An introduction to the tuned-inerter-damper for vibration suppression

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Presentation overview

- The need for vibration suppression devices
- The inerter
- The tuned-inerter-damper (TID)
- Design based on TMD design rules
- Application to MDOF systems
- Experimental results
- Example of TID used to suppress cable vibration
- Summary and Acknowledgements

Vibration suppression: bridges


Millennium bridge, London

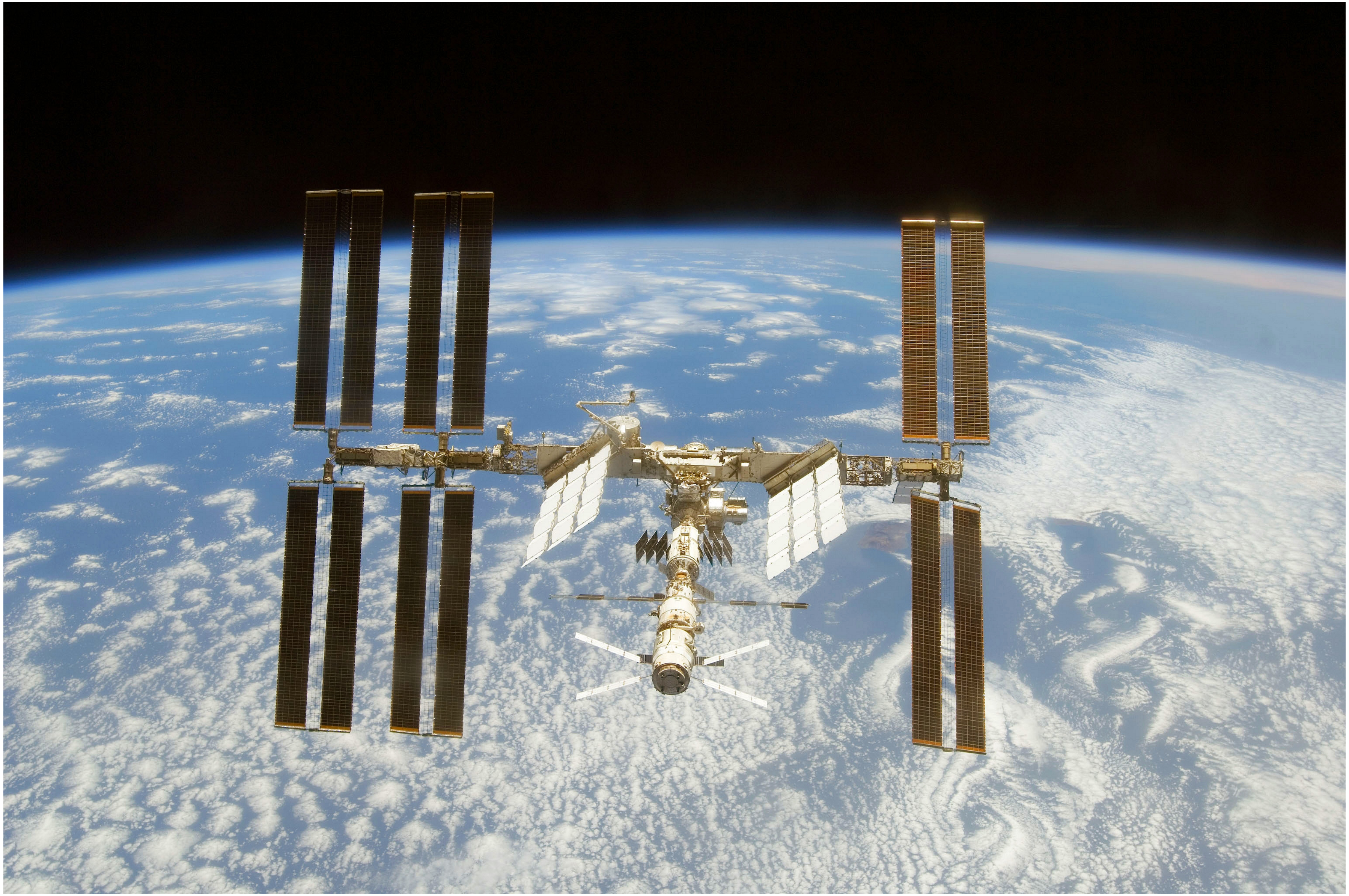

Dongting Lake Bridge 310m central span


Second Severn Crossing, UK

Vibration supression: tall buildings

Taipei 101, completed in 2003, 508 m high. Uses a tuned-mass-damper

Vibration suppression: space structures



International Space Station (ISS) with deployable solar arrays. Attitude control using gyros.

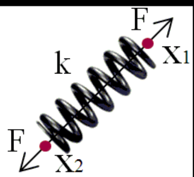
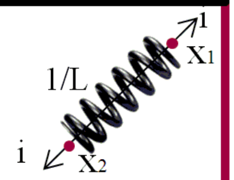
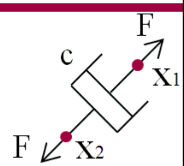
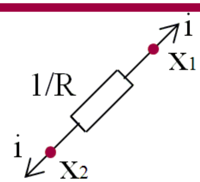
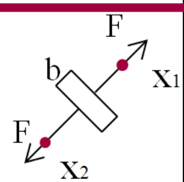
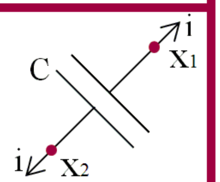
Vibration suppression: helicopters

Sikorsky S-76, uses a bifilar vibration absorbers (centrifugal pendulum absorber)

Other systems

The inerter

The inerter was introduced by Malcolm Smith (Cambridge), to complete the force-current analogy between mechanical and electrical networks.

Mechanical Networks	Electrical Networks
Spring $F=k(x_2-x_1)$ 	**Inductor** $F=1/L(x_2-x_1)$ 
Damper $F=c(\dot{x}_2-\dot{x}_1)$ 	**Resistor** $F=1/R(\dot{x}_2-\dot{x}_1)$ 
Inerter $F=b(\ddot{x}_2-\ddot{x}_1)$ 	**Capacitor** $F=C(\ddot{x}_2-\ddot{x}_1)$ 

Types of inerter

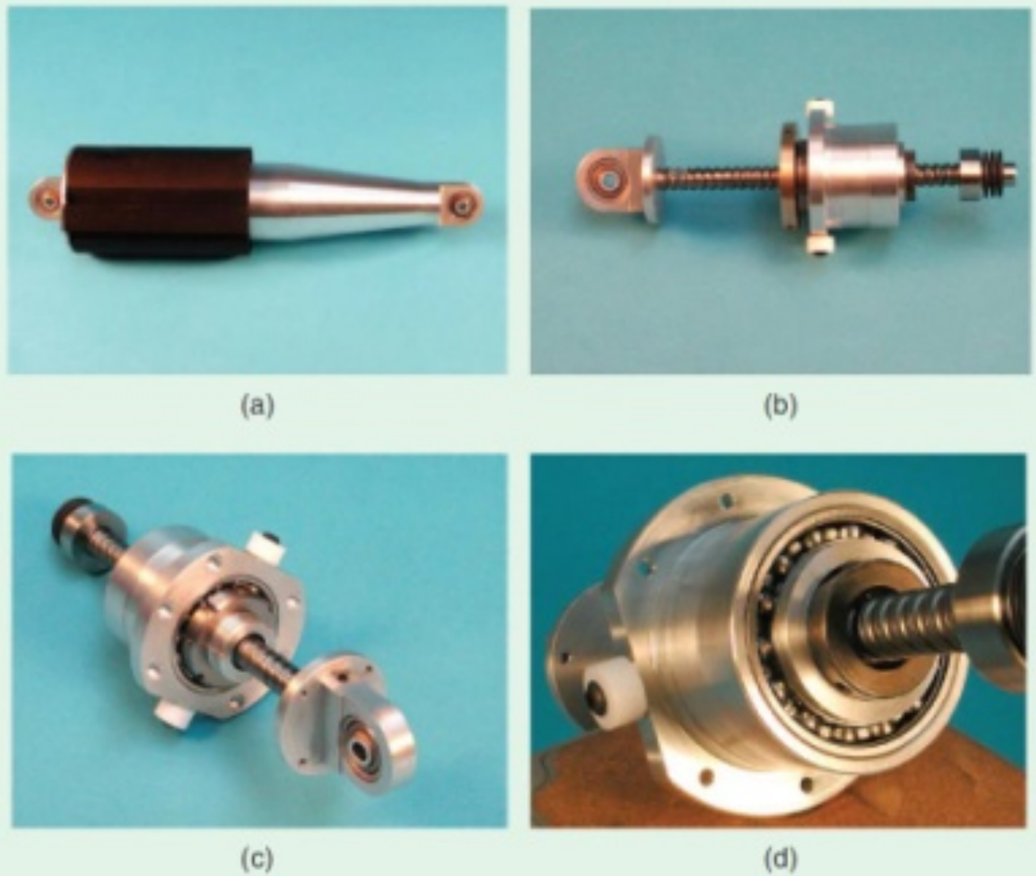
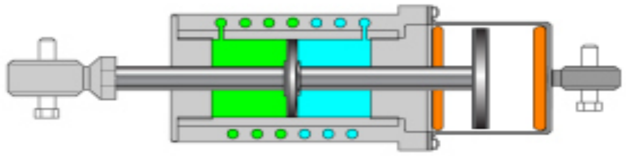
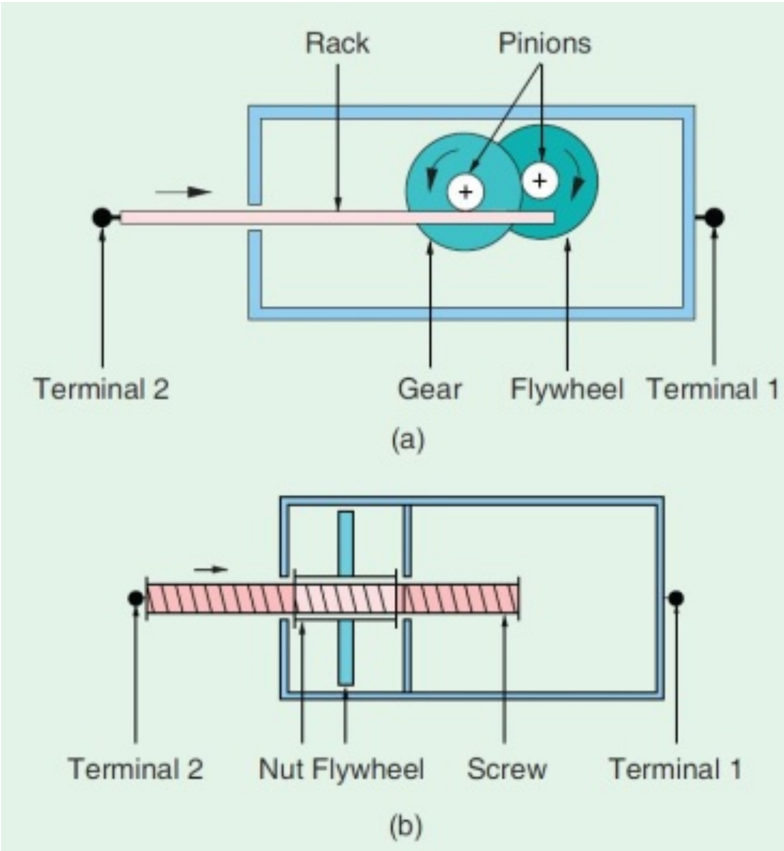


