

Motivation

PROBLEM

- Cable structures are present on most space structures.
- Space structures have demand on weight.
- Cables have an inherent weight.

GOAL

How can we reduce the weight of cables on space structures?

QUESTION

- Can we provide a cable in a form that is lighter than a standard cable?
- Can we provide a cable that is lighter than a standard cable?
- Can we provide a cable that is lighter than a standard cable?

ANSWER

- Design and test of the space structure of a cable.
- Analysis of the cable structure in a manner that can be used to design a cable that is lighter than a standard cable.
- Design and test of the space structure of a cable.


 April 11, 2013
**Toward Modeling of Cable-Harnessed Structures:
 Cable Damping Experiments**
 Kaitlin Spak - Presenter
 Dr. Gregory Agnes
 Dr. Daniel Inman
 Virginia Tech - JPL - U of Michigan

String Length and Tension

String Length and Tension

- String length and tension are important factors in the design of cable structures.
- String length and tension are important factors in the design of cable structures.
- String length and tension are important factors in the design of cable structures.

Space Flight Cables

- M27500-24TG2T4 wire used (24 AWG twisted pairs with twisted copper EMI shielding and Tefzel (ETFE) jacket)
- 1 by 18 in 2 layers over a core wire
- Helicallly twisted
- Tie laced every 4-6'
- Kapton overwrap
- Typical space flight cable



Tension

Cable Tension

- Cable tension is a critical factor in the design of cable structures.
- Cable tension is a critical factor in the design of cable structures.
- Cable tension is a critical factor in the design of cable structures.

Excitation Method

Excitation Method

- Excitation method is a critical factor in the design of cable structures.
- Excitation method is a critical factor in the design of cable structures.
- Excitation method is a critical factor in the design of cable structures.

Cable Ties

Cable Ties

- Cable ties are used to secure cables to structures.
- Cable ties are used to secure cables to structures.
- Cable ties are used to secure cables to structures.

Cable Section

Cable Section

- Cable section is a critical factor in the design of cable structures.
- Cable section is a critical factor in the design of cable structures.
- Cable section is a critical factor in the design of cable structures.

Cable Orientation

Cable Orientation

- Cable orientation is a critical factor in the design of cable structures.
- Cable orientation is a critical factor in the design of cable structures.
- Cable orientation is a critical factor in the design of cable structures.

Test Procedures

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

"Standard Run"

- Cable attached to test fixture with set pins toward shaker
- Typical TIESSON cable size with setting 5 (right) on cable for spin
- Static displacement of cable due to string less than 1 mm
- White noise (random) excitation at 0.5 volts, 0-2000 Hz
- Response measured at driving point by laser vibrometer
- Driving point at 8.5 cm above lower fix
- 2 lbs (0.9 N) cable tension
- Excitation measured by accelerometer 24 cm string
- Low pass 5 kHz filter
- Frequency of interest 0 - 250 Hz
- Test section length of 85A on wire
- Low 20.3 cm buffer zone above and below

CONCLUSIONS

CONCLUSIONS

- Conclusions are drawn from the results of the experiments.
- Conclusions are drawn from the results of the experiments.
- Conclusions are drawn from the results of the experiments.

ACKNOWLEDGMENTS

- Acknowledgments are given to the funding agencies and the support of the project.
- Acknowledgments are given to the funding agencies and the support of the project.
- Acknowledgments are given to the funding agencies and the support of the project.



April 11, 2013

Toward Modeling of Cable-Harnessed Structures: Cable Damping Experiments

Kaitlin Spak - Presenter

Dr. Gregory Agnes

Dr. DANIEL INMAN

Virginia Tech - JPL - U of Michigan

Motivation

PROBLEM

- Cable structures are present on most space structures.
- Space structures have demand on weight.
- Cables have an demand on weight.

GOAL

How can we do a better job of understanding the behavior of cables in space structures?

QUESTION

- Can we predict behavior in space?
- Can we predict behavior in space?
- Can we predict behavior in space?

ANSWER

Can we predict behavior in space?

QUESTION

- Can we predict behavior in space?
- Can we predict behavior in space?
- Can we predict behavior in space?

ANSWER

Can we predict behavior in space?

String Length and Tension

PROBLEM

- Cable structures are present on most space structures.
- Space structures have demand on weight.
- Cables have an demand on weight.

GOAL

How can we do a better job of understanding the behavior of cables in space structures?

Space Flight Cables

- M27500-24TG2T4 wire used (24 AWG twisted pairs with twisted copper EMI shielding and Tefzel (ETFE) jacket)
- 1 by 18 in 2 layers over a core wire
- Helicallly twisted
- Tie laced every 4-6"
- Kapton overwrap
- Typical space flight cable



Tension

PROBLEM

- Cable structures are present on most space structures.
- Space structures have demand on weight.
- Cables have an demand on weight.

GOAL

How can we do a better job of understanding the behavior of cables in space structures?

AIAA

April 11, 2013

Toward Modeling of Cable-Harnessed Structures: Cable Damping Experiments

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

Virginia Tech - JPL - U of Michigan

Cable Ties

PROBLEM

- Cable structures are present on most space structures.
- Space structures have demand on weight.
- Cables have an demand on weight.

GOAL

How can we do a better job of understanding the behavior of cables in space structures?

Excitation Method

PROBLEM

- Cable structures are present on most space structures.
- Space structures have demand on weight.
- Cables have an demand on weight.

GOAL

How can we do a better job of understanding the behavior of cables in space structures?

Test Procedures

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

"Standard Run"

- Cable attached to test fixture with set pins toward shaker
- 100g TROBAM cable ties with setting 5 (right) on cable tie gun
- Static displacement of cable due to string less than 1 mm
- White noise (random) excitation at 0.5 volts, 0-2000 Hz
- Response measured at driving point by laser vibrometer
- Driving point at 8.5 cm above lower fix
- 2 lbs (0.9 N) cable tension
- Excitation measured by accelerometer 24 cm string
- Low pass 5 kHz filter
- Frequency of interest 0 - 250 Hz
- Test section length of 85A on wire
- Low 20.3 cm buffer zone above and below

Cable Orientation

PROBLEM

- Cable structures are present on most space structures.
- Space structures have demand on weight.
- Cables have an demand on weight.

GOAL

How can we do a better job of understanding the behavior of cables in space structures?

Cable Section

PROBLEM

- Cable structures are present on most space structures.
- Space structures have demand on weight.
- Cables have an demand on weight.

GOAL

How can we do a better job of understanding the behavior of cables in space structures?

CONCLUSIONS

CONCLUSIONS

How can we do a better job of understanding the behavior of cables in space structures?

CONCLUSIONS

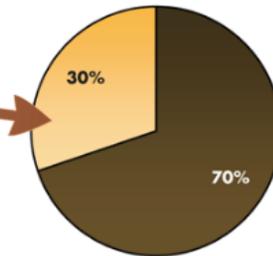
How can we do a better job of understanding the behavior of cables in space structures?

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

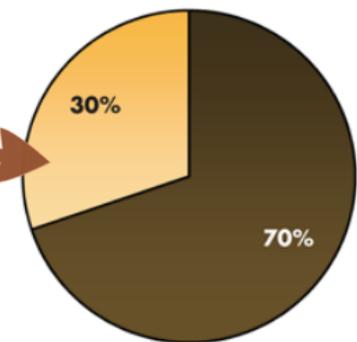
- As high as 30% in some cases
- 10% typical



THE HARNESSES ARE PRESENT ON MOST SPACE STRUCTURES
space structures have decreased in weight
cables have NOT decreased in weight

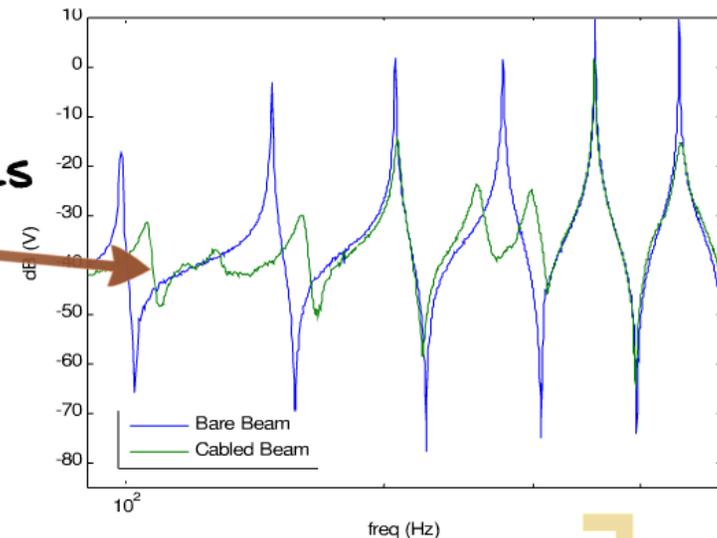
THUS: Cable mass as a percentage of total space structure mass has increased

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



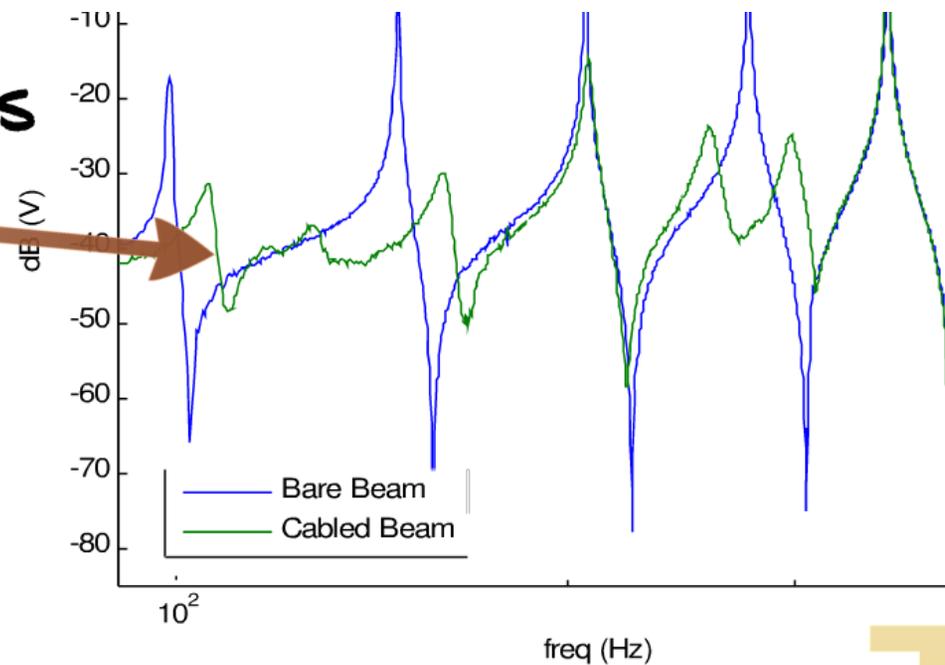
Motivation:

- 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

ables attached to structures
ange 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

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!

