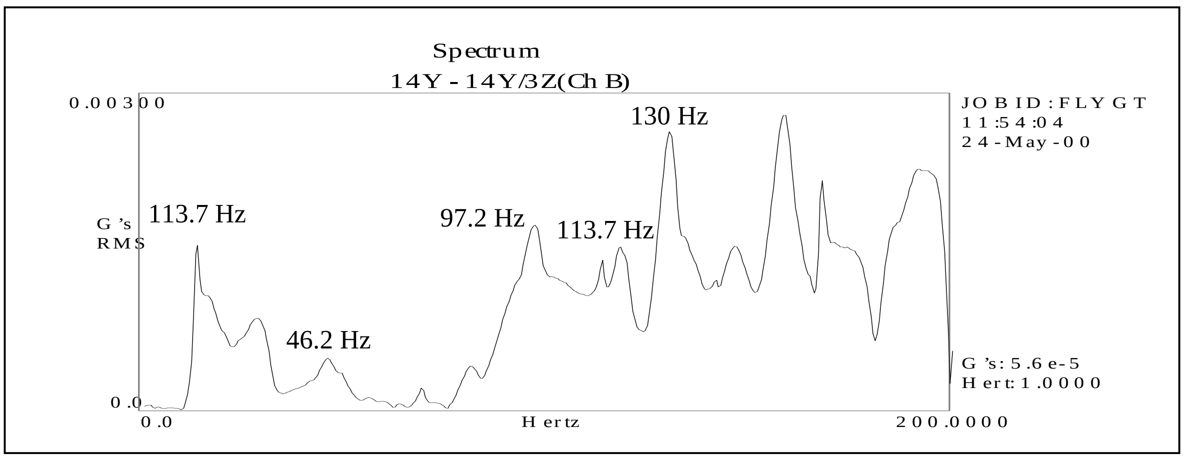
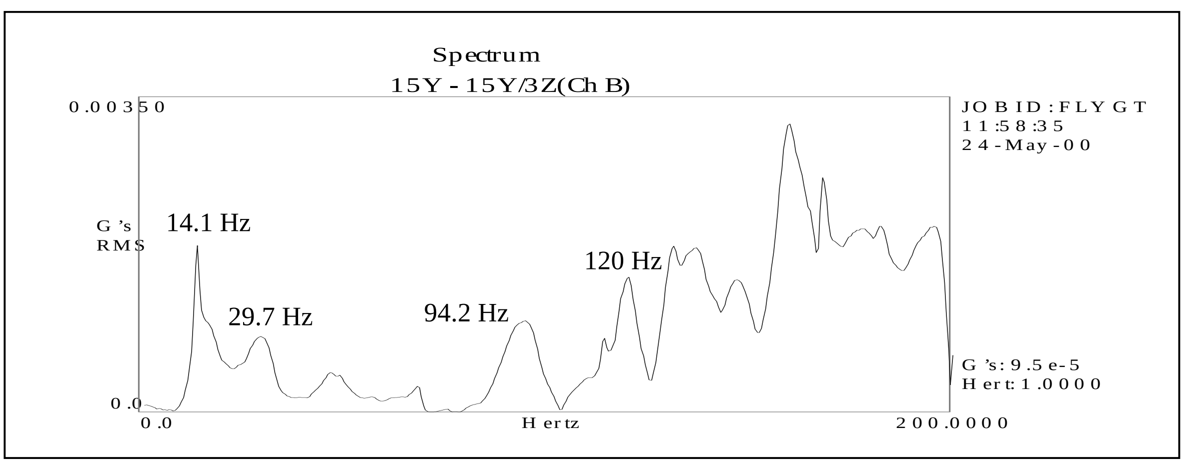
12.2 Hz
48.2 Hz
G's: 0.00022
Hert: 1.0000
0.0
0.0
Hertz
200.0000

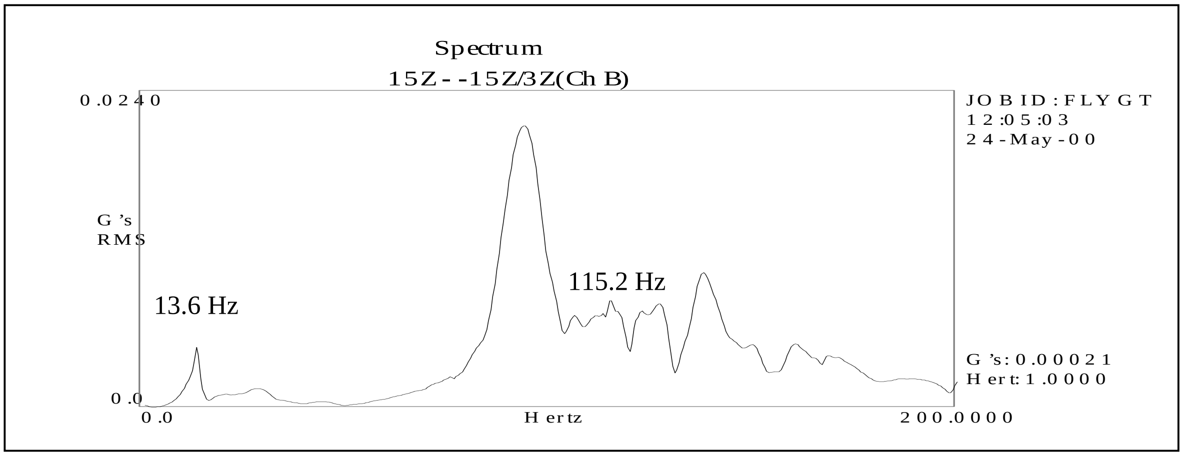

Spectrum
13Y-13Y/3Z(Ch B)
0.00300
JOBID:FLYGT
11:49:15
24-May-00
118.2 Hz
129.7 Hz
14.1 Hz
94.7 Hz
G's
RMS
46.2 Hz
G's: 0.00012
Hert: 1.0000
0.0
0.0
Hertz
200.0000

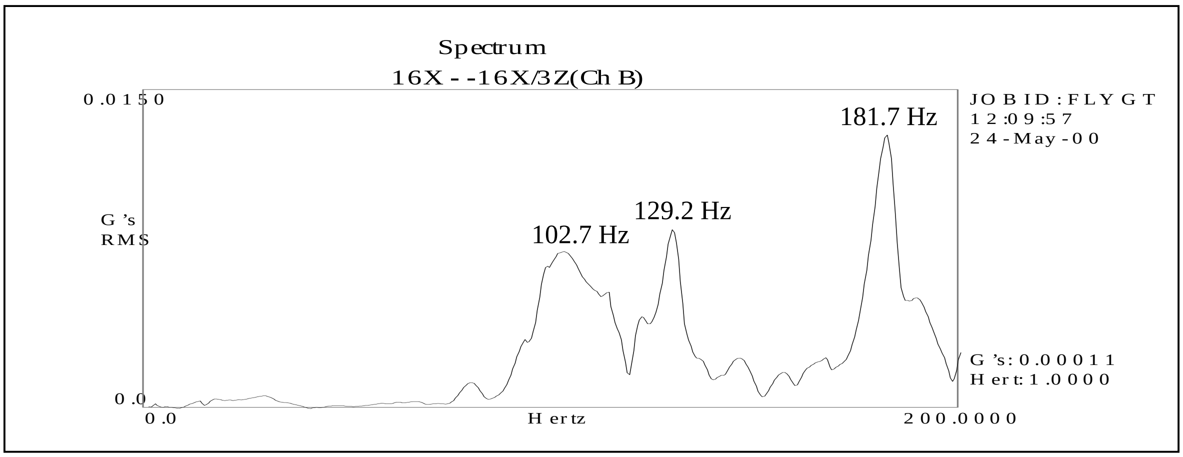

Spectrum
13Z-13Z/3Z(Ch B)
0.0240
JOBID:FLYGT
11:51:39
24-May-00
93.2 Hz
G's
RMS
115 Hz
13.6 Hz
G's: 7.5e-5
Hert: 1.0000
0.0
0.0
Hertz
200.0000

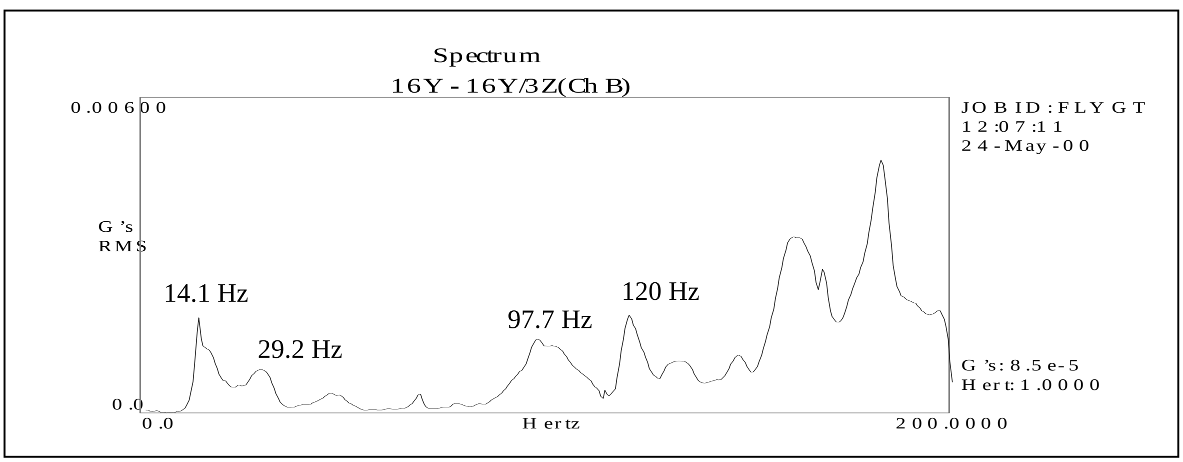

Spectrum
14X - 14X/3Z(Ch B)
0.0120
G's RMS
0.0
0.0
Hertz
200.0000
98.2 Hz
129.2 Hz
JOBID:FLYGT
11:56:33
24-May-00
G's: 6.6e-5
Hert: 1.0000

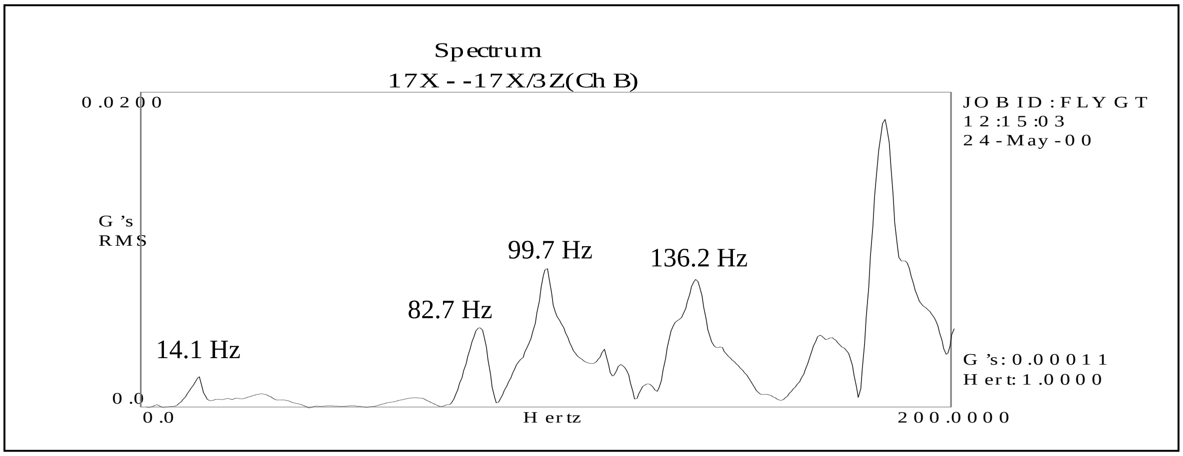

Spectrum
14Y - 14Y/3Z(Ch B)
0.00300
G's RMS
0.0
0.0
Hertz
200.0000
113.7 Hz
46.2 Hz
97.2 Hz
113.7 Hz
130 Hz
JOBID:FLYGT
11:54:04
24-May-00
G's: 5.6e-5
Hert: 1.0000

