Toward Modeling of Cable-Harnessed Structures: Cable Damping Experiments

AIAA

April 11, 2013

Kaitlin Spak - Presenter
Dr. Gregory Agnes
Dr. Daniel Inman

Virginia Tech - JPL - U of Michigan

Motivation

Space Flight Cables

- M27500-26TG2T14 wire used (26 AWG twisted pairs with tinned copper EMI shielding and Tefzel (ETFE) jacket)
- 1 by 18 in 2 layers over a core wire
- Helically twisted
- Tie laced every 4-6"
- Kapton overwrap
- Typical space flight cable

String Length and Tension

Tension

Excitation Method

Cable Ties

Cable Section

Test Procedures

Cable was attached to test fixture. Laser vibrometer measured response to shaker excitation.

"Standard Run"

- Cable attached to test fixture with ______ toward shaker
- TyRap TY525M cable ties with setting 5 (tight) on cable tie gun
- Static displacement of cable due to string less than 1 mm
  - White noise (random) excitation at 0.3 volts, 0-2000 Hz
  - Response measured at driving point by laser vibrometer
    - Driving point at 8.5 cm above lower tie
      - 2 lbs (8.9 N) cable tension
      - Excitation actuated by tensioned 24 cm string
      - Low pass 5 kHz filter
        - Frequency of interest 0 - 250 Hz
          - Test section length of 25.4 cm with two 20.3 cm buffer zones above and below

Cable Orientation

Conclusions

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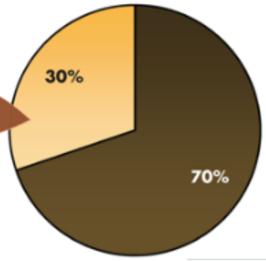
Motivation:

- Cable harnesses are present on most space structures
- Space structures have decreased in weight
- Cables have not decreased in weight

THUS: Cable mass as a percentage of total space structure mass has increased

- As high as 30% in some cases
- 10% typical



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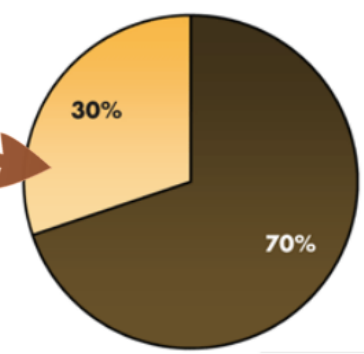
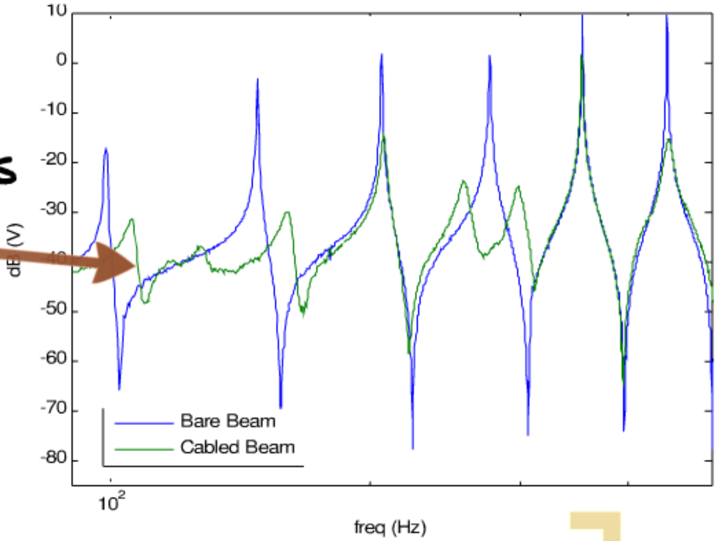


Motivation:

- Cables were previously modeled as lumped mass
- Cables actually act as structural mass
- Cable damping is poorly understood as of yet
- Shear effects are significant

- Cables attached to structures change the dynamics



THUS: Cables should be modeled as structural elements with shear effects and damping, but more research is needed to fully understand the damping mechanisms present

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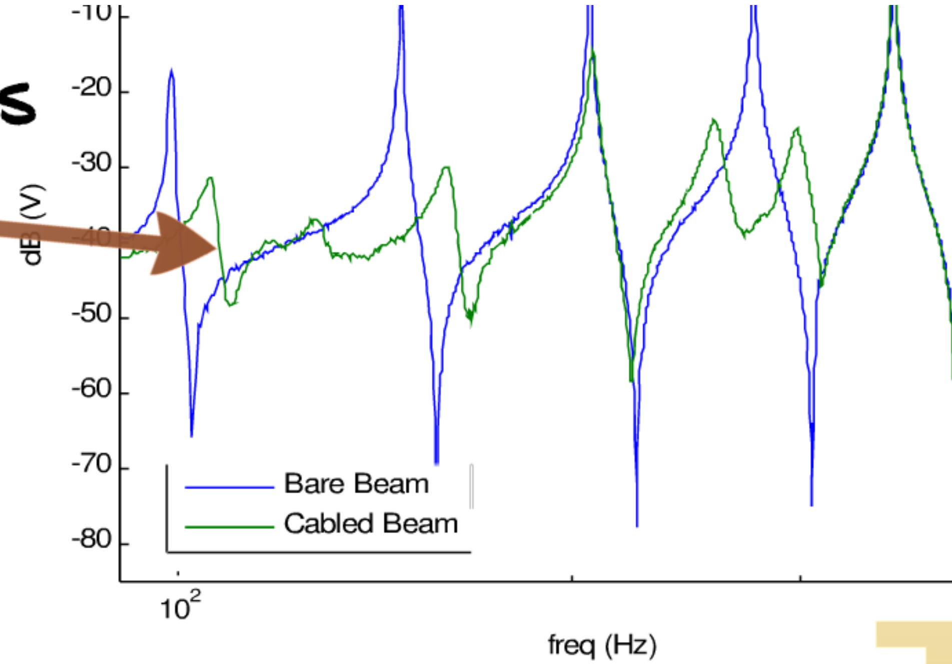

THUS: Cables should be modeled as structural elements with shear effects and damping, but more research is needed to fully understand the damping mechanisms present

Motivation:

- Structure and mass affect the dynamic response of a system
- Knowledge of structural dynamics is important for space structure control and system failure calculations
- Dynamic testing must often be completed before the structure is fully dressed with cables
- There is not yet a reliable predictive cable model for incorporation into structural models

THUS: An accurate damped structural cable model is necessary for accurate control and analysis of space structures!

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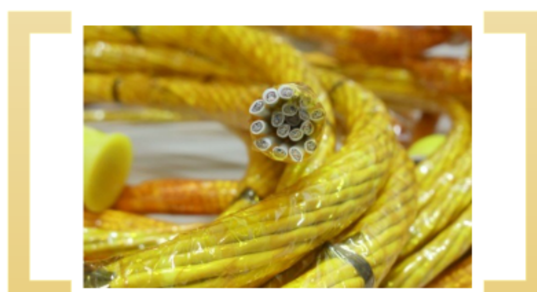
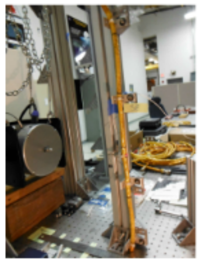


