APPENDICES

APPENDIX A – MEASUREMENT SYSTEM AND CALIBRATION

1. MEASUREMENT SYSTEM

Table A.1 – Measurement system for the identification of a single harmonic force

Equipment	Description	Serial Number
Signal generator & analyser	DSPT Siglab Model 20-42	SN 11251
Signal amplifiers	Rotel stereo integrated amplifiers RA-970 BX	SN 522 45811 SN 434 75550
Shakers	Vibro Pet Model Pet-01 IMV Corp.	SN 40-381-2 SN 40-376-2
Condition amplifiers	Model 480E09 ICP Power Unit	SN 17185 SN 3657 SN 3435 SN 17187
Force transducers	PCB208 B02	SN 12980 SN 12742
Shear accelerometers	PCB U353 B65 PCB U353 B66 PCB B15	SN 20520 SN 44564 SN 50276
Piezoelectric strain gauges	PCB 740 B02 PCB 740 B02	SN 823 SN 857
PC	Pentium 100 MHz "Apollo"	SN 0467570

2. CALIBRATION FACTORS

2.1 Accelerometer/Force Transducer Pair

Alternating voltage signals were measured from both the accelerometer and force transducers. These signals had to be multiplied by a calibration factor to obtain the correct magnitude of the frequency response functions. Since the frequency response function is simply the ratio of the response to the force, a straightforward technique can be applied to determine the calibration factor for each pair of accelerometer/force transducer. The force transducer and accelerometer are attached to the rigid body of known mass (m = 4.02 kg), as depicted in Figure A.1.

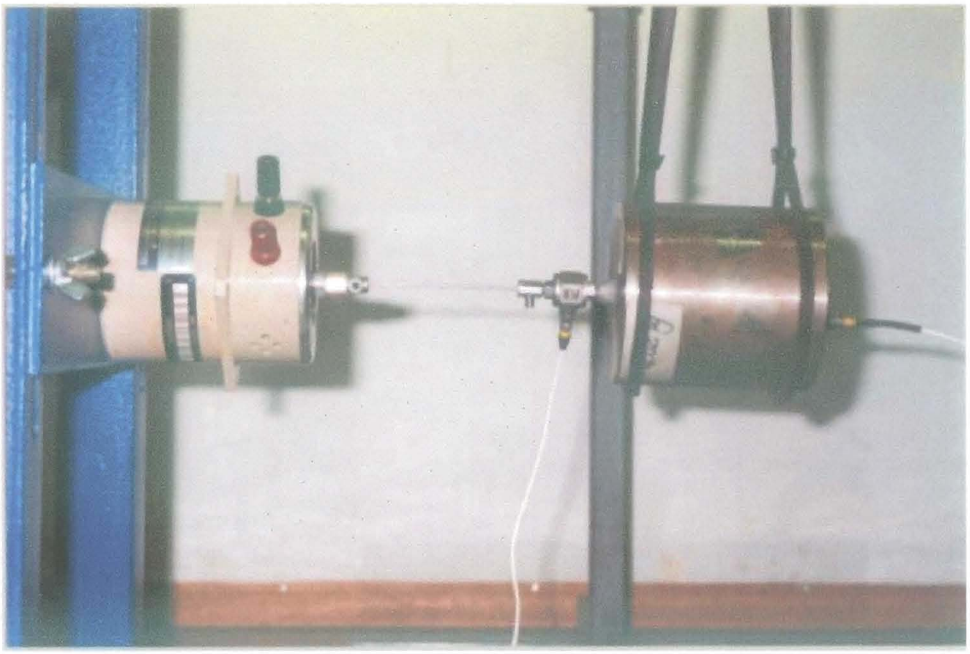


Figure A.1 – Calibration measurement setup

A time-varying force is applied to a rigid body for which the inertance is measured for the specified frequency range. The measured quantity has units of volt/volt and corresponds to:

$$A(\omega) = \frac{\ddot{x}(t)}{f(t)} = \frac{1}{m} \quad \text{(A.1)}$$

from which the overall sensitivity for each pair of accelerometer/transducer can be calculated. Figure A.2 illustrates a typical inertance and coherence measurement for one of the pairs of accelerometer/force transducer used in the experimental measurements. The overall sensitivities are listed in Table A.1.