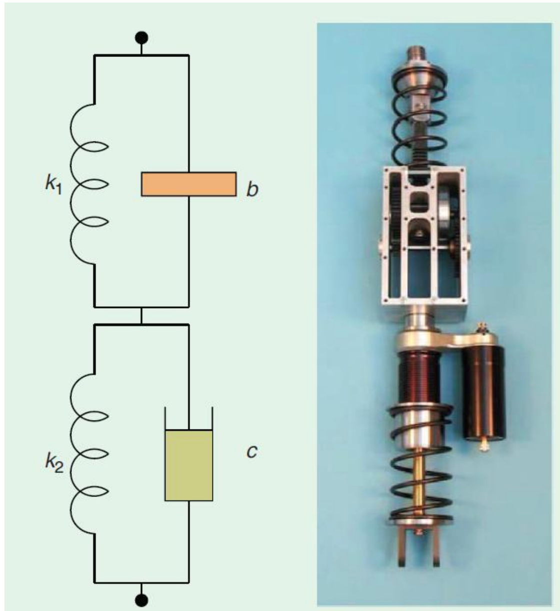
Figure 4. Ballscrew inerter made at Cambridge University Engineering Department; Mass≈1 kg, Inertance (adjustable) = 60-240 kg. (a) Complete with outer case, (b) ballscrew, nut and flywheel, (c) flywheel removed, (d) thrust bearing.



Proposed new ‘Fluid Inerter’

The inerter in Formula 1 suspensions

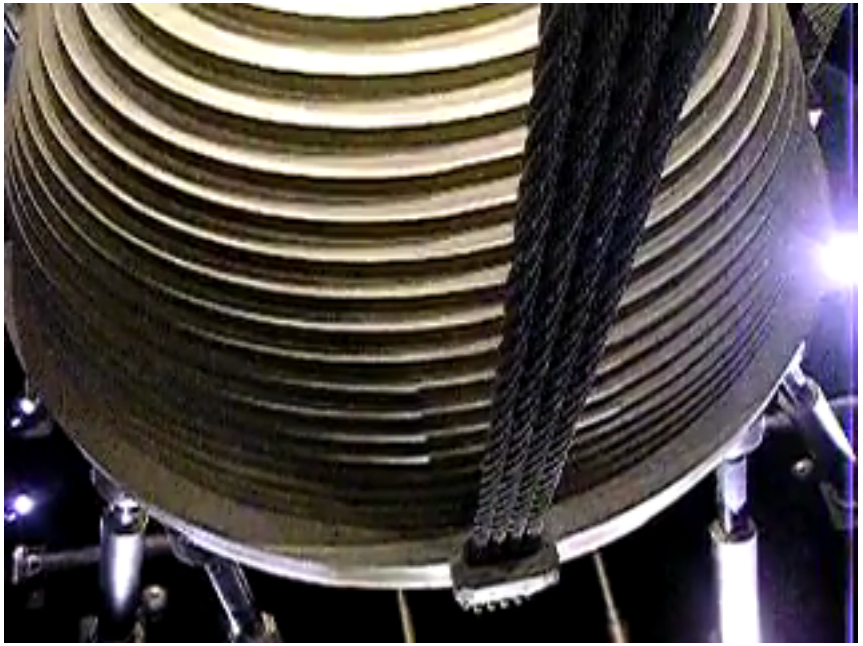


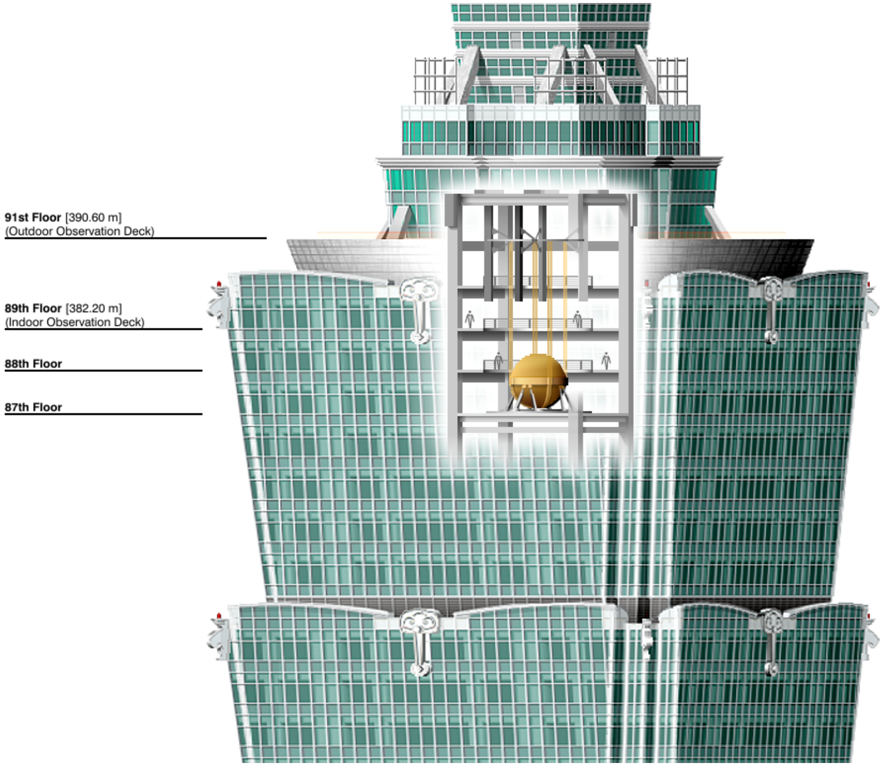


First used by McLaren Mercedes as the “J-damper” in 2005. Inerter unit is tuned to the tire natural frequency to maintain maximum tire contact patch area.

The inerter in structural control

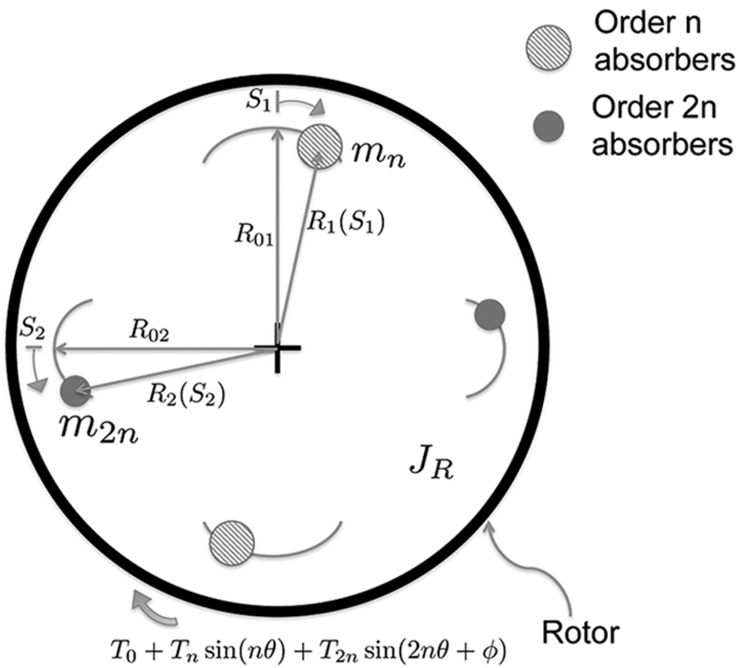
The F1 concept has some similarities to a tuned mass damper (TMD)