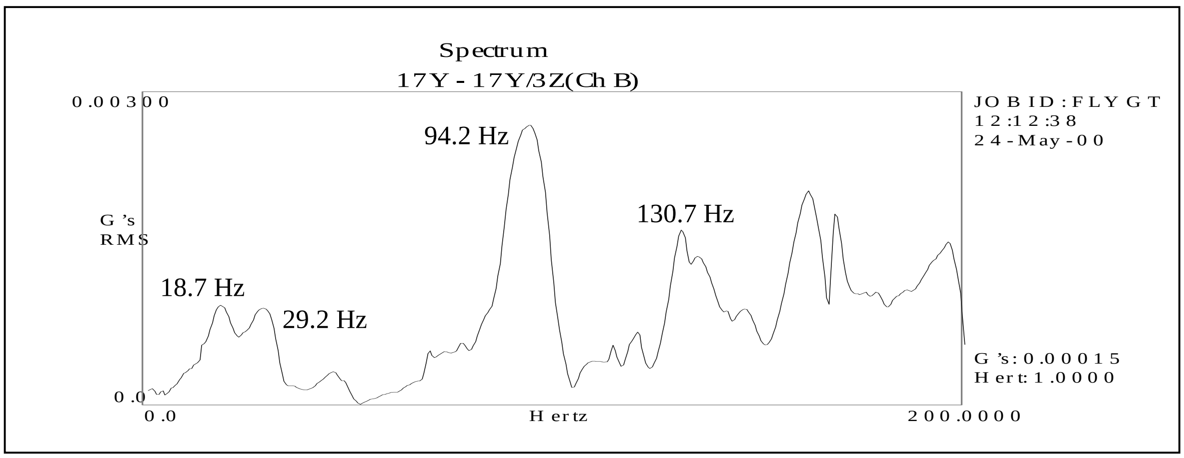

Spectrum
15Y - 15Y/3Z(Ch B)
0.00350
G's RMS
0.0
0.0
Hertz
200.0000
14.1 Hz
29.7 Hz
94.2 Hz
120 Hz
JOBID:FLYGT
11:58:35
24-May-00
G's: 9.5e-5
Hert: 1.0000

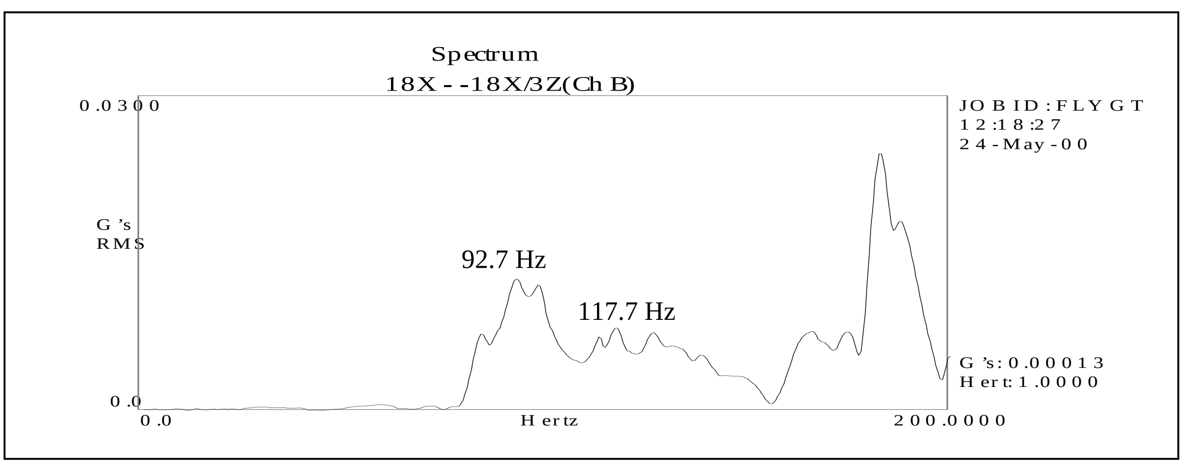

Spectrum
15Z--15Z/3Z(Ch B)
0.0240
G's
RMS
0.0
0.0
Hertz
200.0000
JOB ID:FLYGT
12:05:03
24-May-00
G's: 0.00021
Hert: 1.0000
13.6 Hz
115.2 Hz

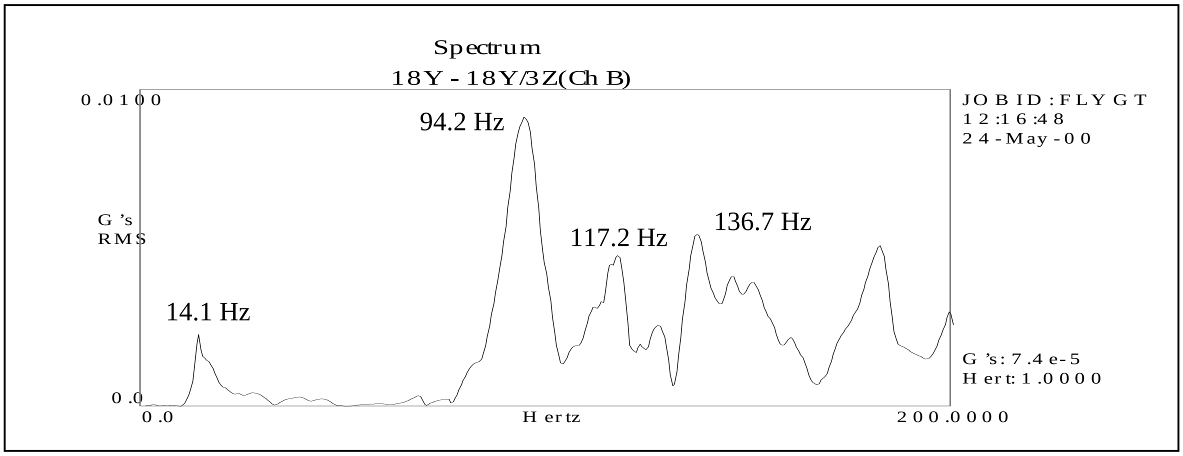

Spectrum
16X--16X/3Z(Ch B)
0.0150
G's
RMS
0.0
0.0
Hertz
200.0000
JOB ID:FLYGT
12:09:57
24-May-00
G's: 0.00011
Hert: 1.0000
181.7 Hz
129.2 Hz
102.7 Hz

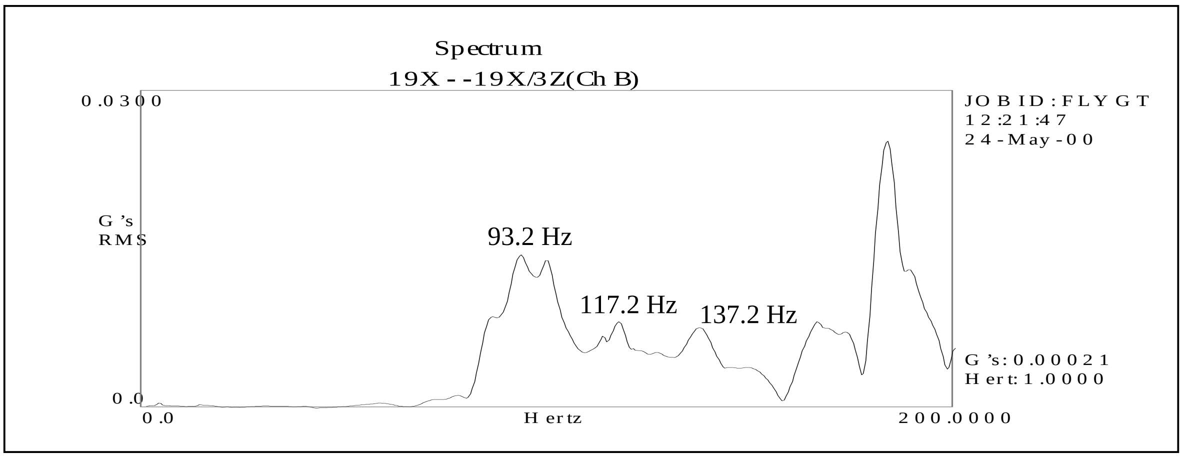

Spectrum
16Y-16Y/3Z(Ch B)
0.00600
G's
RMS
0.0
0.0
Hertz
200.0000
JOB ID:FLYGT
12:07:11
24-May-00
G's: 8.5e-5
Hert: 1.0000
14.1 Hz
29.2 Hz
97.7 Hz
120 Hz

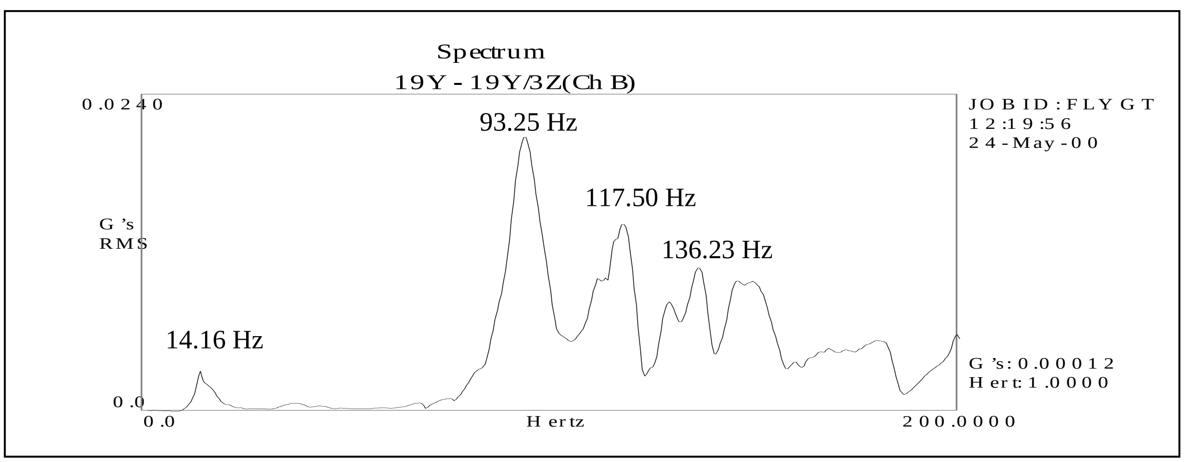

Spectrum
17X - -17X/3Z(Ch B)
0.0200
G's RMS
0.0
0.0
Hertz
200.0000
JOBID:FLYGT
12:15:03
24-May-00
G's: 0.00011
Hert: 1.0000
14.1 Hz
82.7 Hz
99.7 Hz
136.2 Hz

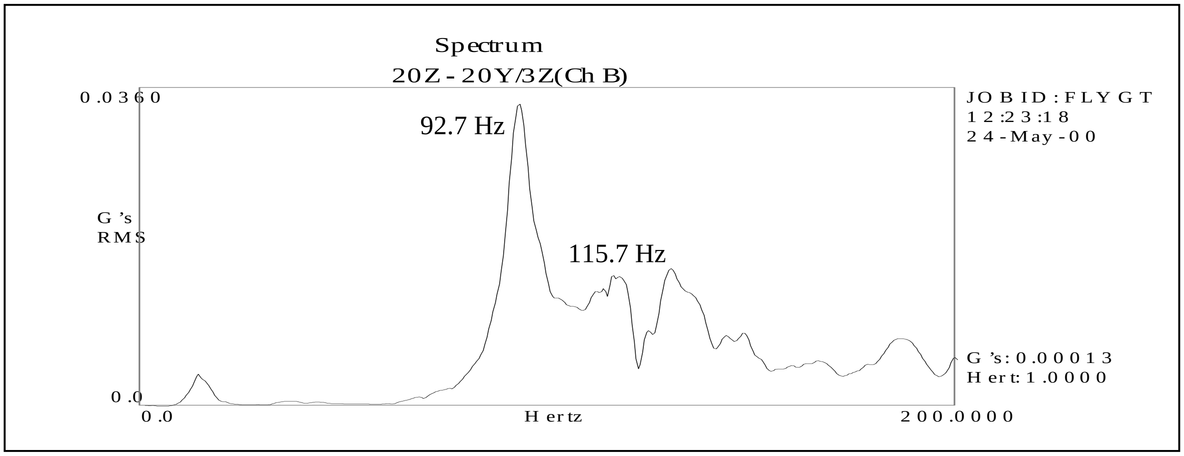

Spectrum
17Y - 17Y/3Z(Ch B)
0.00300
G's RMS
0.0
0.0
Hertz
200.0000
JOBID:FLYGT
12:12:38
24-May-00
G's: 0.00015
Hert: 1.0000
94.2 Hz
130.7 Hz
18.7 Hz
29.2 Hz