Table A.1 – Calibration of accelerometer/force transducer pair

Accelerometer/ force transducer pair	Overall Sensitivity $\left[\frac{V/V}{m.s^{-2}/N}\right]$
SN 44564 & SN 12742	1.1610
SN 20520 & SN 12742	1.2746
SN 44564 & SN 12980	1.1584
SN 20520 & SN 12980	1.2933
SN 50276 & SN 12980	9.9367

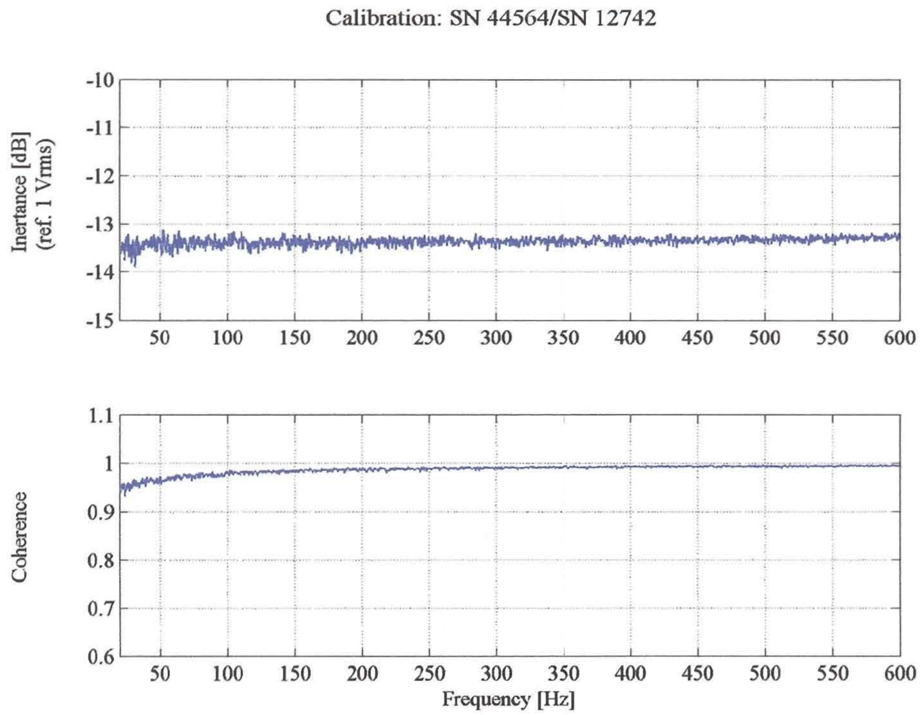


Figure A.2 – Inertance and coherence plots for the calibration of an accelerometer/force transducer pair

2.2 Accelerometers

The accelerometers were calibrated separately with a hand-held calibrator. This calibration was done with the accelerometers still connected to the rest of the measurements system as used in experimental setup. The calibration factors for each of the accelerometers are listed in Table A.2.

Table A.2 – Calibration of accelerometers

Accelerometer	Calibration factor $\left[\frac{m.s^{-2}}{Vrms}\right]$
SN 44564	154.841
SN 20520	172.358
SN 50276	1261.221

2.3 Force Transducers

Having determined the calibration factors for the accelerometers, the calibration factor for each of the force transducers was deduced from the overall sensitivity ratios given in Section 2.1 of this appendix. Two values were obtained for each force transducer, of which the average was used in the force identification process. These calibration values are given in Table A.3.

Table A.3 – Calibration of force transducers

Force transducer	Calibration factor $\left[\frac{N}{Vrms}\right]$
SN 12742	134.297
SN 12980	133.472

2.4 Piezoelectric Strain Gauges

The manufacturer's quoted sensitivities were used to determine the calibration factor for the piezoelectric strain gauges and are given in Table A.4.