Taipei 101 tuned mass damper 660-tonne mass

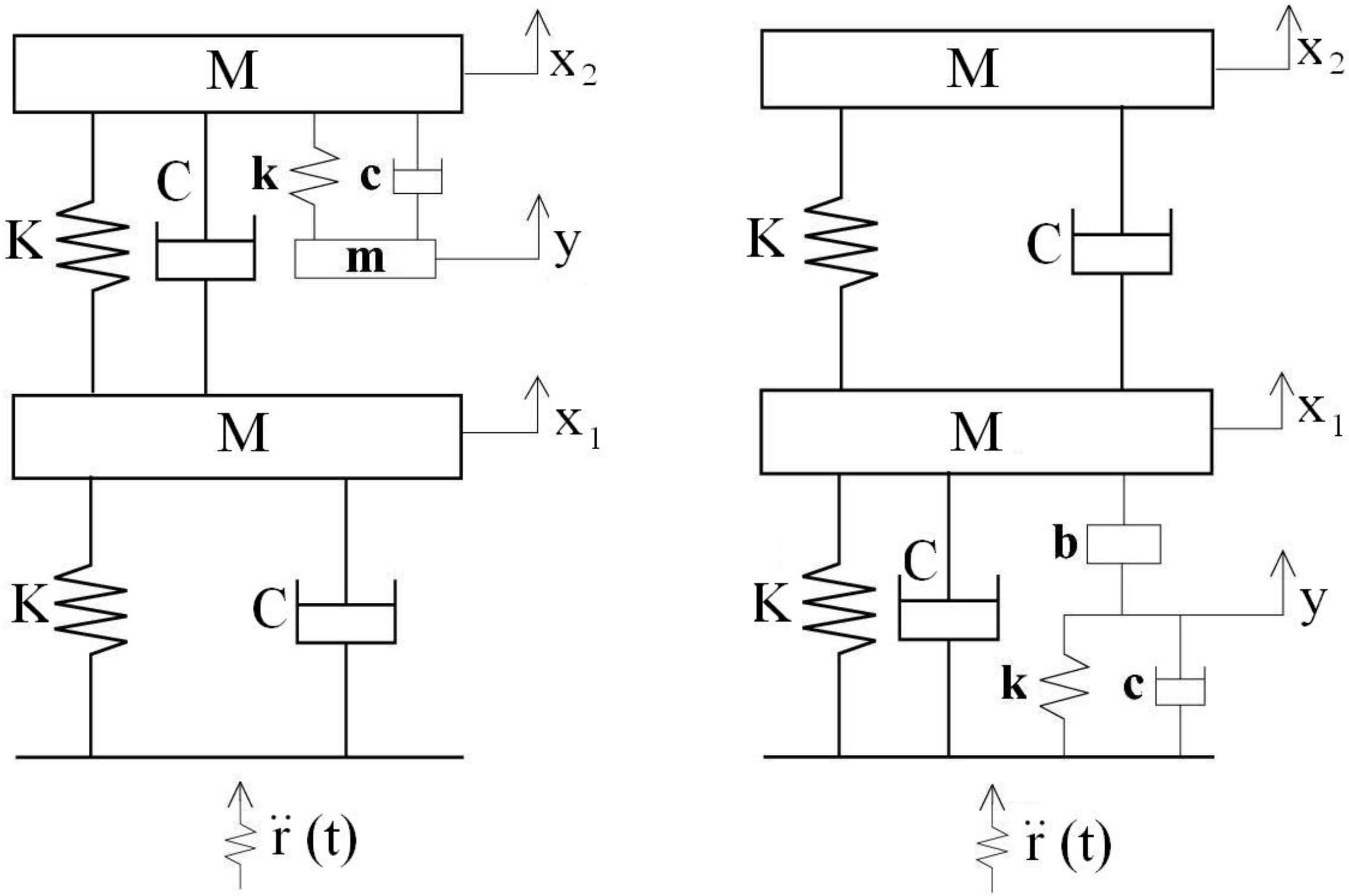
Bifilar vibration absorber



Shaw et. al J. Vib. Acoust. 135(6), 061012 (Aug 06, 2013)

The tuned-inerter-damper (TID)

A tuned-inerter-damper (TID) can be developed using a similar ethos to that described by Den Hartog for the TMD.



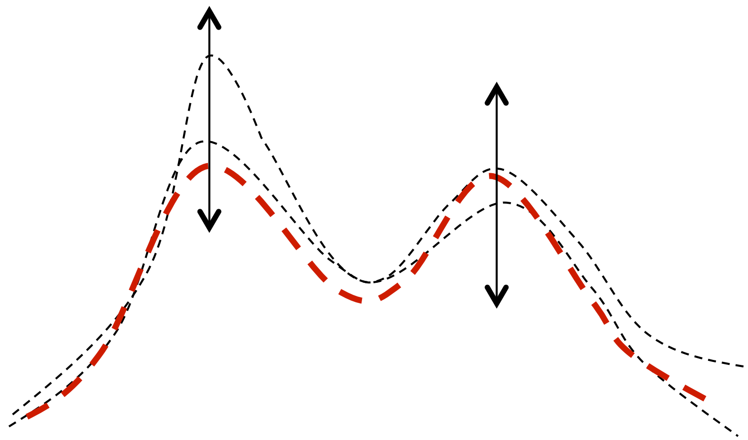
Design and tuning a TID

For base excitation, the following steps are required:

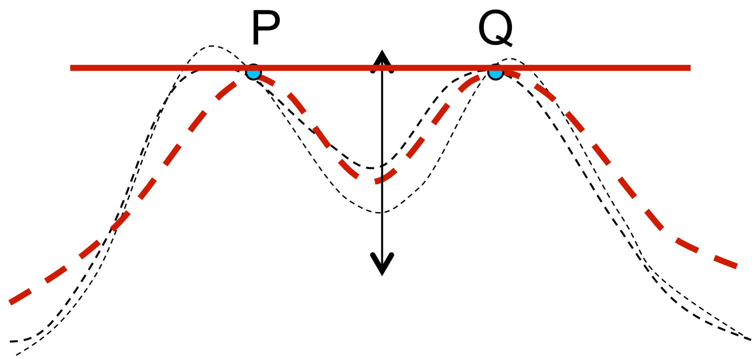
Step 1 Specify inertence to mass ratio:

$$b = \mu_b M$$

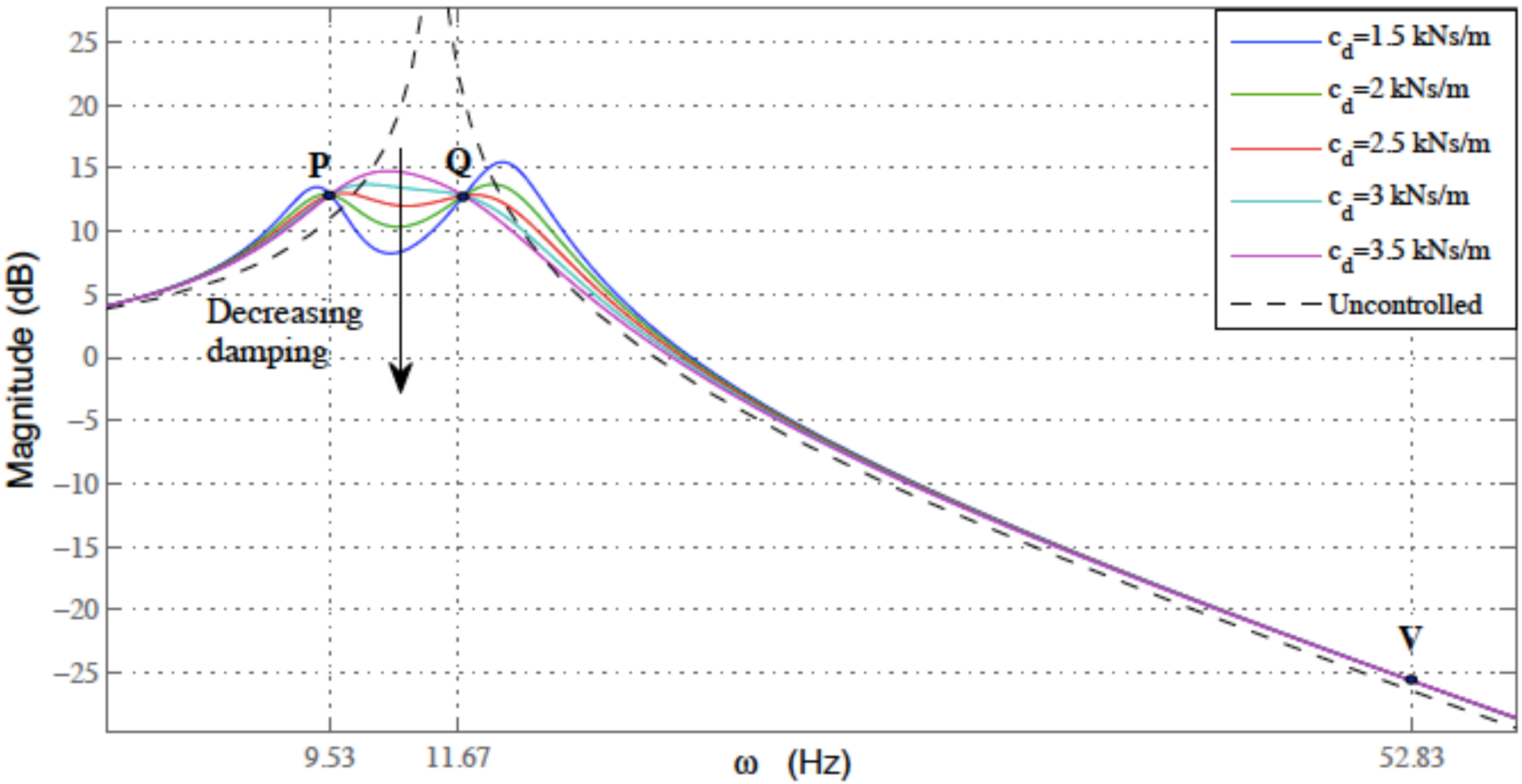
Step 2 Calibrate $k_{d_{\mathrm{TID}}}$ such that the 2 peaks have almost equal ordinates. The TMD tuning rule given by Den Hartog was used as an initial guess.



