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Impact Testing of CX-100 Wind Turbine Blades (MODAL DATA)

SDASL Report # L111625-1

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Approved By: Peter Avitabile

Date: 2/17/2012

ABSTRACT

Experimental modal testing data were collected for a CX-100 9 meter wind turbine blade to provide experimental mode shapes and frequencies. Testing was performed at the National Renewable Energy Laboratory in Boulder, Colorado. The blade was clamped to the fixture on site. The primary purpose of this test was to provide additional modal data to the scientific community. Accelerometer measurements were made under impact excitation.

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1.0 Introduction

1.1 Purpose of Test

The main focus of this work was directed toward the identification of mode shapes for a CX-100 wind turbine blade clamped to a substantial fixture to allow for comparison to previous modeling and testing performed. Measurements were taken in both the edge and flap directions. Measurements were also taken on the fixture.

1.2 Scope of the Report

This report includes a basic discussion of the theories behind the experimental modal analysis technique. This report identifies the impact testing techniques typically employed as well as the reduction of the data to obtain modal data; discussion on general operating data assessment is also included The discussion section summarizes the findings and observations from the testing/analyses performed. The appendices to this report contain additional supporting information regarding the results of testing and analyses performed.

1.3 Personnel involved in the Test and Analysis Efforts

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All testing performed at National Renewable Energy Laboratory on December 1-2, 2011.

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2.0 Theoretical Basis

For the generation of modal data, several commonly used frequency spectra related functions are required. A brief discussion on the theoretical basis for modal characterization is described herein. Some of the applicable modal theory is presented followed by some applicable measurement theory; these set the underlying theory that is utilized. Next a brief discussion on some of the steps taken to obtain the required measurements is provided. Two short descriptions are provided on impact measurements and shaker measurements development.

2.1 Applicable Modal Theory

The equation of motion for a multiple degree of freedom system can be written in matrix form as

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \{F(t)\}$$

If these equations are transformed into the Laplace domain, then

$$\left[[M]s^2 + [C]s + [K]\right]\{X(s)\} = \{F(s)\}$$

which can be written as

$$[B(s)]\{x(s)\} = \{F(s)\} \qquad \Rightarrow \qquad [B(s)]^{-1} = \frac{\{x(s)\}}{\{F(s)\}}$$

The inverse of the system matrix [B(s)] gives the System Transfer Matrix

$$[B(s)]^{-1} = [H(s)] = \frac{\text{Adj}[B(s)]}{\det[B(s)]} = \frac{[A(s)]}{\det[B(s)]}$$

The system transfer function can be written in matrix form in terms of the poles and residues of a system in partial fraction form as

$$\left[H(s)\right] = \sum_{k=1}^{m} \frac{\left[A_k\right]}{\left(s - p_k\right)} + \frac{\left[A_k^*\right]}{\left(s - p_k^*\right)}$$

or as an individual input/output 'ij' term as

$$h_{ij}(s) = \sum_{k=1}^{m} \frac{a_{ijk}(s)}{\left(s - p_k\right)} + \frac{a_{ijk}(s)^*}{\left(s - p_k^*\right)}$$

When the system transfer function is evaluated at s=jω, then the resulting function is called the *Frequency Response Function* (FRF) and is given by

$$\left[H(s)\right]_{s=j\omega} = \left[H(j\omega)\right] = \sum_{k=1}^{m} \frac{\left[A_k\right]}{\left(j\omega - p_k\right)} + \frac{\left[A_k^*\right]}{\left(j\omega - p_k^*\right)}$$

or as an individual input/output 'ij' term as

$$h_{ij}(s)_{s=j\omega} = h(j\omega) = \sum_{k=1}^{m} \frac{a_{ijk}}{\left(j\omega - p_k\right)} + \frac{a_{ijk}^*}{\left(j\omega - p_k^*\right)}$$

In essence, the frequency response function is made up of a collection of single degree of freedom systems summed up over all of the modes of the systems.

Now the system transfer function can be evaluated for a given system pole and can be broken down, through singular valued decomposition techniques, to give

$$\left[H(s)\right]_{s=p_k} = \left\{u_k\right\} \frac{q_k}{s - p_k} \left\{u_k\right\}^T$$

Considering all of the modes of the system, we can write

$$\left[H(s)\right] = \sum_{k=1}^{m} \frac{q_k \left\{u_k\right\}\left\{u_k\right\}^T}{\left(s - p_k\right)} + \frac{q_k \left\{u_k^*\right\}\left\{u_k^*\right\}^T}{\left(s - p_k^*\right)}$$

Notice that from this, a relationship between the residue matrix and the mode shapes of the system can be written. This directly implies that the mode shapes of the system are contained within the residue matrix.

The process of experimental modal analysis is to decompose the frequency response functions into their characteristic poles (frequency and damping) and residues (mode shapes) is a complicated process. The estimation of modal parameters is generally performed over frequency bands of the measured data as shown in Figure 2.1.

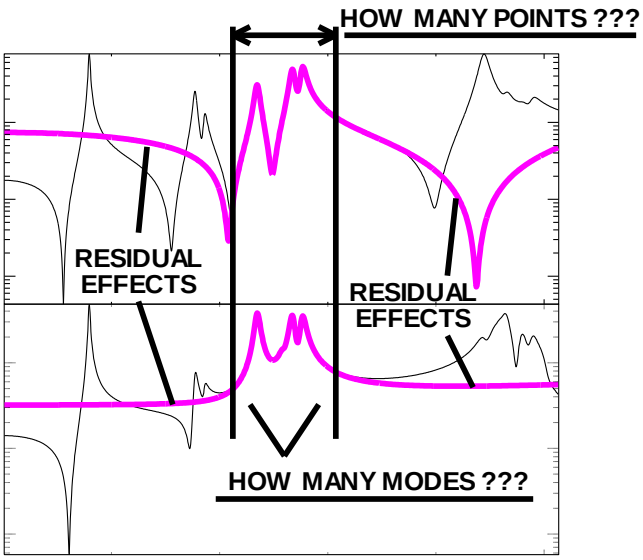


Figure 2.1 - Conceptual Overview of the Modal Parameter Estimation Process

The process of curvefitting essentially attempts to decompose the frequency response function shown in Figure 2.2 into the summation of a set of single degree of freedom frequency responses.

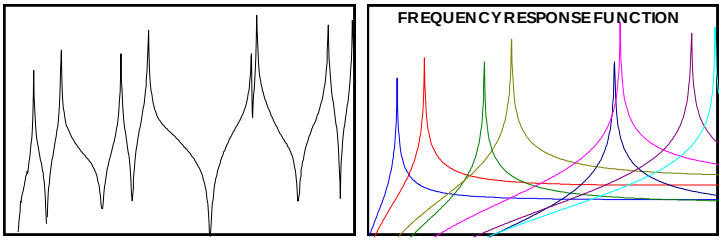


Figure 2.2 - Modal Decomposition of the Frequency Response Function

The frequency, damping and residues or mode shapes can be extracted from every frequency response function. The complete set of frequency response functions is used to extract mode shapes as illustrated in Figures 2.3.

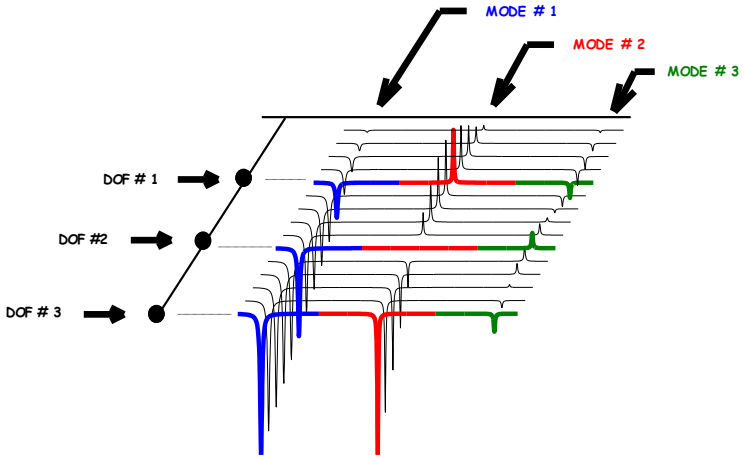


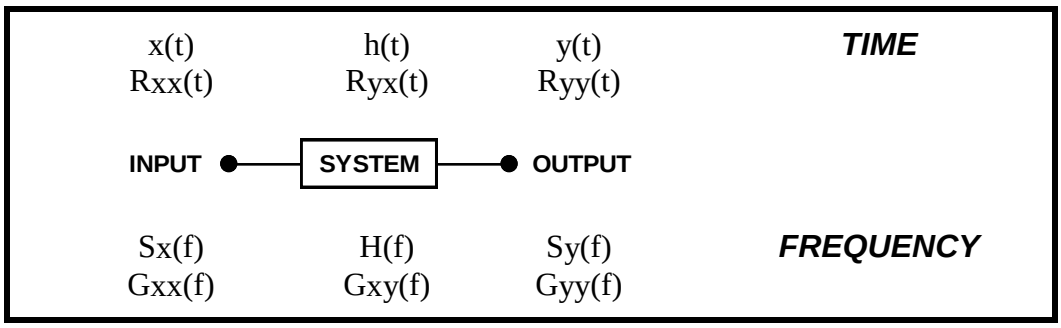
Figure 2.3 - Schematic of Mode Shape Estimation from Measured Data

2.2 Applicable Measurement Theory

From a measurement standpoint, the estimation of either operating data or frequency response data requires response data and reference data. With these linear spectra, averaged functions can be acquired necessary to form the cross power spectra required for the generation of operating data and for frequency response data required for the generation of modal data. One commonly used form of the frequency response function is

$$S_y = H\,S_X \qquad\qquad S_y S_x^* = H S_x S_x^* \Rightarrow H_1 = \frac{G_{yx}}{G_{xx}}$$

The input/output model and definition of linear and square law relationships is shown schematically in Figure 2.4.



where

x(t)	- time domain input to the system	y(t)	- time domain output to the system
Sx(f)	- linear Fourier spectrum of x(t)	Sy(f)	- linear Fourier spectrum of y(t)
H(f)	- system transfer function	h(t)	- system impulse response
Rxx(t)	- autocorrelation of the input signal x(t)	Ryy(t)	- autocorrelation of the output signal y(t)
Gxx(f)	- autopower spectrum of x(t)	Gyy(f)	- autopower spectrum of y(t)
Gyx(f)	- cross power spectrum of y(t) and x(t)	Ryx(t)	- cross correlation of y(t) and x(t)

Figure 2.4 - Definition of Input/Output Measurements

The overall measurement process is not described in detail herein. However, the overview of the process is shown schematically in Figure 2.5. In essence, the analog data is digitized and transformed from the time to the frequency domain (with windows if necessary) to form the linear spectra of the input and output. These functions are used to compute averaged power spectra (auto and cross) to be used to form the frequency response functions and coherence.