Table A.4 – Calibration of piezoelectric strain gauges

Piezoelectric Strain Gauges	Calibration factor $\left[\frac{\mu\varepsilon}{Vrms}\right]$
SN 823	24.595
SN 857	28.3409

APPENDIX B - MODAL ANALYSIS OF FREE-FREE BEAM

Number of averaged Procedures: 100

The identified natural frequencies, modal damping factors and normal modes are listed in Tables B.1 and B.2.

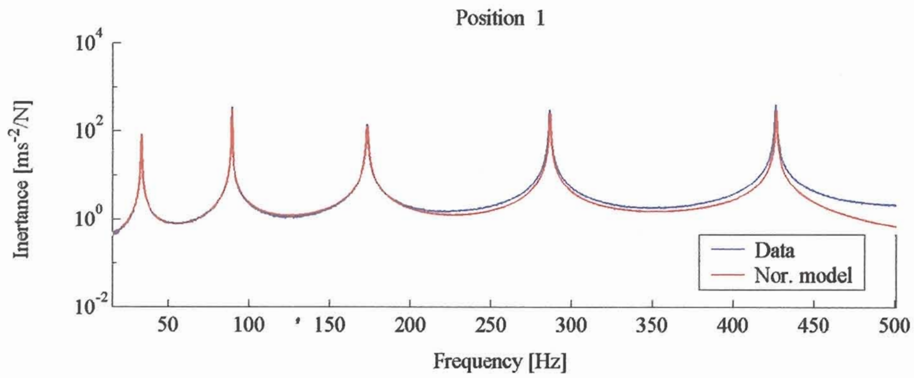
Table B.1 - Natural frequencies and modal damping factors for the free-free beam

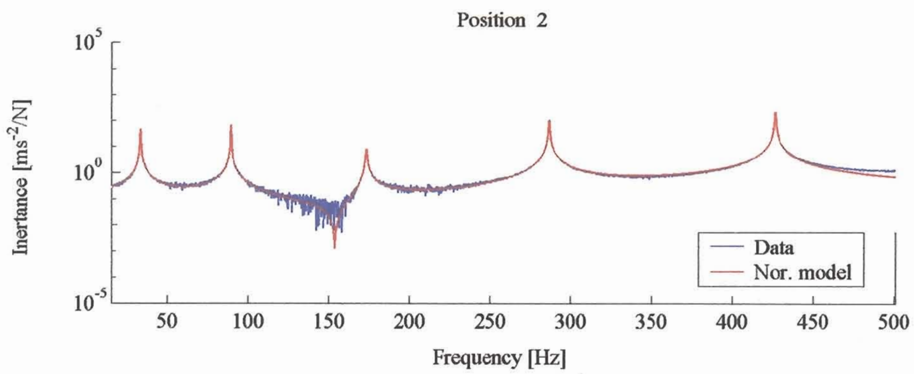
Natural frequencies [Hz]	Modal damping factors x $[10^{-4}]$
32.538	29.313
88.471	7.6010
172.76	17.404
286.01	6.8997
426.03	4.7836

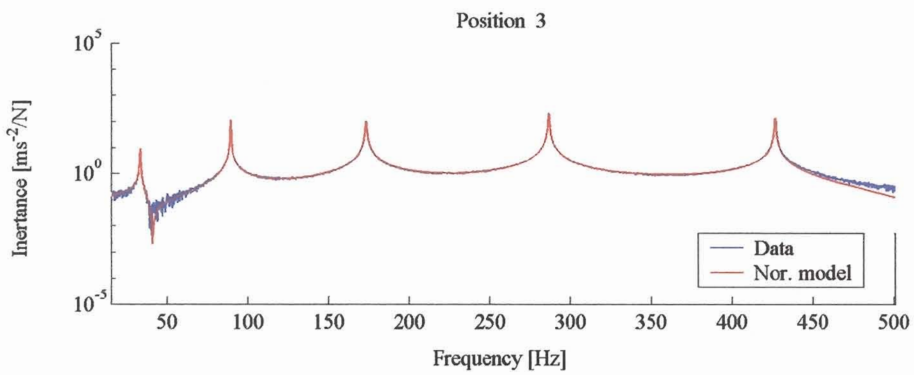
Table B.2 – Identified normal modes for the free-free beam