ure control AND system failure calculations

AMIC testing must often be completed before the stru
y dressed with cables

re is not yet a reliable predictive cable model for
ORATION INTO structural models

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

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



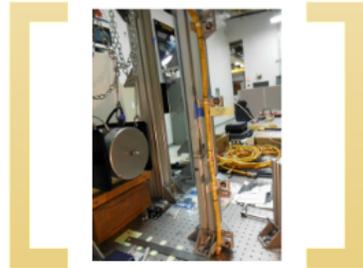


Space Flight Cables

- 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



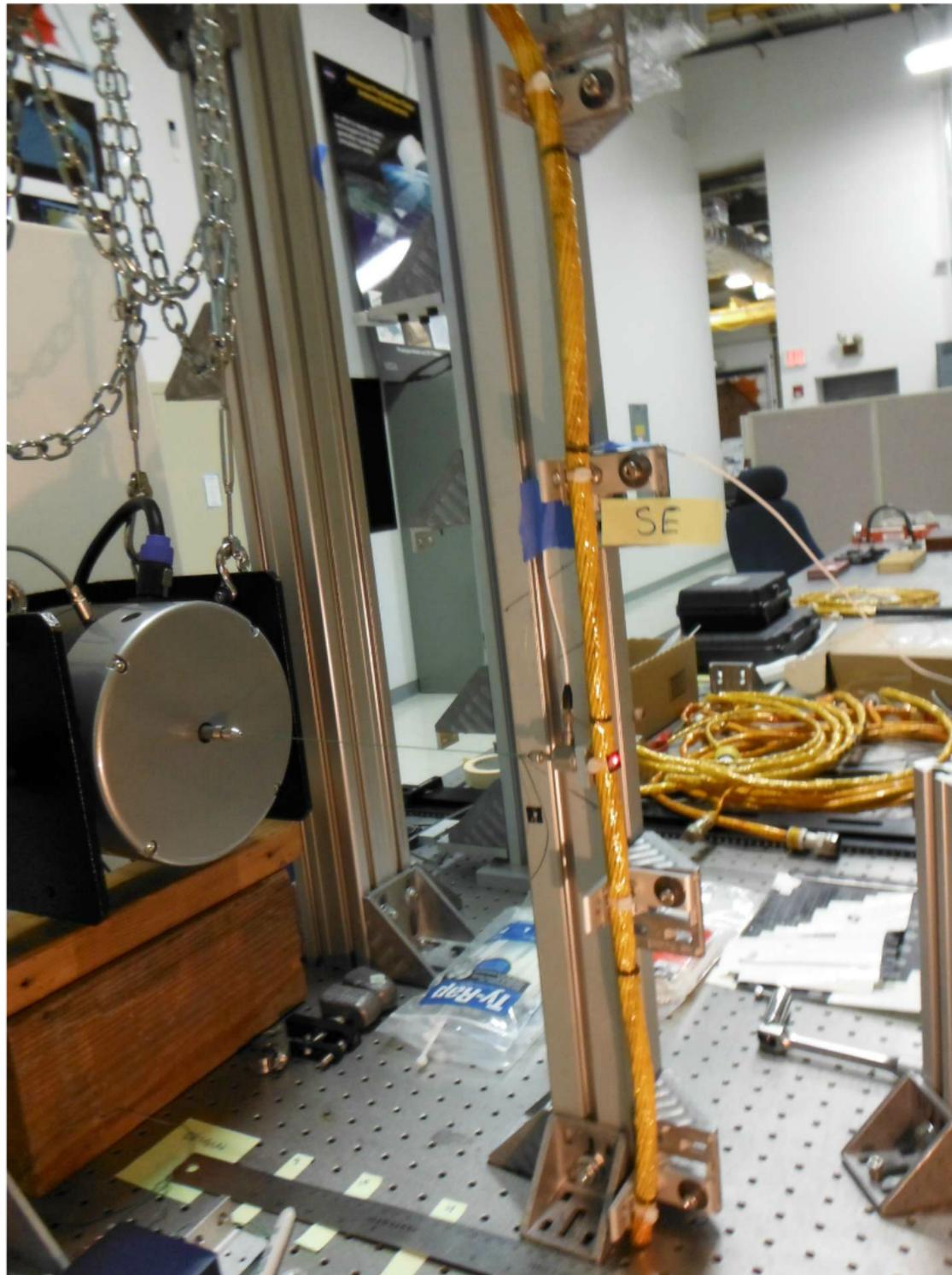
Test Procedures



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

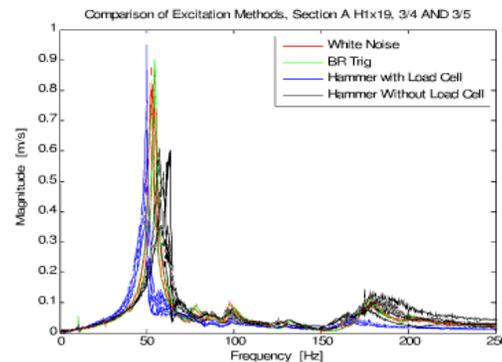
"Standard Run"

- Cable attached to test fixture with coil plane toward shaker
- TyRap TYS2SM 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



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.

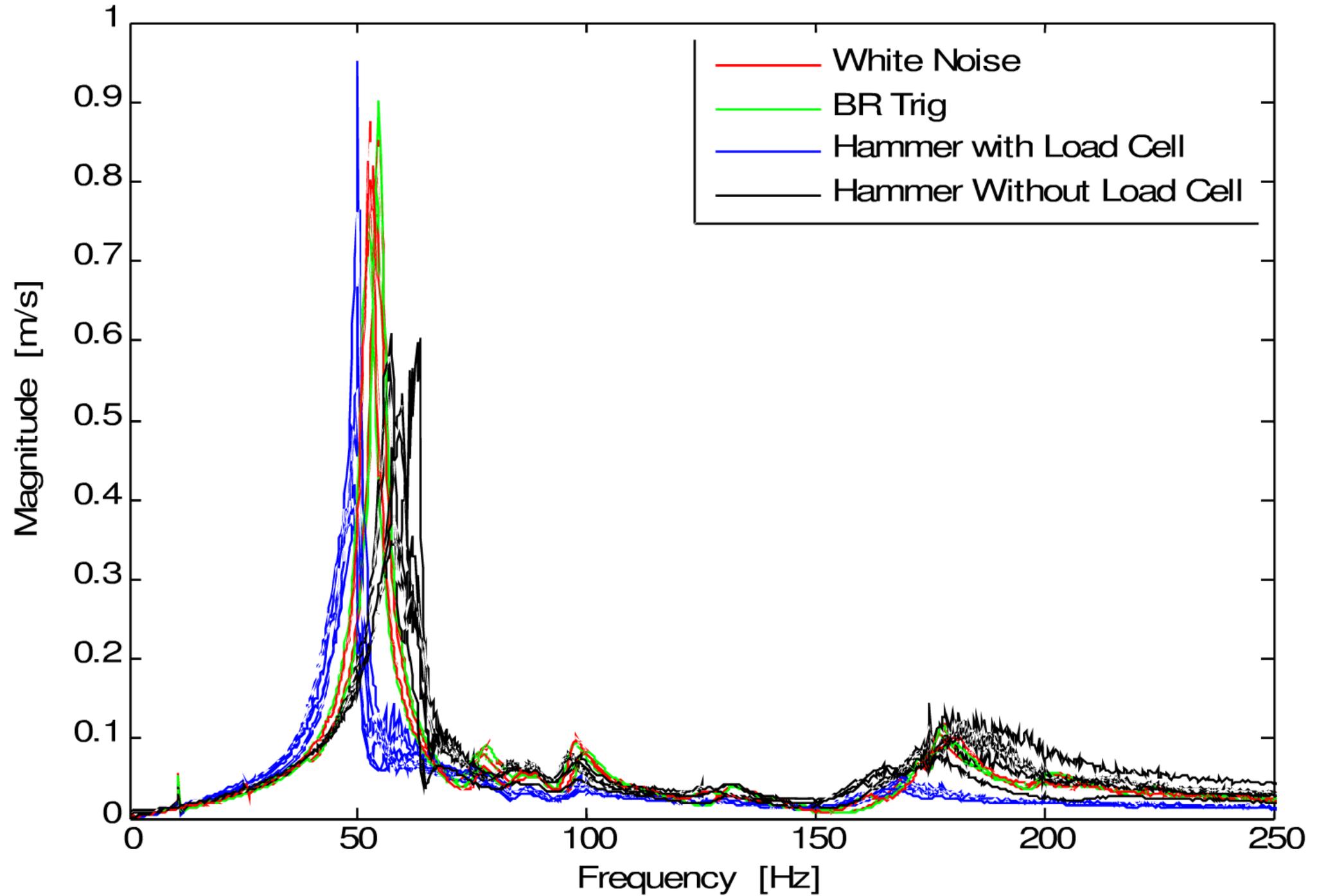


VirginiaTech

JPL

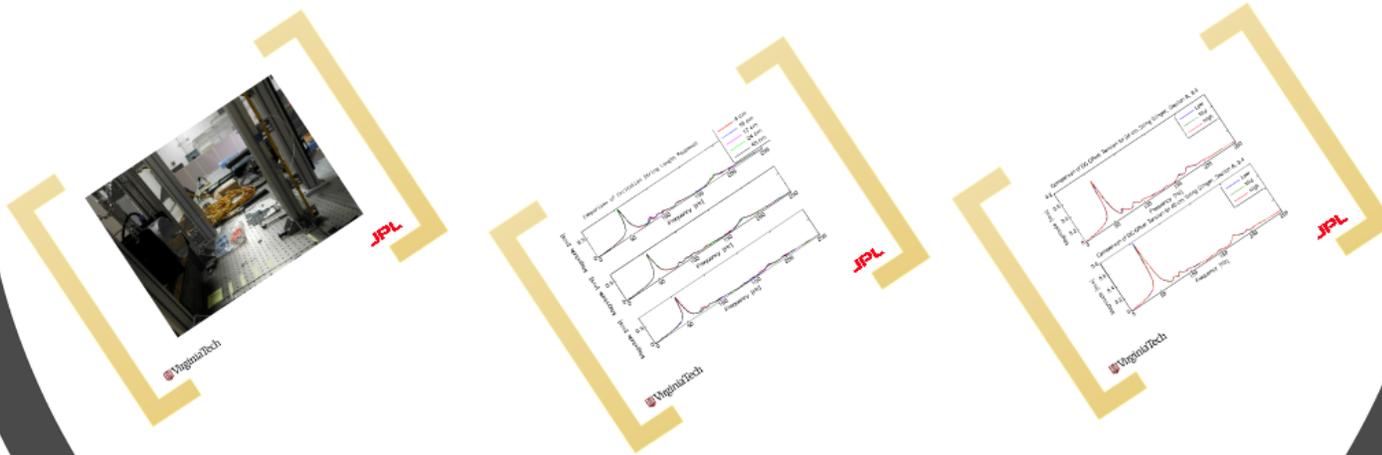
Hammer impacts bounded the white noise and burst random responses.