Test Procedures



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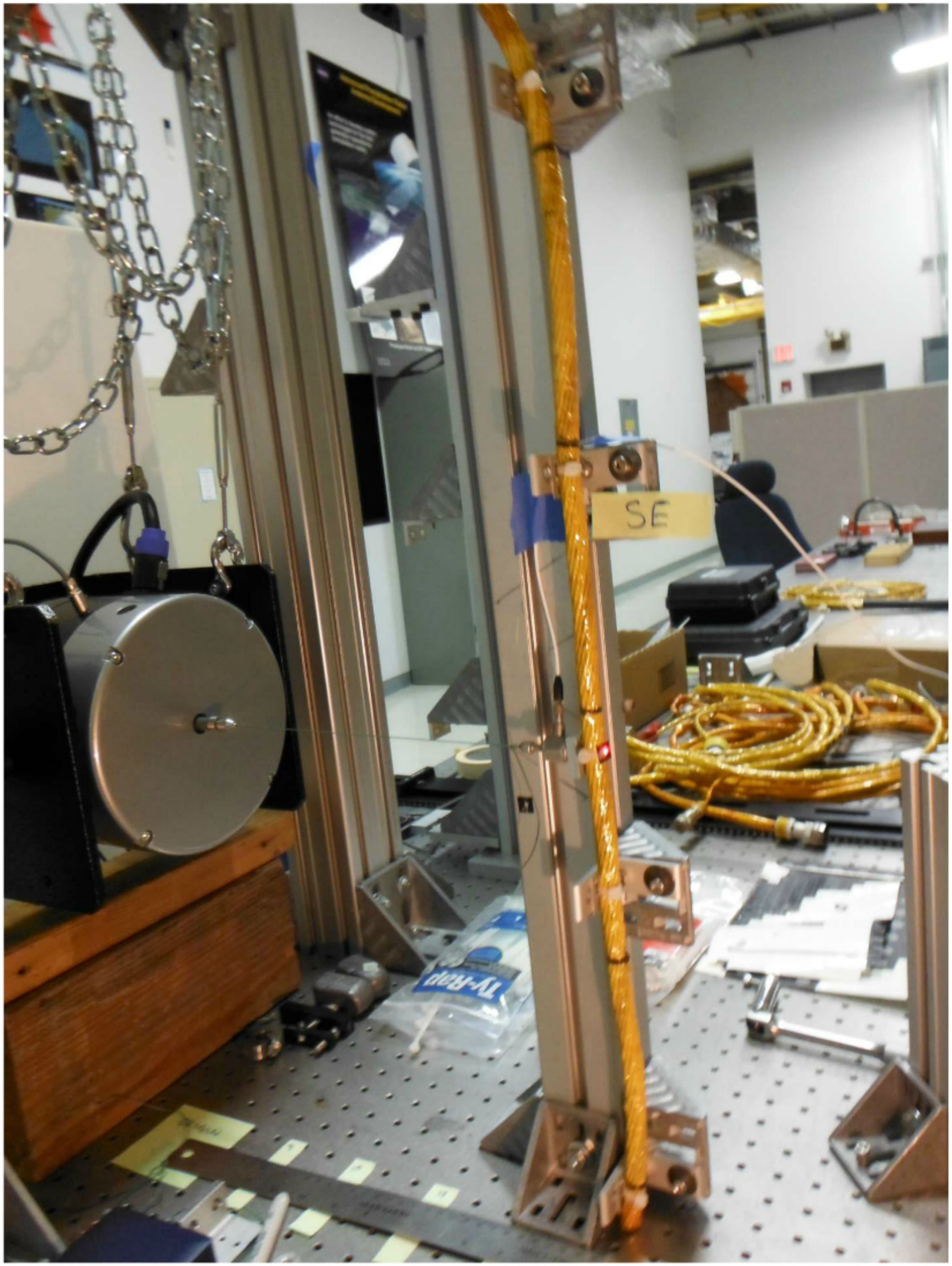
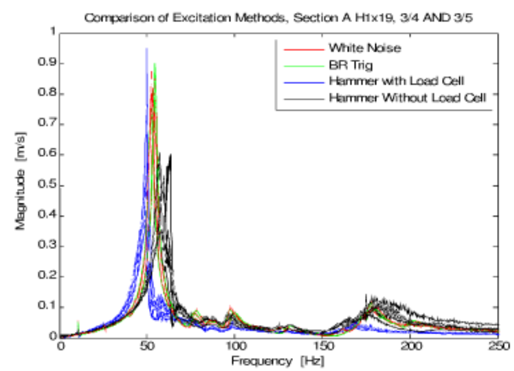
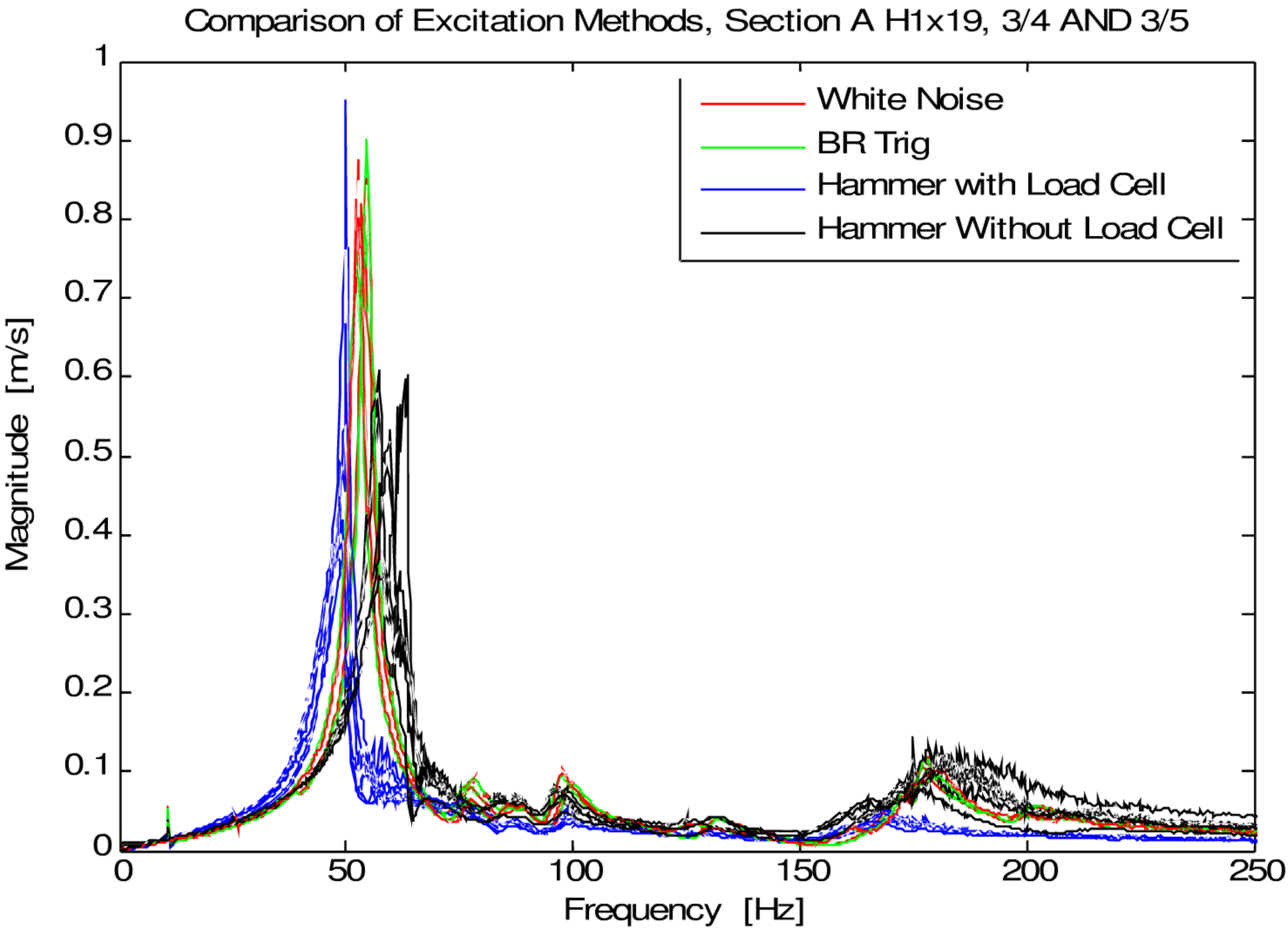

SE
Ty-Rap

Excitation Method

Hammer impact, white noise, and burst random excitation methods were compared.
Looking for validation that the test fixture was not overly influencing the cable response.

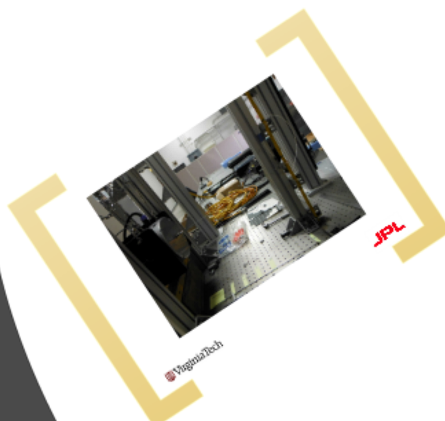


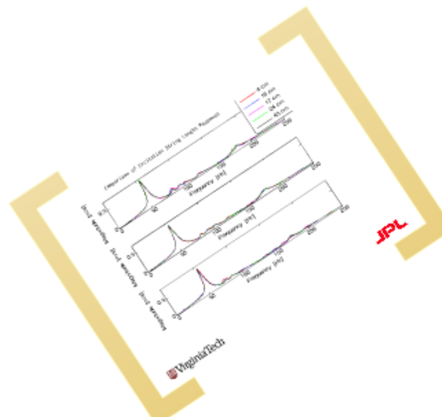
Hammer impacts bounded the white noise and burst random responses.

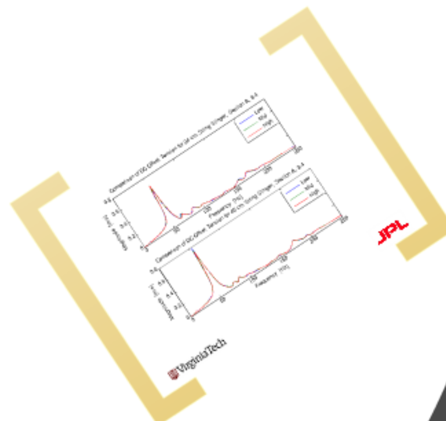

Comparison of Excitation Methods, Section A H1x19, 3/4 AND 3/5
White Noise
BR Trig
Hammer with Load Cell
Hammer Without Load Cell
Magnitude [m/s]
Frequency [Hz]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250