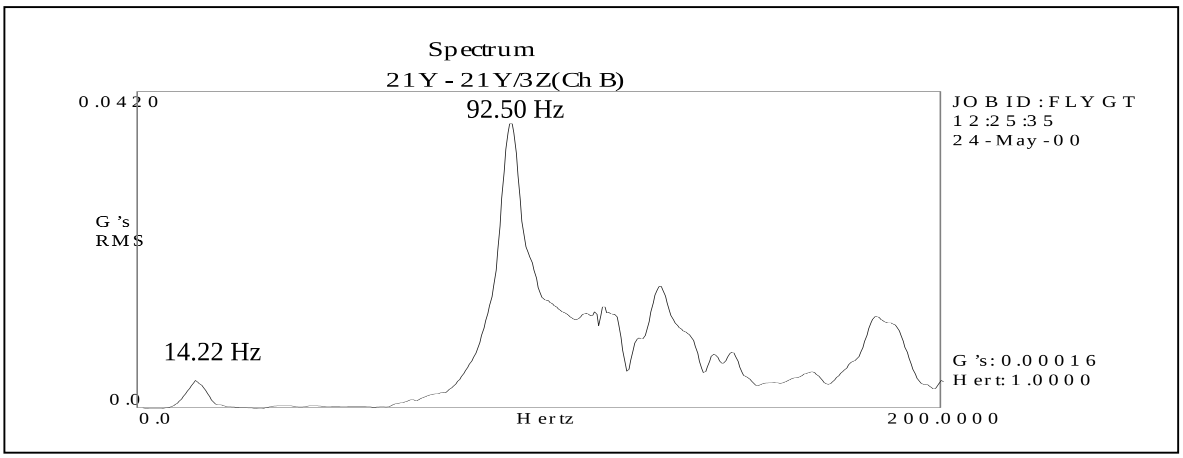

Spectrum
18X - -18X/3Z(Ch B)
0.0300
G's RMS
0.0
0.0
Hertz
200.0000
JOBID:FLYGT
12:18:27
24-May-00
G's: 0.00013
Hert: 1.0000
92.7 Hz
117.7 Hz

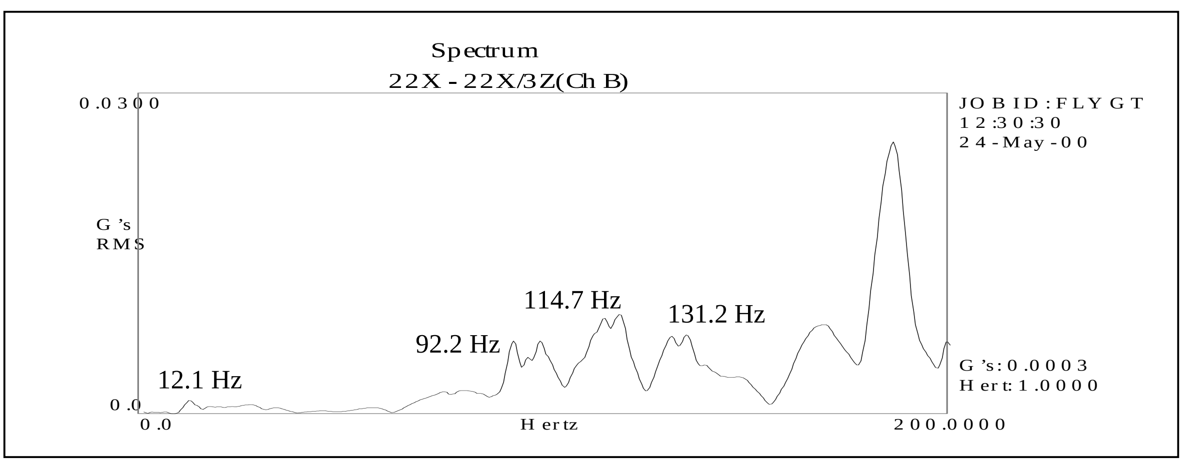

Spectrum
18Y - 18Y/3Z(Ch B)
0.0100
G's
RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
12:16:48
24-May-00
G's: 7.4e-5
Hert: 1.0000
94.2 Hz
117.2 Hz
136.7 Hz
14.1 Hz

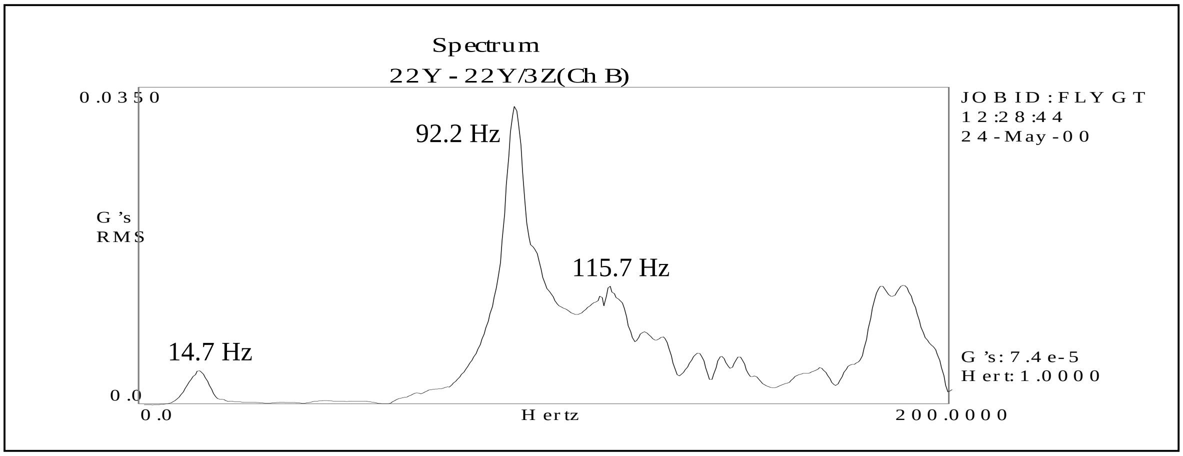

Spectrum
19X - -19X/3Z(Ch B)
0.0300
G's
RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
12:21:47
24-May-00
G's: 0.00021
Hert: 1.0000
93.2 Hz
117.2 Hz
137.2 Hz

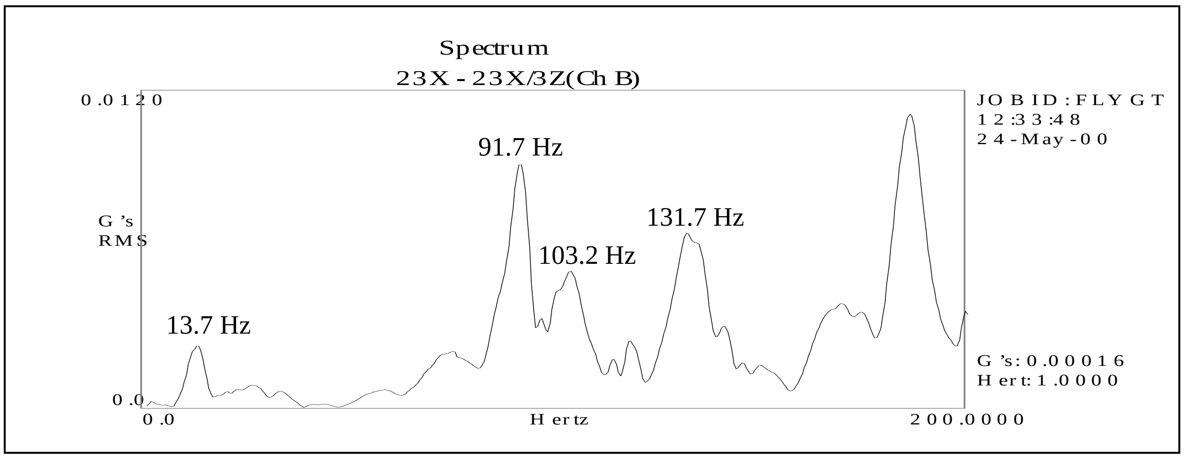

Spectrum
19Y - 19Y/3Z(Ch B)
0.0240
G's
RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
12:19:56
24-May-00
G's: 0.00012
Hert: 1.0000
93.25 Hz
117.50 Hz
136.23 Hz
14.16 Hz

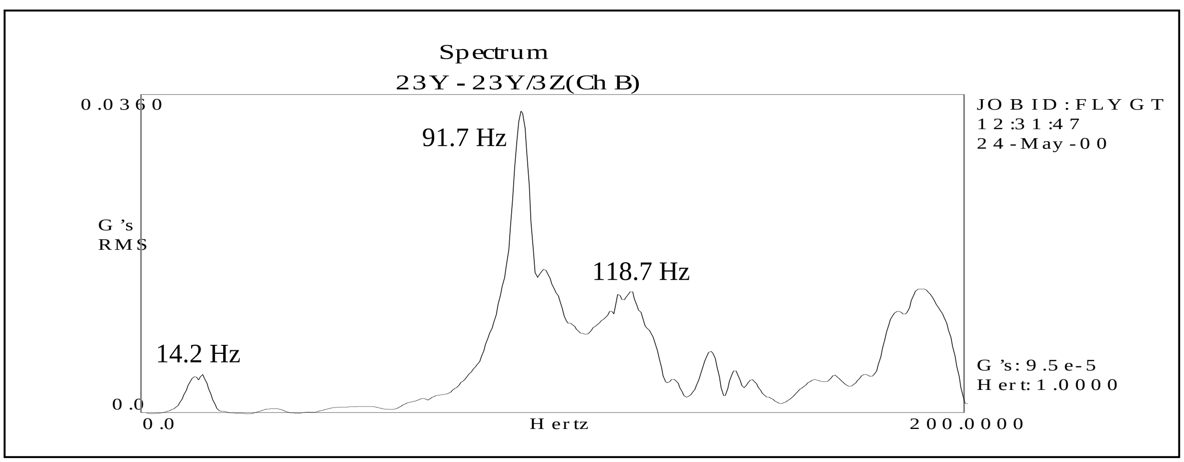

Spectrum
20Z - 20Y/3Z(Ch B)
0.0360
92.7 Hz
115.7 Hz
G's
RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
12:23:18
24-May-00
G's: 0.00013
Hert: 1.0000

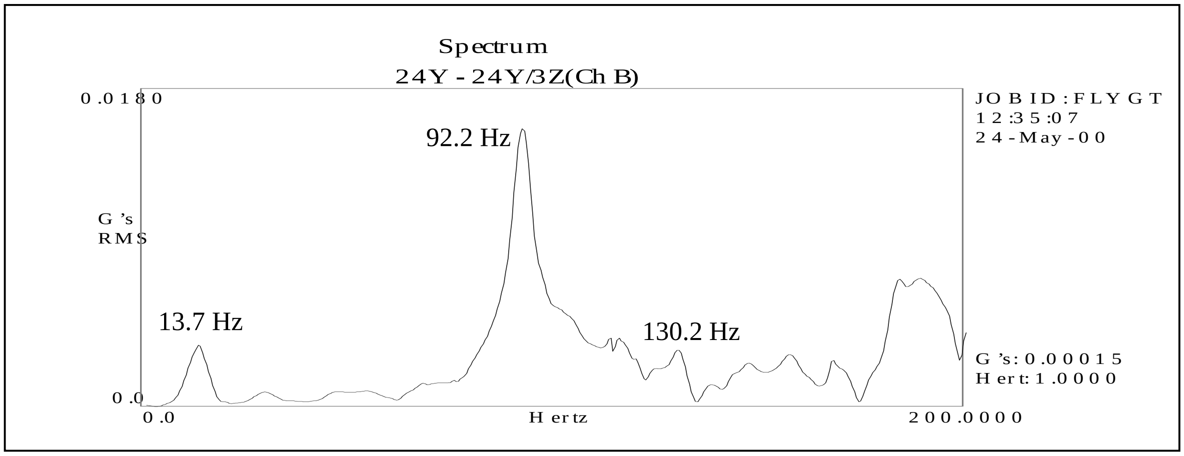

Spectrum
21Y - 21Y/3Z(Ch B)
0.0420
92.50 Hz
14.22 Hz
G's
RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
12:25:35
24-May-00
G's: 0.00016
Hert: 1.0000

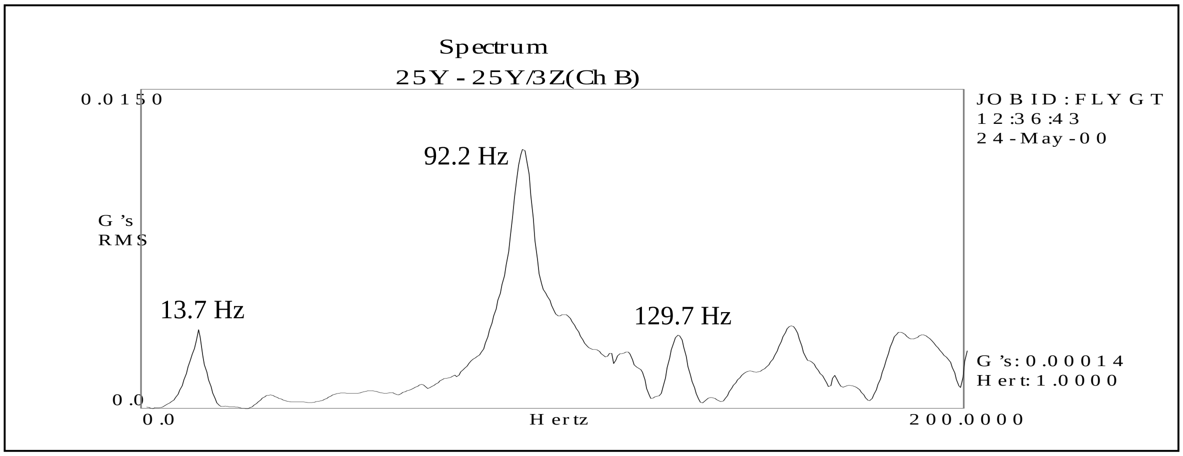

Spectrum
22X - 22X/3Z(Ch B)
0.0300
114.7 Hz
131.2 Hz
92.2 Hz
12.1 Hz
G's
RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
12:30:30
24-May-00
G's: 0.0003
Hert: 1.0000