Comparison of Excitation Methods, Section A H1x19, 3/4 AND 3/5

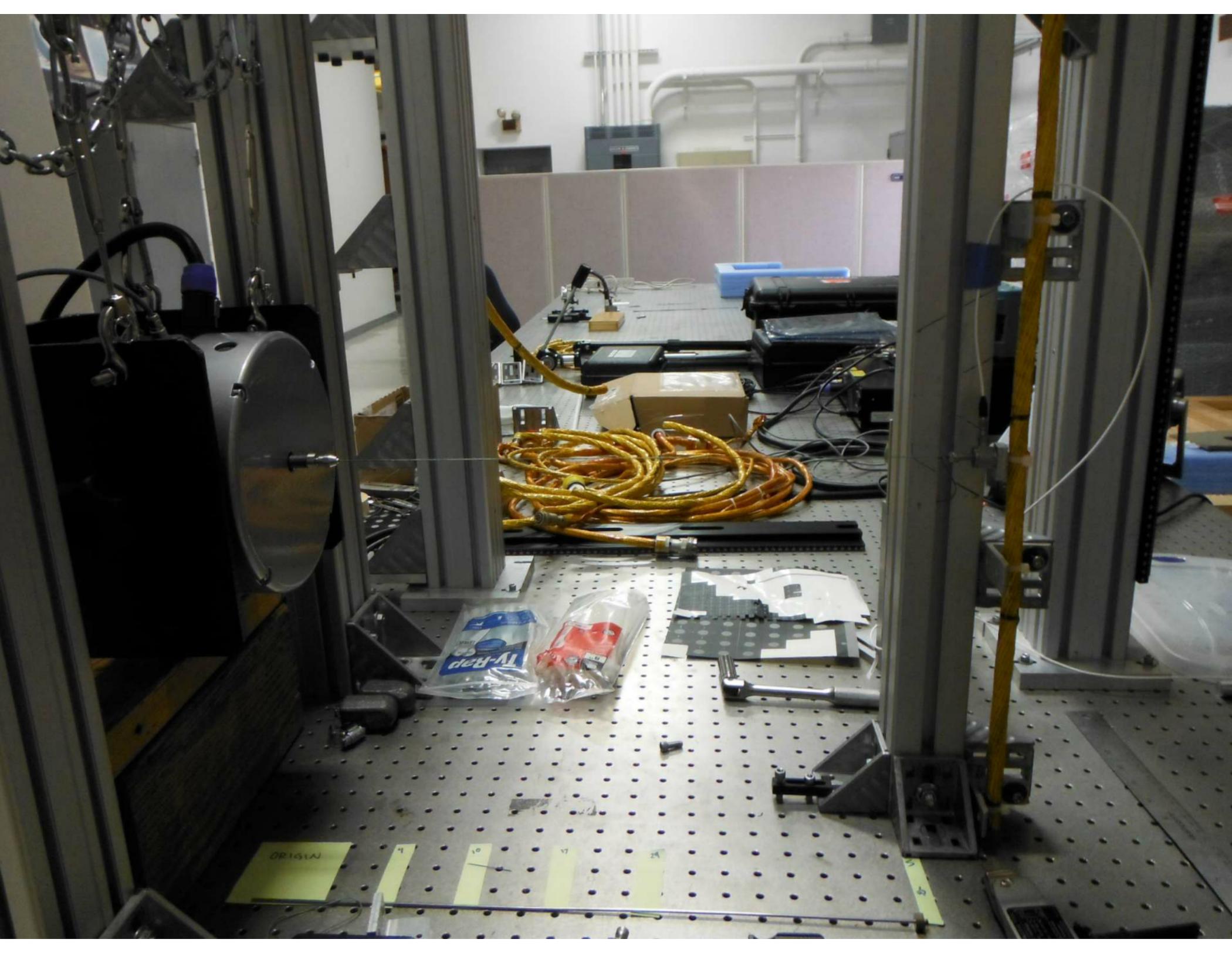


Excitation String Length and Tension

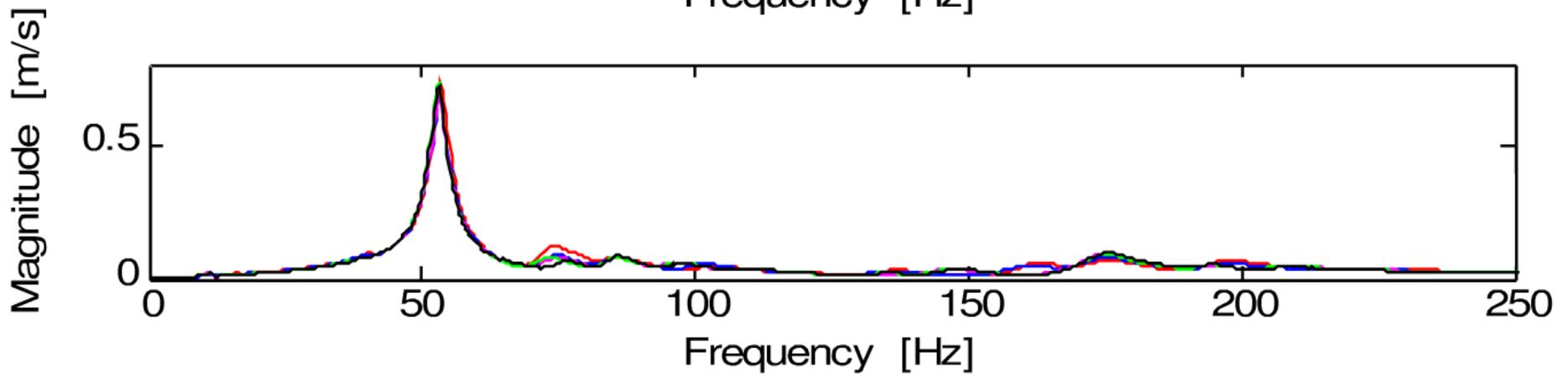
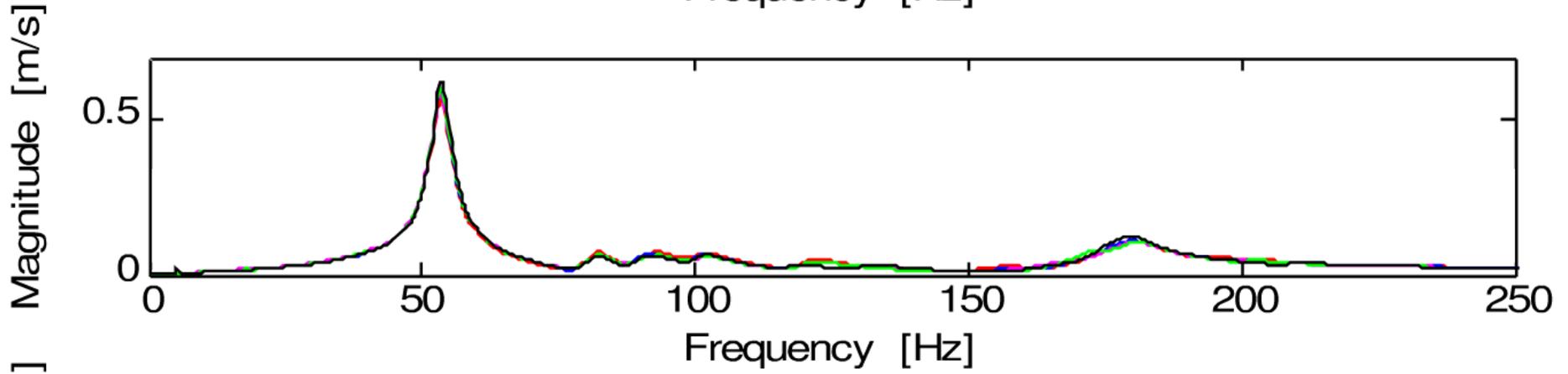
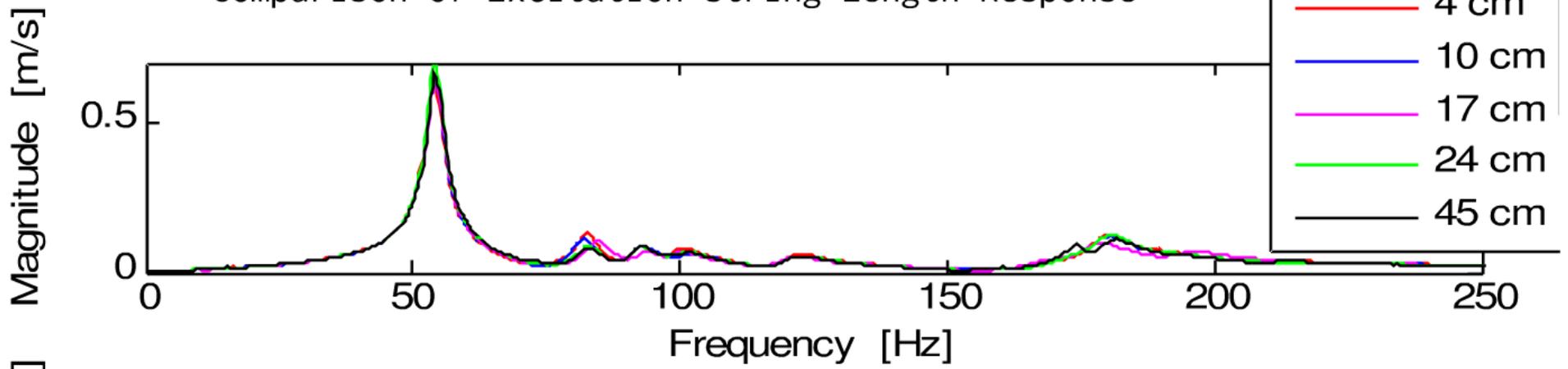
Cable fixture was moved to 4, 10, 17, 24 and 45 cm to vary string length. DC offset on shaker was also adjusted to provide tension variation in the excitation string. Cable was statically deflected less than 1 mm.