Step 3 Calibrate $c_{d_{\mathrm{TID}}}$ such that one of the 2 peaks has a horizontal tangent in one of the two common points



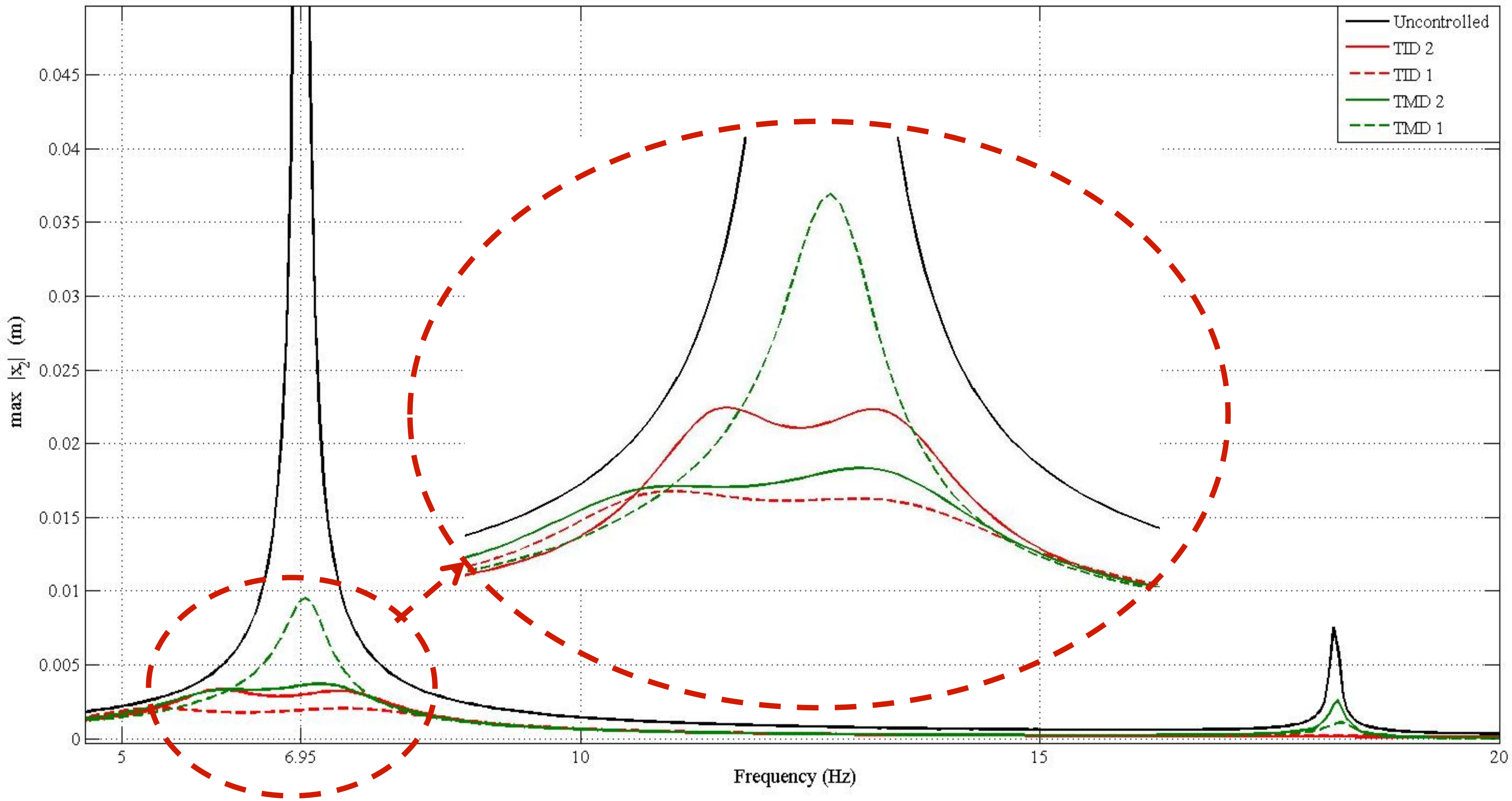
TID tuning example



For base excitation, there are 3 fixed points instead of 2 (as for TMD).
The related cubic equation is solved numerically.

Comparison of TID and TMD

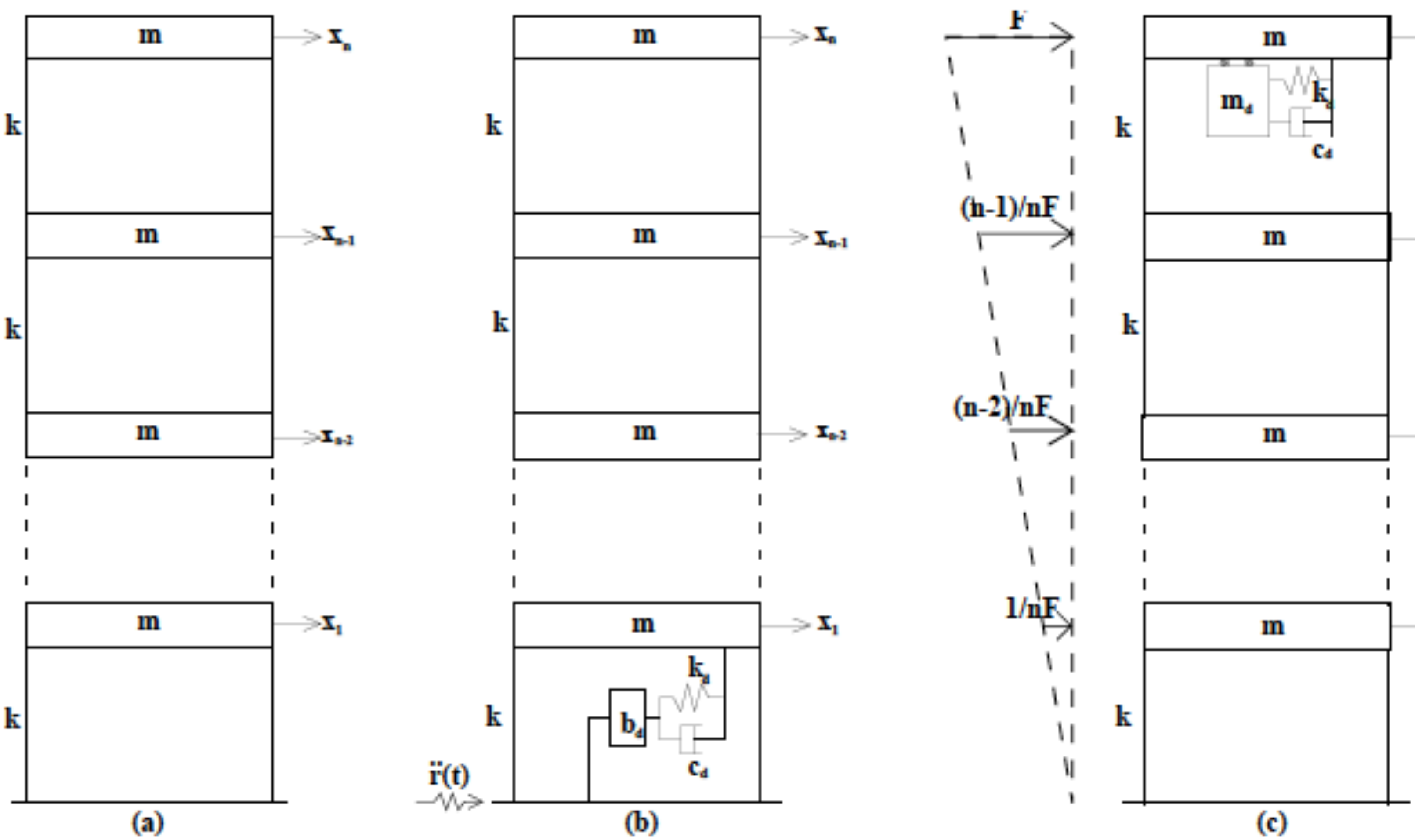
The TID can generate a high inertia force with a relatively low mass.