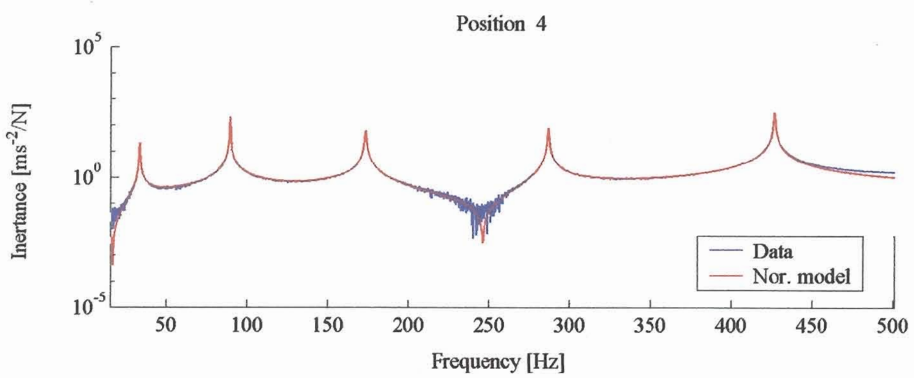
Position	Mode 1 x $[10^{-1}]$	Mode 2 x $[10^{-1}]$	Mode 3 x $[10^{-1}]$	Mode 4 x $[10^{-1}]$	Mode 5 x $[10^{-1}]$
1	7.1528	-7.1878	7.2027	-5.7285	4.7910
2	4.0191	-1.5927	-0.4212	2.1804	-3.6031
3	0.7958	2.7162	-5.0597	4.4827	-2.1790
4	-1.8826	4.9710	-2.9900	-1.6166	4.8615
5	-3.7555	3.4185	2.4462	-5.0856	0.8848
6	-4.3651	0.0434	5.2002	-0.0889	-5.1665
7	-3.7685	-3.1402	2.5276	4.9914	0.6129
8	-1.9486	-4.8481	-2.8685	1.7411	5.1903
9	0.6817	-2.6716	-4.6202	-4.4145	-2.0095
10	3.7753	1.3380	-0.5484	-2.2280	-3.6572
11	7.0687	6.8776	6.4475	6.4463	6.1806

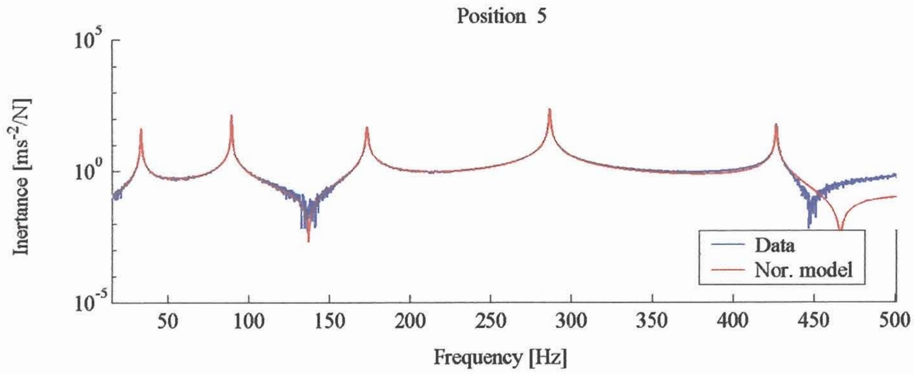
The following figures show the measured frequency response function data and the reconstructed normal mode model obtained after optimisation for the reference position 11. The truncated modes are accounted for by the inclusion of the residual terms in the normal mode model. It can be seen that the normal mode model corresponds fairly well to the experimentally measured data. At the high frequencies the normal mode model deviates slightly from the measured data due to the residuals of the truncated modes.