Excitation String Length and Tension

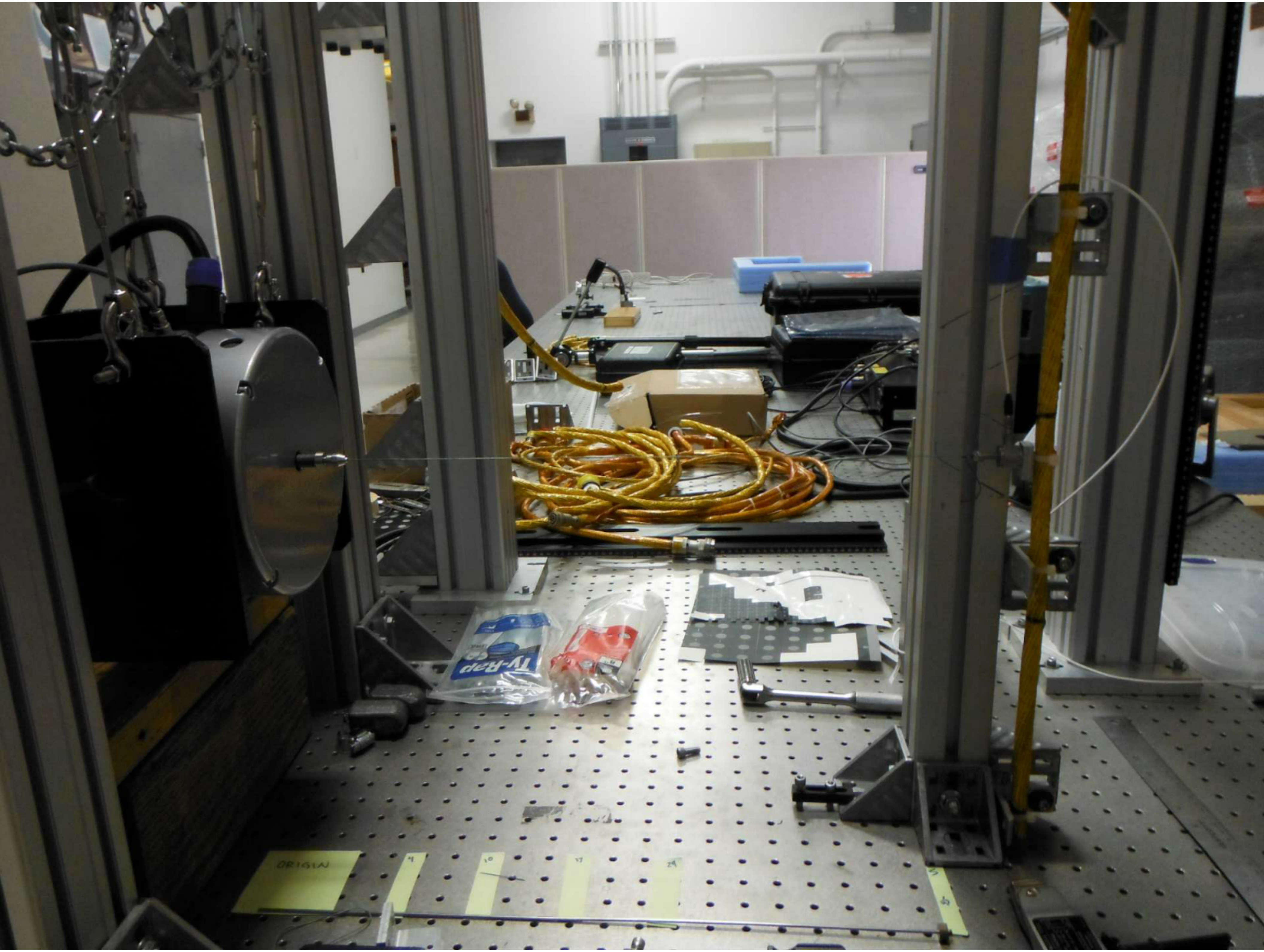
Cable fixture was moved to 4, 10, 17, 24 and 45 cm to vary string length. DC offset on shaker was also adjusted to provide tension variation in the excitation string. Cable was statically deflected less than 1 mm.