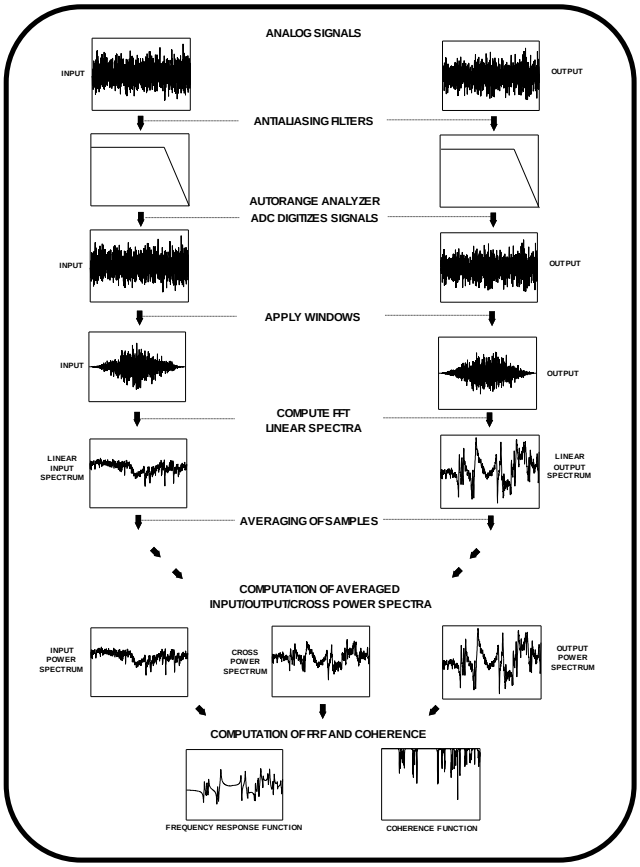


Figure 2.5 - The Overall Measurement Process

For the development of a modal model, the measurement of the input excitation and response of the system due to that excitation is necessary. This allows for the development of an averaged frequency response function. Using these frequency response functions, modal parameter estimation algorithms are used to extract the characteristic modal information. An overview of the process is shown schematically in Figure 2.6.

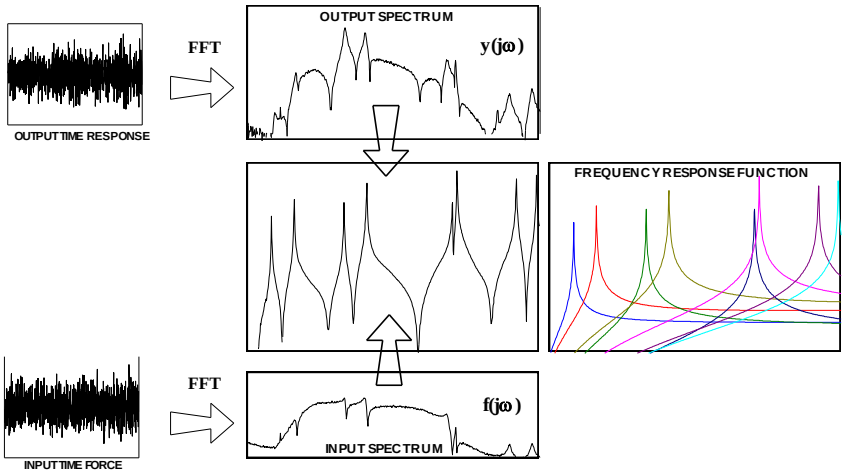


Figure 2.6 - Overview of Measurement Development

2.3 Typical Impact Measurement

Generally, impact frequency response functions can be obtained through averaging time data and forming averaged functions directly or through time data that is captured directly to disk. In either event, the acquired time data is then used with some trigger levels to initial the start of one record or block of data. This process is continued until all averages are completed or until the entire stream of time data is completed. Basically, the time signals are transformed from the time to the frequency domain using the FFT algorithm. These linear spectra are used to form auto and cross power spectra, which are then averaged. These averaged power spectra are then used to formulate the frequency response function and the coherence. These FRFs are then used in the modal parameter estimation process to extract modal information. Typical representative data used is shown in Figure 2.7.

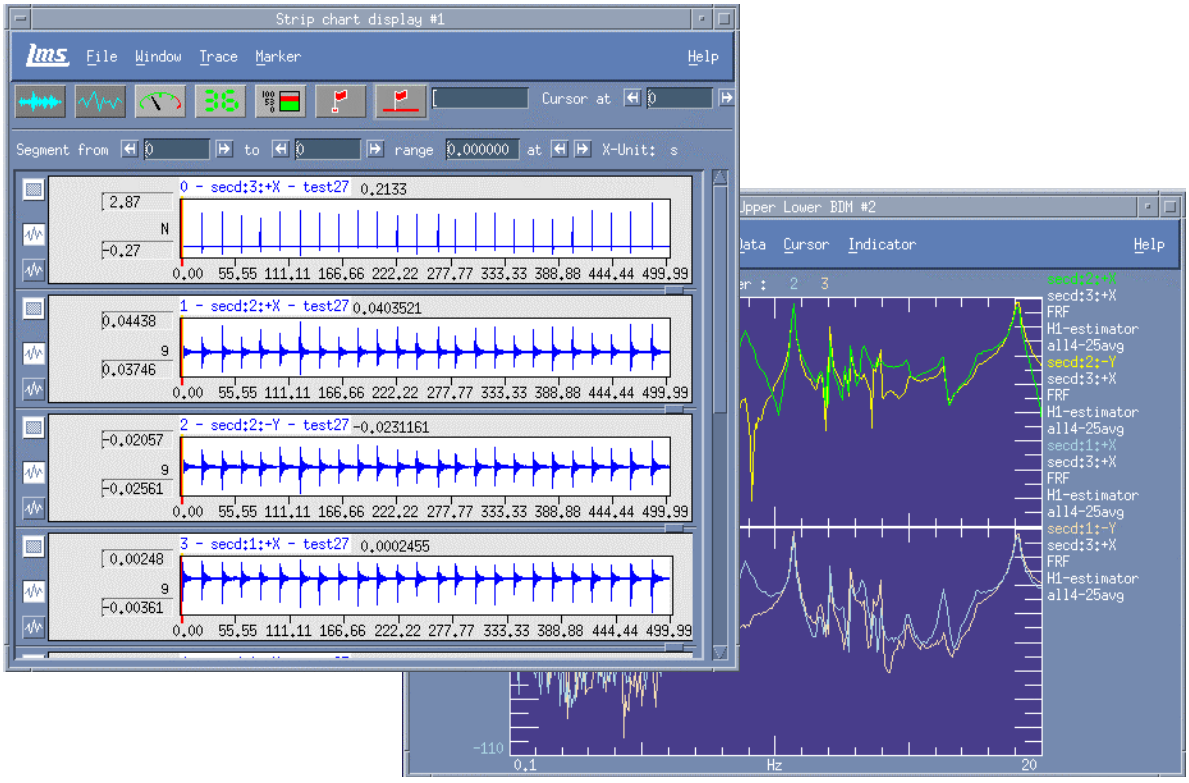


Figure 2.7 - Typical Impact Measurement Data Development

3.0 DATA/RESULTS/REMARKS - IMPORTANT TEST/ANALYSES PERFORMED

An impact test was conducted on the blade. This section will describe the various tests and modal analyses performed.

The CX-100 wind turbine blade is a 9 meter blade manufactured by TPI composites. The blade was clamped to a substantial fixture on site. Figure 3-1 shows a picture of the blade mounted to the fixture.

Figure 3-1. Blade Mounted to Fixture

Data was acquired for the purpose of modal characterization.

All equipment used during testing can be viewed in the equipment list located in Appendix A.

The blade was tested clamped to a substantial fixture and was impacted with a calibrated small impact sledgehammer.

Measurements were taken at 14 points on the blade by accelerometers in both the flapwise and edgewise directions. Measurements were also taken at 7 points on the fixture by accelerometers in both the flapwise and edgewise directions. Impacts were made at two points in the flapwise direction and two points in the edgewise direction. Accelerometer locations and impact points are shown in Figure 3-2. Photos of the test setup can be found in Appendix B.

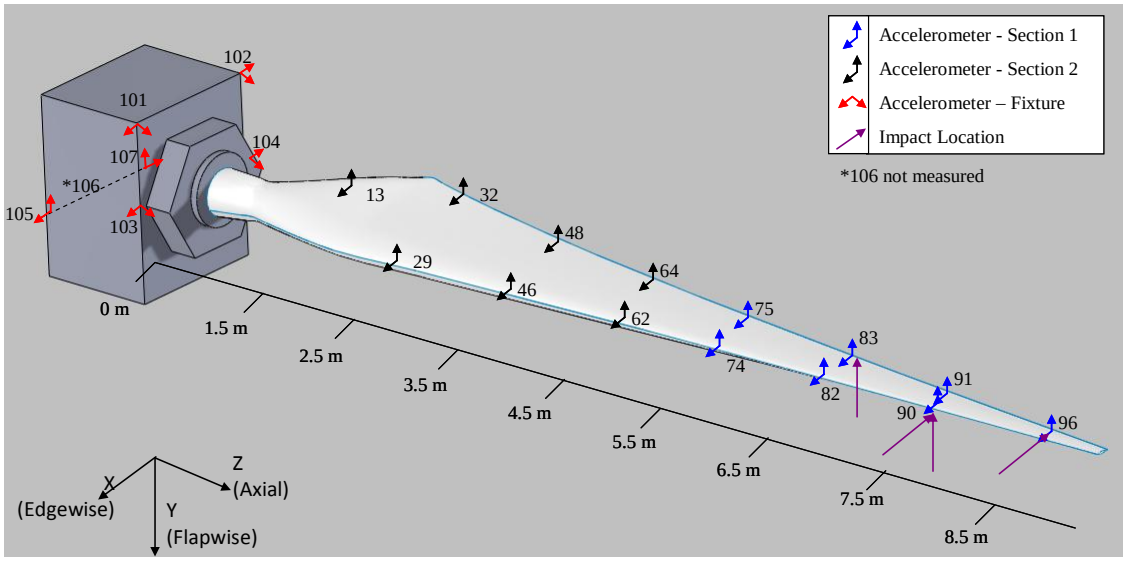


Figure 3-2 Impact points with accelerometer locations.

To gather data in both directions, two single-axis accelerometers were mounted to a block at each measurement point. A representative accelerometer mount is shown in Figure B-2. Impact data was acquired for each measurement point using five averages. LMS Test.Lab 10a was used for all data acquisition.

The acquired FRFs were used in the LMS PolyMAX modal parameter estimation algorithm. Several representative FRFs are shown in Appendix C. The FRFs were evaluated over the tested frequency range in order to extract poles. A stability diagram was used to select the best approximation of the root and then the data was fit using the frequency domain residue extraction. The frequencies and damping for the modes in the 0-50 Hz bandwidth are given in Table 3-1.

Table 3-1. Fixed-Free CX-100 Frequencies and Modes

Mode	Frequency (Hz)	Damping	Description
1	4.272	0.19%	Flap
2	6.216	0.29%	Edge
3	11.454	0.24%	Flap
4	20.004	0.36%	Edge
5	22.644	0.33%	Flap
6	35.018	0.34%	Flap
7	45.900	0.61%	Torsion
8	47.457	0.45%	Edge

The resulting mode shapes are shown in Appendix C.
All test set up and log sheets are included in Appendix D.