Notice that the TID reduces the amplitude around the second mode

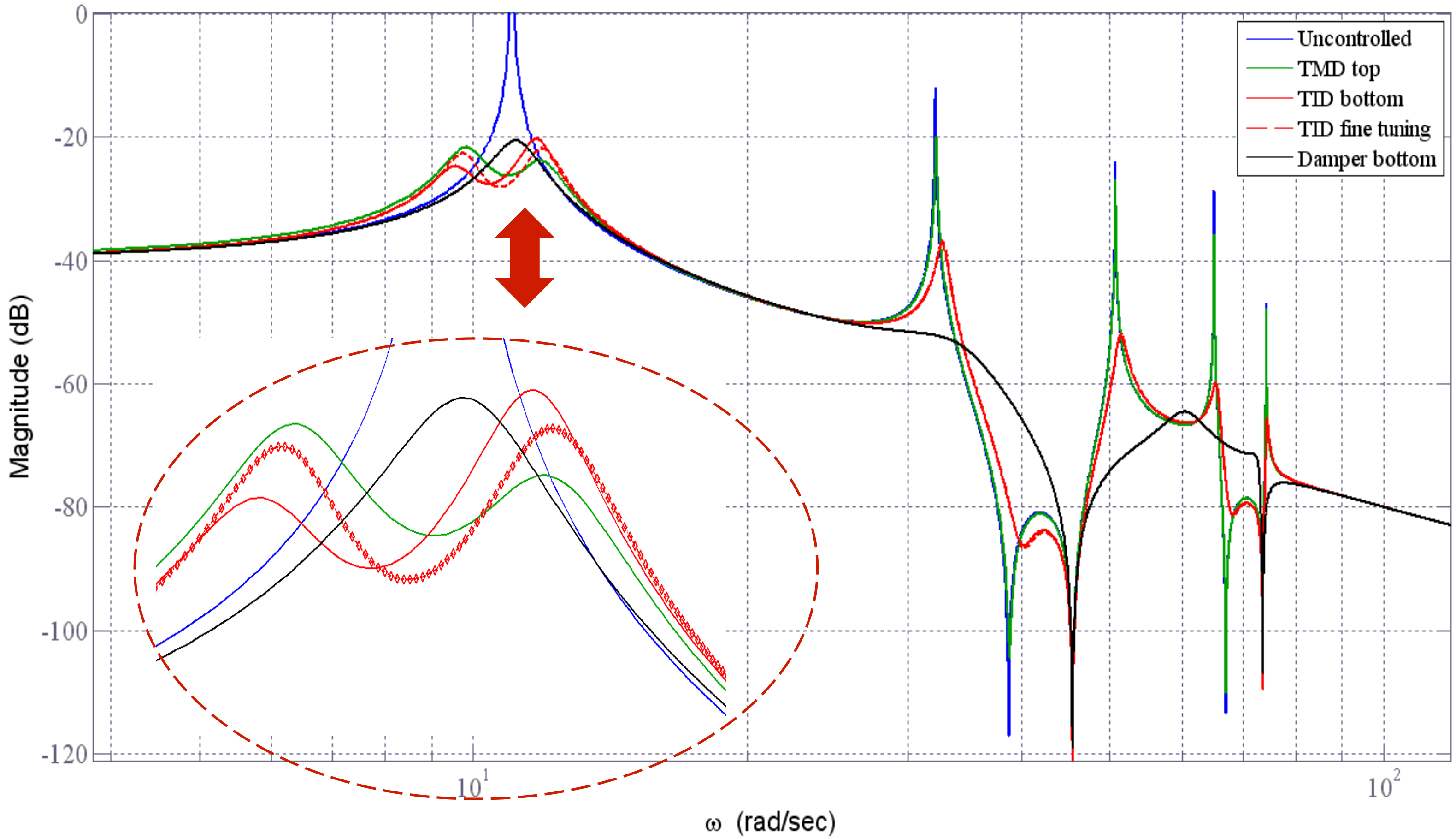
More degrees-of-freedom

The concept can be extended to more degrees-of-freedom



More degrees-of-freedom

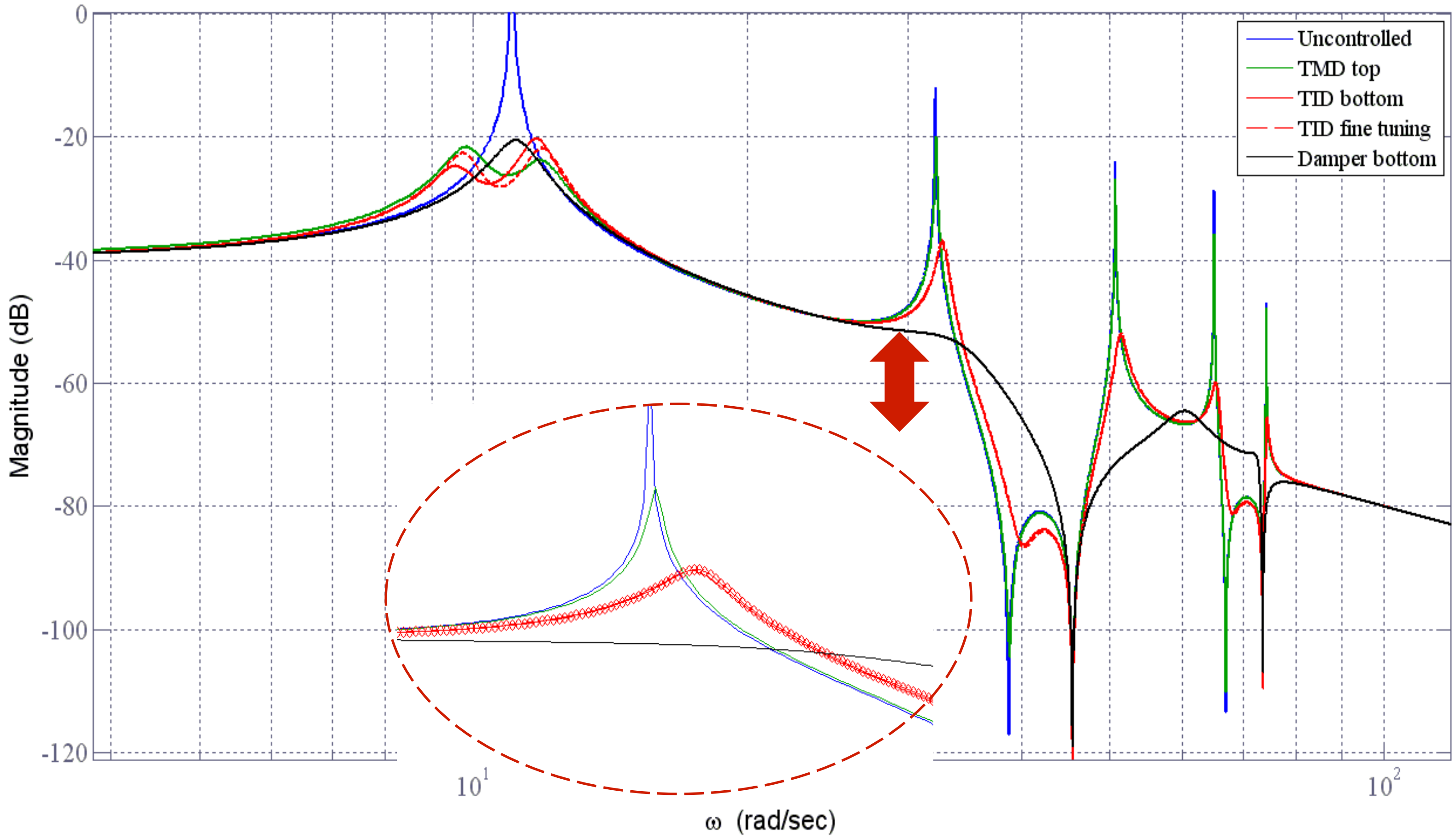
A five degree-of-freedom system with sinusoidal base excitation.



The damper curve is for a damper constant that is 12 times larger than the TID damper

Effect on higher modes

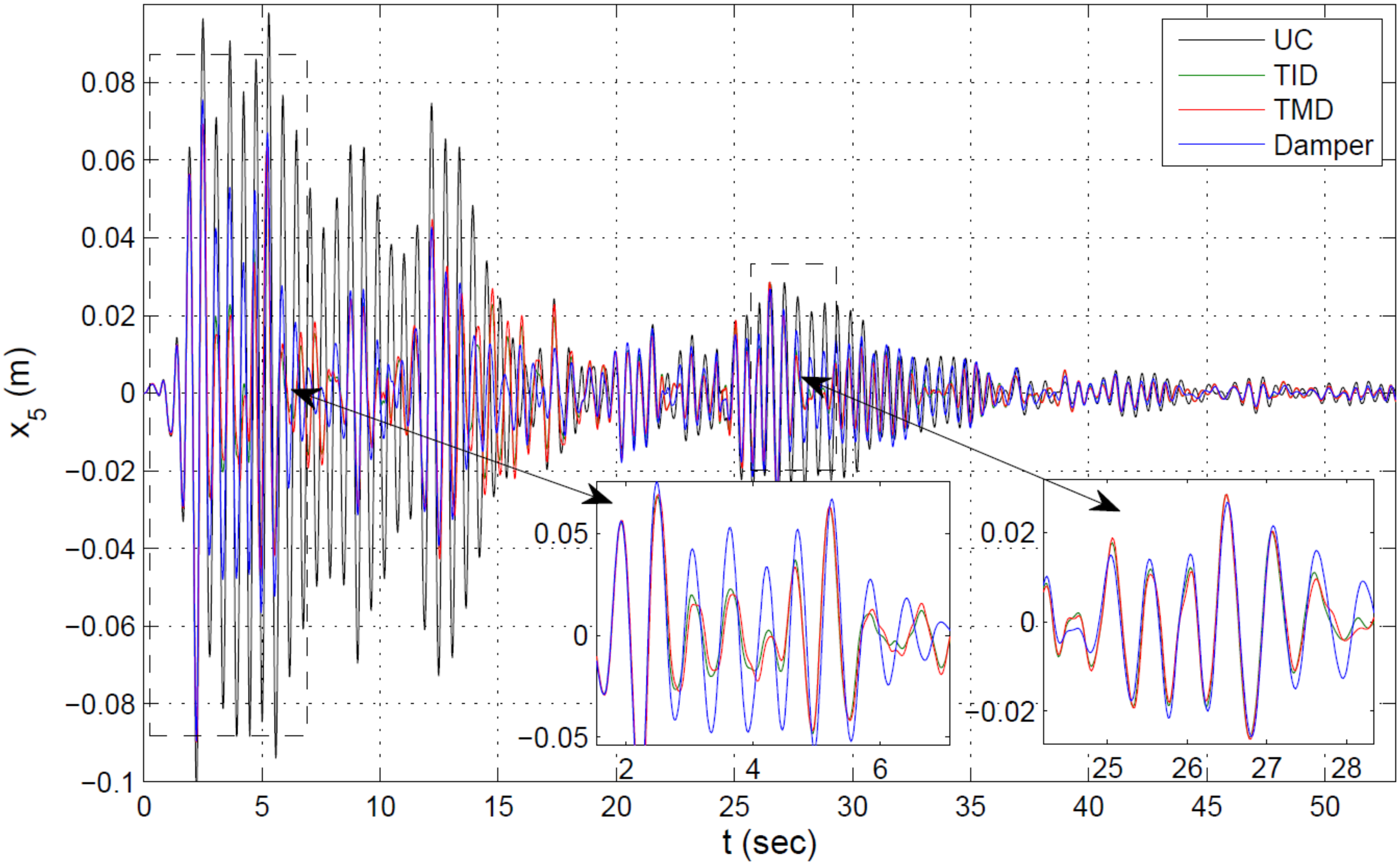
A five degree-of-freedom system with sinusoidal base excitation.