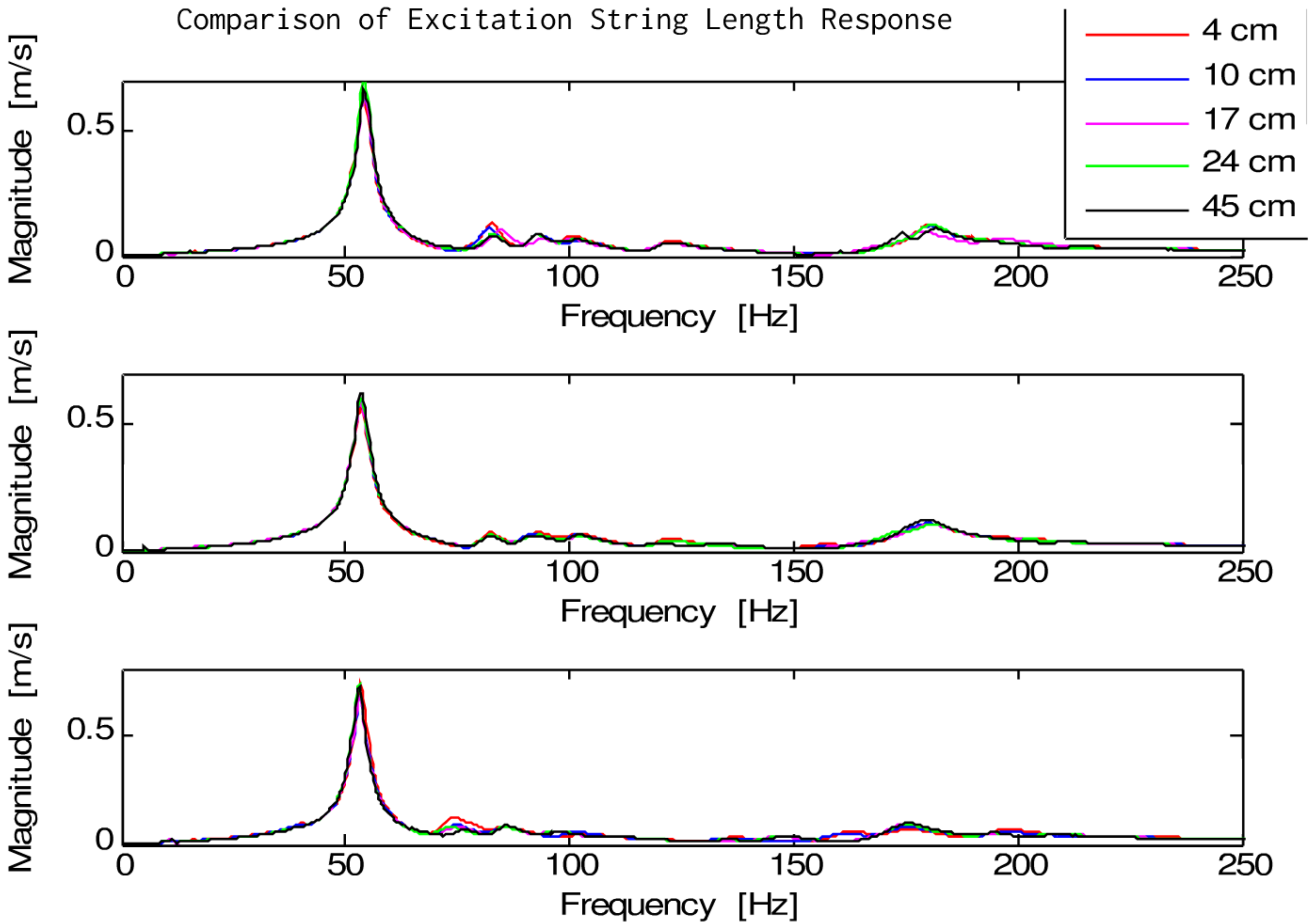


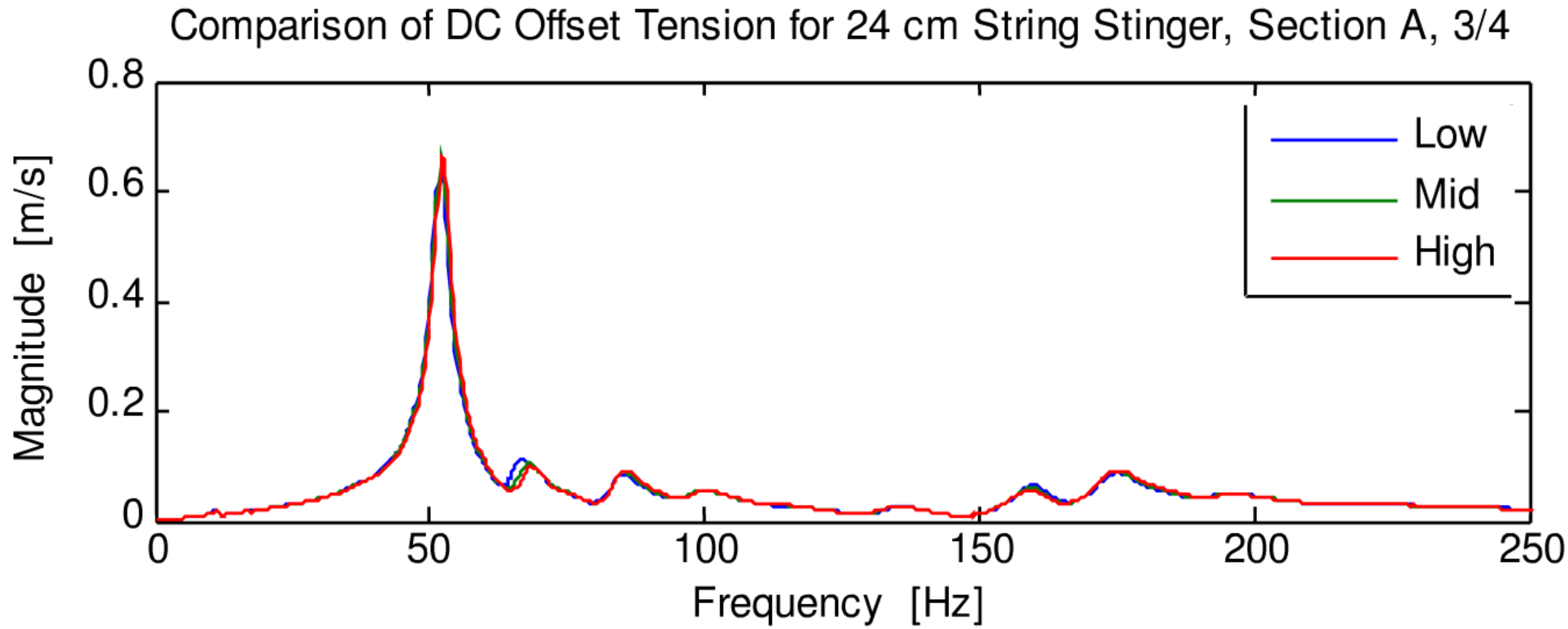


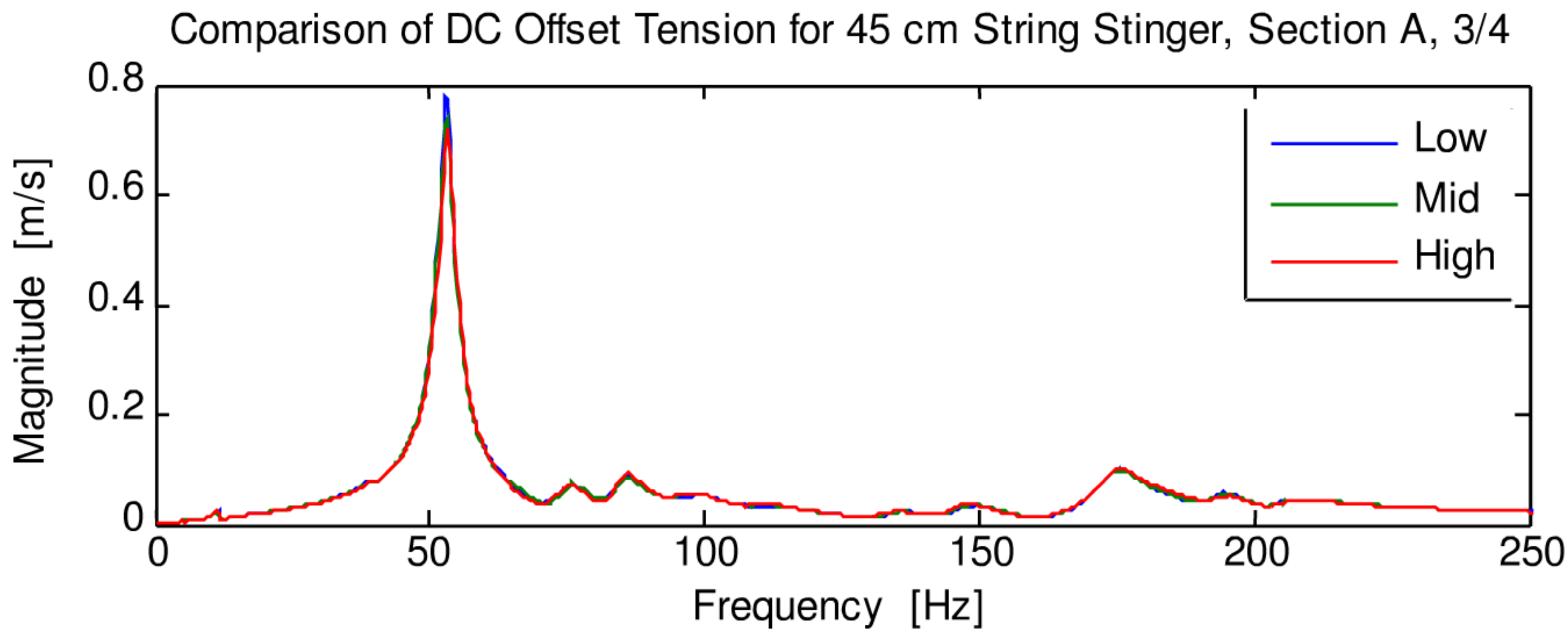


Neither string length nor tension affected the dynamic response.


ORIGIN
Ty-Rap

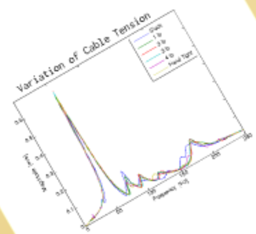

Comparison of Excitation String Length Response
4 cm
10 cm
17 cm
24 cm
45 cm
Magnitude [m/s]
0.5
0
0
50
100
150
200
250
Frequency [Hz]

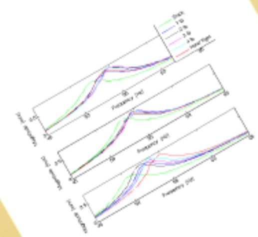

Comparison of DC Offset Tension for 24 cm String Stinger, Section A, 3/4
Magnitude [m/s]
0
0.2
0.4
0.6
0.8
Frequency [Hz]
0
50
100
150
200
250
Low
Mid
High


Comparison of DC Offset Tension for 45 cm String Stinger, Section A, 3/4
Magnitude [m/s]
0
0.2
0.4
0.6
0.8
Frequency [Hz]
0
50
100
150
200
250
Low
Mid
High

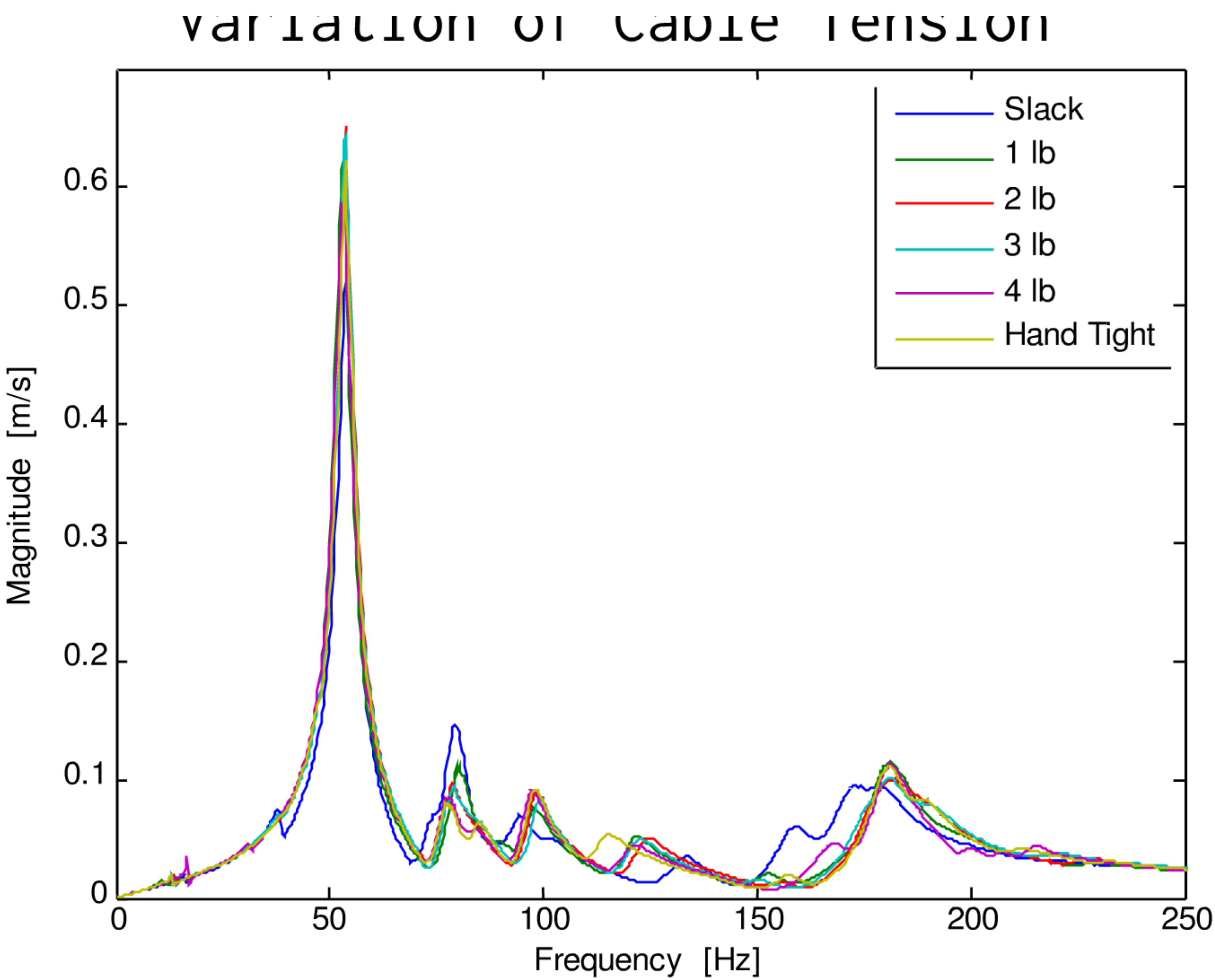
Cable Tension

Cable tension was varied, from slack to 4 lbs. A hand-tight case was also tested, where the cable was simply pulled tight and attached similar to common installation methods.