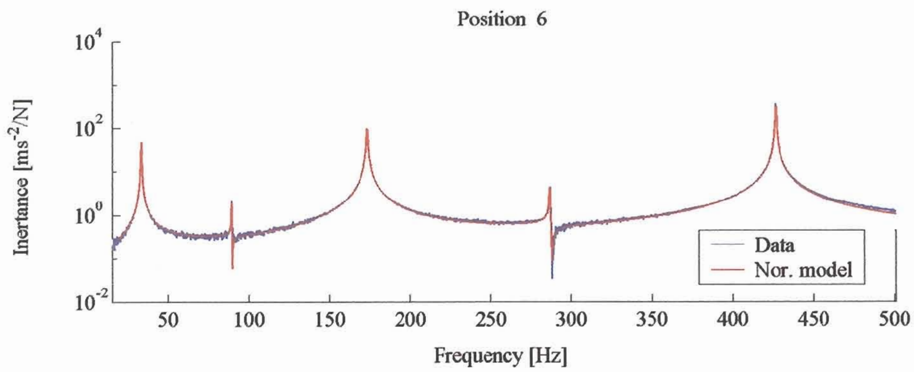

Position 1
Inertance [ms^{-2}/N]
10^4
10^2
10^0
10^{-2}
50 100 150 200 250 300 350 400 450 500
Frequency [Hz]
Data
Nor. model

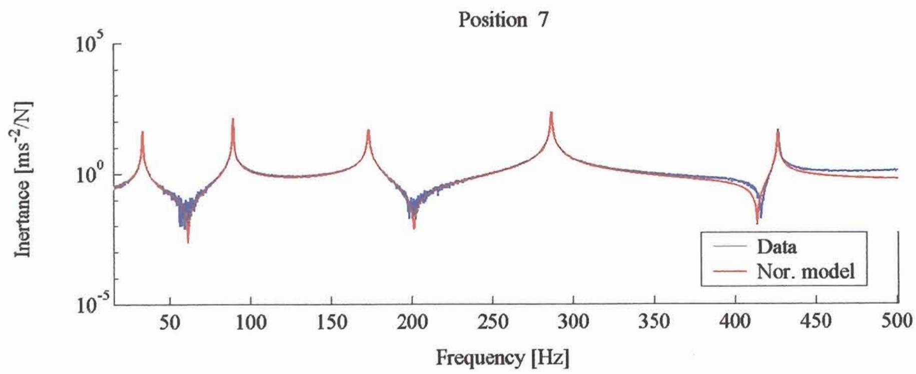

Position 2
Inertance [ms^{-2}/N]
10^5
10^0
10^{-5}
50 100 150 200 250 300 350 400 450 500
Frequency [Hz]
Data
Nor. model

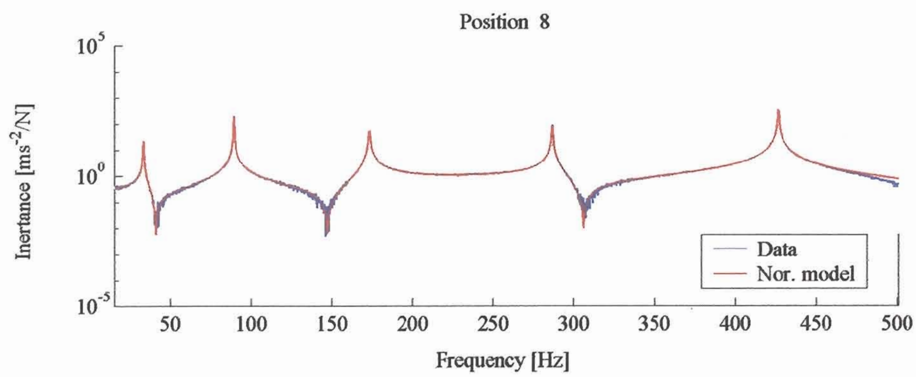

Position 3
Inertance [ms^{-2}/N]
10^5
10^0
10^{-5}
50 100 150 200 250 300 350 400 450 500
Frequency [Hz]
Data
Nor. model