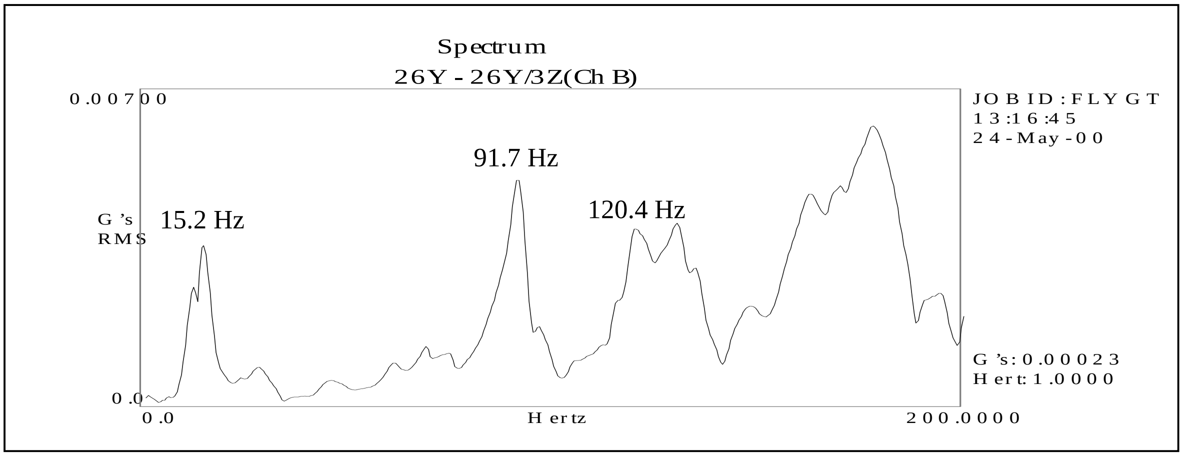

Spectrum
22Y - 22Y/3Z(Ch B)
0.0350
G's
RMS
0.0
0.0
Hertz
200.0000
JOBID: FLYGT
12:28:44
24-May-00
G's: 7.4e-5
Hert: 1.0000
92.2 Hz
115.7 Hz
14.7 Hz

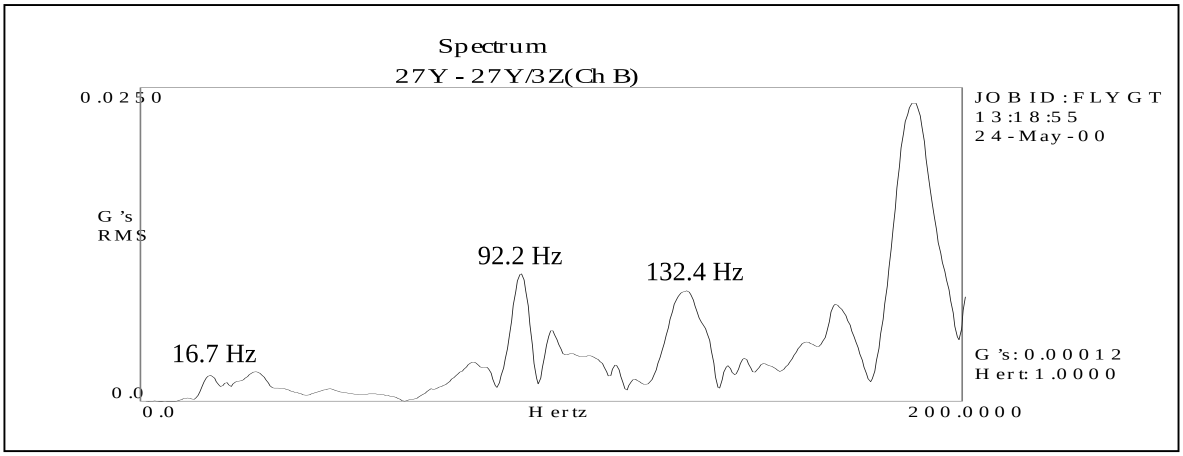

Spectrum
23X - 23X/3Z(Ch B)
0.0120
G's
RMS
0.0
0.0
Hertz
200.0000
JOBID: FLYGT
12:33:48
24-May-00
G's: 0.00016
Hert: 1.0000
91.7 Hz
131.7 Hz
103.2 Hz
13.7 Hz

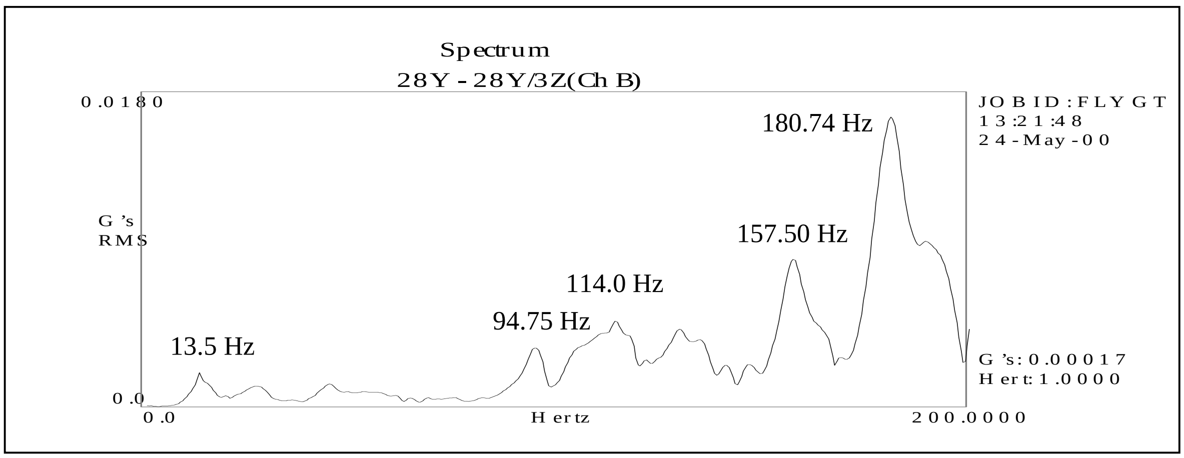

Spectrum
23Y - 23Y/3Z(Ch B)
0.0360
G's
RMS
0.0
0.0
Hertz
200.0000
JOBID: FLYGT
12:31:47
24-May-00
G's: 9.5e-5
Hert: 1.0000
91.7 Hz
118.7 Hz
14.2 Hz

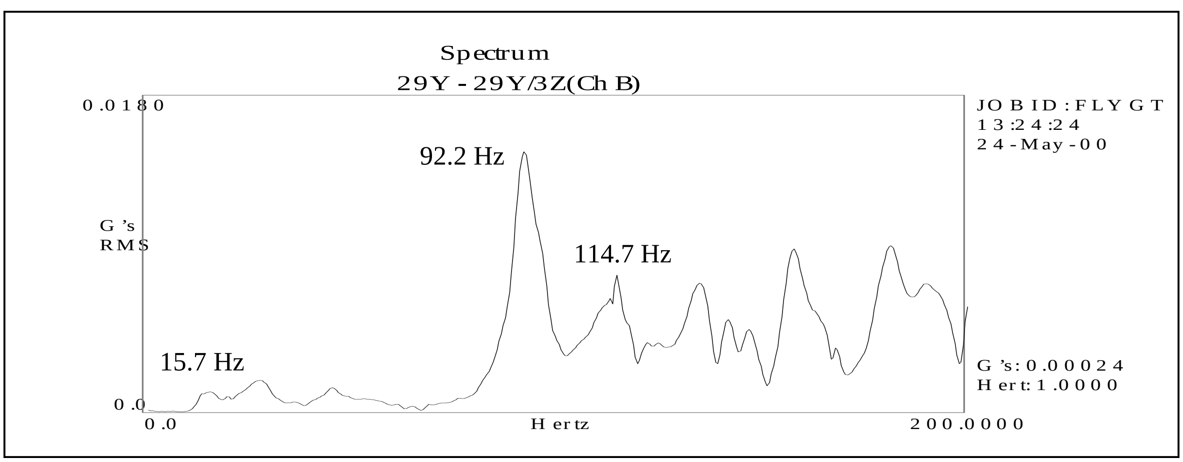

Spectrum
24Y - 24Y/3Z(Ch B)
0.0180
G's
RMS
0.0
0.0
Hertz
200.0000
92.2 Hz
13.7 Hz
130.2 Hz
JOB ID: FLYGT
12:35:07
24-May-00
G's: 0.00015
Hert: 1.0000

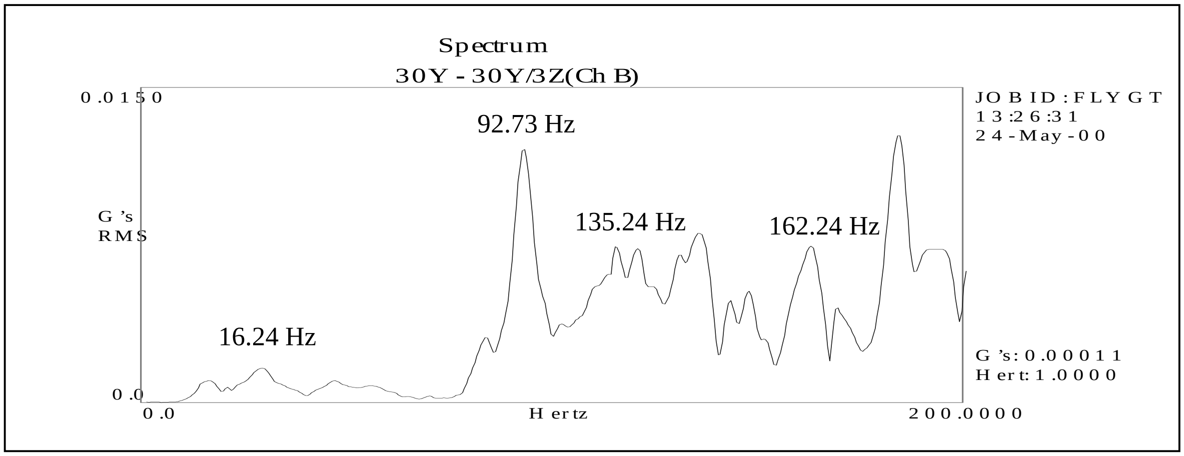

Spectrum
25Y - 25Y/3Z(Ch B)
0.0150
G's
RMS
0.0
0.0
Hertz
200.0000
92.2 Hz
13.7 Hz
129.7 Hz
JOB ID: FLYGT
12:36:43
24-May-00
G's: 0.00014
Hert: 1.0000

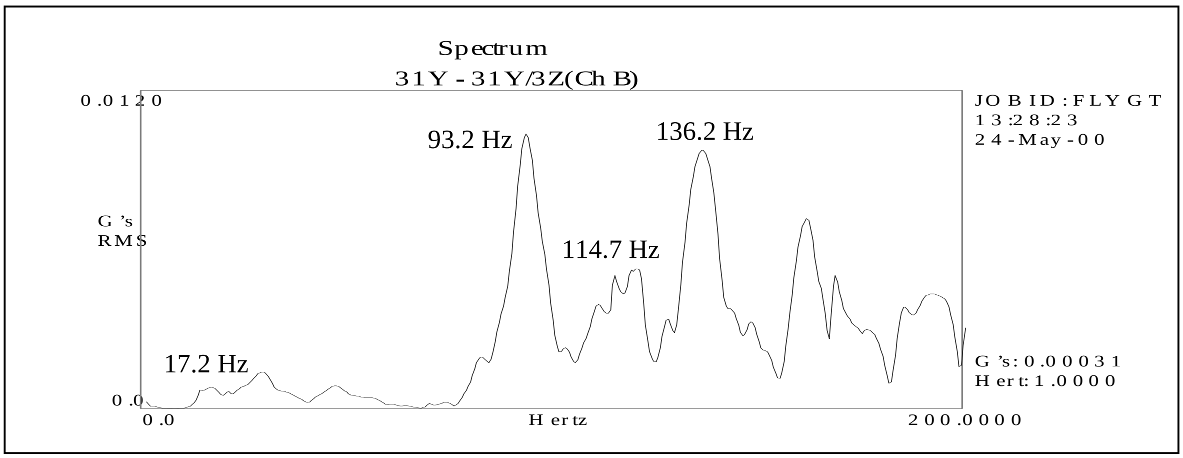

Spectrum
26Y - 26Y/3Z(Ch B)
0.00700
G's
RMS
0.0
0.0
Hertz
200.0000
91.7 Hz
15.2 Hz
120.4 Hz
JOB ID: FLYGT
13:16:45
24-May-00
G's: 0.00023
Hert: 1.0000