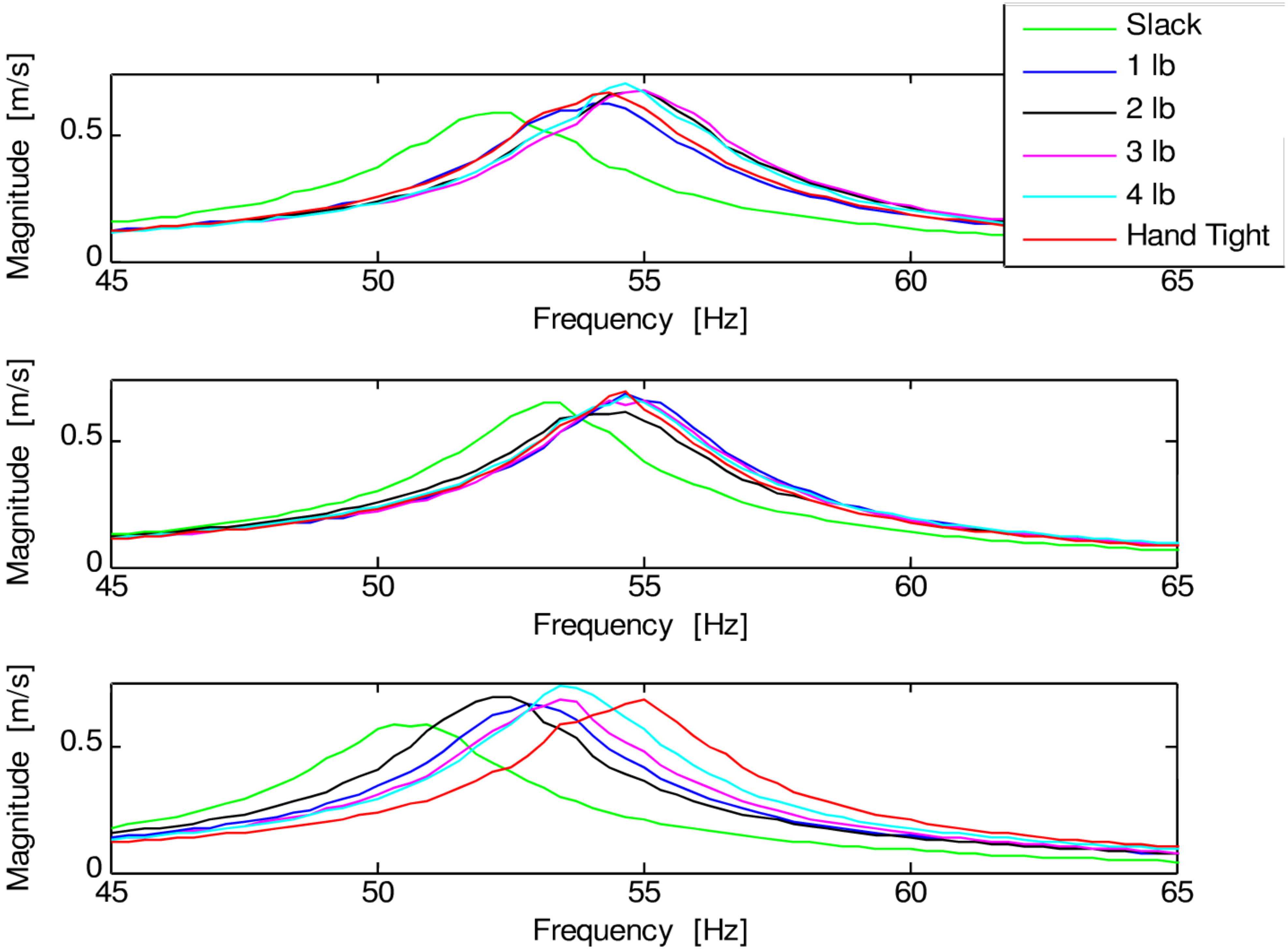




Cable frequency increased with increasing tension; a hand-pulled cable showed similar results; slack cable had significant differences.

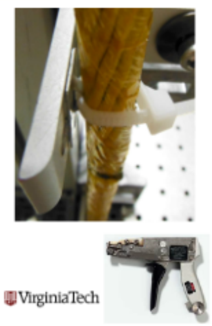


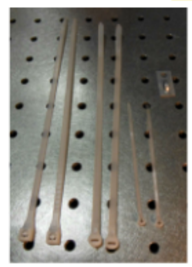
Variation of Cable Tension
Slack
1 lb
2 lb
3 lb
4 lb
Hand Tight
Magnitude [m/s]
Frequency [Hz]
0
0.1
0.2
0.3
0.4
0.5
0.6
0
50
100
150
200
250

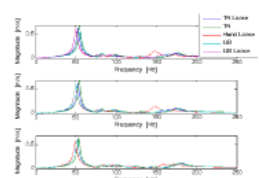

Slack
1 lb
2 lb
3 lb
4 lb
Hand Tight
Magnitude [m/s]
0.5
0
45
50
55
60
65
Frequency [Hz]
Magnitude [m/s]
0.5
0
45
50
55
60
65
Frequency [Hz]
Magnitude [m/s]
0.5
0
45
50
55
60
65
Frequency [Hz]

Cable Tie Attachment

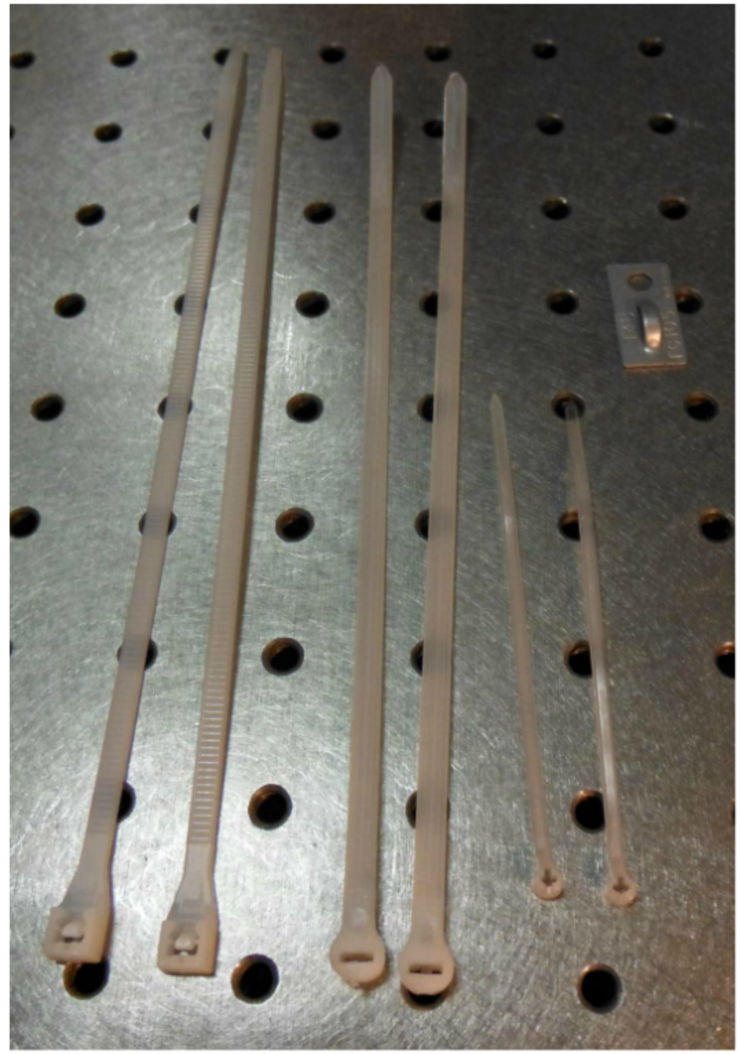
Cable tie attachments were varied in both tightness of cable tie as measured by a cable tie gun, and type and size of cable tie.