The TID reduces the amplitude in the higher modes

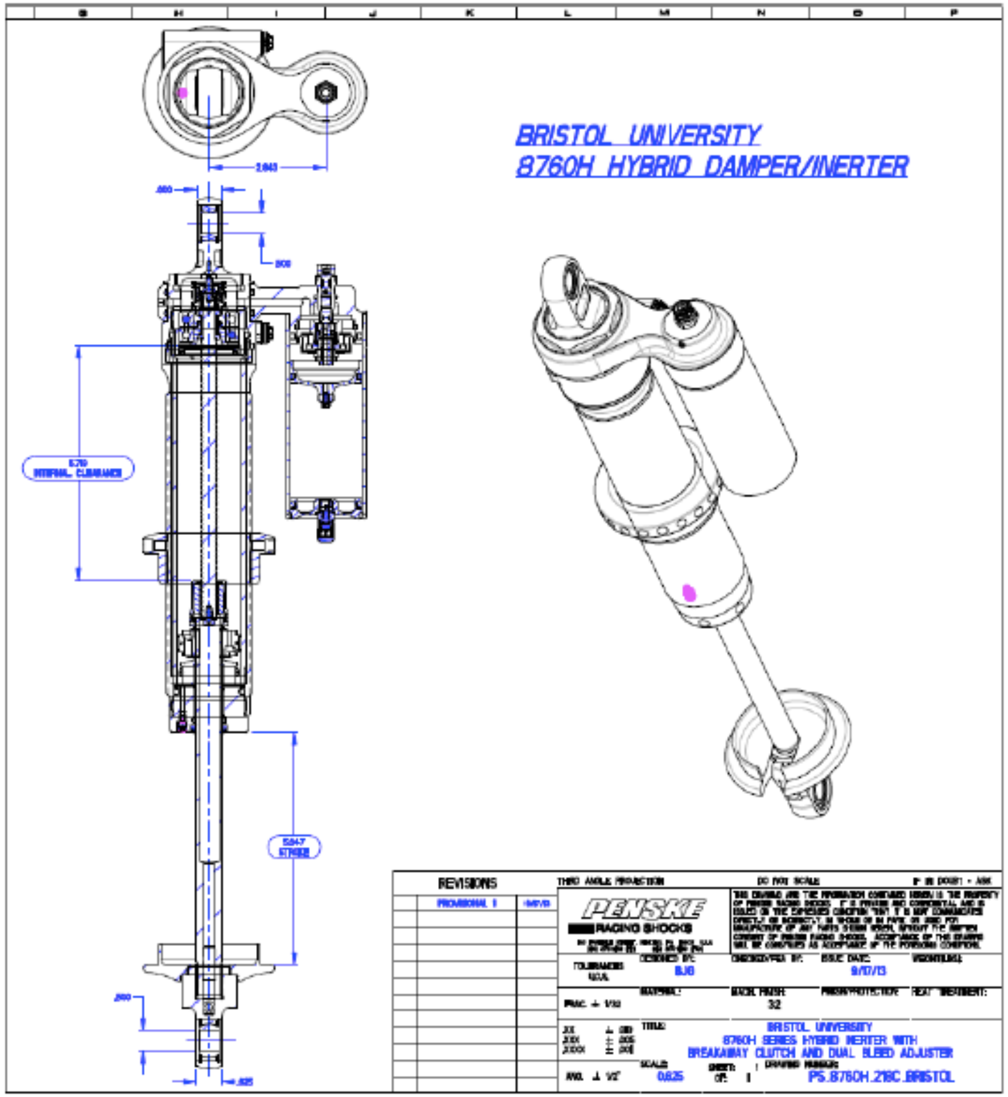
TID: Earthquake excitation

A five degree-of-freedom system with El Centro base excitation.



Commercial inerter from Penske

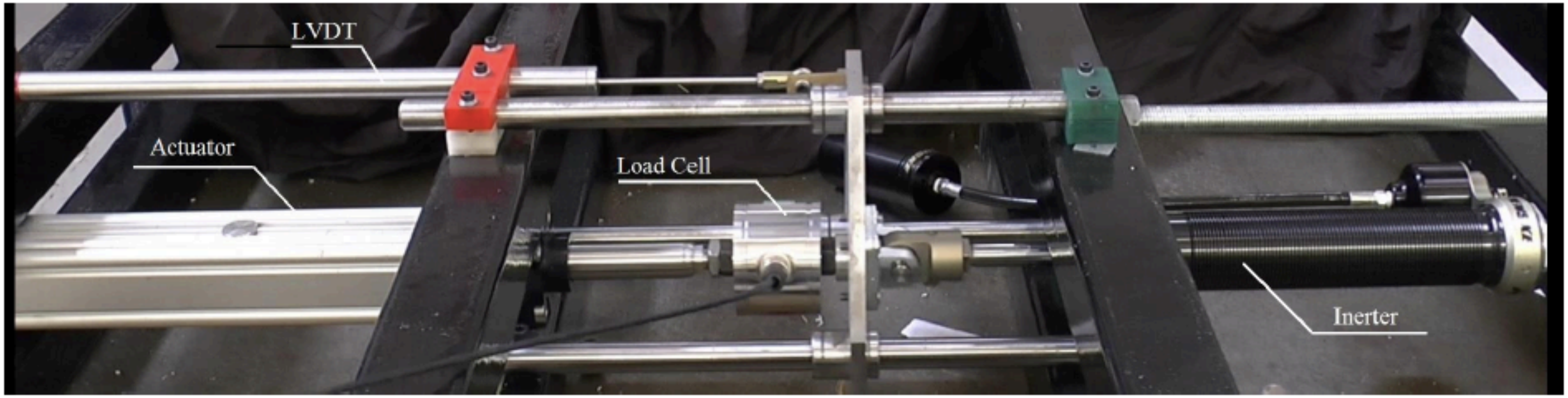
2.25kg mass and the maximum inertance is 75kg

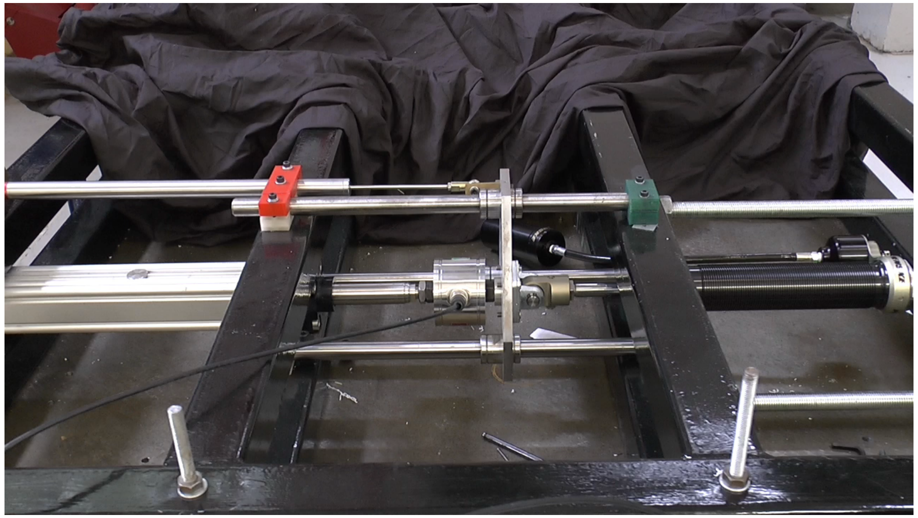


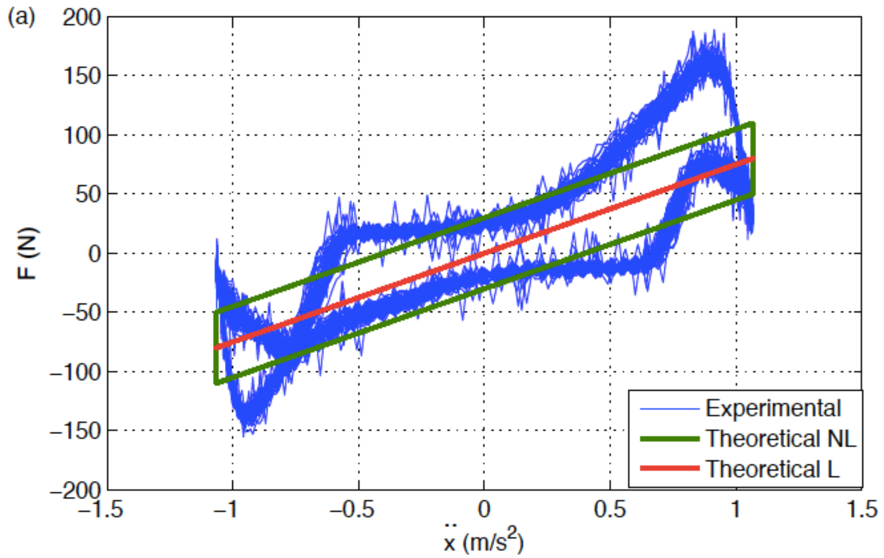
The maximum stroke is 140mm, dry friction damping approx 30Ns/m

TID: hybrid tests

The Penske inerter was used in a series of hybrid experimental tests to simulate a TID