The measurement data is stored in universal file format as:
“NREL_CX100_120111_Measurements.unv”

The geometry is stored as:
“CX_100_and_Fixture_Geometry.unv”

The mode shapes are stored as:
“NREL_CX100_NoSaddle_Shapes.unv”

Appendix A
Equipment List

Table A-1. Equipment List

Name	Model	Serial No.	Sensitivity
Small Modal Impact Sledgehammer	086C20	12021	1 mV/lbf
Accelerometer Pt. 13+X	336C	11342	1.00800 V/g
Accelerometer Pt. 13-Y	336C	11328	1.02200 V/g
Accelerometer Pt. 29+X	336C	14968	1.01500 V/g
Accelerometer Pt. 29-Y	336C	13473	1.02400 V/g
Accelerometer Pt. 32+X	336C	12313	1.02300 V/g
Accelerometer Pt. 32-Y	336C31	8975	0.97240 V/g
Accelerometer Pt. 46+X	336C31	8867	1.00080 V/g
Accelerometer Pt. 46-Y	336C31	8870	1.00600 V/g
Accelerometer Pt. 48+X	336C	14970	0.98000 V/g
Accelerometer Pt. 48-Y	336C	15522	1.01300 V/g
Accelerometer Pt. 62+X	336C31	8873	0.99430 V/g
Accelerometer Pt. 62-Y	336C	11337	1.05400 V/g
Accelerometer Pt. 64+X	336C	11320	1.02600 V/g
Accelerometer Pt. 64-Y	336C	11326	1.01400 V/g
Accelerometer Pt. 74+X	336C	11335	1.04800 V/g
Accelerometer Pt. 74-Y	336C	11336	1.01800 V/g
Accelerometer Pt. 75+X	336C	13477	1.00300 V/g
Accelerometer Pt. 75-Y	336C	11324	1.02500 V/g
Accelerometer Pt. 82+X	336C	13472	1.00900 V/g
Accelerometer Pt. 82-Y	336C	11329	1.01500 V/g
Accelerometer Pt. 83+X	336C	15518	1.01000 V/g
Accelerometer Pt. 83-Y	336C31	8857	1.00910 V/g
Accelerometer Pt. 90+X	336C	15520	1.10000 V/g
Accelerometer Pt. 90-Y	336C31	8865	1.01162 V/g
Accelerometer Pt. 91+X	336C	11330	1.00800 V/g
Accelerometer Pt. 91-Y	336C	15519	1.02000 V/g
Accelerometer Pt. 96+X	336C	11334	1.03100 V/g
Accelerometer Pt. 96-Y	336C	11333	1.02100 V/g
Accelerometer Pt. 101+X	336C	13476	1.00200 V/g
Accelerometer Pt. 101+Z	336C	13480	1.01300 V/g
Accelerometer Pt. 102-X	336C	11332	1.01900 V/g
Accelerometer Pt. 102+Z	336C	15521	0.99000 V/g
Accelerometer Pt. 103+X	336C	11321	1.02100 V/g
Accelerometer Pt. 103+Z	336C	14978	1.02000 V/g
Accelerometer Pt. 104-X	336C	11322	1.01000 V/g
Accelerometer Pt. 104+Z	336C	11327	1.00400 V/g
Accelerometer Pt. 105+X	336C	14977	1.02200 V/g
Accelerometer Pt. 105-Y	336C	13474	0.99400 V/g
Accelerometer Pt. 107-X	336C	11339	1.03300 V/g
Accelerometer Pt. 107-Y	336C	14979	0.94000 V/g

Appendix B
Test Photos

Figure B-1. Blade Mounted to Fixture.

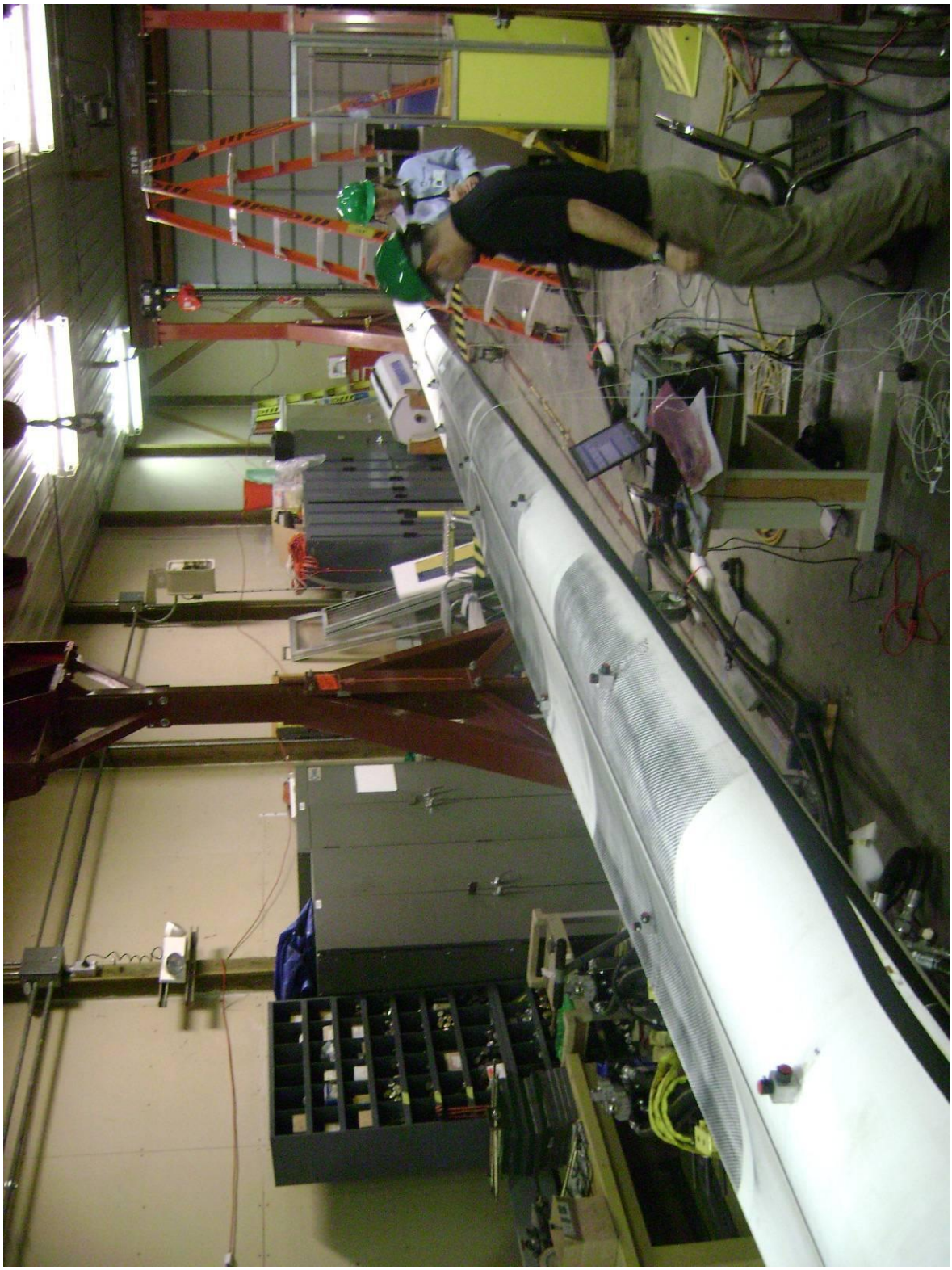


Figure B-2. General View of Accelerometers on Blade

Figure B-3. Back of Fixture.

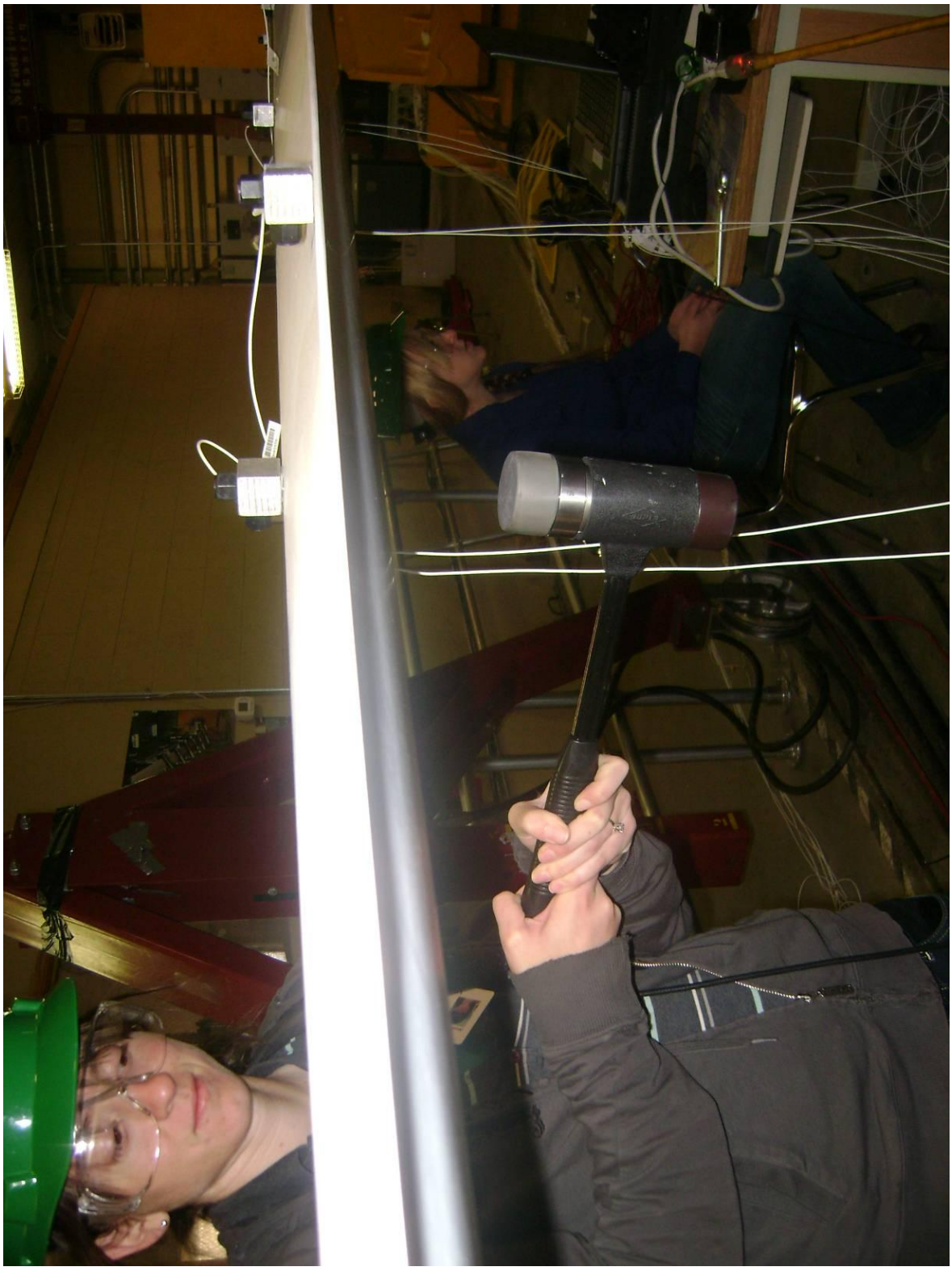


Figure B-4. Impacting in Flapwise Direction.