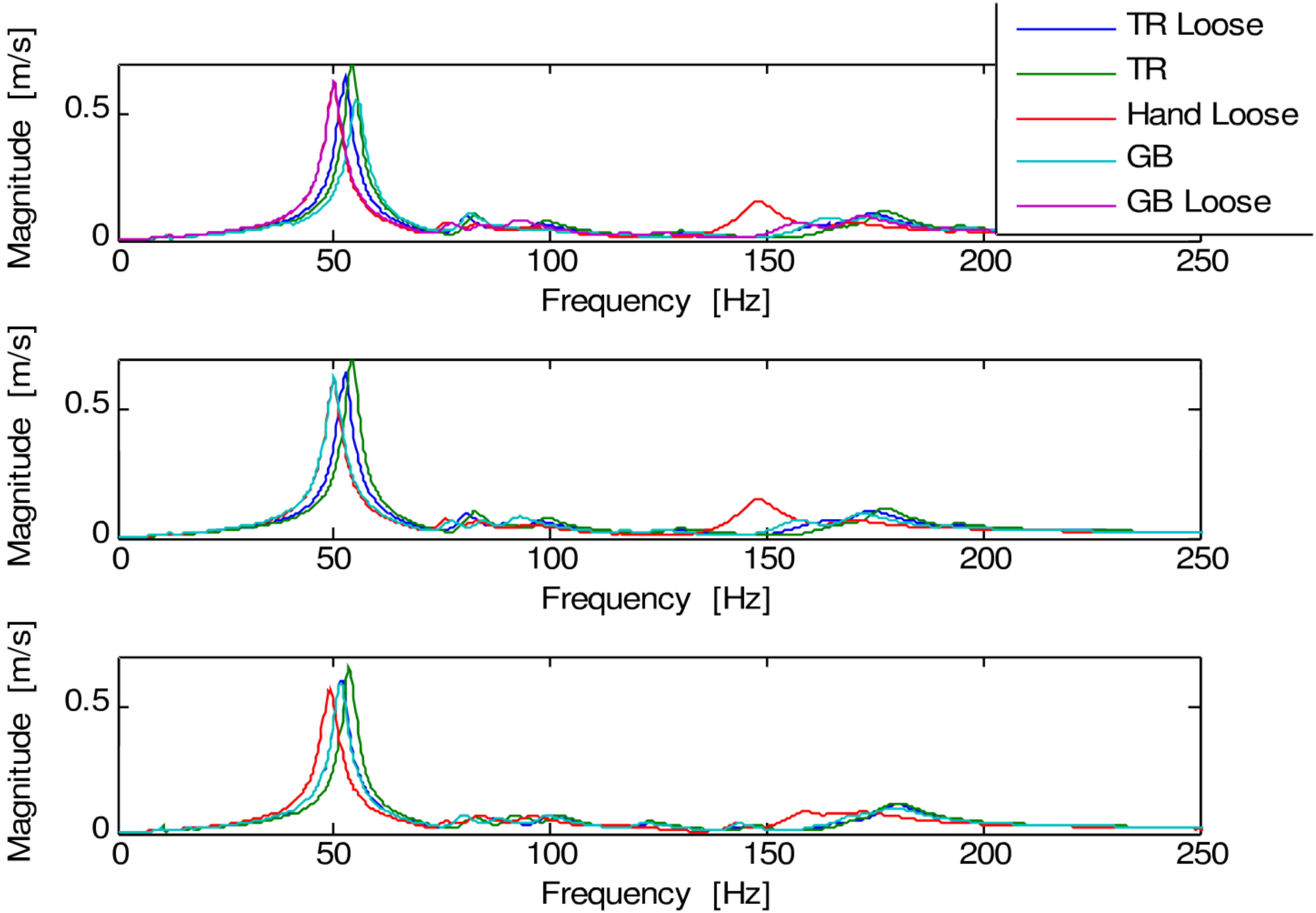


Tight cable ties behaved similarly, regardless of type; loose cable ties had greater variation from test to test.



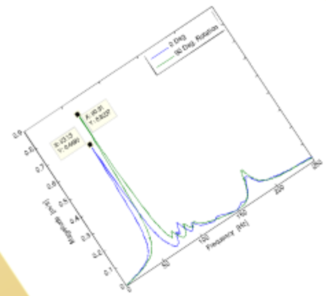
VirginiaTech

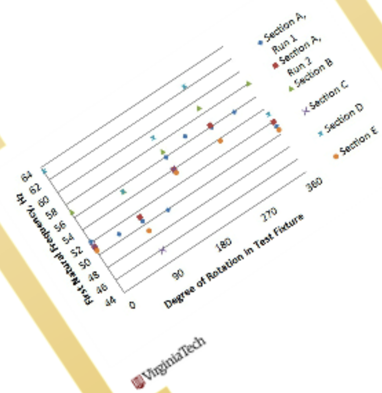
JPL


TR Loose
TR
Hand Loose
GB
GB Loose
Magnitude [m/s]
Frequency [Hz]
0
0.5
0
50
100
150
200
250

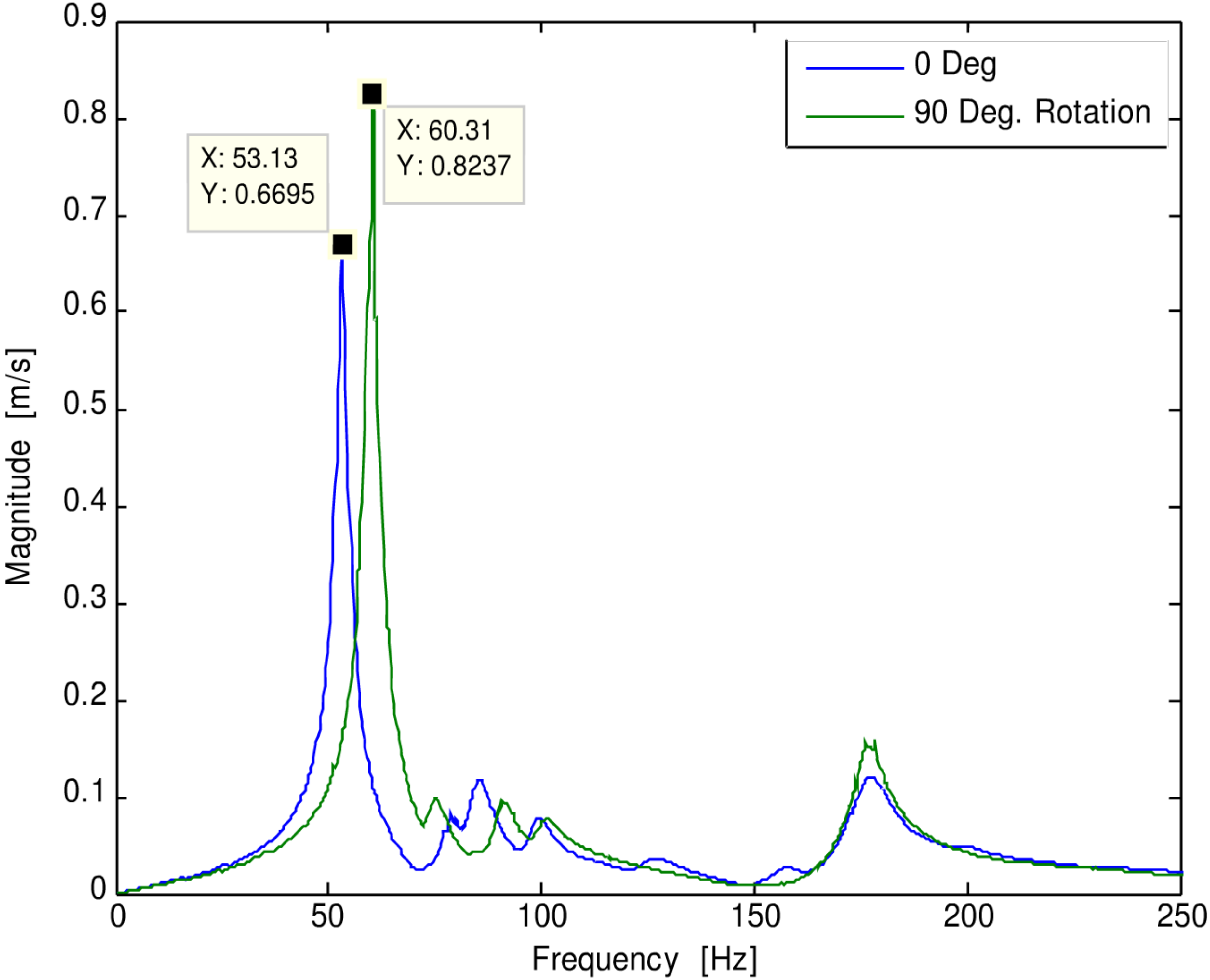
Cable Orientation

After noticing that cables had distinctly bi-modal first frequencies, cable orientation in the test fixture was investigated.

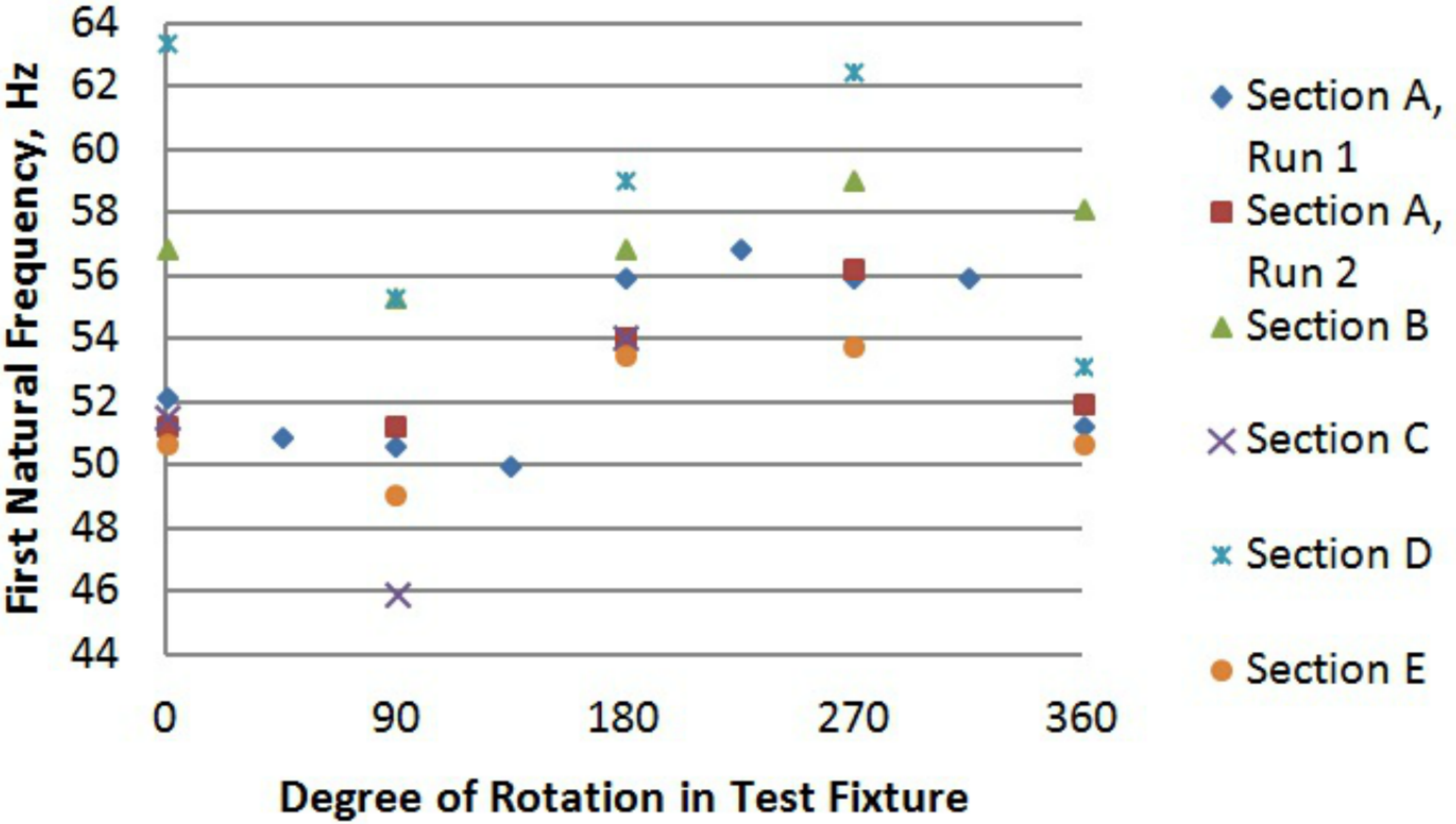




Natural frequency changed as coil plane was rotated; rotation of cable orientation shifts the first natural frequency in a roughly sinusoidal pattern.