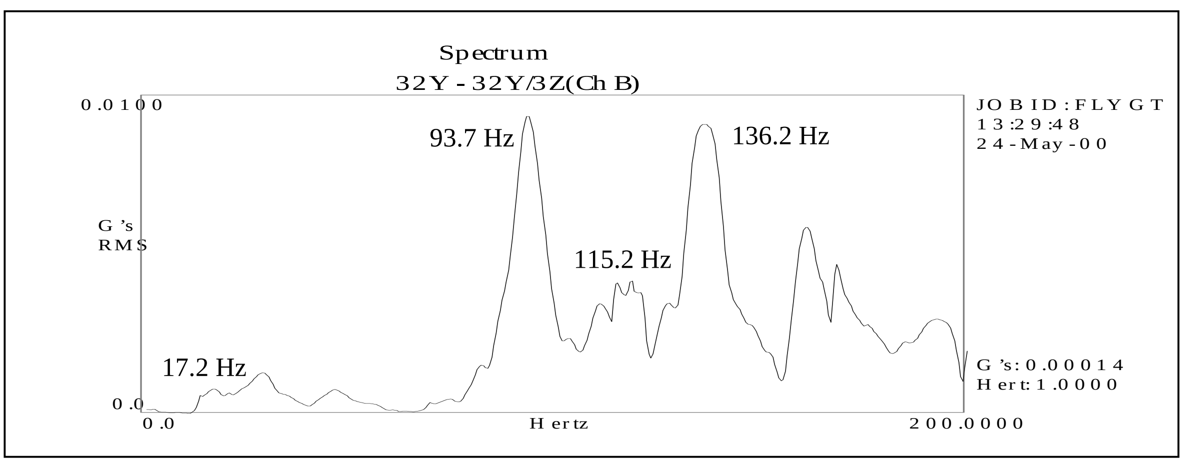

Spectrum
27Y - 27Y/3Z(Ch B)
0.0250
G's
RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
13:18:55
24-May-00
G's: 0.00012
Hert: 1.0000
16.7 Hz
92.2 Hz
132.4 Hz

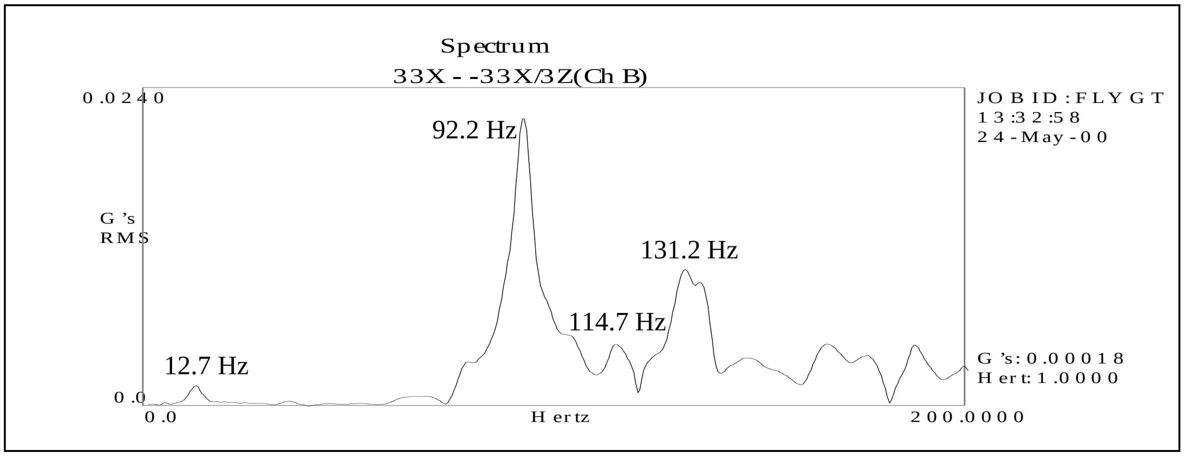

Spectrum
28Y - 28Y/3Z(Ch B)
0.0180
G's
RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
13:21:48
24-May-00
G's: 0.00017
Hert: 1.0000
13.5 Hz
94.75 Hz
114.0 Hz
157.50 Hz
180.74 Hz

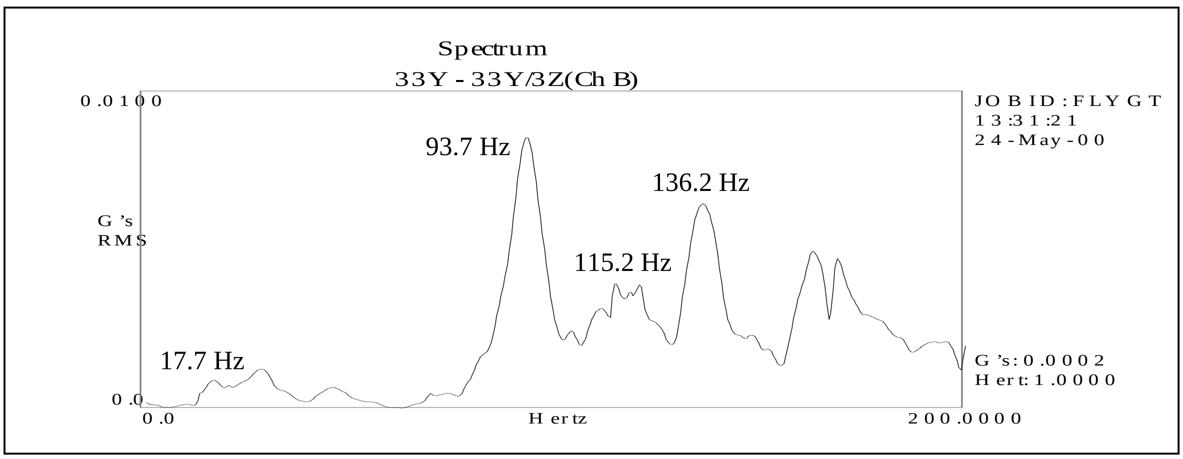

Spectrum
29Y - 29Y/3Z(Ch B)
0.0180
G's
RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
13:24:24
24-May-00
G's: 0.00024
Hert: 1.0000
15.7 Hz
92.2 Hz
114.7 Hz

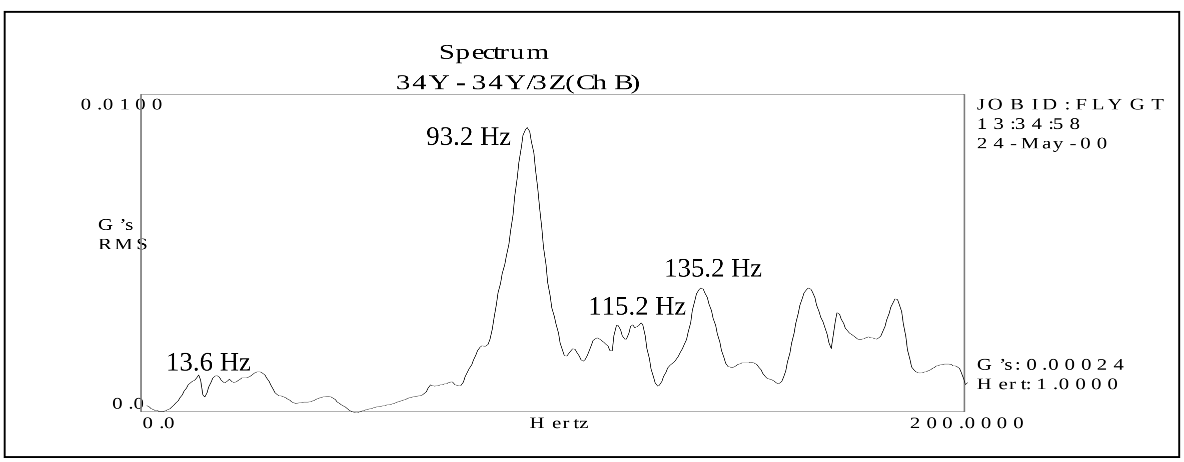

Spectrum
30Y - 30Y/3Z(Ch B)
0.0150
G's RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
13:26:31
24-May-00
G's: 0.00011
Hert: 1.0000
92.73 Hz
135.24 Hz
162.24 Hz
16.24 Hz

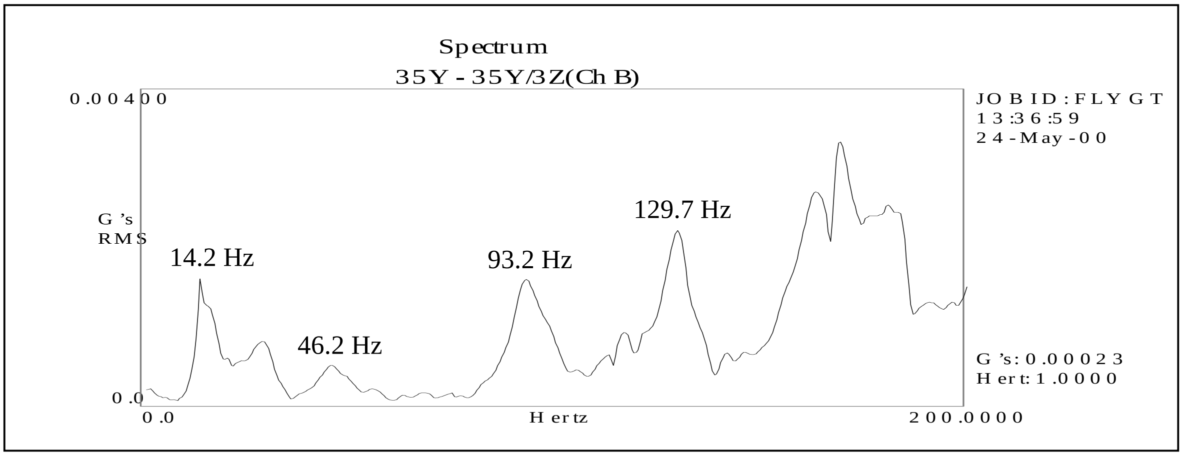

Spectrum
31Y - 31Y/3Z(Ch B)
0.0120
G's RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
13:28:23
24-May-00
G's: 0.00031
Hert: 1.0000
93.2 Hz
136.2 Hz
114.7 Hz
17.2 Hz

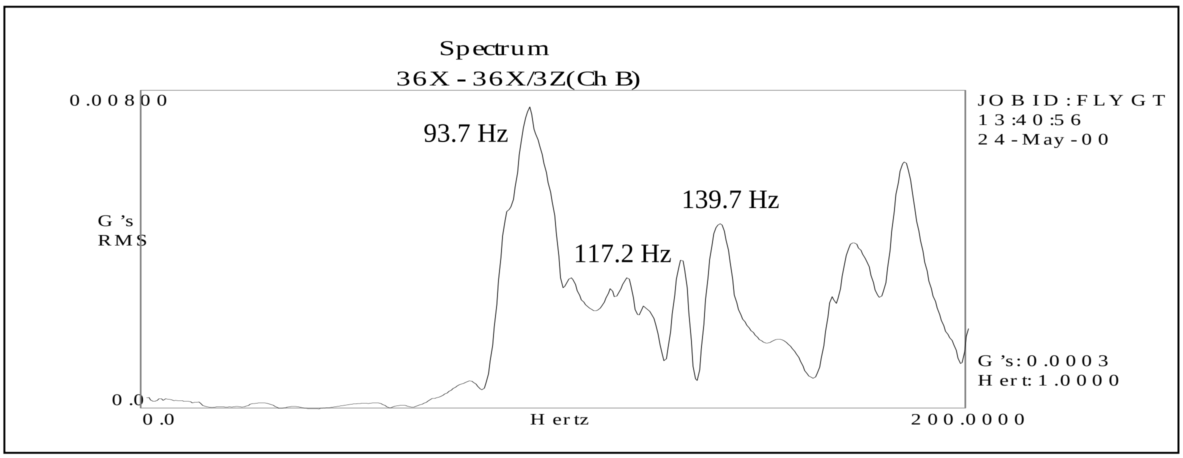

Spectrum
32Y - 32Y/3Z(Ch B)
0.0100
G's RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
13:29:48
24-May-00
G's: 0.00014
Hert: 1.0000
93.7 Hz
136.2 Hz
115.2 Hz
17.2 Hz