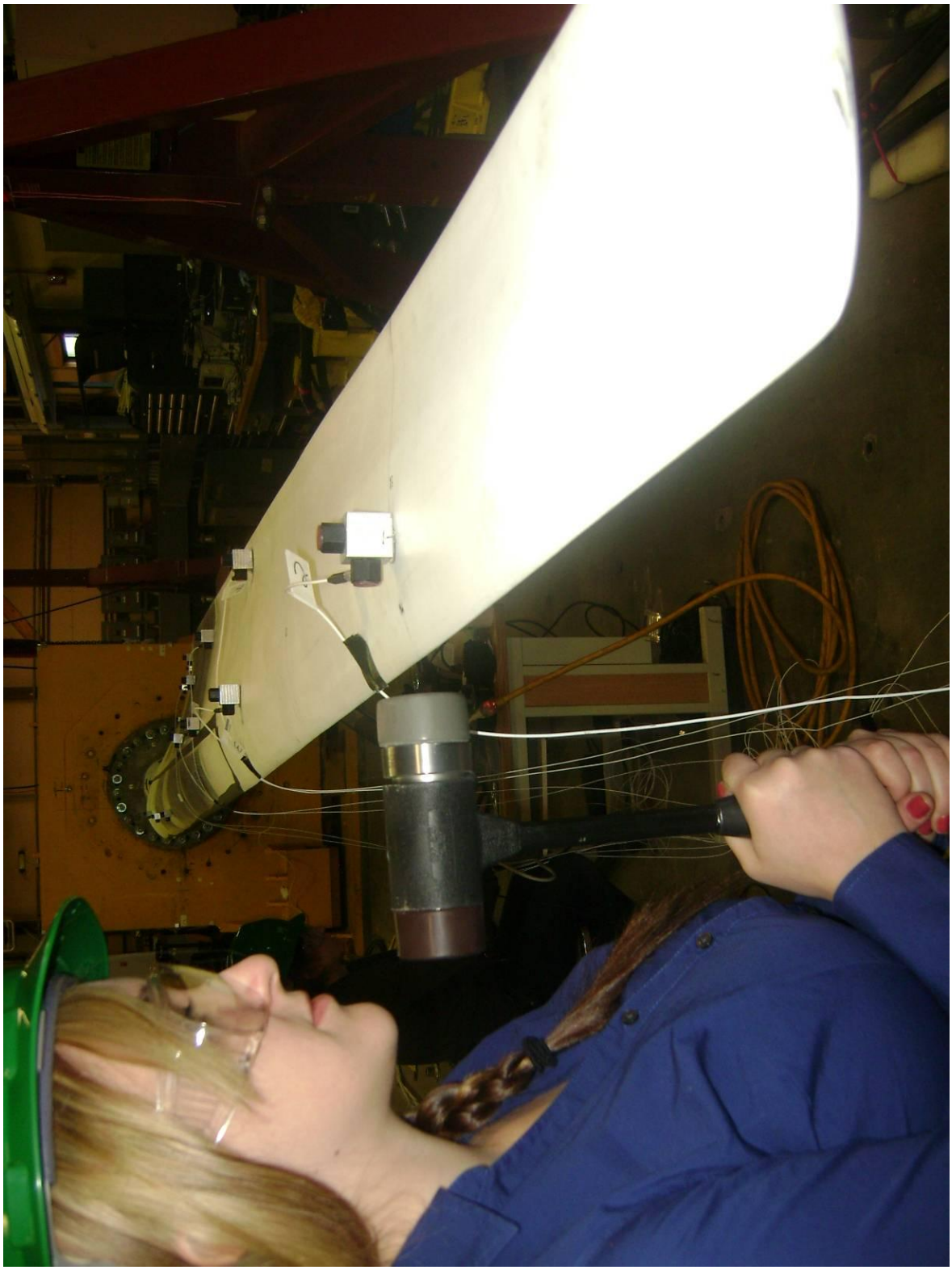


Figure B-5. Impacting in Edgwise Direction.

Figure B-6. Accelerometer on Mounting Block: Point 90, Top View.

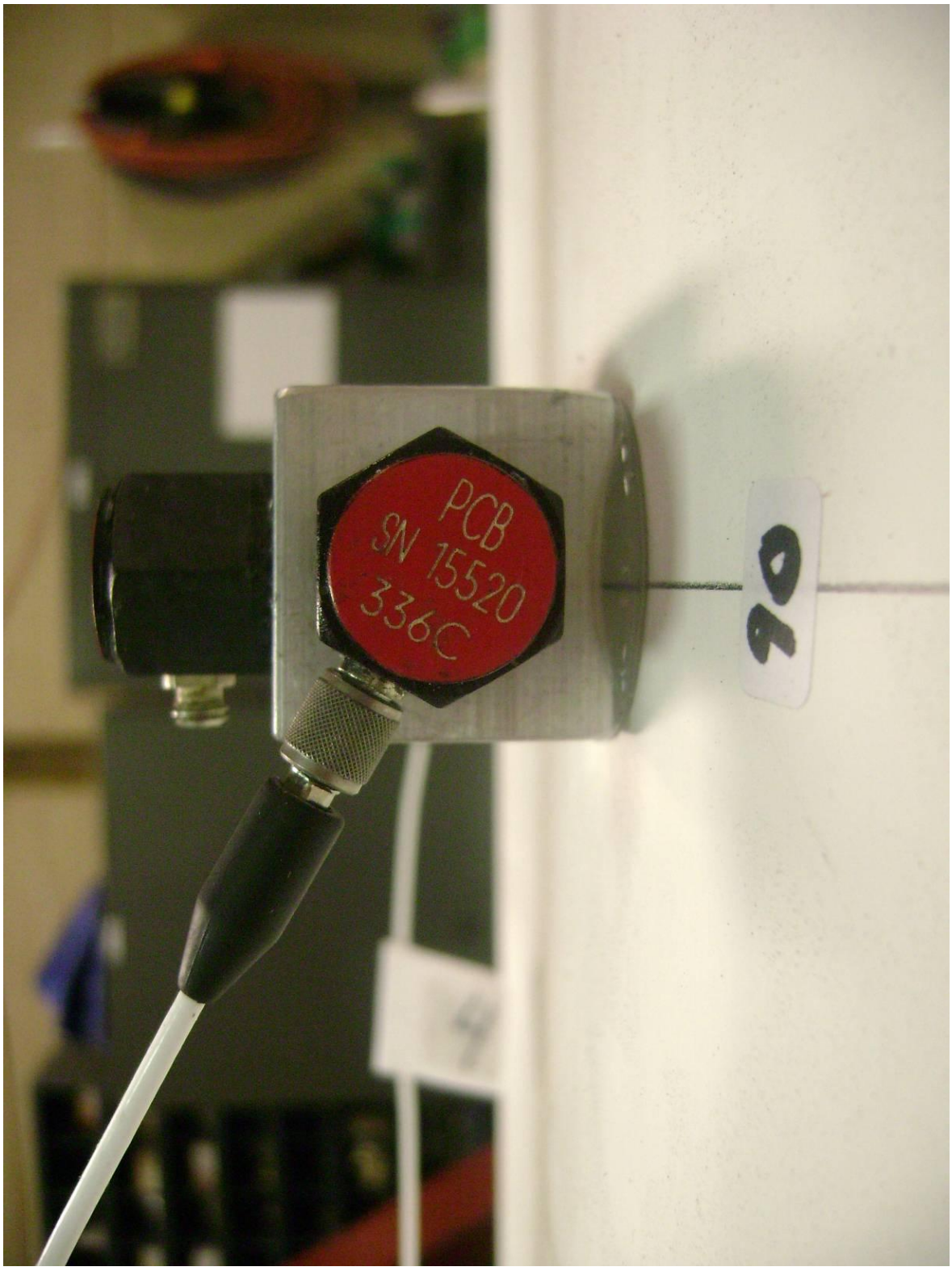


Figure B-7. Accelerometer on Mounting Block: Point 90, Side View

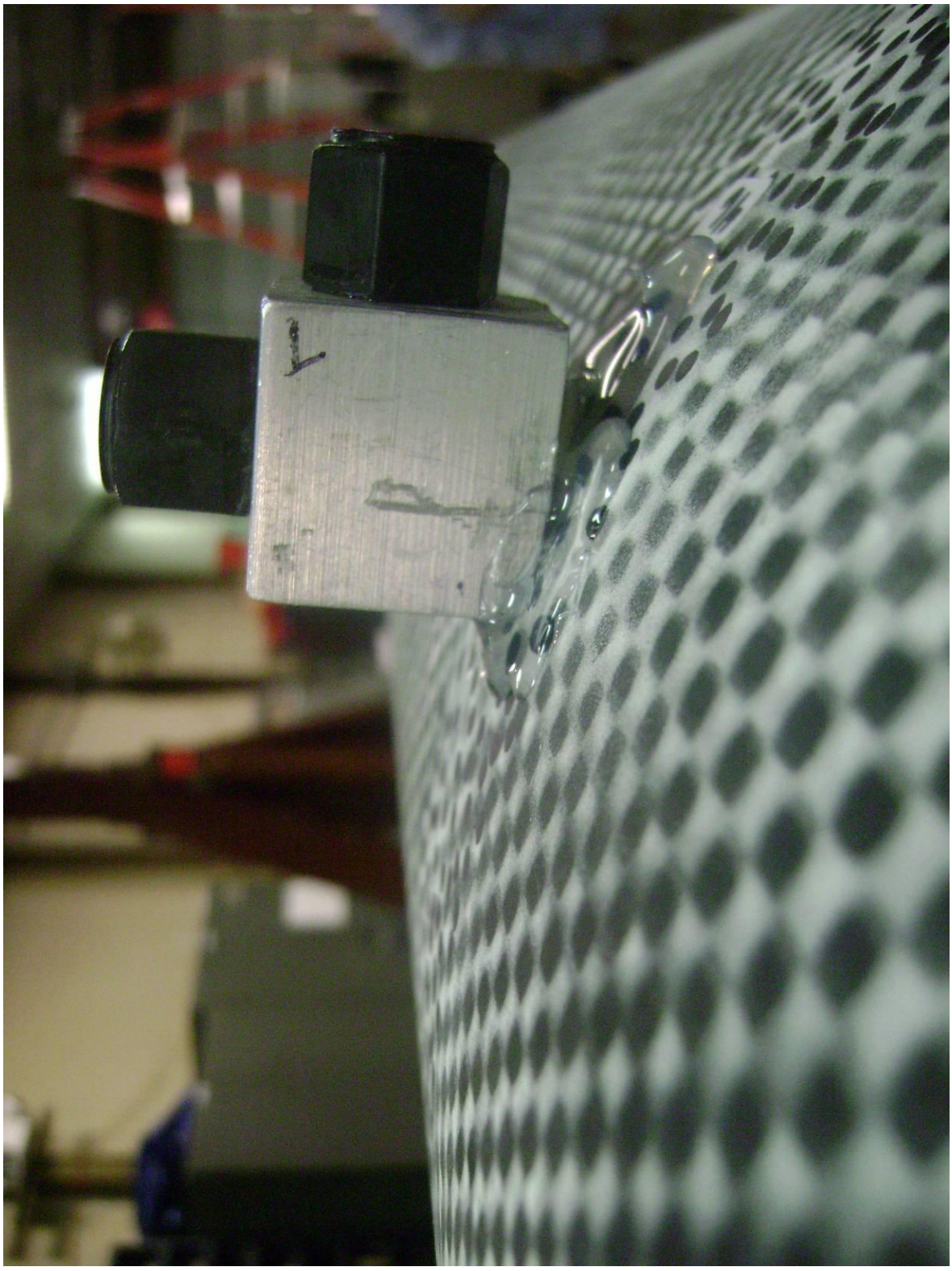


Figure B-8. Accelerometer Kept Level with Glue.

Figure B-9. Accelerometer on Fixture.