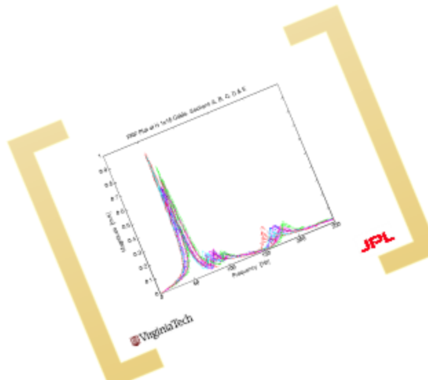


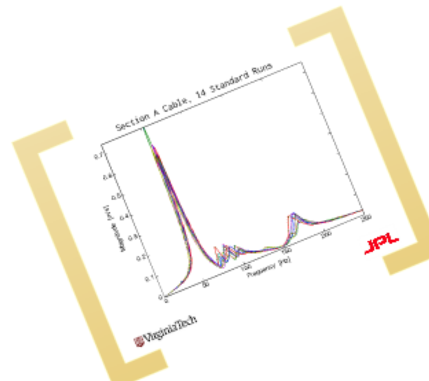
0 Deg
90 Deg. Rotation
X: 53.13
Y: 0.6695
X: 60.31
Y: 0.8237
Magnitude [m/s]
Frequency [Hz]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
50
100
150
200
250


First Natural Frequency, Hz
64
62
60
58
56
54
52
50
48
46
44
0
90
180
270
360
Degree of Rotation in Test Fixture
Section A, Run 1
Section A, Run 2
Section B
Section C
Section D
Section E

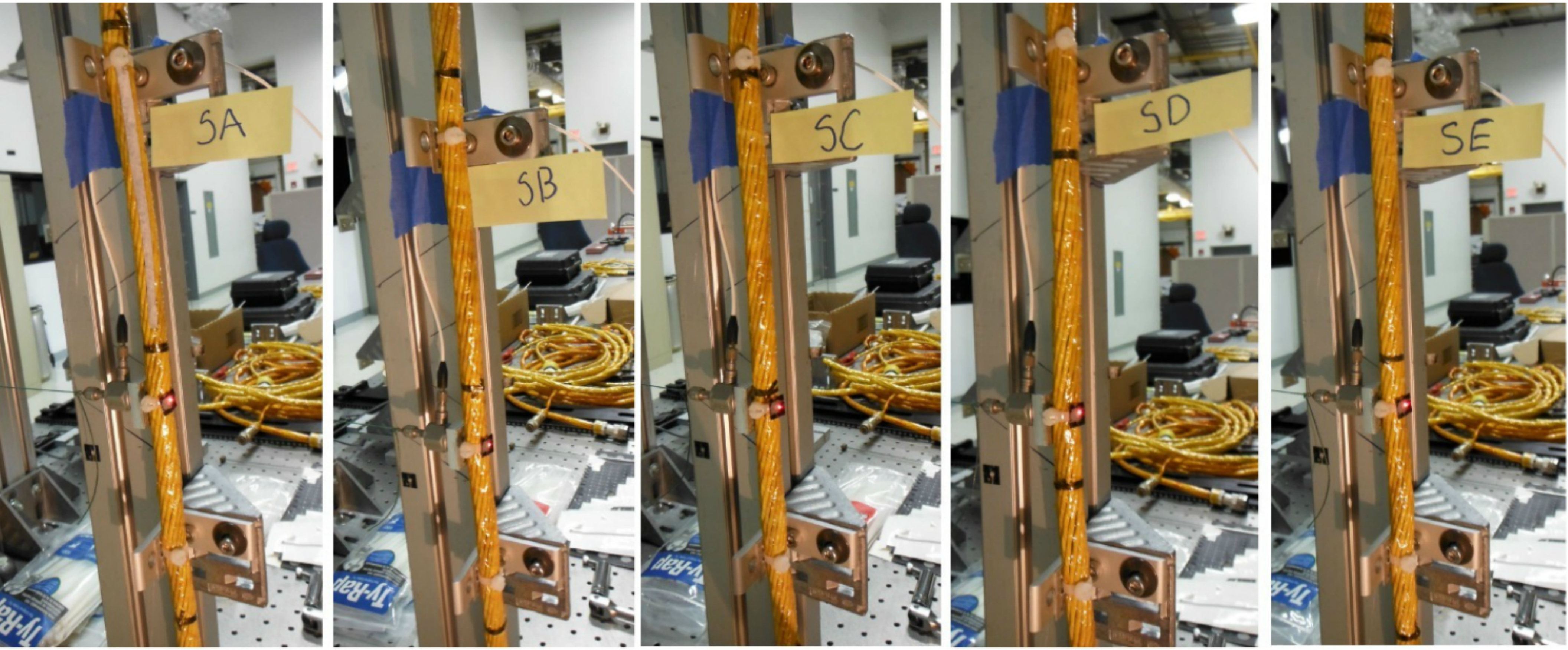
Cable Section Comparison

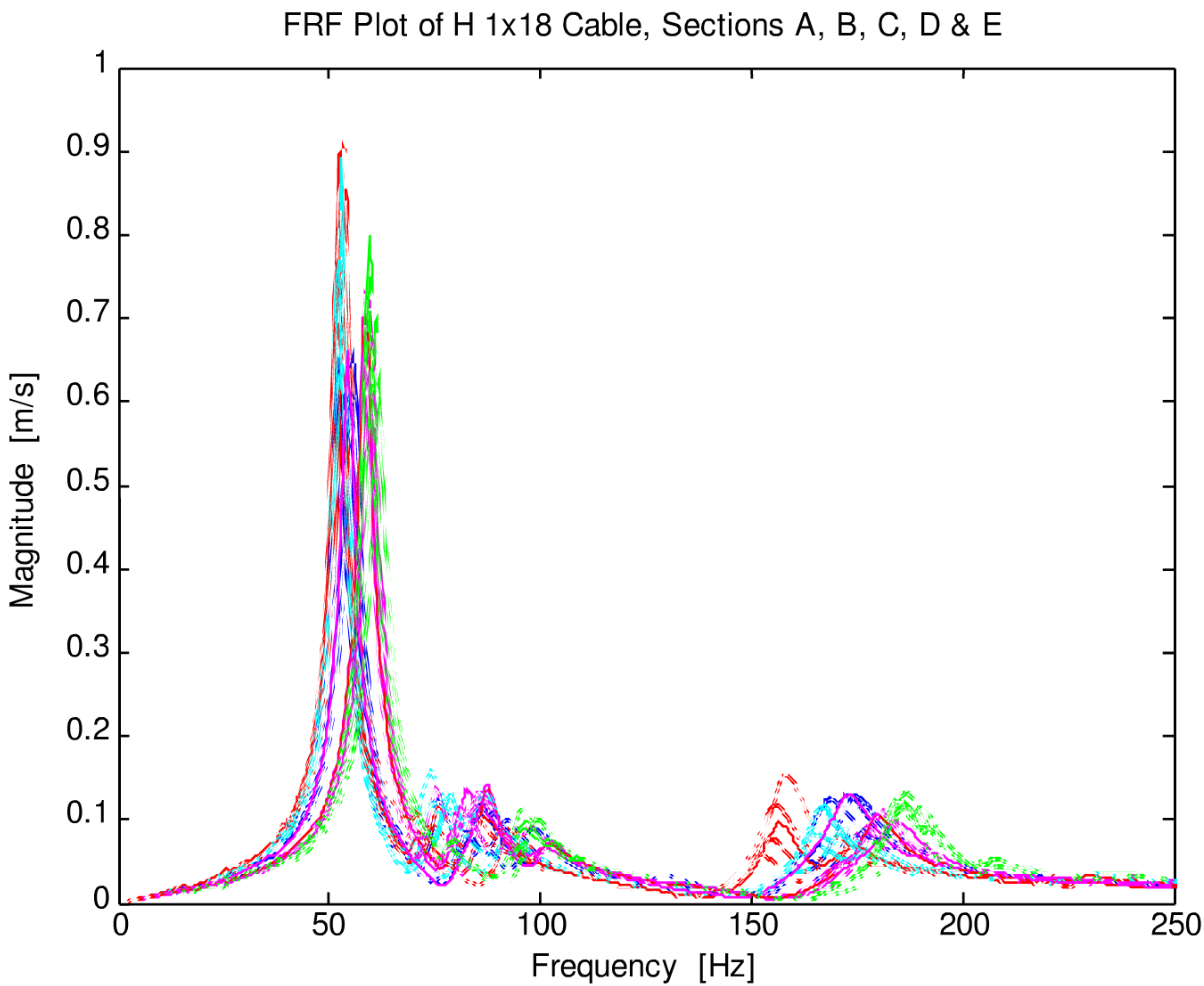
A length of 1 by 18 cable was cut into five similar sections, and standard runs of the sections were compared.