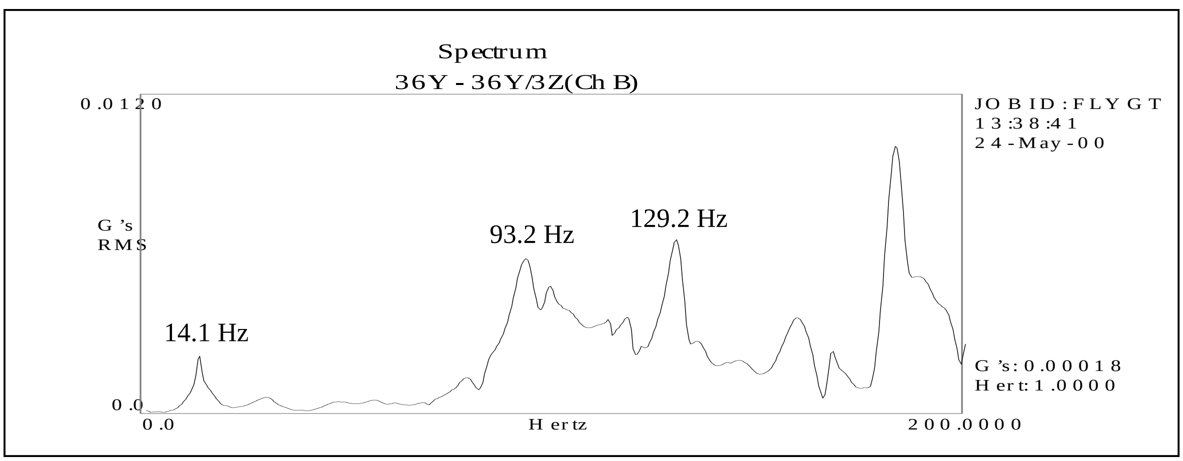

Spectrum
33X - -33X/3Z(Ch B)
0.0240
G's
RMS
0.0
0.0
Hertz
200.0000
JOBID:FLYGT
13:32:58
24-May-00
G's: 0.00018
Hert: 1.0000
92.2 Hz
131.2 Hz
114.7 Hz
12.7 Hz

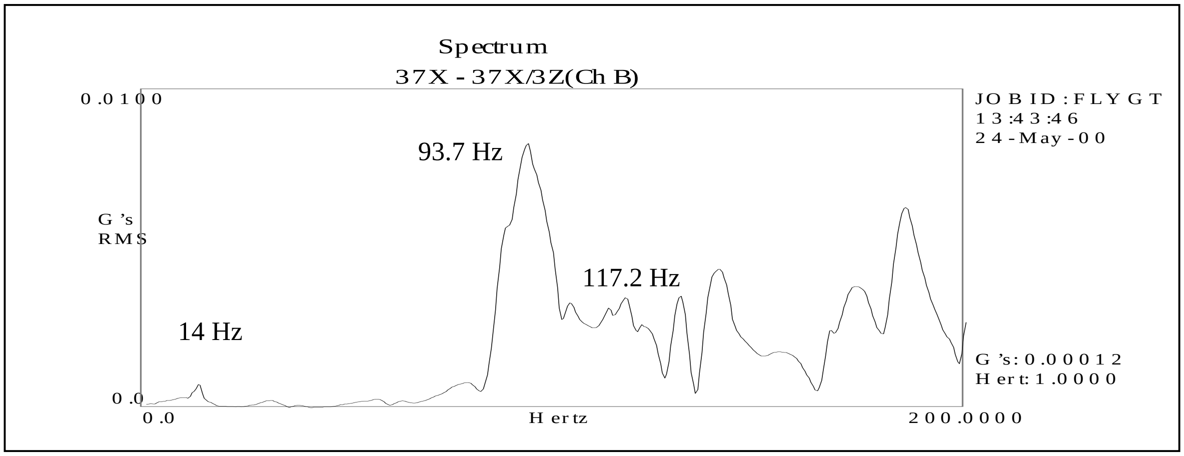

Spectrum
33Y - 33Y/3Z(Ch B)
0.0100
G's
RMS
0.0
0.0
Hertz
200.0000
JOBID:FLYGT
13:31:21
24-May-00
G's: 0.0002
Hert: 1.0000
93.7 Hz
136.2 Hz
115.2 Hz
17.7 Hz

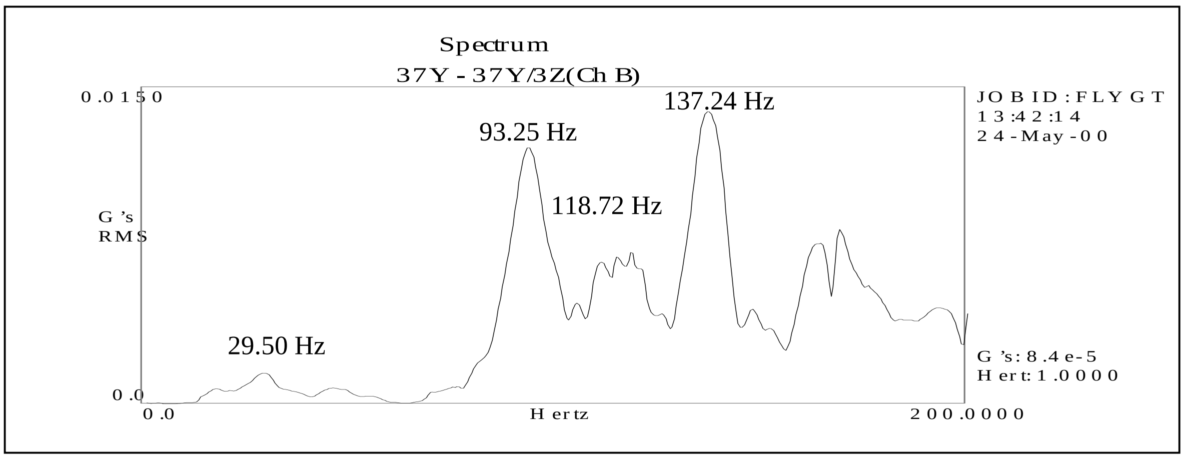

Spectrum
34Y - 34Y/3Z(Ch B)
0.0100
G's
RMS
0.0
0.0
Hertz
200.0000
JOBID:FLYGT
13:34:58
24-May-00
G's: 0.00024
Hert: 1.0000
93.2 Hz
135.2 Hz
115.2 Hz
13.6 Hz

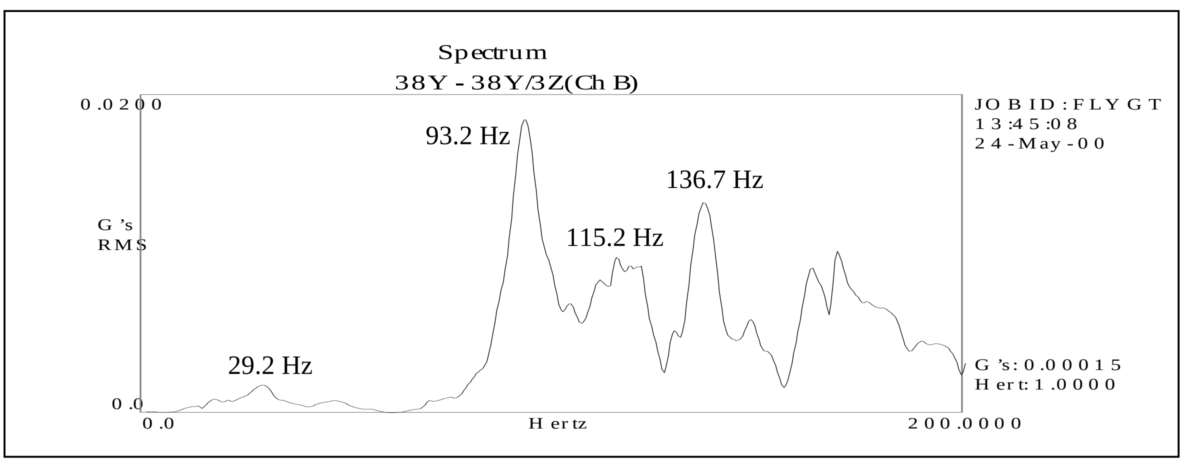

Spectrum
35Y - 35Y/3Z(Ch B)
0.00400
JOB ID: FLYGT
13:36:59
24-May-00
G's
RMS
14.2 Hz
46.2 Hz
93.2 Hz
129.7 Hz
G's: 0.00023
Hert: 1.0000
0.0
0.0
Hertz
200.0000

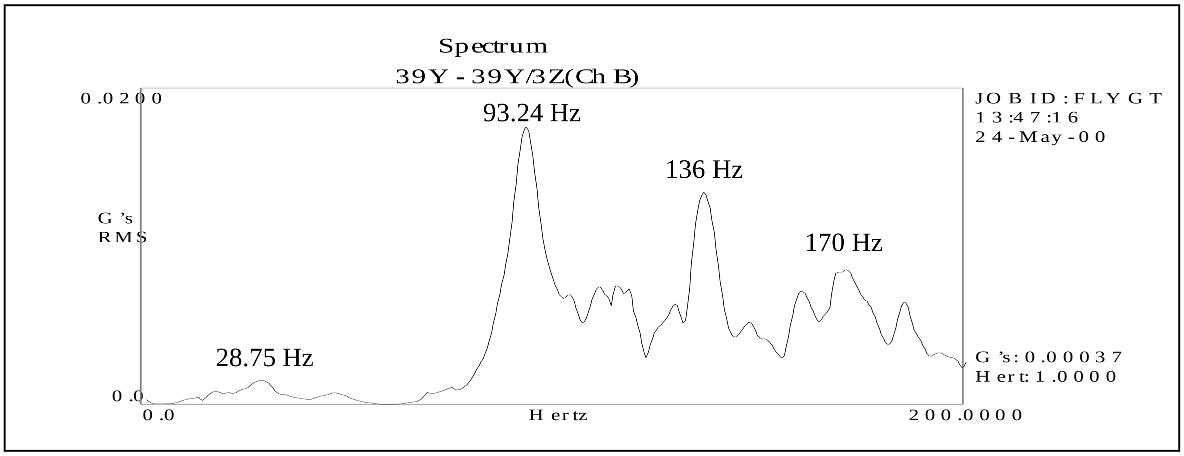

Spectrum
36X - 36X/3Z(Ch B)
0.00800
JOB ID: FLYGT
13:40:56
24-May-00
G's
RMS
93.7 Hz
117.2 Hz
139.7 Hz
G's: 0.0003
Hert: 1.0000
0.0
0.0
Hertz
200.0000

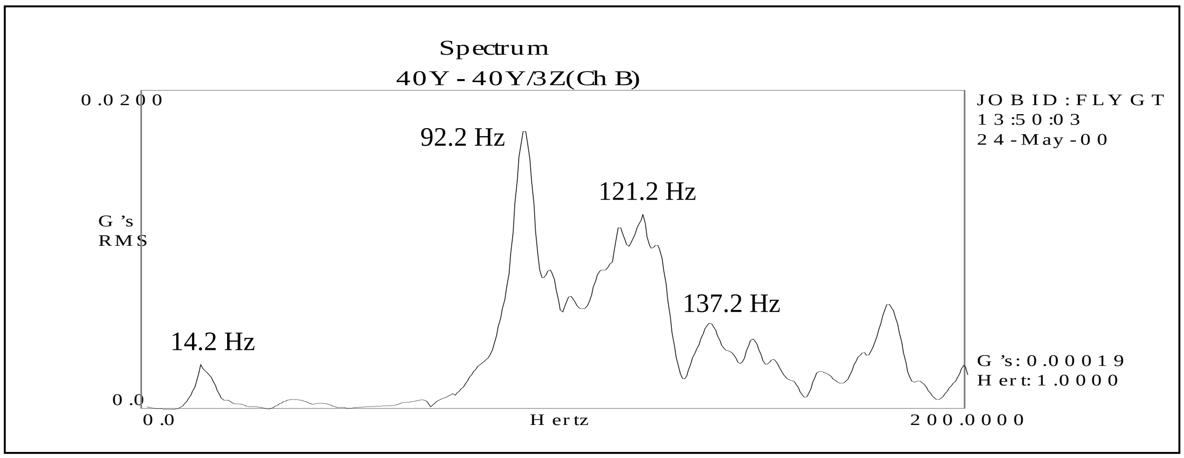

Spectrum
36Y - 36Y/3Z(Ch B)
0.0120
JOB ID: FLYGT
13:38:41
24-May-00
G's
RMS
14.1 Hz
93.2 Hz
129.2 Hz
G's: 0.00018
Hert: 1.0000
0.0
0.0
Hertz
200.0000