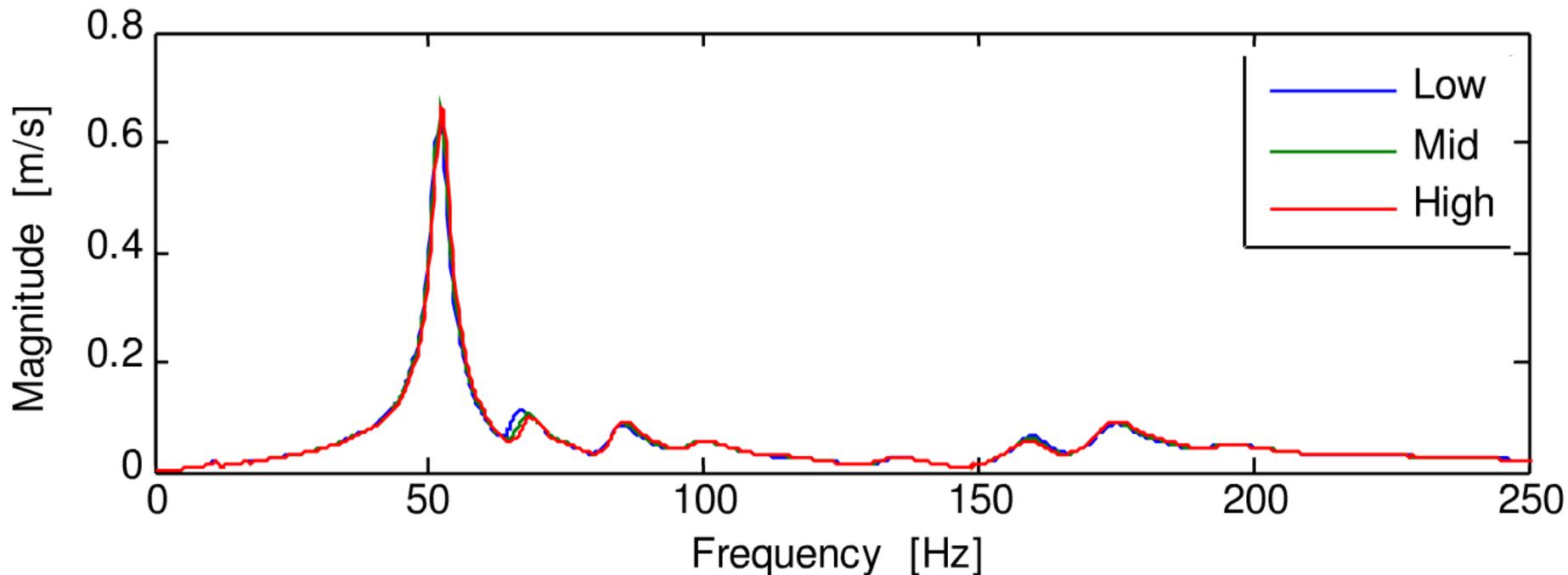
Neither string length nor tension
affected the dynamic response.



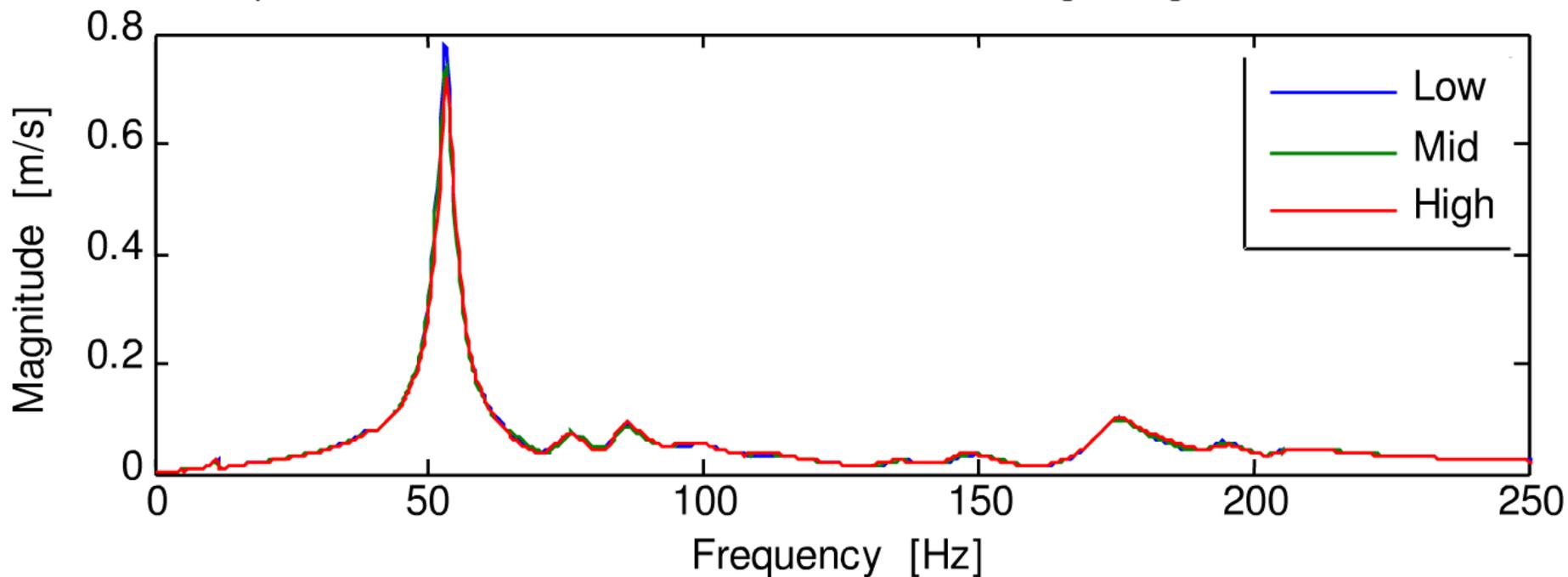
Comparison of Excitation String Length Response