Appendix C
Sample FRFs and Mode Shapes

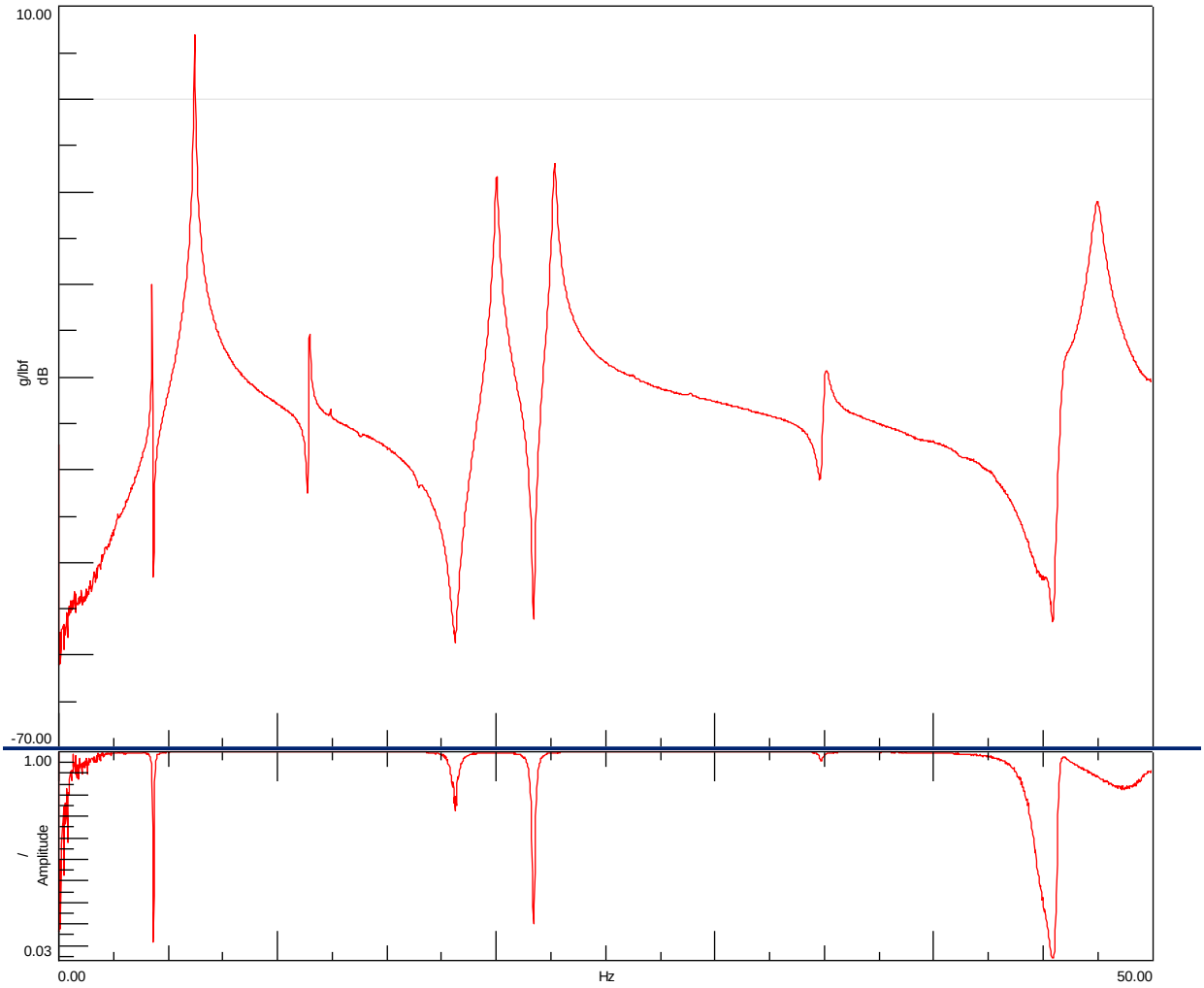


Figure C-1. Drive Point FRF and Coherence at 90X (Edgewise)

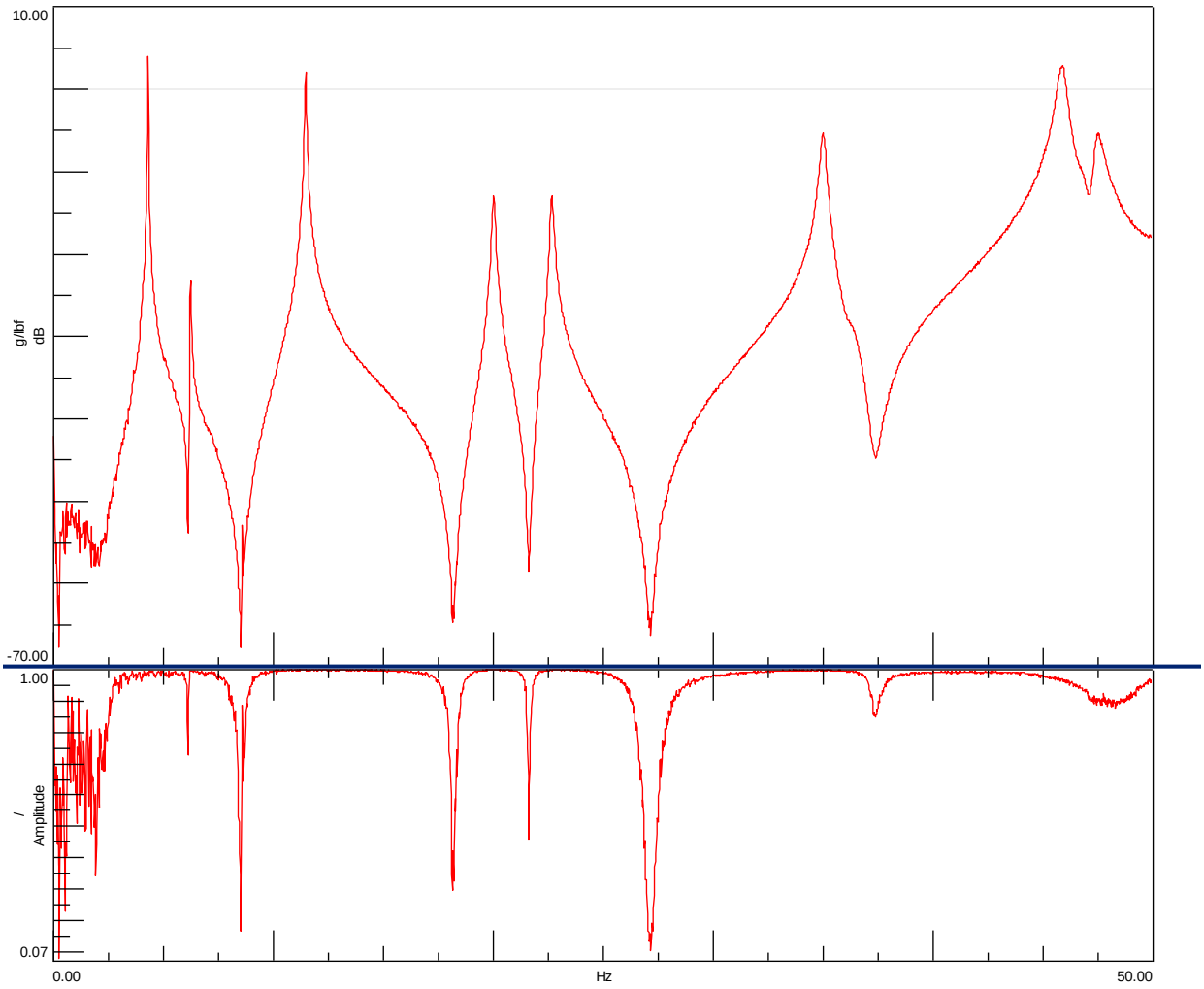


Figure C-2. Drive Point FRF and Coherence at 83Y (Flapwise)