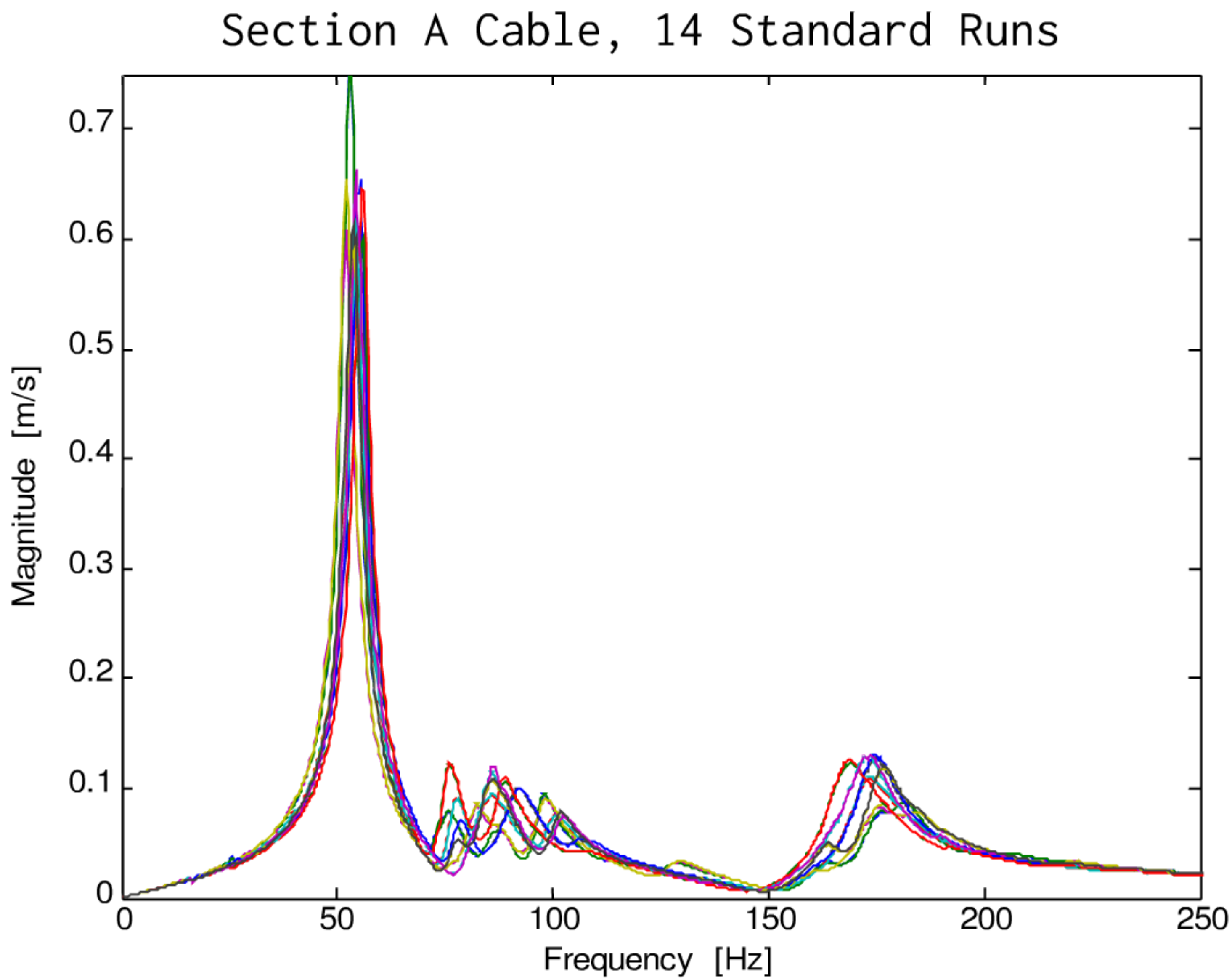




Variation in cable sections is significant!


5A
5B
5C
5D
5E
Ty-Rap


FRF Plot of H 1x18 Cable, Sections A, B, C, D & E
Magnitude [m/s]
Frequency [Hz]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250


Section A Cable, 14 Standard Runs
Magnitude [m/s]
Frequency [Hz]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
50
100
150
200
250

Conclusions:

- Things that matter:

Cable tension, cable orientation, cable section, zip tie tightness

- Things that don't:

Excitation method, excitation string length and tension*, zip tie type

- Things to keep studying:

Damping, sectional and standard run variations
Consideration of a statistical approach for beam parameters

As well as expanding the availability of experimental cable data, a few of the factors that must be controlled for repeatable vibration testing have been identified.

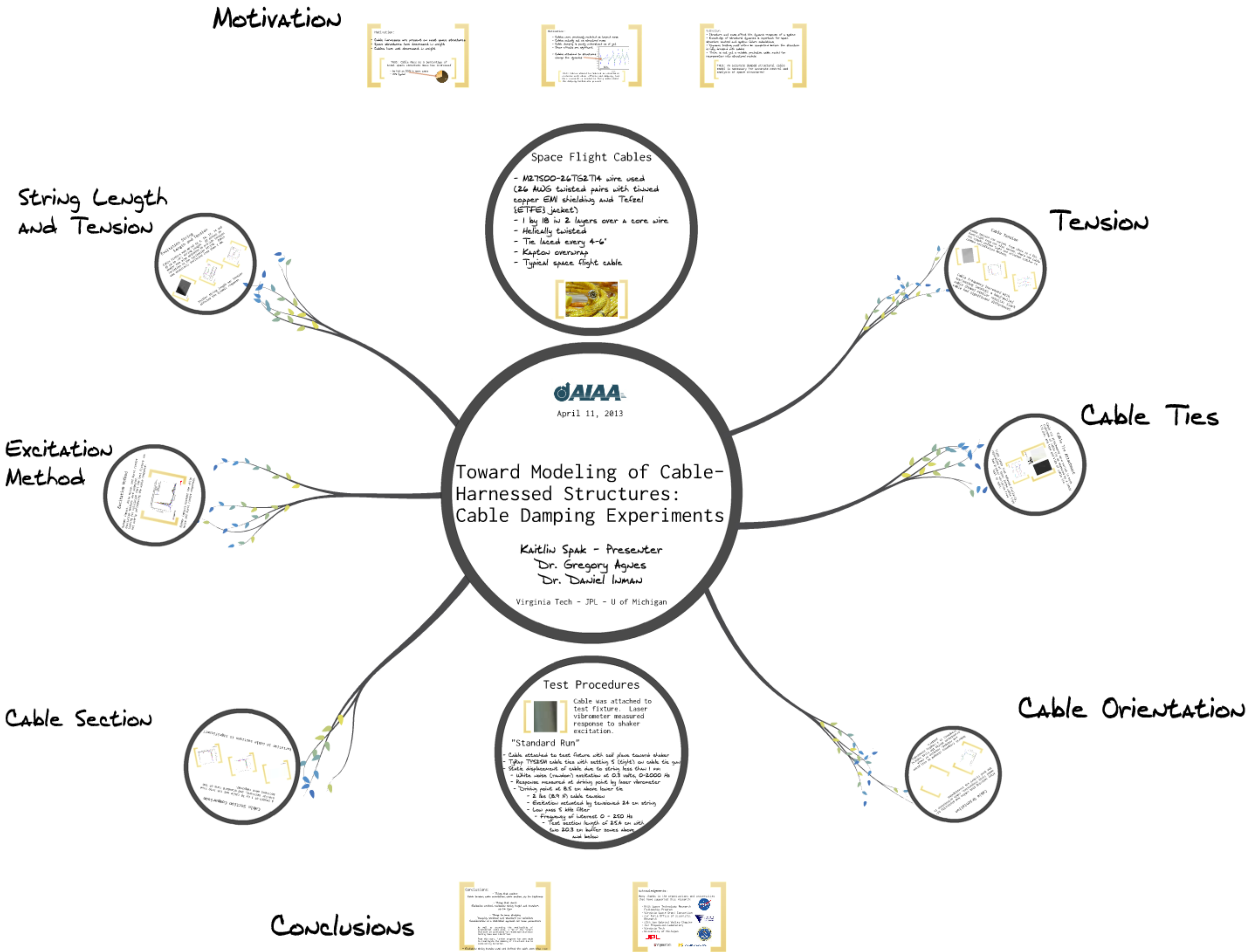
From this work, further progress has been made to investigate the damping of structures due to cable wiring harnesses.

* Excitation string tension must not deflect the cable more than 1 mm

Acknowledgements:

Many thanks to the organizations and universities that have supported this research:

- NASA Space Technology Research Fellowship Program
- Virginia Space Grant Consortium
- Air Force Office of Scientific Research
- AIAA San Gabriel Valley Chapter
- Jet Propulsion Laboratory
- Virginia Tech
- University of Michigan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