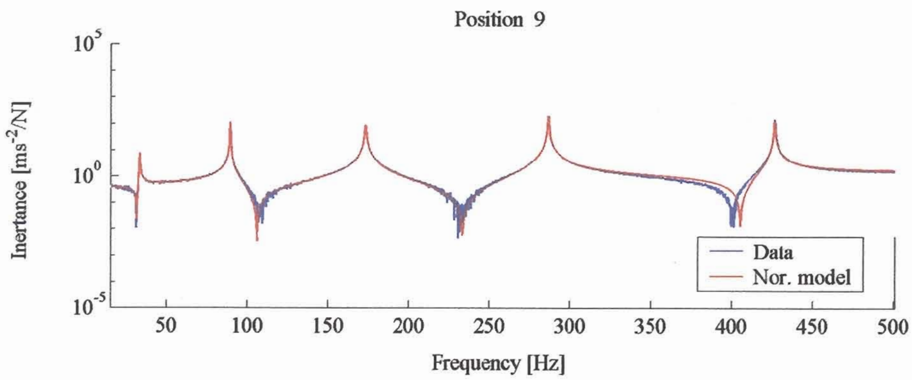

Position 4
Inertance [ms^{-2}/N]
10^5
10^0
10^{-5}
50 100 150 200 250 300 350 400 450 500
Frequency [Hz]
Data
Nor. model


Position 5
Inertance [ms^-2/N]
Frequency [Hz]
Data
Nor. model

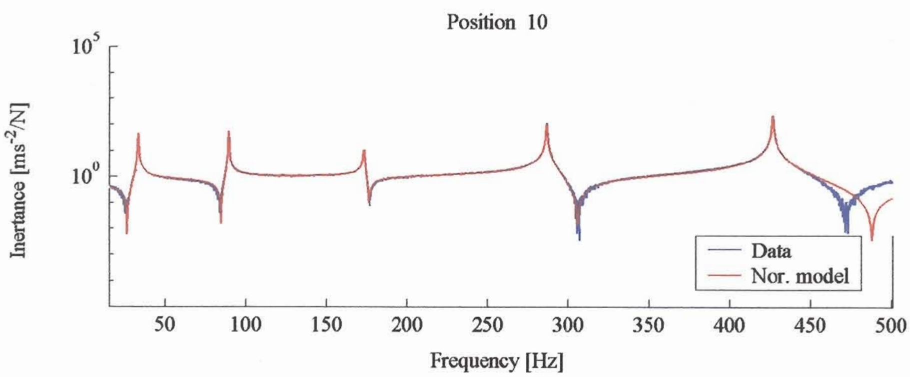

Position 6
Inertance [ms^-2/N]
Frequency [Hz]
Data
Nor. model


Position 7
Inertance [ms^-2/N]
Frequency [Hz]
Data
Nor. model

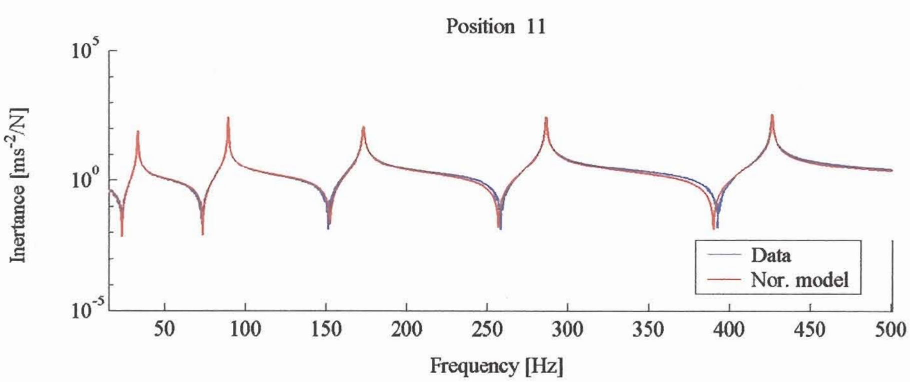

Position 8
Inertance [ms^-2/N]
Frequency [Hz]
Data
Nor. model



Position 9
Inertance [ms^-2/N]
10^5
10^0
10^-5
50
100
150
200
250
300
350
400
450
500
Frequency [Hz]
Data
Nor. model



Position 10
Inertance [ms^-2/N]
10^5
10^0
50
100
150
200
250
300
350
400
450
500
Frequency [Hz]
Data
Nor. model



Position 11
Inertance [ms^-2/N]
10^5
10^0
10^-5
50
100
150
200
250
300
350
400
450
500
Frequency [Hz]
Data
Nor. model