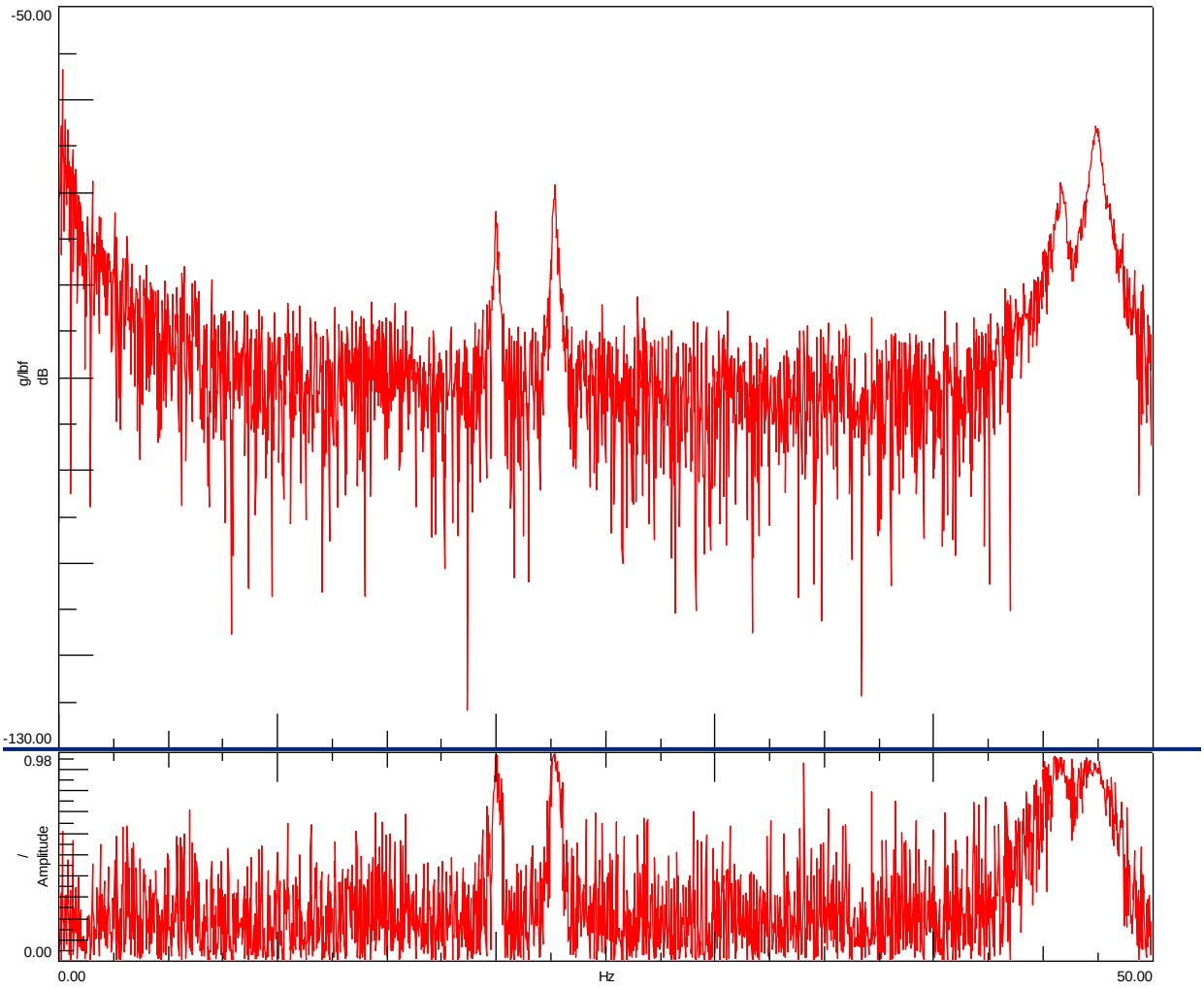


Figure C-3. Typical Fixture Measurement, Pt 101X

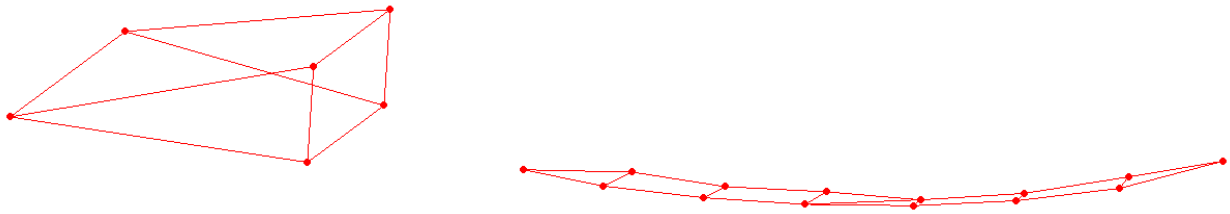


Figure C-4. Mode 1, 4.272 Hz

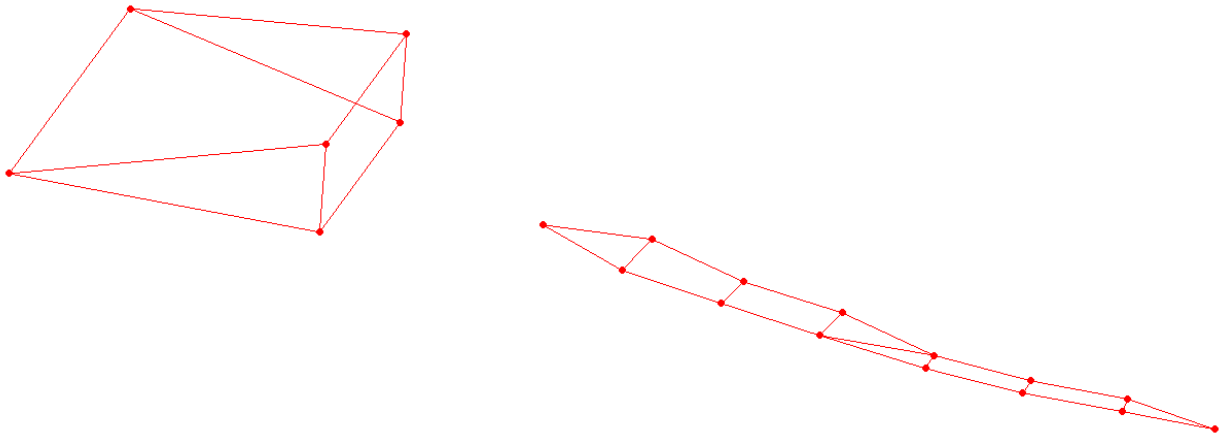


Figure C-5. Mode 2, 6.216 Hz

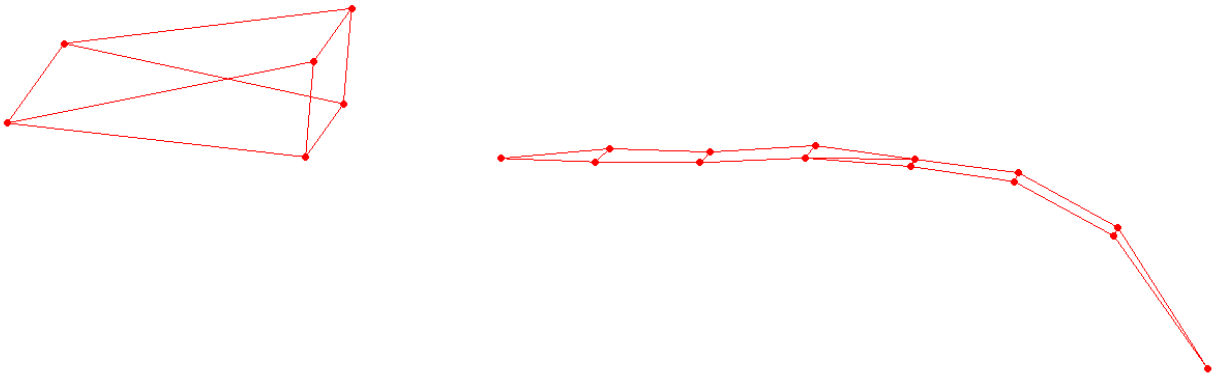


Figure C-6. Mode 3, 11.454 Hz

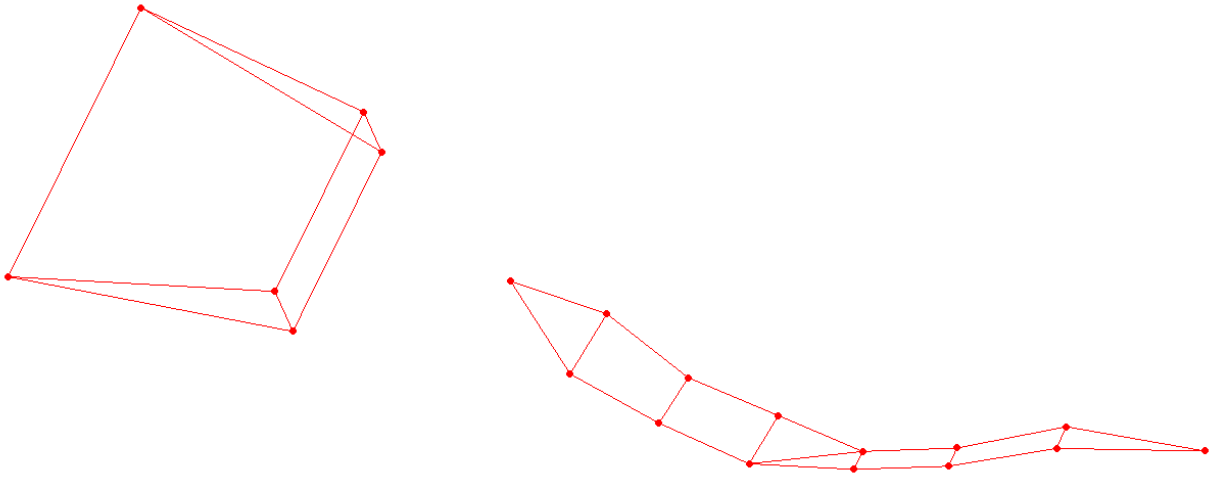


Figure C-7. Mode 4, 20.004 Hz

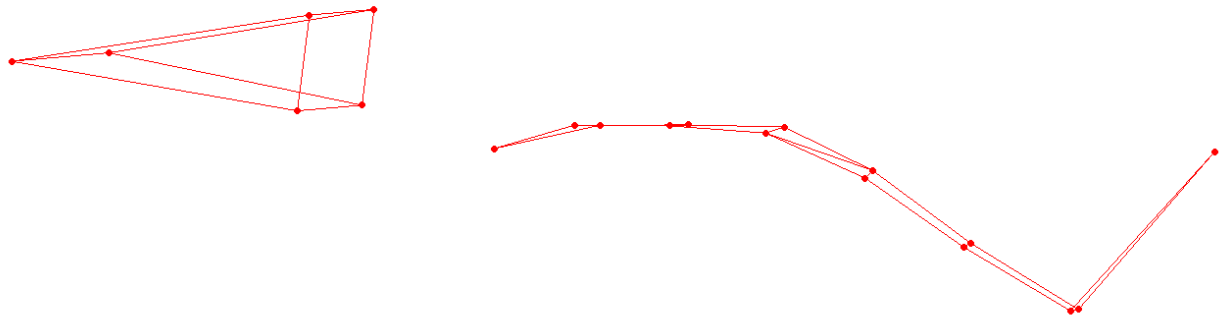


Figure C-8. Mode 5, 22.644 Hz

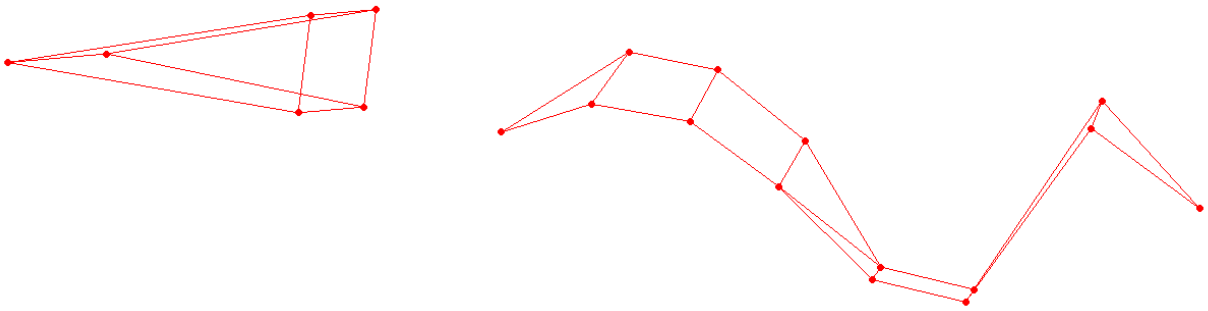


Figure C-9. Mode 6, 35.018 Hz

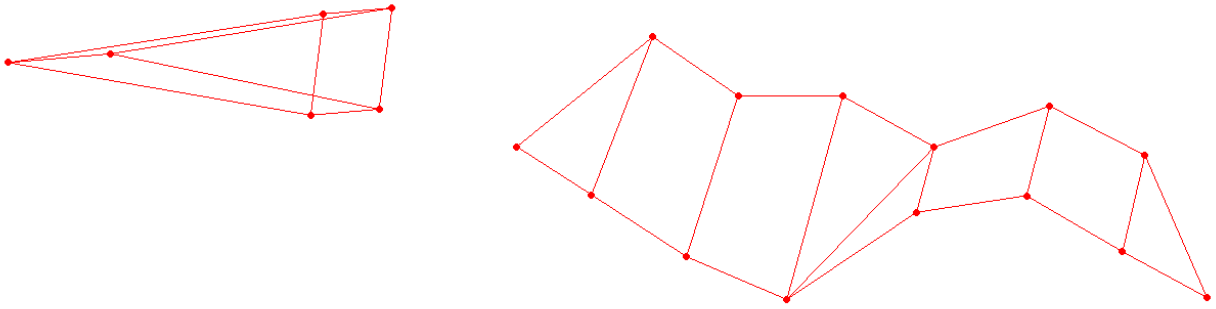


Figure C-10. Mode 7, 45.900 Hz

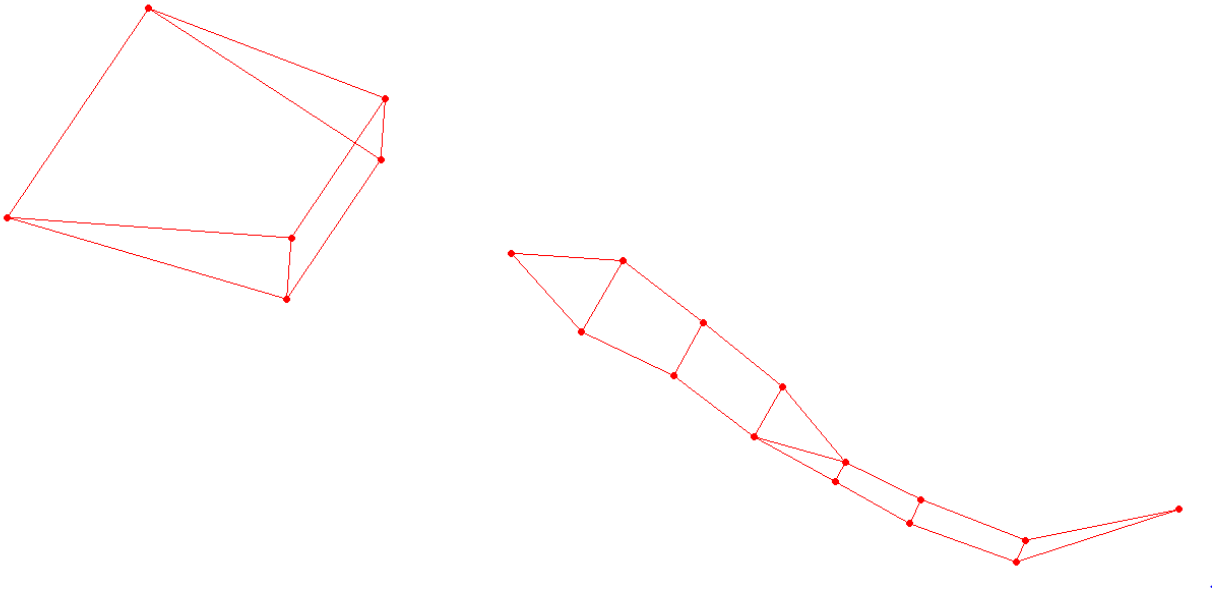


Figure C-11. Mode 8, 47.457 Hz

Appendix D
Test Sheets

1

TEST SETUP SUMMARY SHEET

Project: NREL CX-100 Date: 12/2/2011

Test: Blade no saddles References: LMS accelerometers

MODAL TEST SETUP

SOURCE SHAKER ☐ Number of Inputs: 1
IMPACT ☒ Number of References: 7 per test

Shaker Signal: ☐Burst Random ____% Block ☐Chirp ☐Random ☐Pseudo ☐Stepped Sine

SIGNAL PROCESSING PARAMATERS

Block Size: 256/200 ~~512/400~~ 1024/800 (2048/1600) 4096/3200 8192/6400

Frequency Center Freq ~~50 Hz~~ 25 Hz JH 12/2/11 Bandwidth ~~100 Hz~~ → 50Hz JH 12/2/11

FRF Type H_1 H_2 H_v

Input Window Type: ☑Rectangular ☐Hanning ☐Flattop ☐Force ☐Exponential ☐_____

Input Window Type: ☐Rectangular ☐Hanning ☐Flattop ☐Force ☐Exponential ☐_____

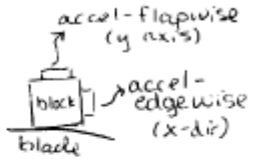
SKETCH OF TEST SETUP

trigger level: 0.010765 V

pre trigger 0.03 s

side view

averages



Julie Harvie

(1)