Comparison of DC Offset Tension for 24 cm String Stinger, Section A, 3/4

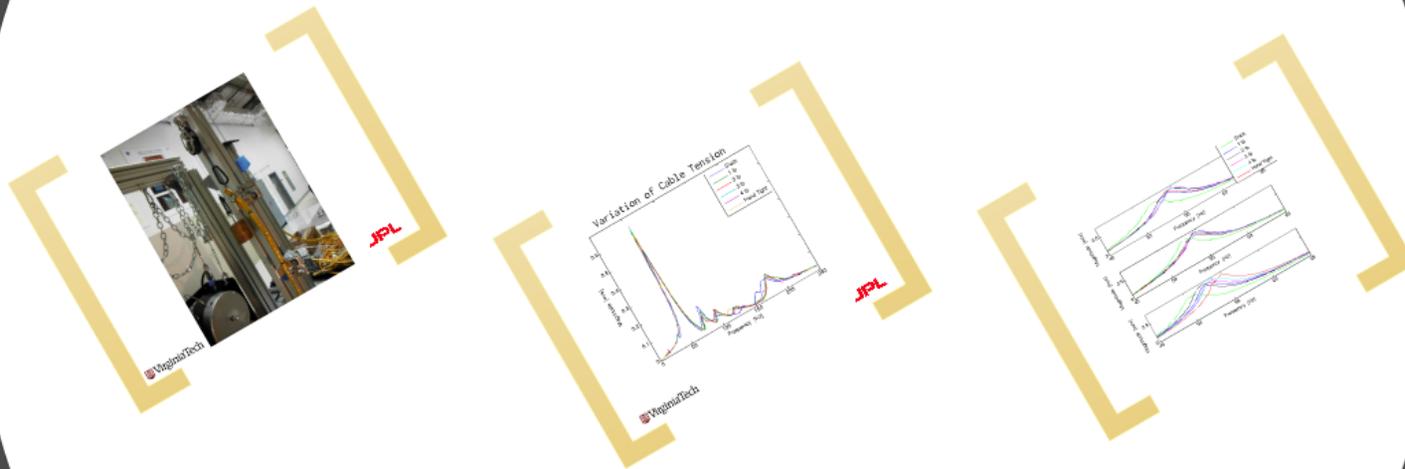


Comparison of DC Offset Tension for 45 cm String Stinger, Section A, 3/4

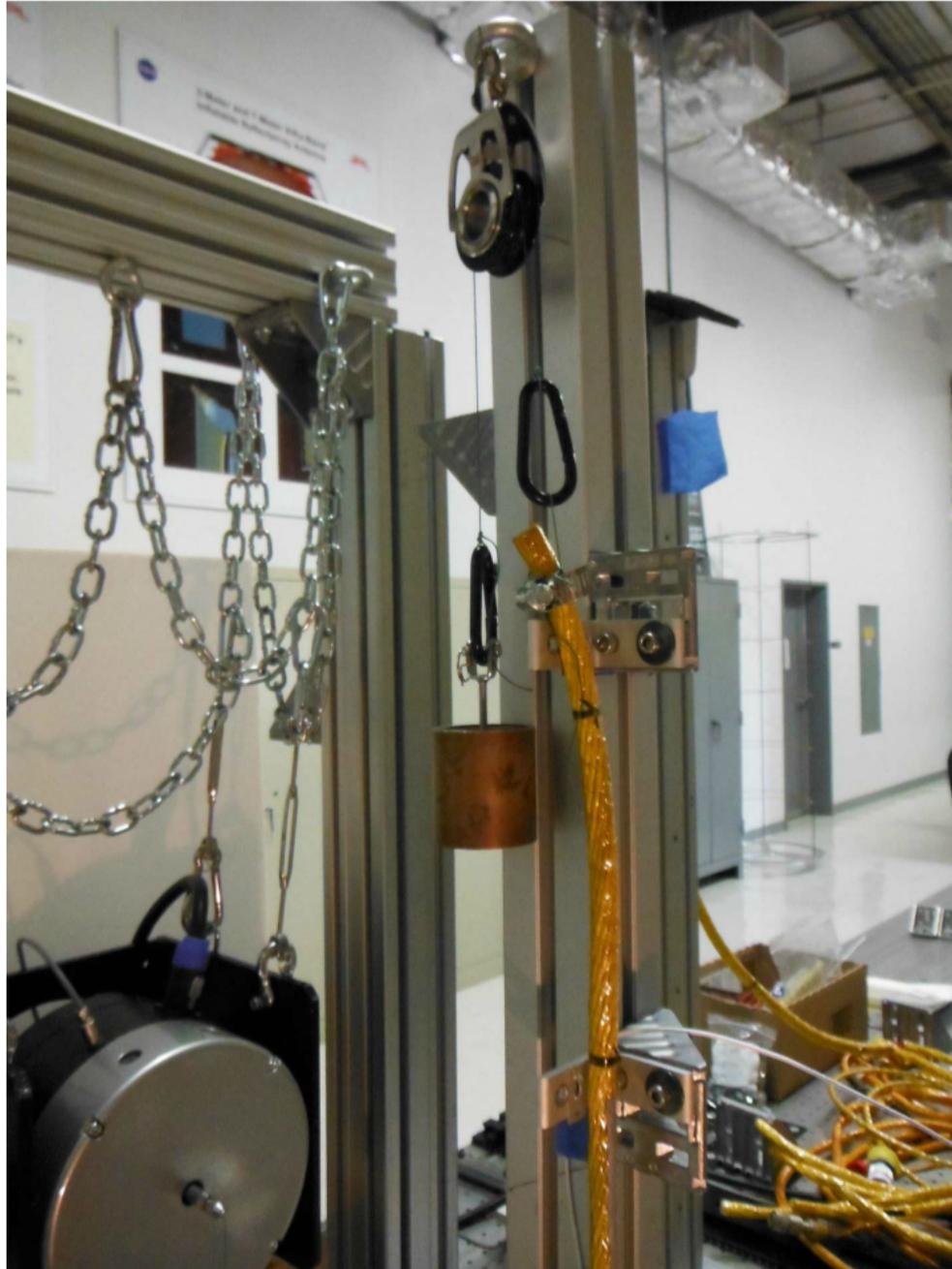


Cable Tension

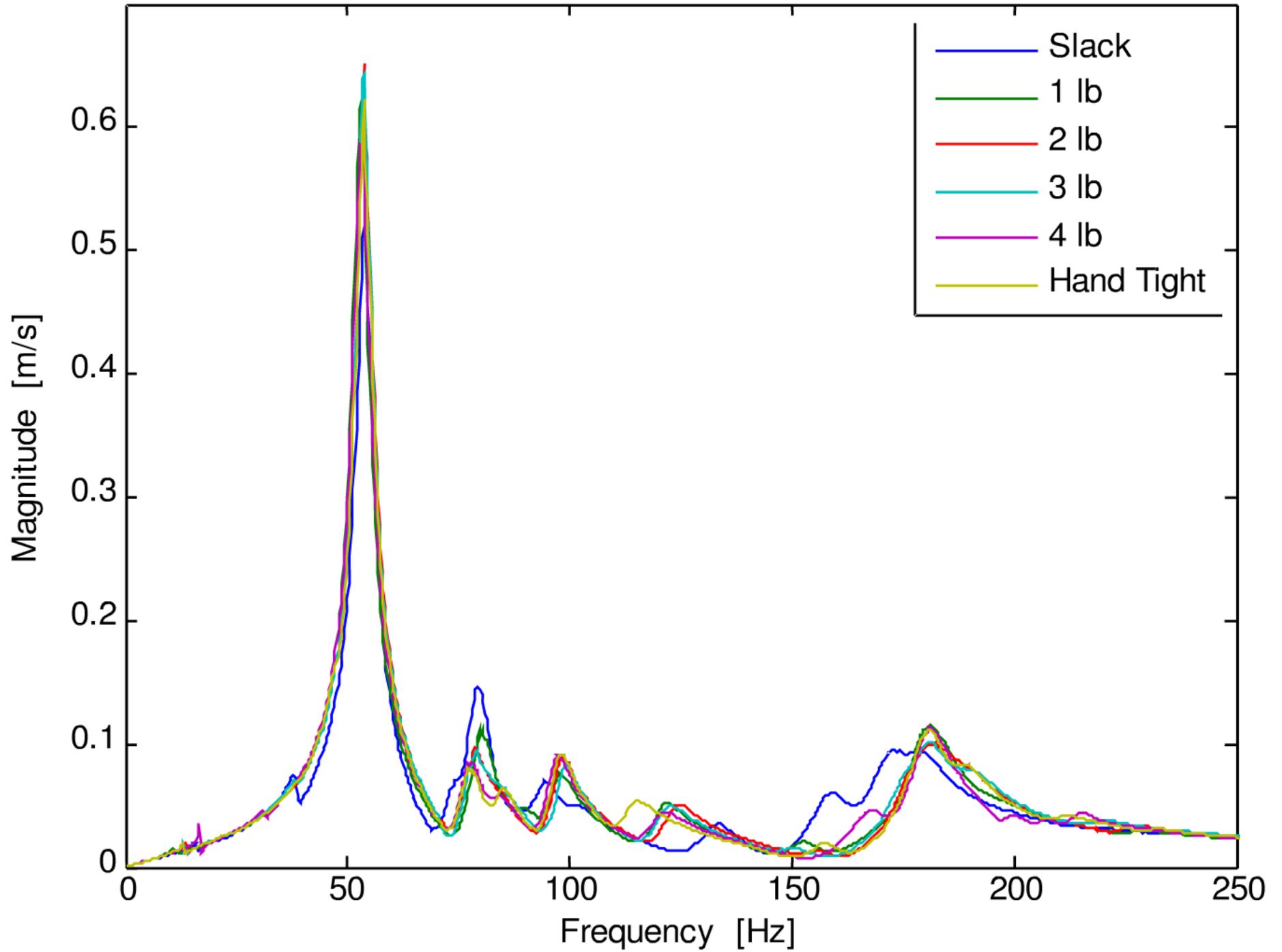
Cable tension was varied, from slack to 4 lbs. A hand-tight case was also tested, where the cable was simply pulled tight and attached similar to common installation methods.

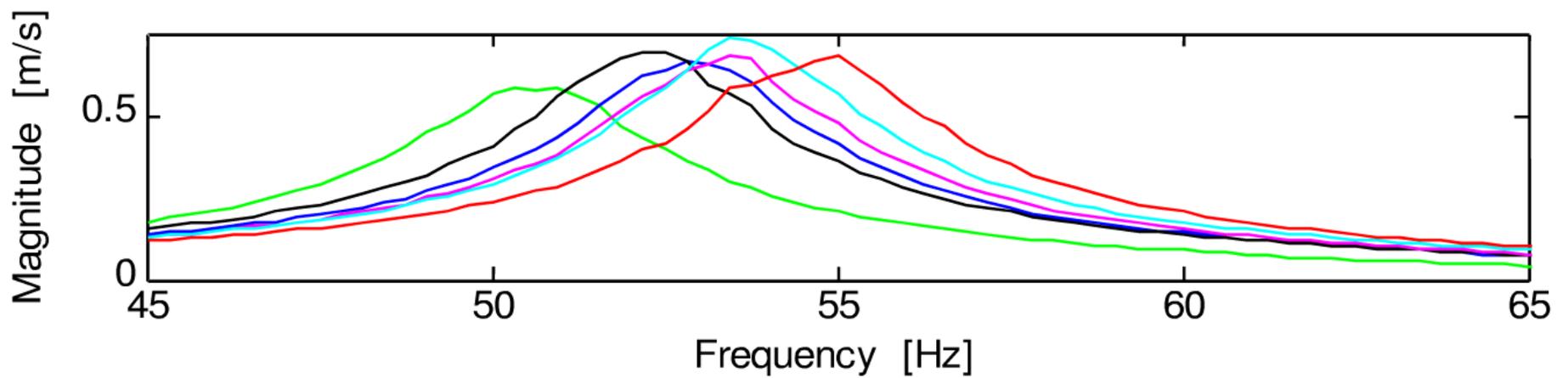
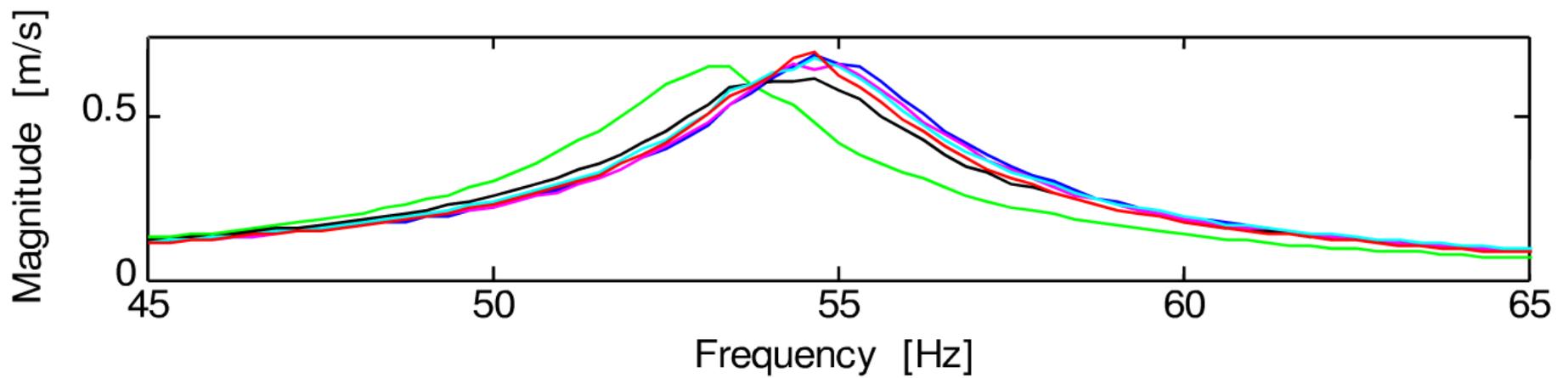
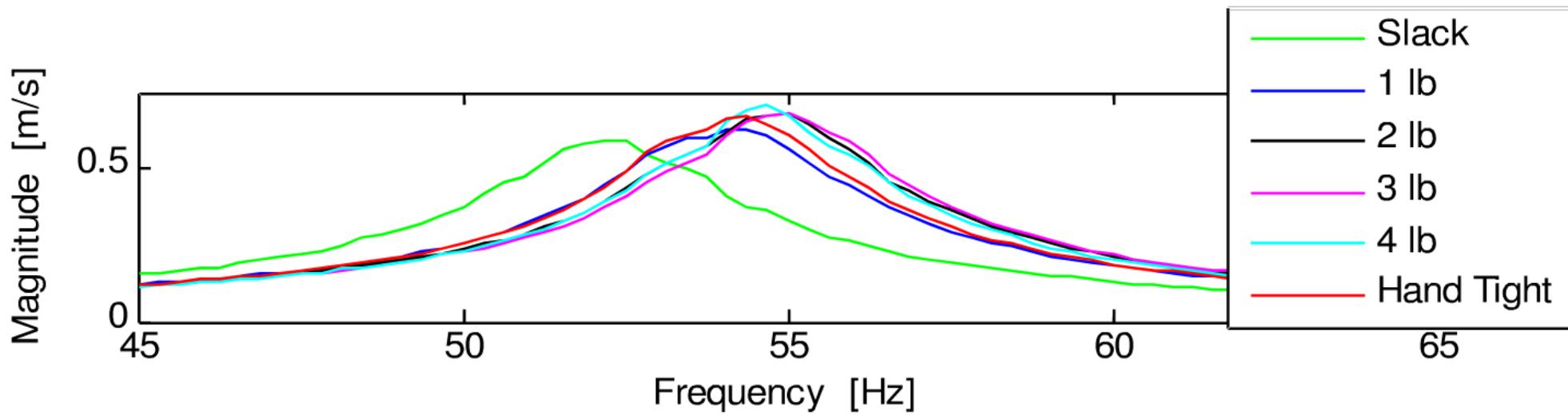


Cable frequency increased with increasing tension; a hand-pulled cable showed similar results; slack cable had significant differences.