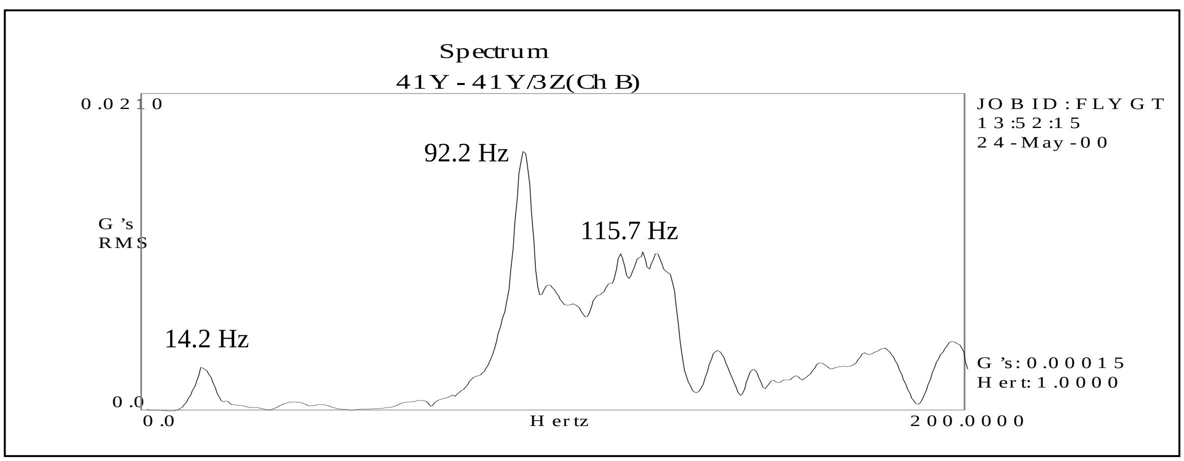

Spectrum
37X - 37X/3Z(Ch B)
0.0100
G's RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
13:43:46
24-May-00
G's: 0.00012
Hert: 1.0000
93.7 Hz
117.2 Hz
14 Hz

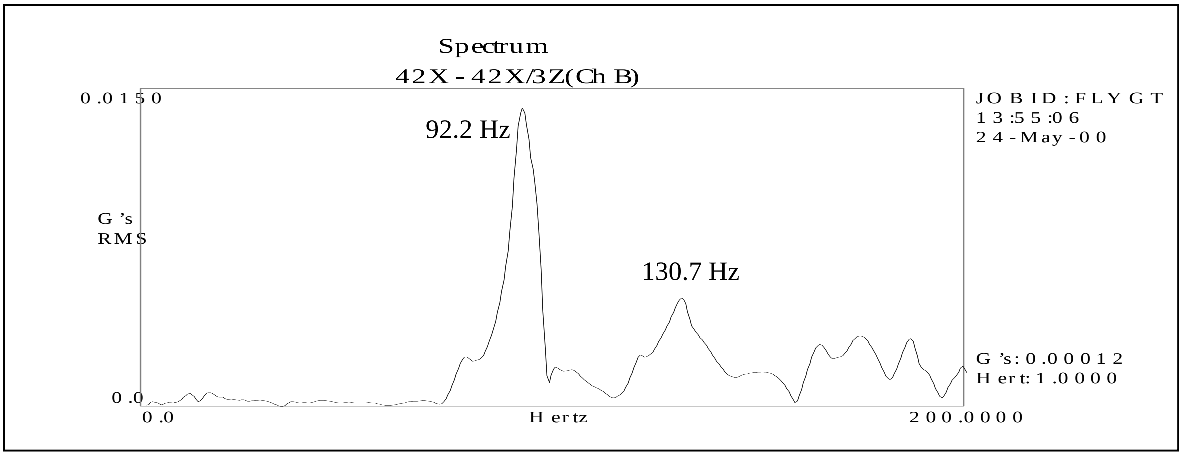

Spectrum
37Y - 37Y/3Z(Ch B)
0.0150
G's RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
13:42:14
24-May-00
G's: 8.4e-5
Hert: 1.0000
137.24 Hz
93.25 Hz
118.72 Hz
29.50 Hz

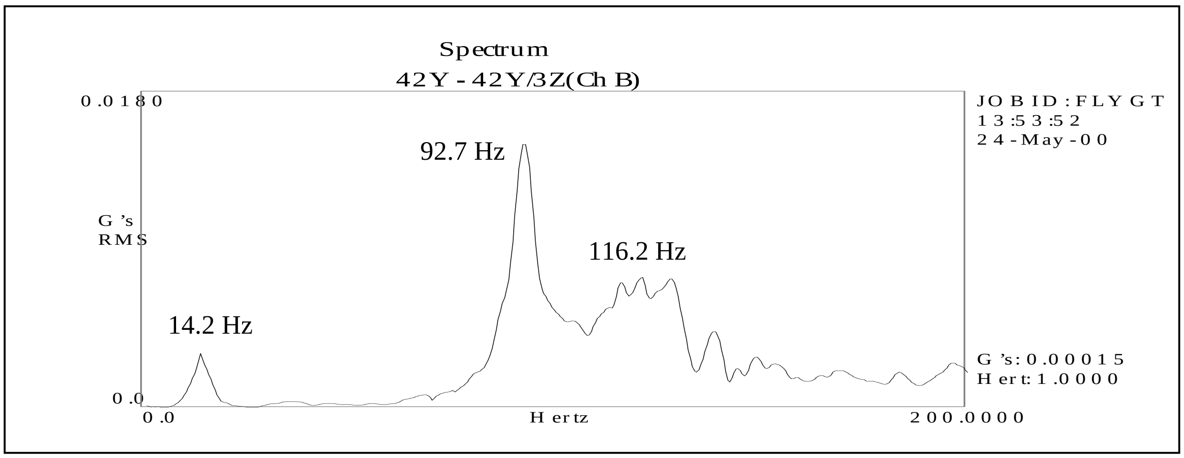

Spectrum
38Y - 38Y/3Z(Ch B)
0.0200
G's RMS
0.0
0.0
Hertz
200.0000
JOB ID: FLYGT
13:45:08
24-May-00
G's: 0.00015
Hert: 1.0000
93.2 Hz
136.7 Hz
115.2 Hz
29.2 Hz

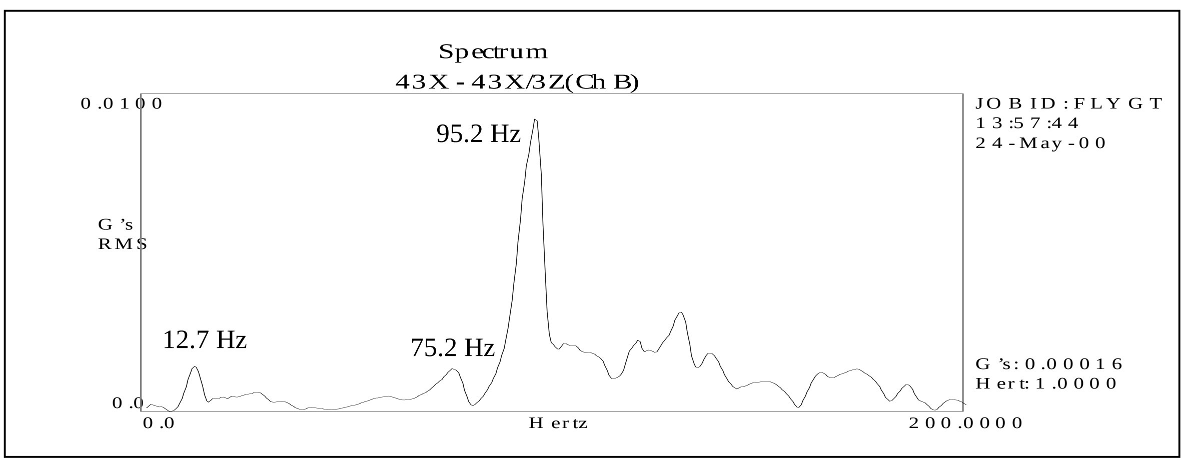

Spectrum
39Y - 39Y/3Z(Ch B)
0.0200
93.24 Hz
136 Hz
170 Hz
28.75 Hz
G's RMS
0.0
0.0
Hertz
200.0000
JOBID:FLYGT
13:47:16
24-May-00
G's: 0.00037
Hert: 1.0000

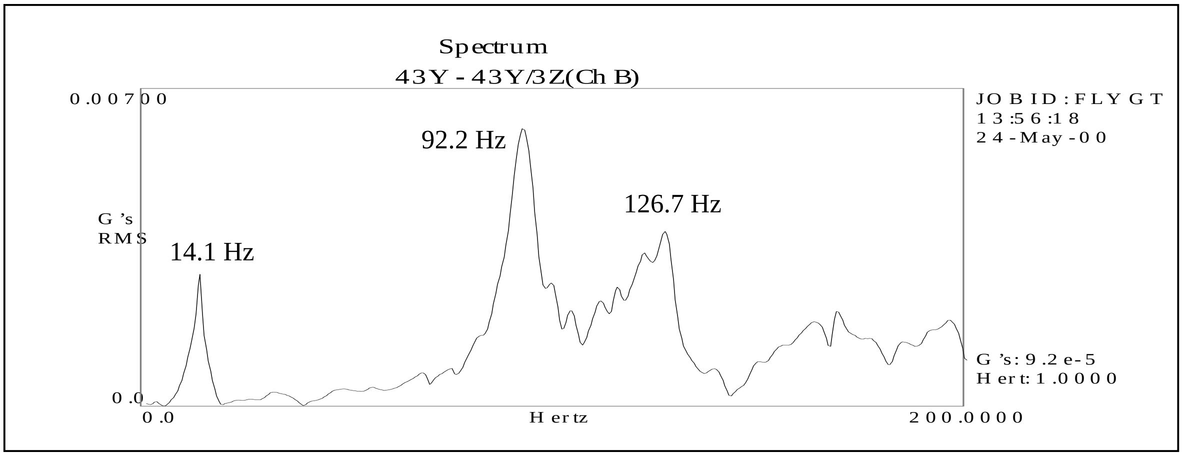

Spectrum
40Y - 40Y/3Z(Ch B)
0.0200
92.2 Hz
121.2 Hz
137.2 Hz
14.2 Hz
G's RMS
0.0
0.0
Hertz
200.0000
JOBID:FLYGT
13:50:03
24-May-00
G's: 0.00019
Hert: 1.0000


Spectrum
41Y - 41Y/3Z(Ch B)
0.0210
92.2 Hz
115.7 Hz
14.2 Hz
G's RMS
0.0
0.0
Hertz
200.0000
JOBID:FLYGT
13:52:15
24-May-00
G's: 0.00015
Hert: 1.0000


Spectrum
42X - 42X/3Z(Ch B)
0.0150
G's RMS
0.0
0.0
Hertz
200.0000
92.2 Hz
130.7 Hz
JOB ID: FLYGT
13:55:06
24-May-00
G's: 0.00012
Hert: 1.0000

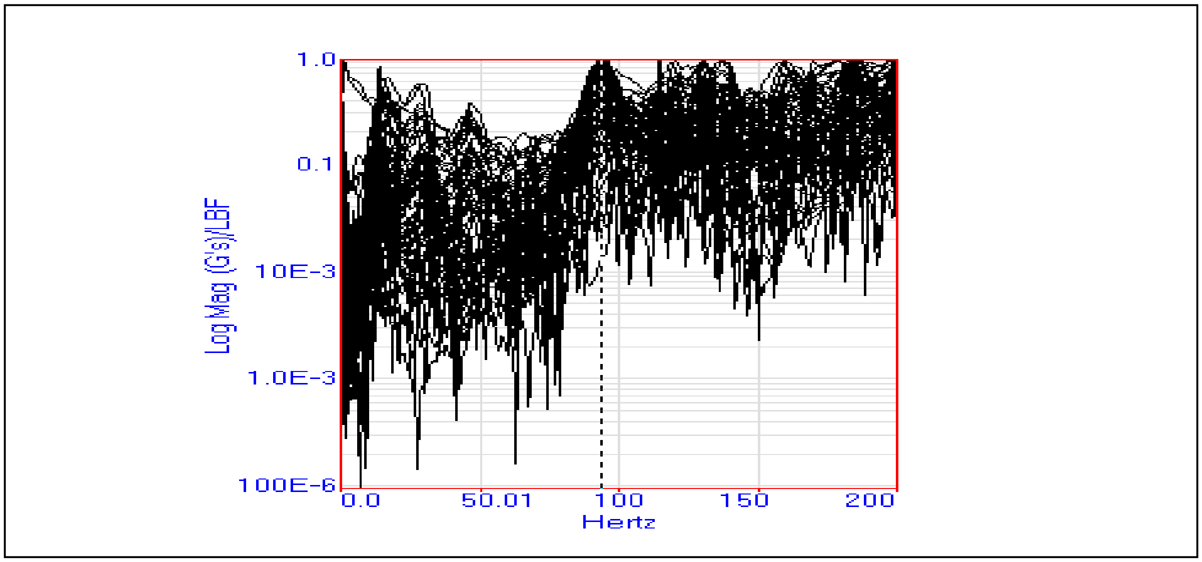

Spectrum
42Y - 42Y/3Z(Ch B)
0.0180
G's RMS
0.0
0.0
Hertz
200.0000
92.7 Hz
116.2 Hz
14.2 Hz
JOB ID: FLYGT
13:53:52
24-May-00
G's: 0.00015
Hert: 1.0000


Spectrum
43X - 43X/3Z(Ch B)
0.0100
G's RMS
0.0
0.0
Hertz
200.0000
95.2 Hz
12.7 Hz
75.2 Hz
JOB ID: FLYGT
13:57:44
24-May-00
G's: 0.00016
Hert: 1.0000