MODAL PARAMETER ESTIMATION SUMMARY SHEET

Project: NREL_CX100_120111_900d Date: 1/12/12

Test: 11 References: 83:-Y, 90:-Y, 90:-X, 96:-X

Analysis: 11 Sift: —

MODAL PARAMETER ESTIMATION

SINGLE DOF METHODS

Reference Used: _____

Method: ☐Amplitude ☐Complex Amplitude ☐Co-Quad ☐Polynomial ☐Residual Terms

Frequency Bands _____ _____ _____ _____ _____

LSCE / RFP / POLYMAX - POLE ESTIMATION

Bandwidth – Hz	# of modes	Residuals (U L B N)
0 – 15	3	L
15 – 50	5	U

4.272 (0.19%) - 1st Flap
6.216 (0.29%) - 1st Edge
11.454 (0.24%) - 2nd Flap
20.004 (0.36%) - 2nd Edge
22.644 (0.33%) - 3rd Flap
35.018 (0.34%) - 4th Flap
45.900 (0.61%) - 1st Torsion
47.457 (0.45%) - 3rd Edge

RESIDUE ESTIMATION

Bandwidth – Hz	# of modes	Method (C R)	Residuals (U L B N)	Processing Name
0 – 50	9	C	U	NREL_CX100_AllRef_AllRsp

Structural Dynamics and Acoustic Systems Laboratory
University of Massachusetts Lowell
http://sdasl.uml.edu

Modal Parameter Estimation Summary Sheet
Rev 071509

Twenty Twelve
1/12/12

(1)

Model PCB 336C or 336C21

Accelerometer list (All nominal sensitivities: 1 V/g)

Point	Edge (x)	Flap (y)
96	11334 ✓	11333 ✓
90	15520 ✓	8865 ✓
91	11330 ✓	15519 ✓
82	13472 ✓	11329 ✓
83	15518 ✓	8857 ✓
74	8851 ✓ *	11336 ✓
75	13477 ✓	11324 ✓
62	8873 ✓	11337 ✓
64	11320 ✓	11326 ✓
46	8867 ✓	8870 ✓
48	14970 ✓	15522 ✓
29	14968 ✓	13473 ✓
32	12313 ✓	8975 ✓
13	11342 ✓	11328 ✓

Fixture on next page

*74 edge changed to 11335

(2)

Point	Edge (x)	Flap (Y)
101	13476 (+)	13480 - Z axis (+)
102	11332 (-)	11317** -Z axis (+)
103	11321 (+)	11335*** -Z axis (+)
104	11322 (-)	11327 -Z axis (+)
105	14977 (+)	13474 (-)
* 106	15521	14978
107	11339 (-)	14979 (-)

* Pt. 106 not measured due to inadequate number of red accels.

** Pt. 102: +Z accel changed to 15521

*** Pt. 103: +Z accel changed to 14978

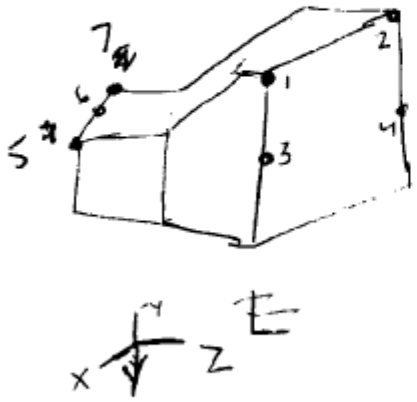
(3)

LMS Channel Setup - Section 1 (Tip)

Ch 2: Pt 96
Ch 3: Pt 90
Ch 4: Pt 91
Ch 5: Pt 82
Ch 6: Pt 83
Ch 7: Pt 74
Ch 8: Pt 75

(4)

Fixture Coordinates



Pt	Dimensions in m
1	(0.1, -0.094, -0.015)
2	(-0.1, -0.094, -0.015)
3	(0.1, 0, -0.015)
4	(-0.1, 0, -0.015)
5	(-0.15, -0.01, -0.295)
6	(0, -0.01, -0.295)
7	(0.15, -0.01, -0.295)

(5)

12/2/11

Note blade is slightly skewed
(might have everything rotated slightly as compared to previous tests)

(1)

(Marinone) Pt #	X (m)	
96	0	
90	0	
91	-0.1982	✓
82	0	✓
83	-0.1936	✓
74	0	✓
75	-0.1992	✓
62	0.1948	✓
64	-0.3803	✓
46	0.1916	✓
48	-0.3835	✓
29	0.189	✓
32	-0.5826	✓
13	-0.3824	✓

Data Save Convention:

Impact Pt	Impact Direction	Accel Location/Dir	File Name
90	-X	Tip / Edge	90_-X
96	-X	Tip / Edge	96_-X
90	+Y	Tip / Edge	90_+Y
83	+Y	Tip / Edge	83_+Y
90	-X	Tip / Flap	90_-X 1
96	-X	Tip / Flap	96_-X 1
90	+Y	Tip / Flap	90_+Y 1
83	+Y	Tip / Flap	83_+Y 1
90	-X	Root / Edge	90_-X2 *
96	-X	Root / Edge	96_-X2 *
90	+Y	Root / Edge	90_+Y2
83	+Y	Root / Edge	83_+Y 2
90	-X	Root / Flap	90_-X3
96	-X	Root / Flap	96_-X3
90	+Y	Root / Flap	90_+Y 3
83	+Y	Root / Flap	

* Note: 2 tests were performed in this configuration. The bad data (incorrect points/sensitivities) are saved in section "Junk Data"

(3)

Fixture Test

Impact Pt	Impact Dir	Accel Location / Dir	Fil Name
90	-X	fixture/x-axis	90_-X 4
96	-X	fixture / x-axis	96_-X4
90	+Y	fixture/x-axis	90_+Y 4
83	+Y	fixture/x-axis	83_+Y 4
90	-X	fixture / y+z axes	90_-X 5
96	-X	fixture / y+z axes	96_-X 5
90	+Y	fixture / y+z axes	90_+Y 5
83	+Y	fixture / y+z axes	

- Note measurements actually impacted in -Y dir. although saved as +Y dir.

Appendix E

Universal File Format Specifications

NOTE: While this appendix identifies the typical universal file format, there is no guarantee that all vendors follow this format exactly.

Universal Dataset Number: 58

Name: Function at Nodal DOF
Status: Current
Owner: Test
Revision Date: 23-Apr-1993

Record 1: Format(80A1)
Field 1 - ID Line 1

NOTE

ID Line 1 is generally used for the function description.

Record 2: Format(80A1)
Field 1 - ID Line 2

Record 3: Format(80A1)
Field 1 - ID Line 3

NOTE

ID Line 3 is generally used to identify when the function was created. The date is in the form DD-MMM-YY, and the time is in the form HH:MM:SS, with a general Format(9A1,1X,8A1).

Record 4: Format(80A1)
Field 1 - ID Line 4

Record 5: Format(80A1)
Field 1 - ID Line 5

Record 6: Format(2(I5,I10),2(1X,10A1,I10,I4))
DOF Identification
Field 1 - Function Type
0 - General or Unknown
1 - Time Response
2 - Auto Spectrum
3 - Cross Spectrum
4 - Frequency Response Function
5 - Transmissibility
6 - Coherence
7 - Auto Correlation
8 - Cross Correlation
9 - Power Spectral Density (PSD)
10 - Energy Spectral Density (ESD)
11 - Probability Density Function
12 - Spectrum
13 - Cumulative Frequency Distribution
14 - Peaks Valley
15 - Stress/Cycles
16 - Strain/Cycles
17 - Orbit
18 - Mode Indicator Function
19 - Force Pattern
20 - Partial Power
21 - Partial Coherence
22 - Eigenvalue

23 - Eigenvector
24 - Shock Response Spectrum
25 - Finite Impulse Response Filter
26 - Multiple Coherence
27 - Order Function

Field 2 - Function Identification Number
Field 3 - Version Number, or sequence number
Field 4 - Load Case Identification Number
0 - Single Point Excitation
Field 5 - Response Entity Name ("NONE" if unused)
Field 6 - Response Node
Field 7 - Response Direction
0 - Scalar
1 - +X Translation 4 - +X Rotation
-1 - -X Translation -4 - -X Rotation
2 - +Y Translation 5 - +Y Rotation
-2 - -Y Translation -5 - -Y Rotation
3 - +Z Translation 6 - +Z Rotation
-3 - -Z Translation -6 - -Z Rotation
Field 8 - Reference Entity Name ("NONE" if unused)
Field 9 - Reference Node
Field 10 - Reference Direction (same as field 7)

NOTE

Fields 8, 9, and 10 are only relevant if field 4 is zero.

Record 7: Format(3I10,3E13.5)
Data Form
Field 1 - Ordinate Data Type
2 - real, single precision
4 - real, double precision
5 - complex, single precision
6 - complex, double precision
Field 2 - Number of data pairs for uneven abscissa spacing, or number of data values for even abscissa spacing
Field 3 - Abscissa Spacing
0 - uneven
1 - even (no abscissa values stored)
Field 4 - Abscissa minimum (0.0 if spacing uneven)
Field 5 - Abscissa increment (0.0 if spacing uneven)
Field 6 - Z-axis value (0.0 if unused)

Record 8: Format(I10,3I5,2(1X,20A1))
Abscissa Data Characteristics
Field 1 - Specific Data Type
0 - unknown
1 - general
2 - stress
3 - strain
5 - temperature
6 - heat flux
8 - displacement
9 - reaction force

11 - velocity
12 - acceleration
13 - excitation force
15 - pressure
16 - mass
17 - time
18 - frequency
19 - rpm
20 - order

Field 2 - Length units exponent
Field 3 - Force units exponent
Field 4 - Temperature units exponent

NOTE

Fields 2, 3 and 4 are relevant only if the Specific Data Type is General, or in the case of ordinates, the response/reference direction is a scalar, or the functions are being used for nonlinear connectors in System Dynamics Analysis. See Addendum 'A' for the units exponent table.

Field 5 - Axis label ("NONE" if not used)
Field 6 - Axis units label ("NONE" if not used)

NOTE

If fields 5 and 6 are supplied, they take precendence over program generated labels and units.

Record 9: Format(I10,3I5,2(1X,20A1))
Ordinate (or ordinate numerator) Data Characteristics

Record 10: Format(I10,3I5,2(1X,20A1))
Ordinate Denominator Data Characteristics

Record 11: Format(I10,3I5,2(1X,20A1))
Z-axis Data Characteristics

NOTE

Records 9, 10, and 11 are always included and have fields the same as record 8. If records 10 and 11 are not used, set field 1 to zero.

Record 12:
Data Values

Case	Ordinate Type	Precision	Abscissa Spacing	Format
1	real	single	even	6E13.5
2	real	single	uneven	6E13.5
3	complex	single	even	6E13.5
4	complex	single	uneven	6E13.5
5	real	double	even	4E20.12
6	real	double	uneven	2(E13.5,E20.12)
7	complex	double	even	4E20.12
8	complex	double	uneven	E13.5,2E20.12

NOTE

See Addendum 'B' for typical FORTRAN READ/WRITE statements for each case.

General Notes:

1. ID lines may not be blank. If no information is required, the word "NONE" must appear in columns 1 through 4.

2. ID line 1 appears on plots in Finite Element Modeling and is used as the function description in System Dynamics Analysis.

3. Dataloaders use the following ID line conventions
   ID Line 1 - Model Identification
   ID Line 2 - Run Identification
   ID Line 3 - Run Date and Time
   ID Line 4 - Load Case Name

4. Coordinates codes from MODAL-PLUS and MODALX are decoded into node and direction.

5. Entity names used in System Dynamics Analysis prior to I-DEAS Level 5 have a 4 character maximum. Beginning with Level 5, entity names will be ignored if this dataset is preceded by dataset 259. If no dataset 259 precedes this dataset, then the entity name will be assumed to exist in model bin number 1.