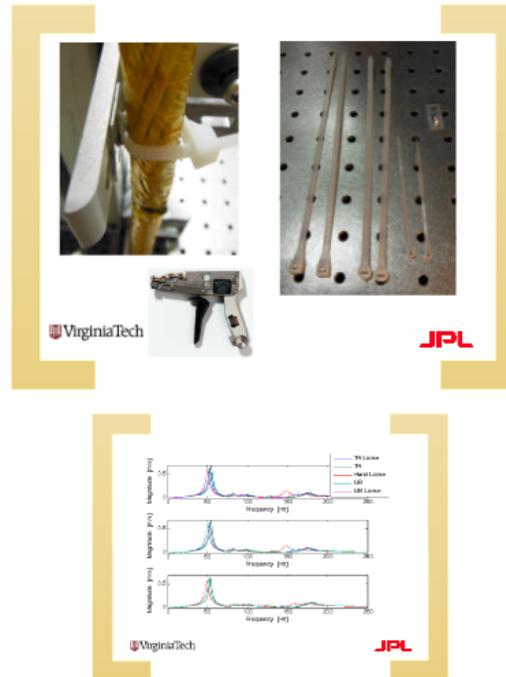
VARIATION OF CABLE TENSION





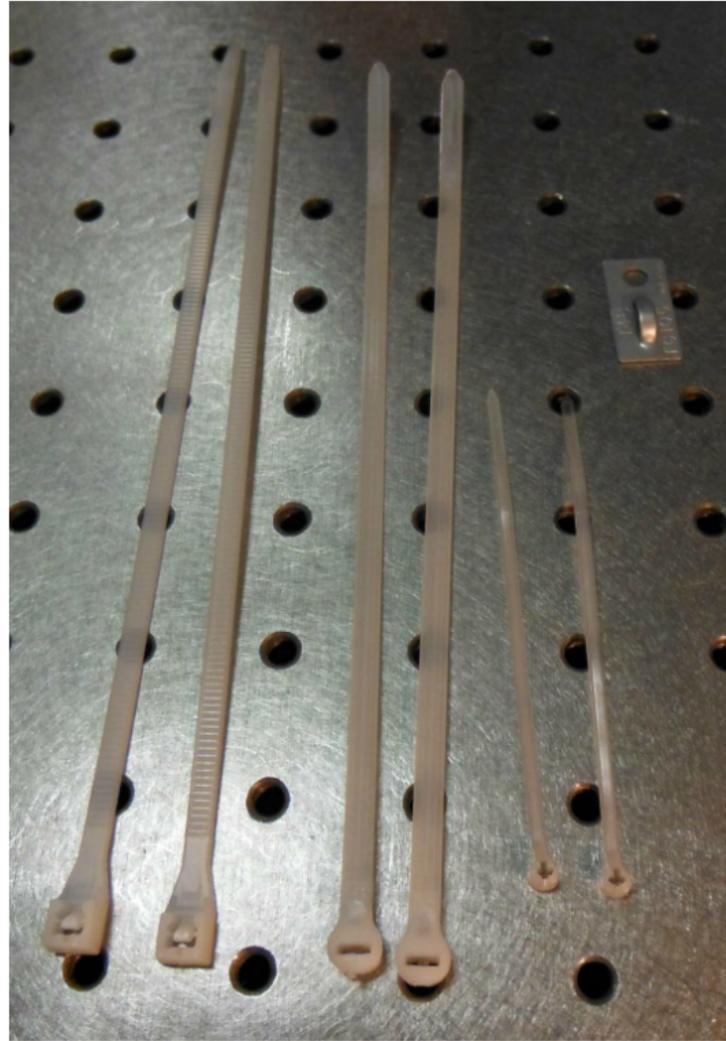
Cable Tie Attachment

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.



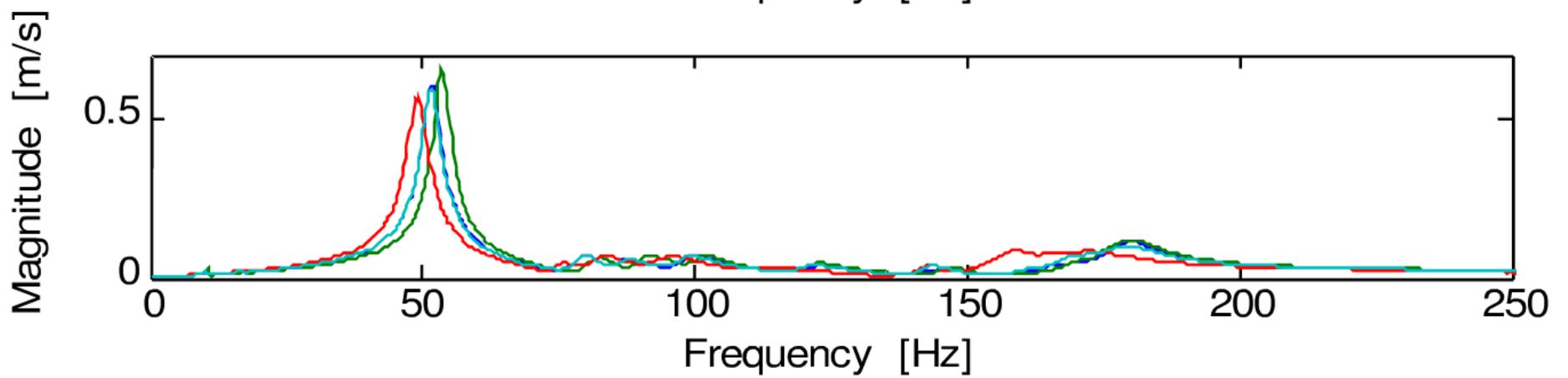
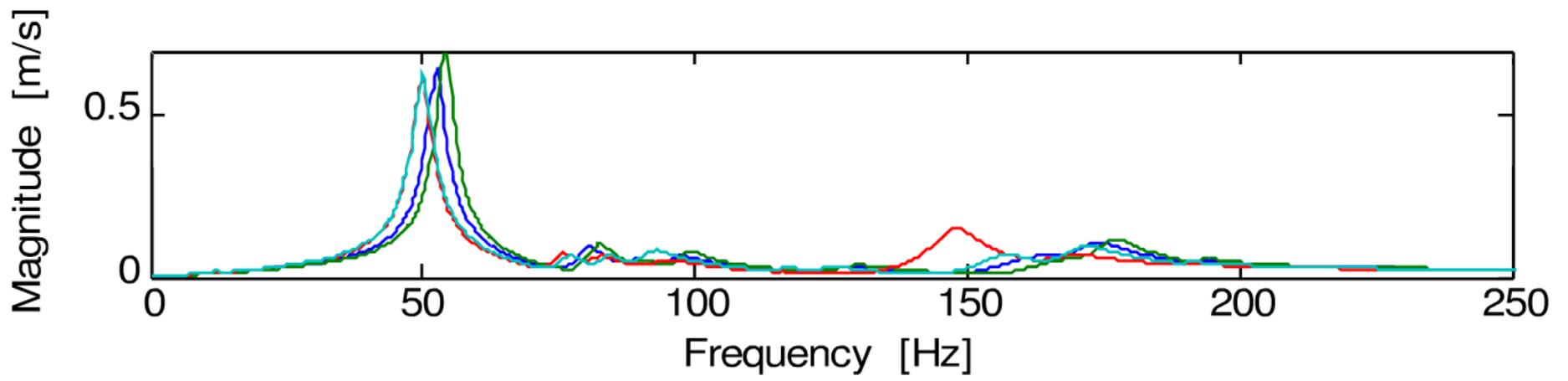
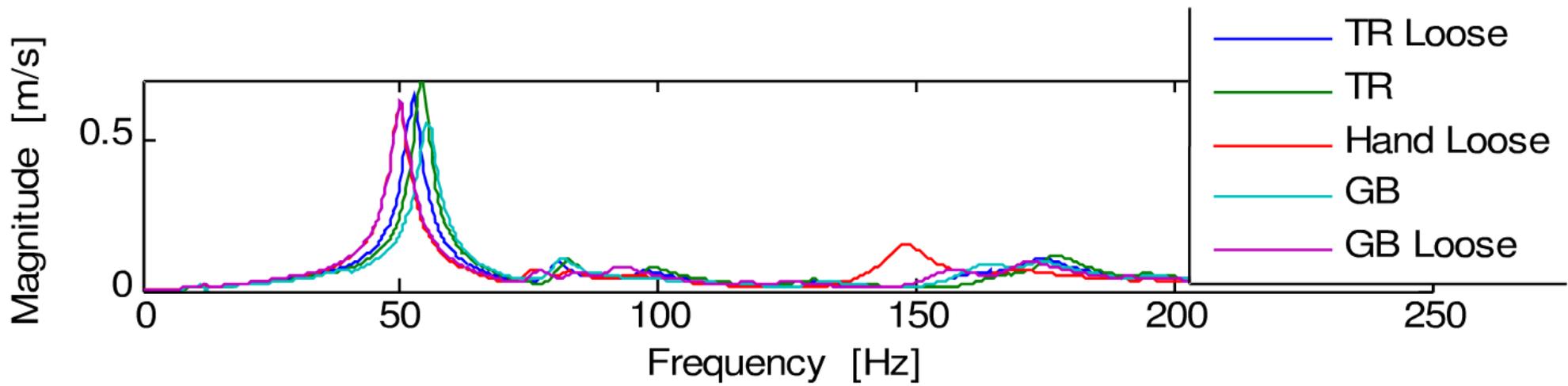
Tight cable ties behaved similarly, regardless of type; loose cable ties had greater variation from test to test.