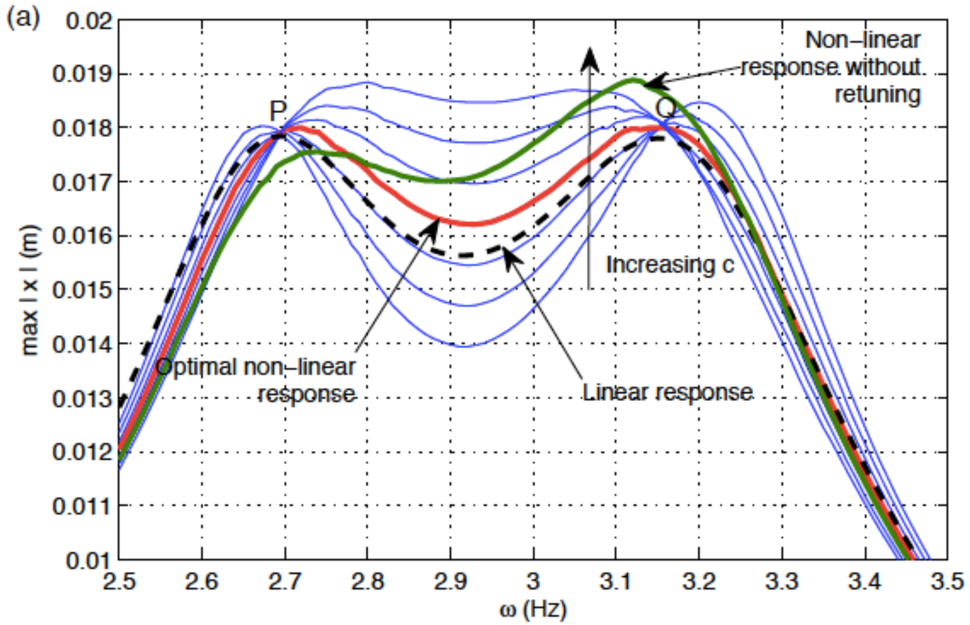


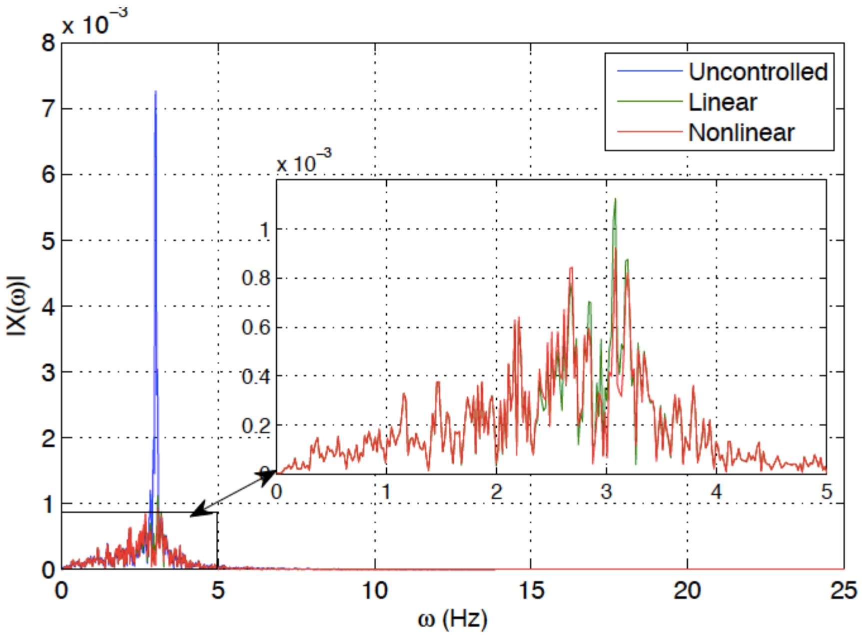




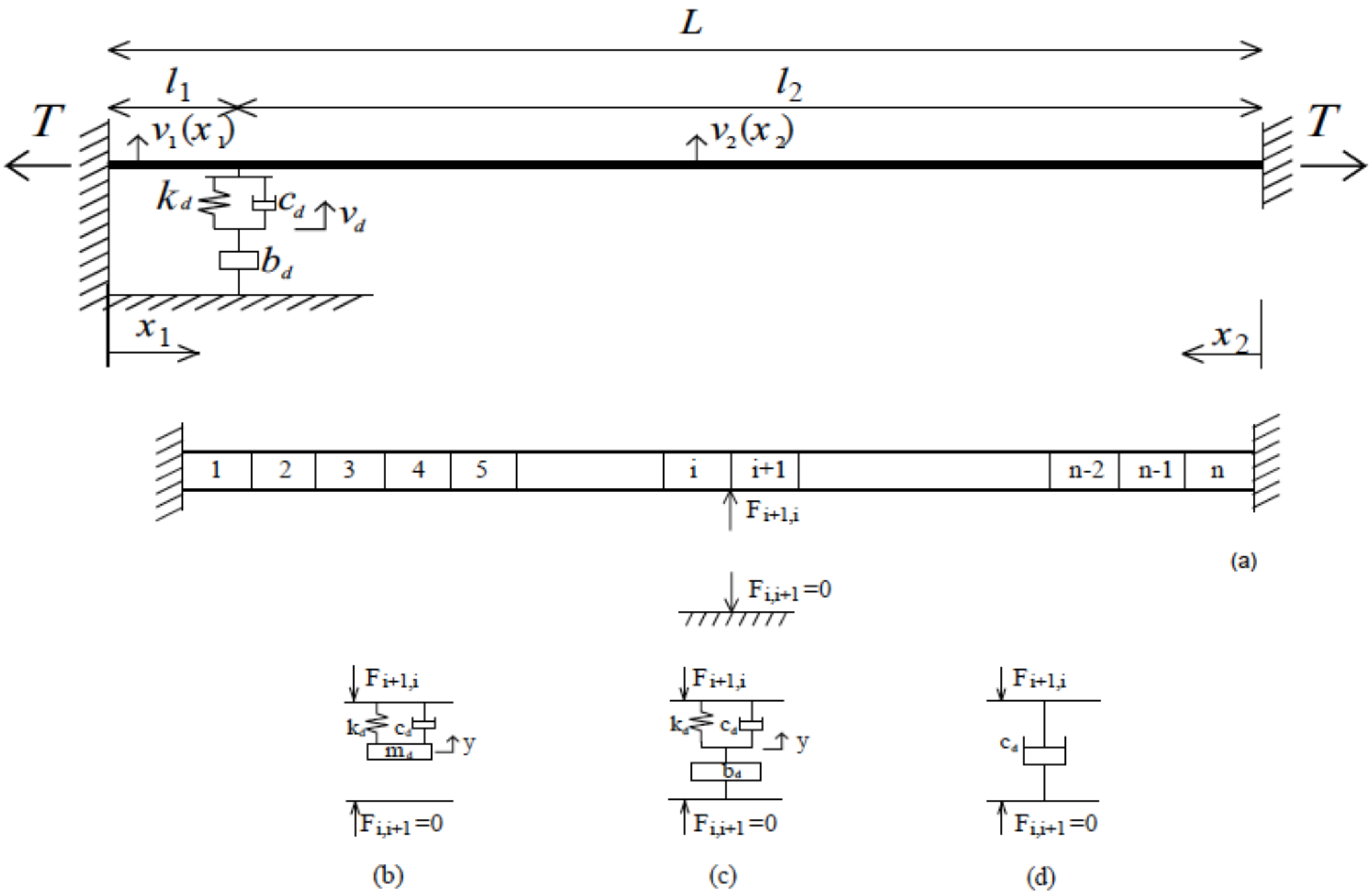
TID: validated nonlinear model

The experimental results were used to validate the numerical model.