6. Record 10 is ignored by System Dynamics Analysis unless load case = 0. Record 11 is always ignored by System Dynamics Analysis.

7. In record 6, if the response or reference names are "NONE" and are not overridden by a dataset 259, but the corresponding node is non-zero, System Dynamics Analysis adds the node and direction to the function description if space is sufficie

8. ID line 1 appears on XY plots in Test Data Analysis along with ID line 5 if it is defined. If defined, the axis units labels also appear on the XY plot instead of the normal labeling based on the data type of the function.

9. For functions used with nonlinear connectors in System Dynamics Analysis, the following requirements must be adhered to:

   a) Record 6: For a displacement-dependent function, the function type must be 0; for a frequency-dependent function, it must be 4. In either case, the load case identification number must be 0.

   b) Record 8: For a displacement-dependent function, the specific data type must be 8 and the length units exponent must be 0 or 1; for a frequency-dependent function, the specific data type must be 18 and the length units exponent must be 0. In either case, the other units exponents must be 0.

   c) Record 9: The specific data type must be 13. The temperature units exponent must be 0. For an ordinate numerator of force, the length and force units exponents must be 0 and 1, respectively. For an ordinate numerator of moment, the length and force units exponents must be 1 and 1, respectively.

d) Record 10: The specific data type must be 8 for stiffness and hysteretic damping; it must be 11 for viscous damping. For an ordinate denominator of translational displacement, the length units exponent must be 1; for a rotational displacement, it must be 0. The other units exponents must be 0.

e) Dataset 217 must precede each function in order to define the function's usage (i.e. stiffness, viscous damping, hysteretic damping).

Addendum A

In order to correctly perform units conversion, length, force, and temperature exponents must be supplied for a specific data type of General; that is, Record 8 Field 1 = 1. For example, if the function has the physical dimensionality of Energy (Force * Length), then the required exponents would be as follows:

Length = 1
Force = 1 Energy = L * F
Temperature = 0

Units exponents for the remaining specific data types should not be supplied. The following exponents will automatically be used.

Table - Unit Exponents

Specific Data Type	Direction: Translational Length	Translational Force	Translational Temp	Rotational Length	Rotational Force	Rotational Temp
0	0	0	0	0	0	0
1	(requires input to fields 2,3,4)					
2	-2	1	0	-1	1	0
3	0	0	0	0	0	0
5	0	0	1	0	0	1
6	1	1	0	1	1	0
8	1	0	0	0	0	0
9	0	1	0	1	1	0
11	1	0	0	0	0	0
12	1	0	0	0	0	0
13	0	1	0	1	1	0
15	-2	1	0	-1	1	0
16	-1	1	0	1	1	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0

NOTE

Units exponents for scalar points are defined within System Analysis prior to reading this dataset.

Addendum B

There are 8 distinct combinations of parameters which affect the details of READ/WRITE operations. The parameters involved are

Ordinate Data Type, Ordinate Data Precision, and Abscissa Spacing. Each combination is documented in the examples below. In all cases, the number of data values (for even abscissa spacing) or data pairs (for uneven abscissa spacing) is NVAL. The abcissa is always real single precision. Complex double precision is handled by two real double precision variables (real part followed by imaginary part) because most systems do not directly support complex double precision.

CASE 1

REAL
SINGLE PRECISION
EVEN SPACING

```
 Order of data in file          Y1   Y2   Y3   Y4   Y5   Y6
                          Y7   Y8   Y9   Y10  Y11  Y12
                                .
                                .
                                .
```

Input

```
        REAL Y(6)
         .
         .
         .
        NPRO=0
       10 READ(LUN,1000,ERR=  ,END=  )(Y(I),I=1,6)
     1000 FORMAT(6E13.5)
        NPRO=NPRO+6
         .
         .   code to process these six values
         .
        IF(NPRO.LT.NVAL)GO TO 10
         .
         .  continued processing
         .
```

Output

```
        REAL Y(6)
         .
         .
         .
        NPRO=0
       10 CONTINUE
         .
         .   code to set up these six values
         .
        WRITE(LUN,1000,ERR=  )(Y(I),I=1,6)
     1000 FORMAT(6E13.5)
        NPRO=NPRO+6

        IF(NPRO.LT.NVAL)GO TO 10
         .
         .  continued processing
         .
```

CASE 2

REAL
SINGLE PRECISION
UNEVEN SPACING

Order of data in file X1 Y1 X2 Y2 X3 Y3
X4 Y4 X5 Y5 X6 Y6
.
.
.

Input

```
      REAL X(3),Y(3)
       .
       .
       .
      NPRO=0
     10 READ(LUN,1000,ERR=  ,END=  )(X(I),Y(I),I=1,3)
   1000 FORMAT(6E13.5)
      NPRO=NPRO+3
       .
       .   code to process these three values
       .
      IF(NPRO.LT.NVAL)GO TO 10
       .
       .  continued processing
       .
```

Output

```
      REAL X(3),Y(3)
       .
       .
       .
      NPRO=0
     10 CONTINUE
       .
       .   code to set up these three values
       .
      WRITE(LUN,1000,ERR=  )(X(I),Y(I),I=1,3)
   1000 FORMAT(6E13.5)
      NPRO=NPRO+3
      IF(NPRO.LT.NVAL)GO TO 10
       .
       .  continued processing
       .
```

CASE 3

COMPLEX
SINGLE PRECISION
EVEN SPACING

Order of data in file RY1 IY1 RY2 IY2 RY3 IY3
RY4 IY4 RY5 IY5 RY6 IY6
.
.
.

Input

```
      COMPLEX Y(3)
       .
       .
       .
      NPRO=0
```

```
 10 READ(LUN,1000,ERR=  ,END=  )(Y(I),I=1,3)
1000 FORMAT(6E13.5)
   NPRO=NPRO+3
    .
    .   code to process these six values
    .
   IF(NPRO.LT.NVAL)GO TO 10
    .
    .  continued processing
    .
```

Output

```
   COMPLEX Y(3)
    .
    .
    .
   NPRO=0
 10 CONTINUE
    .
    .   code to set up these three values
    .
   WRITE(LUN,1000,ERR=  )(Y(I),I=1,3)
1000 FORMAT(6E13.5)
   NPRO=NPRO+3
   IF(NPRO.LT.NVAL)GO TO 10
    .
    .  continued processing
    .
```

CASE 4

COMPLEX
SINGLE PRECISION
UNEVEN SPACING

```
Order of data in file        X1   RY1  IY1  X2  RY2  IY2
                          X3   RY3  IY3  X4  RY4  IY4

                           .
                           .
                           .
```

Input

```
   REAL X(2)
   COMPLEX Y(2)
    .
    .
    .
   NPRO=0
 10 READ(LUN,1000,ERR=  ,END=  )(X(I),Y(I),I=1,2)
1000 FORMAT(6E13.5)
   NPRO=NPRO+2
    .
    .   code to process these two values
    .
   IF(NPRO.LT.NVAL)GO TO 10
    .
    .  continued processing
    .
```

Output

```
      REAL X(2)
      COMPLEX Y(2)
       .
       .
       .
      NPRO=0
   10 CONTINUE
       .
       .  code to set up these two values
       .
      WRITE(LUN,1000,ERR=  )(X(I),Y(I),I=1,2)
 1000 FORMAT(6E13.5)
      NPRO=NPRO+2
      IF(NPRO.LT.NVAL)GO TO 10
       .
       .  continued processing
       .
```

CASE 5

REAL
DOUBLE PRECISION
EVEN SPACING

Order of data in file Y1 Y2 Y3 Y4
Y5 Y6 Y7 Y8
.
.
.

Input

```
      DOUBLE PRECISION Y(4)
       .
       .
       .
      NPRO=0
   10 READ(LUN,1000,ERR=  ,END=  )(Y(I),I=1,4)
 1000 FORMAT(4E20.12)
      NPRO=NPRO+4
       .
       .  code to process these four values
       .
      IF(NPRO.LT.NVAL)GO TO 10
       .
       .  continued processing
       .
```

Output

```
      DOUBLE PRECISION Y(4)
       .
       .
       .
      NPRO=0
   10 CONTINUE
       .
       .  code to set up these four values
       .
      WRITE(LUN,1000,ERR=  )(Y(I),I=1,4)
 1000 FORMAT(4E20.12)
```

```
      NPRO=NPRO+4
      IF(NPRO.LT.NVAL)GO TO 10
       .
       . continued processing
       .
```

CASE 6

REAL
DOUBLE PRECISION
UNEVEN SPACING

Order of data in file X1 Y1 X2 Y2
X3 Y3 X4 Y4
.
.
.

Input

```
      REAL X(2)
      DOUBLE PRECISION Y(2)
       .
       .
       .
      NPRO=0
   10 READ(LUN,1000,ERR=  ,END=  )(X(I),Y(I),I=1,2)
 1000 FORMAT(2(E13.5,E20.12))
      NPRO=NPRO+2
       .
       .  code to process these two values
       .
      IF(NPRO.LT.NVAL)GO TO 10
       .
       . continued processing
       .
```

Output

```
      REAL X(2)
      DOUBLE PRECISION Y(2)
       .
       .
       .
      NPRO=0
   10 CONTINUE
       .
       .  code to set up these two values
       .
      WRITE(LUN,1000,ERR=  )(X(I),Y(I),I=1,2)
 1000 FORMAT(2(E13.5,E20.12))
      NPRO=NPRO+2
      IF(NPRO.LT.NVAL)GO TO 10
       .
       . continued processing
       .
```

CASE 7

COMPLEX
DOUBLE PRECISION
EVEN SPACING

Order of data in file RY1 IY1 RY2 IY2

```
                    RY3   IY3   RY4   IY4
                     .
                     .
                     .
```

Input

```
      DOUBLE PRECISION Y(2,2)
       .
       .
       .
      NPRO=0
   10 READ(LUN,1000,ERR=  ,END=  )((Y(I,J),I=1,2),J=1,2)
 1000 FORMAT(4E20.12)
      NPRO=NPRO+2
       .
       .   code to process these two values
       .
      IF(NPRO.LT.NVAL)GO TO 10
       .
       .  continued processing
       .
```

Output

```
      DOUBLE PRECISION Y(2,2)
       .
       .
       .
      NPRO=0
   10 CONTINUE
       .
       .   code to set up these two values
       .
      WRITE(LUN,1000,ERR=  )((Y(I,J),I=1,2),J=1,2)
 1000 FORMAT(4E20.12)
      NPRO=NPRO+2
      IF(NPRO.LT.NVAL)GO TO 10
       .
       .  continued processing
       .
```

CASE 8

COMPLEX
DOUBLE PRECISION
UNEVEN SPACING

```
 Order of data in file        X1   RY1    IY1
                     X2   RY2    IY2
                      .
                      .
                      .
```

Input

```
      REAL X
      DOUBLE PRECISION Y(2)
       .
       .
       .
      NPRO=0
   10 READ(LUN,1000,ERR=  ,END=  )(X,Y(I),I=1,2)
 1000 FORMAT(E13.5,2E20.12)
      NPRO=NPRO+1
```

```
      .
      .   code to process this value
      .
     IF(NPRO.LT.NVAL)GO TO 10
      .
      .  continued processing
      .
```

Output

```
     REAL X
     DOUBLE PRECISION Y(2)
      .
      .
      .
     NPRO=0
   10 CONTINUE
      .
      .   code to set up this value
      .
     WRITE(LUN,1000,ERR=  )(X,Y(I),I=1,2)
 1000 FORMAT(E13.5,2E20.12)
     NPRO=NPRO+1
     IF(NPRO.LT.NVAL)GO TO 10
      .
      .  continued processing
      .
```