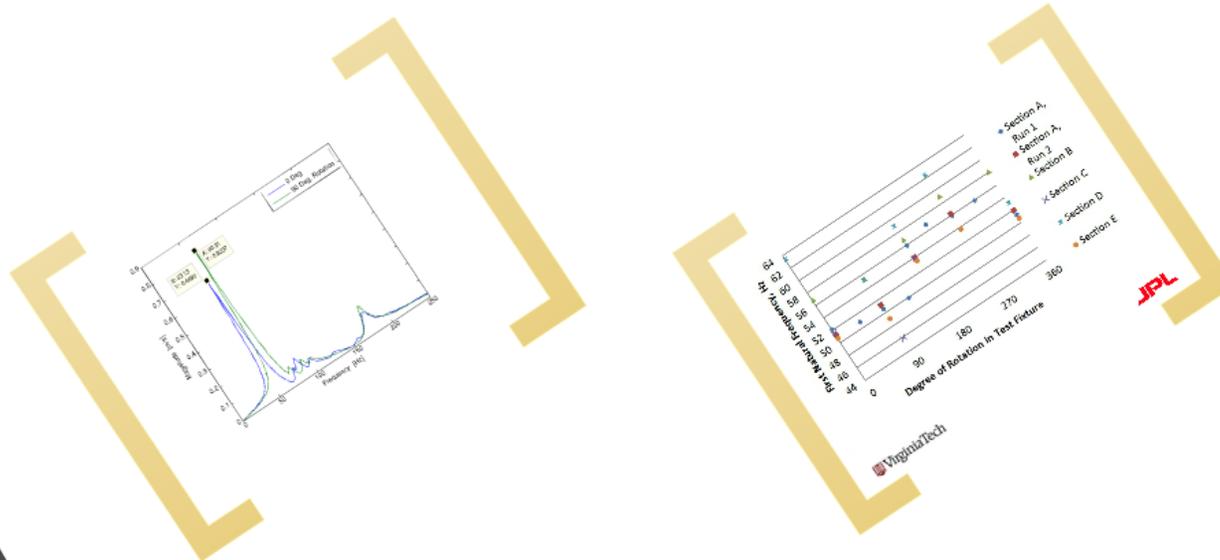
 VirginiaTech

JPL

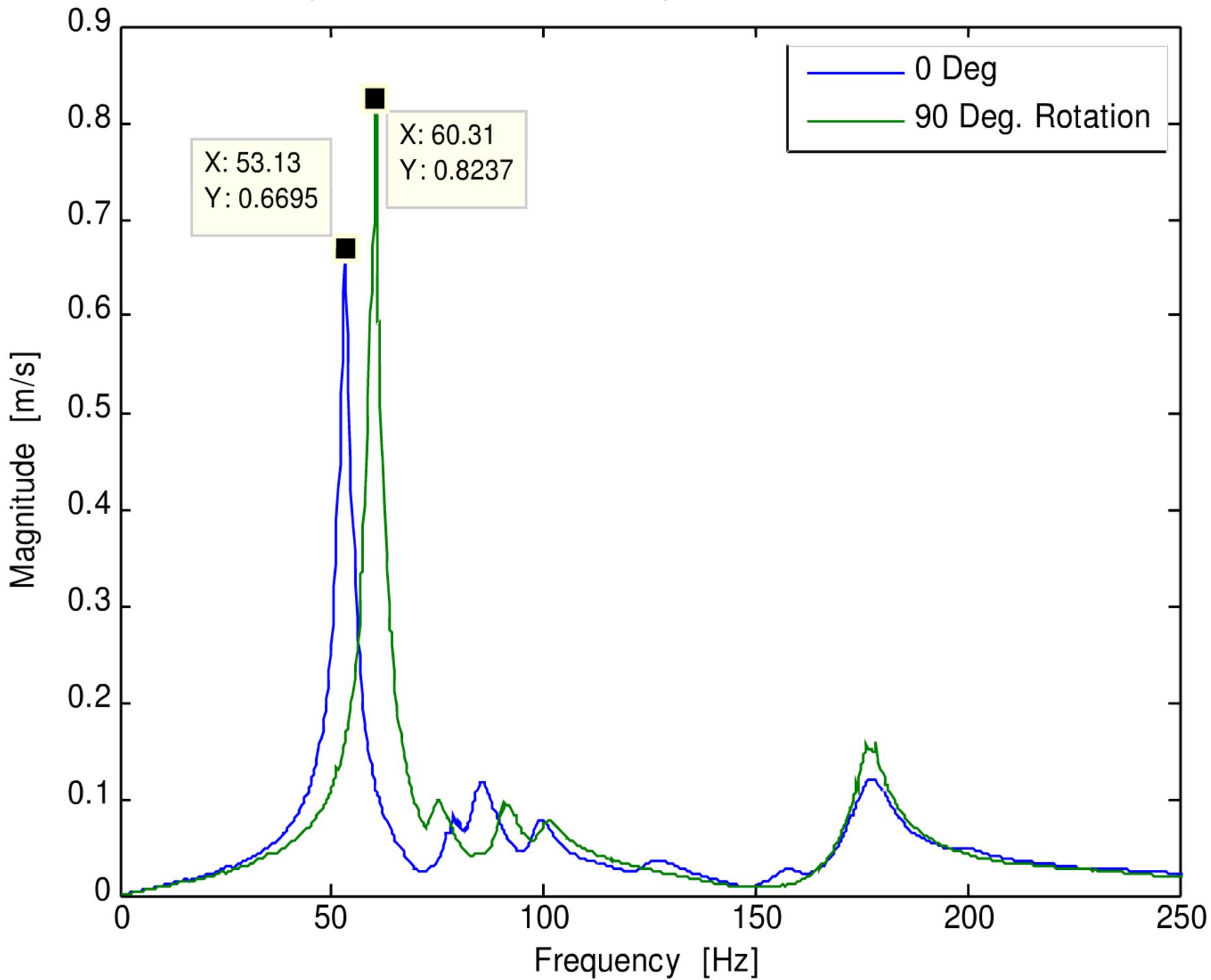


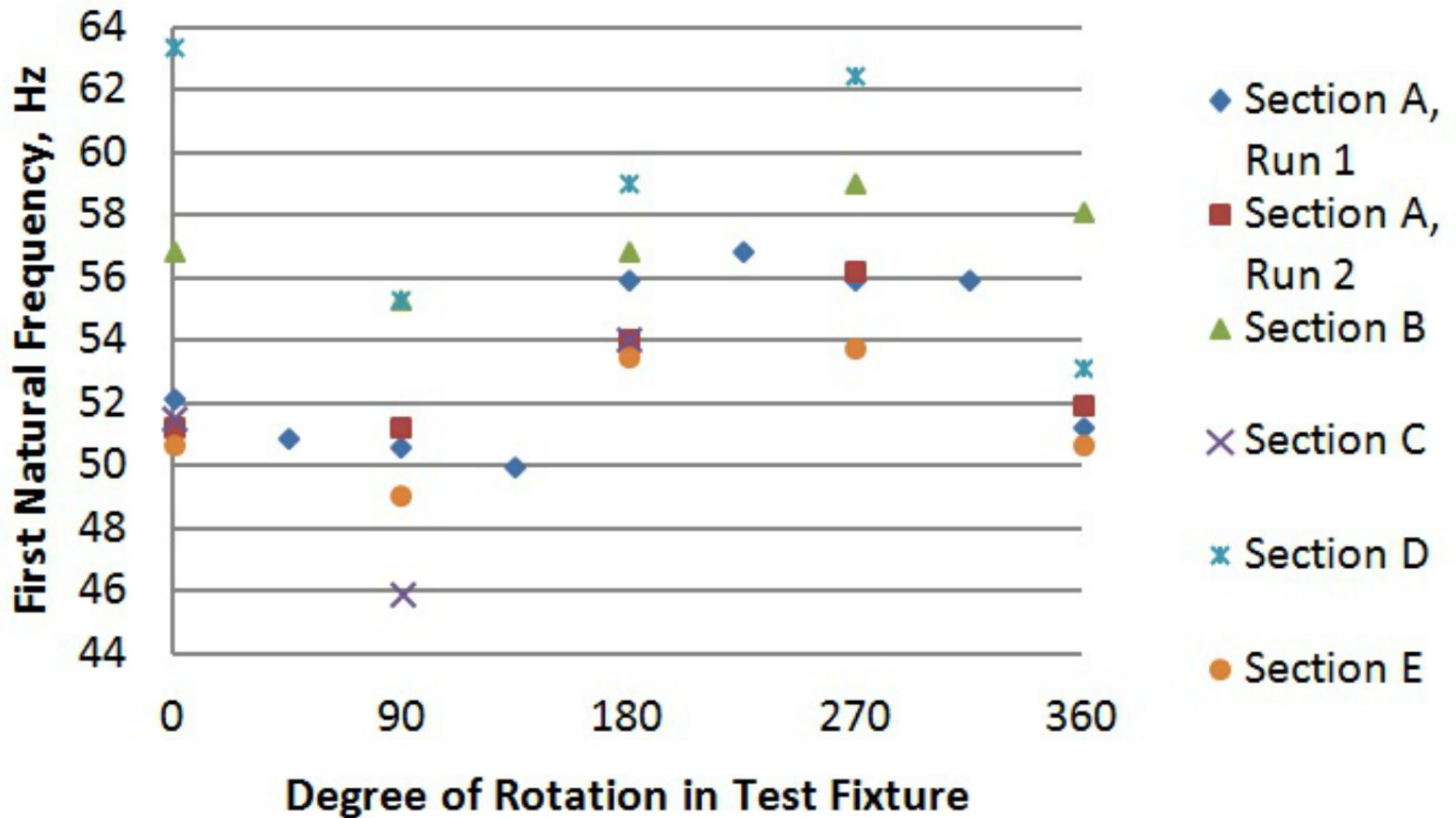
Cable Orientation

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



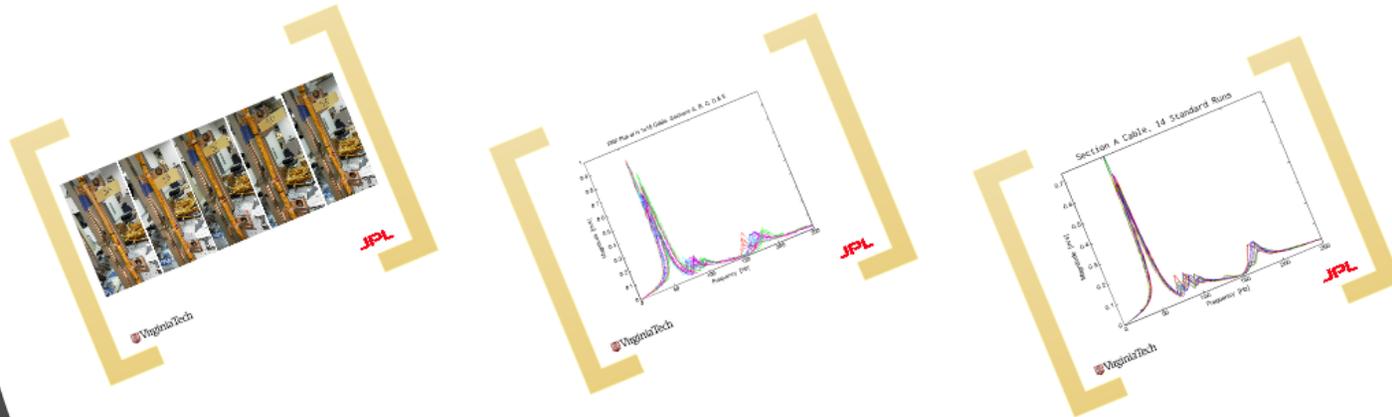
Natural frequency changed as coil plane was rotated; rotation of cable orientation shifts the first natural frequency in a roughly sinusoidal pattern.