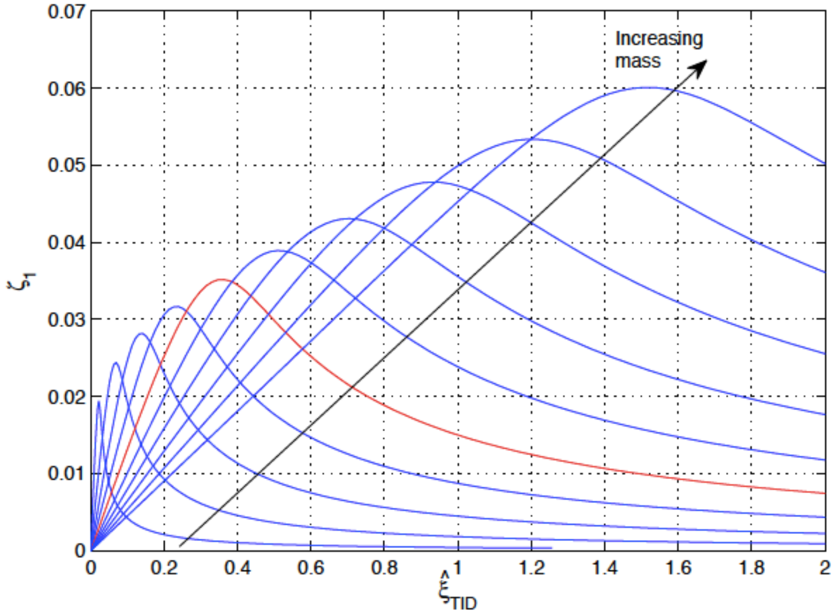
TID: applied to cable vibration

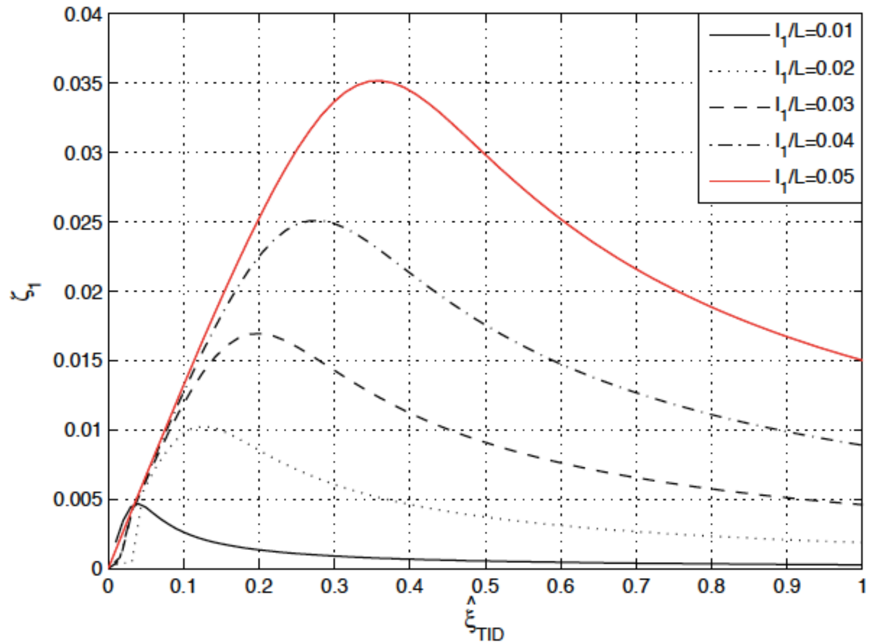


Finite element model used to discretize the cable

TID: cable results

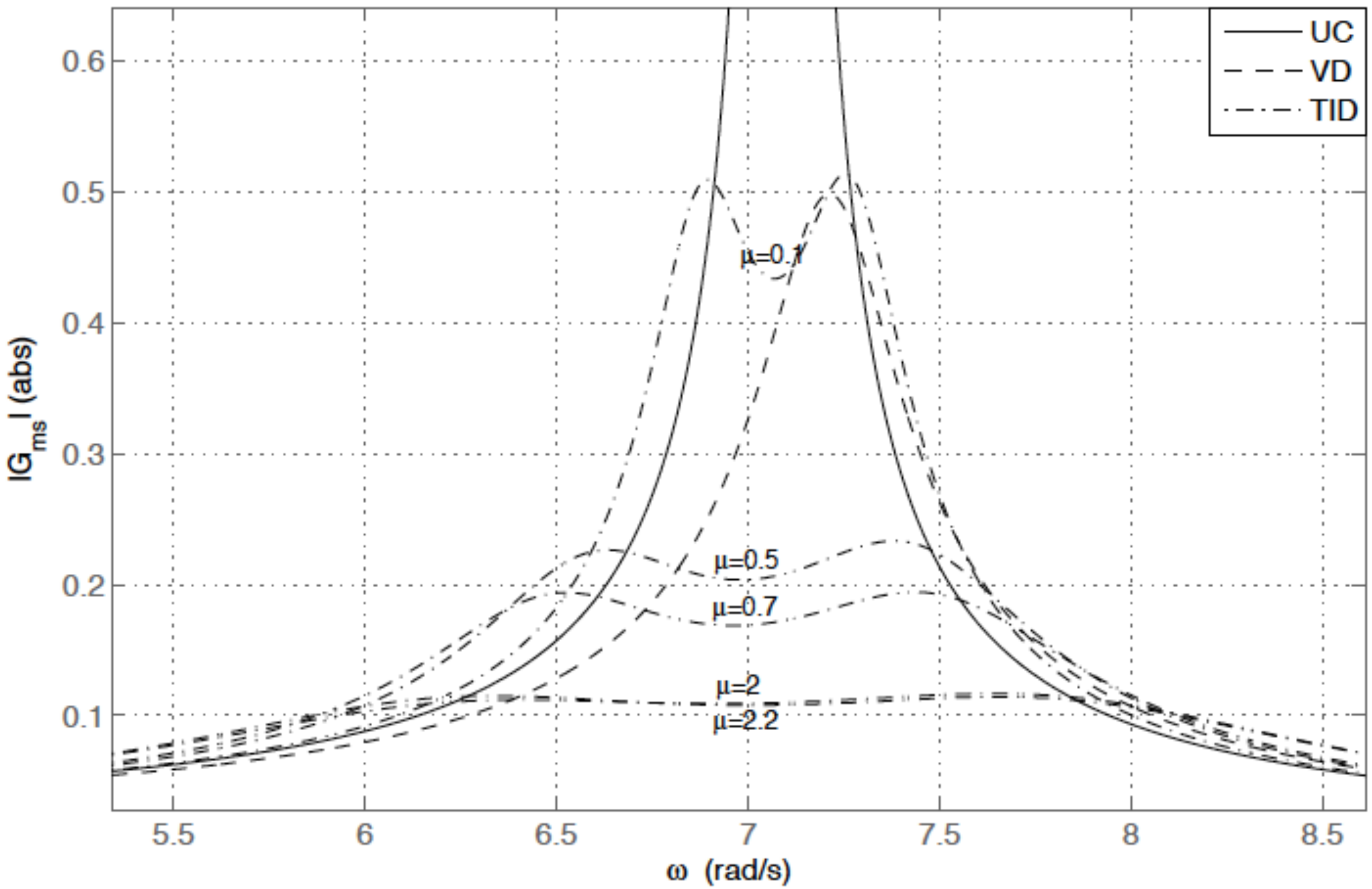
Increasing mass (inertance) or distance ratio, increases modal damping in cable up to a maxium, and then decreases the value





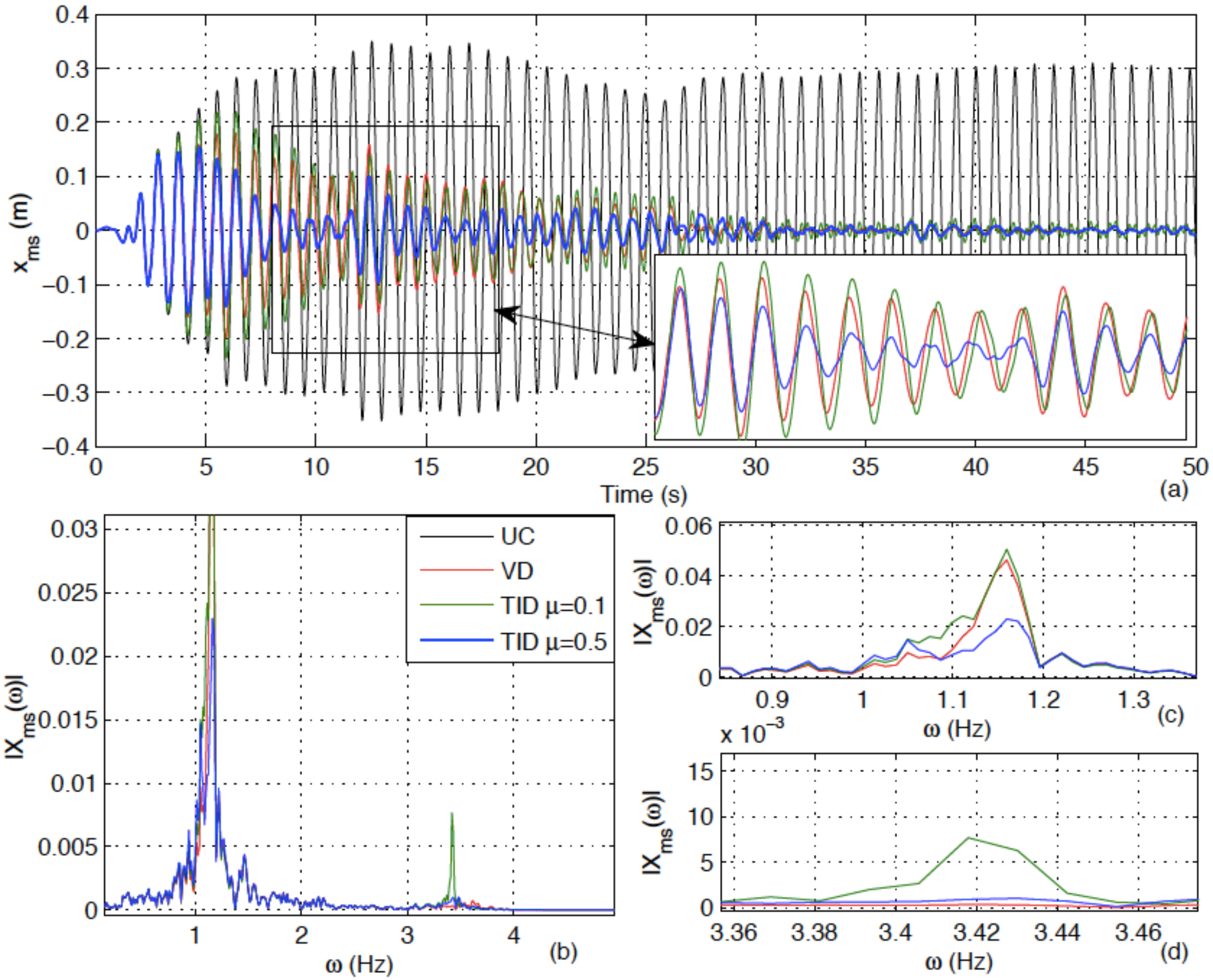
TID: cable results

Bode plots for TID on a single cable, showing mode 1 resonance



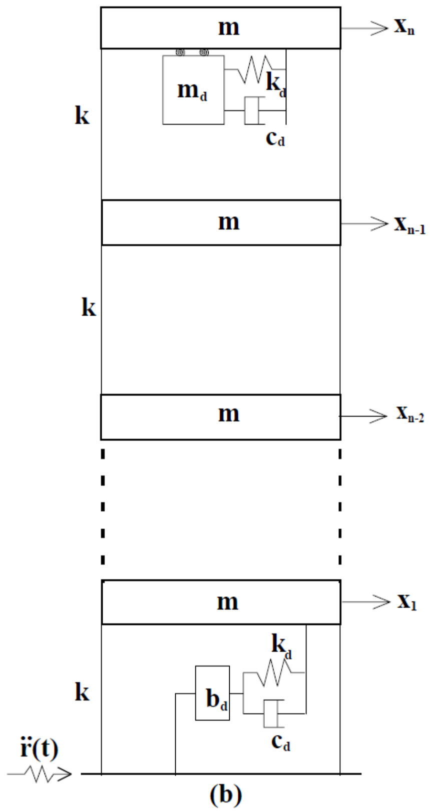
TID: cable results

Earthquake excitation for TID on a single cable



TID: Summary

- The TID is a new concept (Tuned Viscous Mass Damper, TVMD 2011)
- A TID can be designed using simple rules like a TMD
- A TID is optimum at the base of the structure
- The TID can produce high inertial forces with a lower overall mass – application for lightweight structures
- The TID can damp amplitudes of higher modes
- It is at an early stage of experimental testing and development



Papers:
Lazar IF, Neild SA & Wagg DJ (2014) Earthquake Engineering and Structural Dynamics, 43(8), 1129-1147.
Lazar I.F., Neild S.A., and Wagg, D.J. (under review). Vibration suppression of cables with attached tuned inerter dampers. Engineering Structures.

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New Engineering Building: The Diamond

Where is Sheffield?


The Peak District

Acknowledgements

EPSRC
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Research Council

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Thank you for your attention