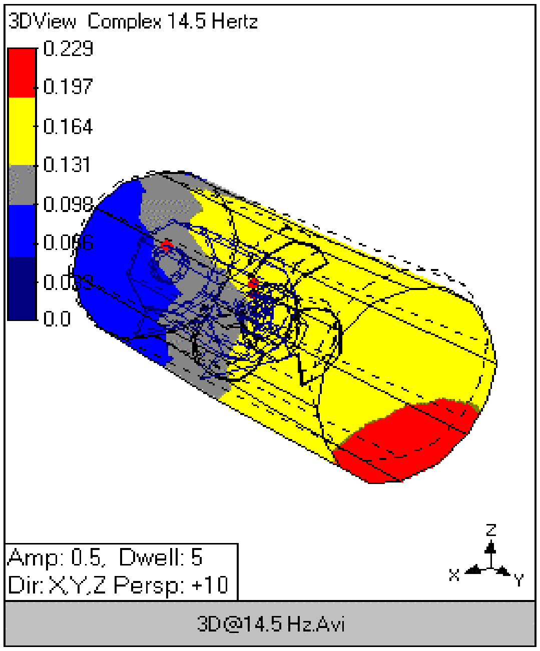


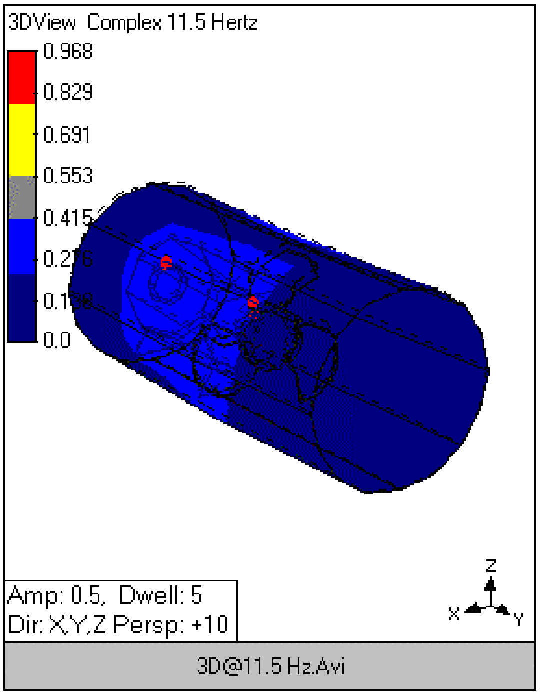

## MeScopeVES Analysis Data

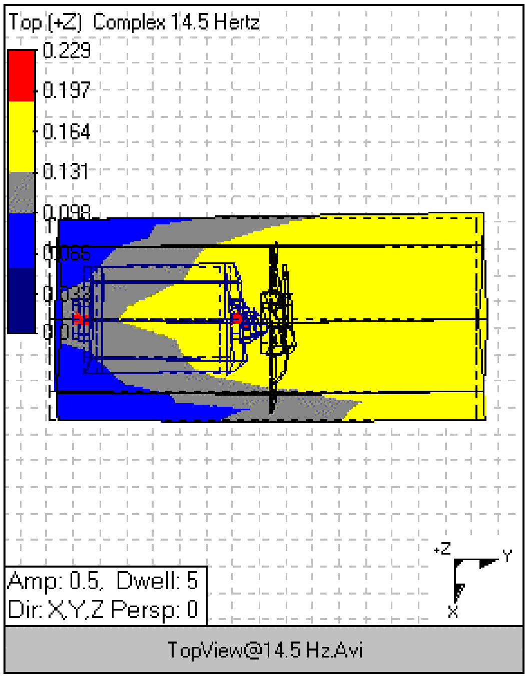
Overlaid FRF Traces (0 to 200 Hz)

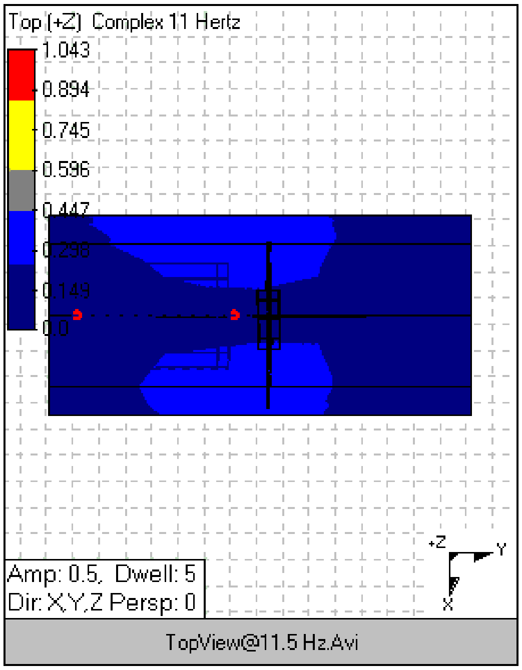


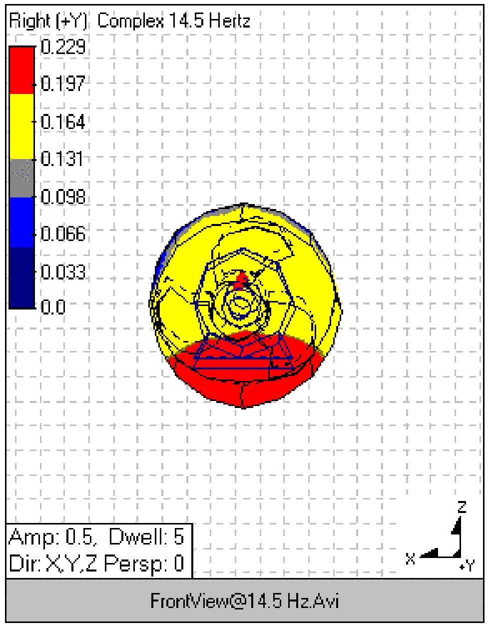
# Modal Movies

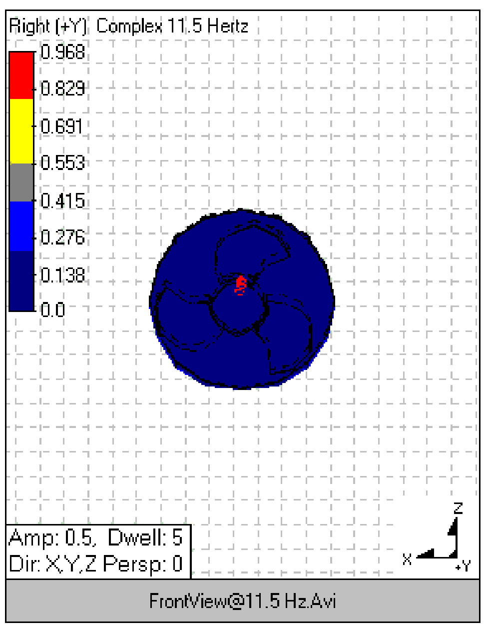


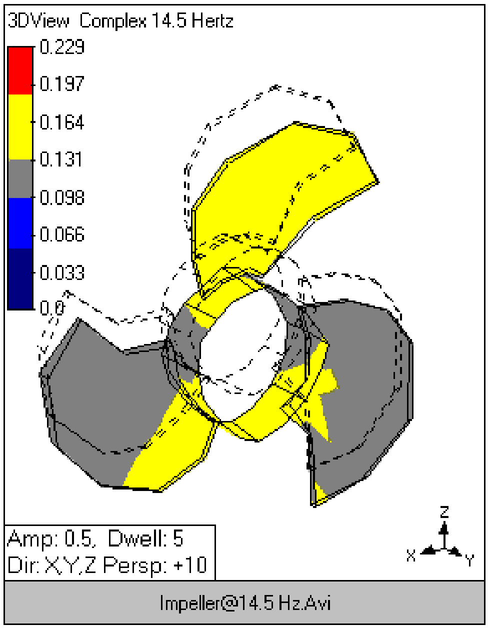



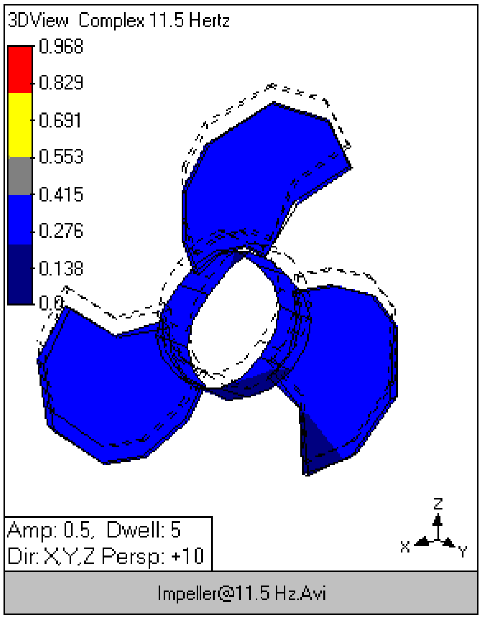

Top (+Z) Complex 14.5 Hertz
0.229
0.197
0.164
0.131
0.098
Amp: 0.5, Dwell: 5
Dir: X,Y,Z Persp: 0
+Z
Y
X
TopView@14.5 Hz.Avi


Top (+Z) Complex 11 Hertz
1.043
0.894
0.745
0.596
Amp: 0.5, Dwell: 5
Dir: X,Y,Z Persp: 0
+Z
Y
X
TopView@11.5 Hz.Avi


Right (+Y) Complex 14.5 Hertz
0.229
0.197
0.164
0.131
0.098
0.066
0.033
0.0
Amp: 0.5, Dwell: 5
Dir: X,Y,Z Persp: 0
Z
X
+Y
FrontView@14.5 Hz.Avi


Right (+Y) Complex 11.5 Hertz
0.968
0.829
0.691
0.553
0.415
0.276
0.138
0.0
Amp: 0.5, Dwell: 5
Dir: X,Y,Z Persp: 0
Z
X
+Y
FrontView@11.5 Hz.Avi


3DView Complex 14.5 Hertz
0.229
0.197
0.164
0.131
0.098
0.066
0.033
0.0
Amp: 0.5, Dwell: 5
Dir: X,Y,Z Persp: +10
Z
X
Y
Impeller@14.5 Hz.Avi


3DView Complex 11.5 Hertz
0.968
0.829
0.691
0.553
0.415
0.276
0.138
0.0
Amp: 0.5, Dwell: 5
Dir: X,Y,Z Persp: +10
Z
X
Y
Impeller@11.5 Hz.Avi

# Conclusion

The HLW FLYGT Mixer pump has a resonance at 85.9 Hz (6x RPM), which is two times the blade pass frequency of the mixer pump. This resonance frequency is being excited by the blade pass frequency of the propeller. Resonance is defined, as a natural frequency that is excited by a forcing function, such as unbalance or the number of blades on a fan or pump unit. A resonance frequency will amplify the energy input from the forcing function, causing a dramatic (and often disastrous) rise in vibration amplitude. The FLYGT Mixer will always have a natural resonance of 85.9 Hz unless there is a design change to its structure. The mixer will also have a blade pass frequency at three times running speed, because of the three blade propeller design. There are several options that can be considered to help correct the FLYGT Mixer resonance problem.

### 1. Change the Speed

Change the mixer speed to move the exciting force away from the natural frequency. A 10 – 15 percent speed change on either side of the natural frequency will lower the vibration amplitudes.

### 2. Change the Mass

Increase the mass of the FLYGT Mixer to decrease its natural frequency. This can be calculated as,

$$\mathbf{fn} = \frac{\mathbf{1}}{\mathbf{2}}\pi\sqrt{\mathbf{k}/\underline{\mathbf{m}}} \qquad (9)$$

where:
**fn** = Natural Frequency
**k** = Stiffness
**m** = Mass
$\frac{\mathbf{1}}{\mathbf{2}}\pi$ = Constant

### 3. Change the Stiffness

Increase the stiffness of the FLYGT Mixer to increase the natural frequency. This can be calculated as,

$$\mathbf{fn} = \frac{\mathbf{1}}{\mathbf{2}}\pi\sqrt{\underline{\mathbf{k}}/\mathbf{m}} \qquad (10)$$

## Recommendation

The FLYGT Mixer will always have a blade pass frequency at three times running speed (exciting force), because of the three blade propeller design. Reducing the mixer speed to 650 RPM (10.83 Hz) from 860 RPM (14.33 Hz) will reduce the vibration amplitudes by moving the exciting force away from the mixer's natural frequency of 85.9 Hz.

## References

[1] "Is It a Mode Shape, or an Operating Deflection Shape?" Sound & Vibration Magazine, (March, 1997).
[2] Mark H. Richardson "Structural Dynamics Measurements", SD2000 April 11-16, 1999 (page 4, figure 4).
[3] Mark H. Richardson "Fundamentals of the Discrete Fourier Transform", Sound & Vibration Magazine, (March, 1978).
[4] PCB Piezotronics, Inc. Modal Hammer Model 086C41 Operating Manual (page 3, figure 4.2c).