Cable Section Comparison

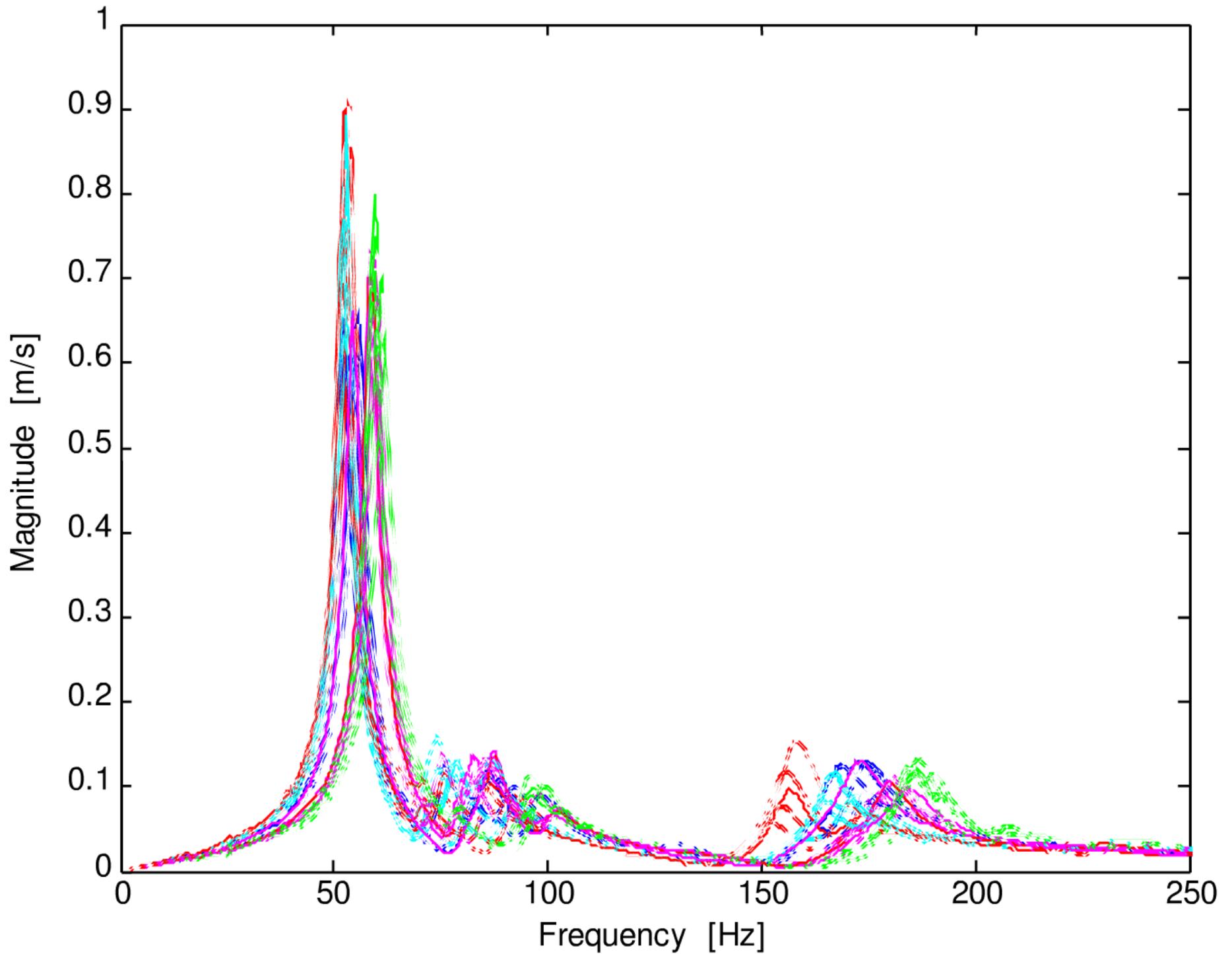
A length of 1 by 18 cable was cut into five similar sections, and standard runs of the sections were compared.



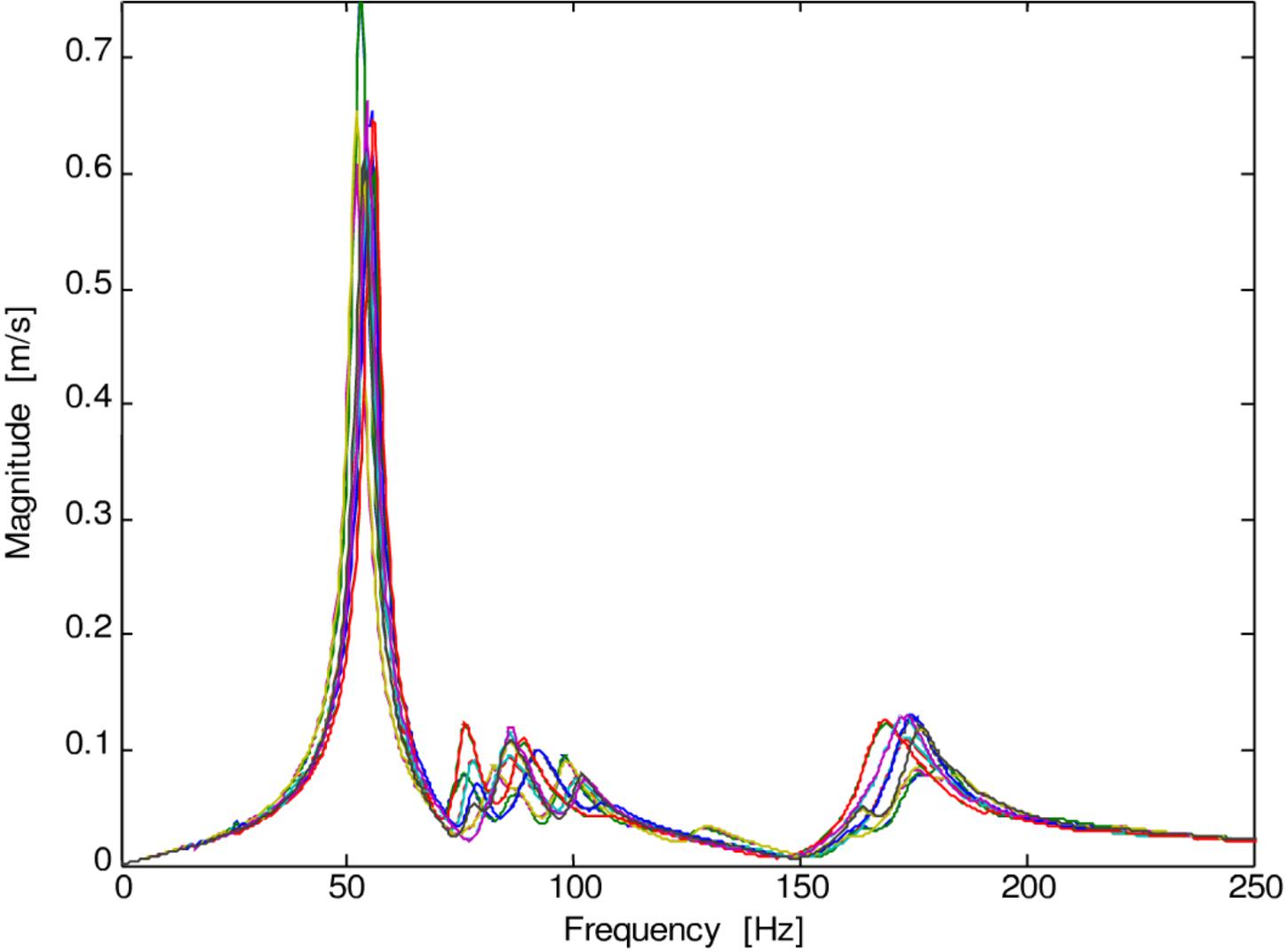
Variation in cable sections is significant!



FRF Plot of H 1x18 Cable, Sections A, B, C, D & E



Section A Cable, 14 Standard Runs



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.

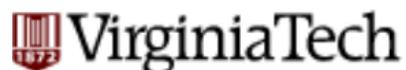
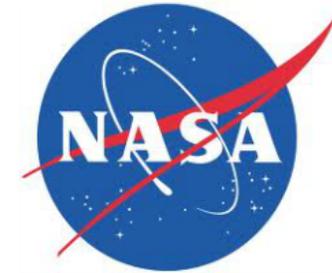
From this work, further progress has been made to investigate the damping of structures due to cable wiring harnesses.

* 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



Motivation

PROBLEM

- Cable structures are present on most space structures.
- Space structures have demands on weight.
- Cables have an inherent in-flight.

GOAL

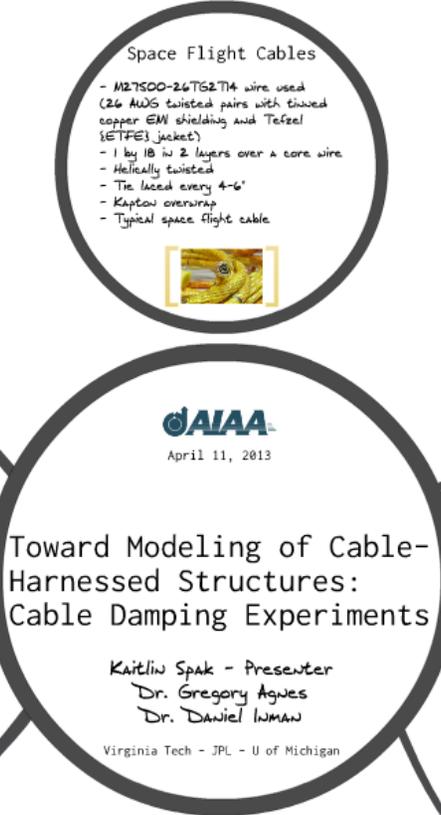
Understand the behavior of cables in space structures.

RESEARCH

- Cables are present in a broad range of applications.
- Cables are a major component of a system.
- Cables are a major component of a system.

RESEARCH

- Understand and model the dynamic behavior of a system.
- A number of research questions are addressed for space structures.
- System behavior will be compared with the structure.
- How can the cable structure be modeled for the purpose of simulation?



String Length and Tension

String Length and Tension

- String length and tension are critical parameters for cable dynamics.
- String length affects the natural frequency of the cable.
- Tension affects the wave speed and the natural frequency.

Space Flight Cables

- M27500-24TG2T4 wire used (24 AWG twisted pairs with twisted copper EMI shielding and Tefzel (ETFE) jacket)
- 1 by 18 in 2 layers over a core wire
- Helicallly twisted
- Tie laced every 4-6"
- Kapton overwrap
- Typical space flight cable



Tension

Cable Tension

- Cable tension is a critical parameter for cable dynamics.
- Tension affects the wave speed and the natural frequency.
- Tension affects the cable's ability to support its own weight.

Cable Ties

Cable Ties

- Cable ties are used to secure cables to structures.
- Cable ties can affect the cable's dynamic behavior.
- Cable ties can introduce additional mass and stiffness.

Excitation Method

Excitation Method

- Excitation methods include shaker excitation and laser vibrometry.
- Shaker excitation is used to measure the cable's response to a known input.
- Laser vibrometry is used to measure the cable's response to a known input.

Cable Section

Cable Section

- Cable section is a critical parameter for cable dynamics.
- Cable section affects the cable's natural frequency.
- Cable section affects the cable's ability to support its own weight.

Test Procedures

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

"Standard Run"

- Cable attached to test fixture with set pins toward shaker
- Taper TROBON cable ties with setting 5 (right) on cable tie gun
- Static displacement of cable due to string less than 1 mm
- White noise (random) excitation at 0.5 volts, 0-2000 Hz
- Response measured at driving point by laser vibrometer
- Driving point at 8.5 cm above lower fix
- 2 lbs (0.9 N) cable tension
- Excitation measured by accelerometer 24 cm string
- Low pass 5 kHz filter
- Frequency of interest 0 - 250 Hz
- Test section length of 85 cm on wire
- Low 20.3 cm buffer zone above and below

Cable Orientation

Cable Orientation

- Cable orientation is a critical parameter for cable dynamics.
- Cable orientation affects the cable's natural frequency.
- Cable orientation affects the cable's ability to support its own weight.

CONCLUSIONS

Conclusions

- The cable structure is a critical component of space structures.
- The cable structure affects the system's dynamic behavior.
- The cable structure affects the system's ability to support its own weight.

References

- 1. JPL Space Systems Research
- 2. JPL Space Systems Research
- 3. JPL Space Systems Research