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Design of adjustable Tuned Mass Dampers using elastomeric O-rings

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Background

Motivations:

(1) Choice of TMD: For the structures where the dynamic strains are (a) ***LOW*** (b) ***LOCALISED TO INACCESSIBLE REGIONS***

(2) Choice of elastomeric O-ring: (a) ***SIMPLE YET ADJUSTABLE*** (b) ***USEFUL LEVELS OF DAMPING*** (c) ***RELIABLE AND INEXPENSIVE.***

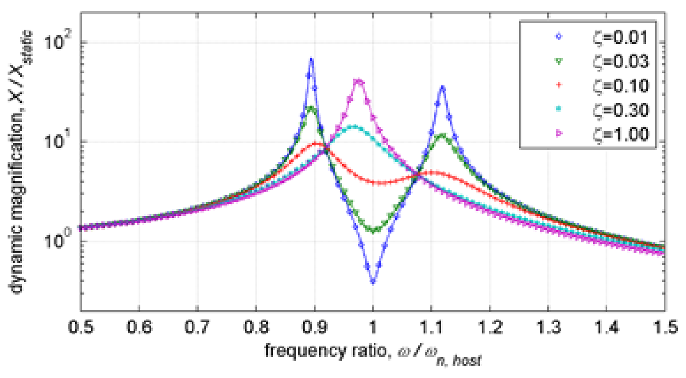
Engineering Scenario: Boring bar head

Requirements for the damper:

(1) Lightweight

(2) Suppress the rigid body translational vibration

(3) Work over the selected frequency ranges



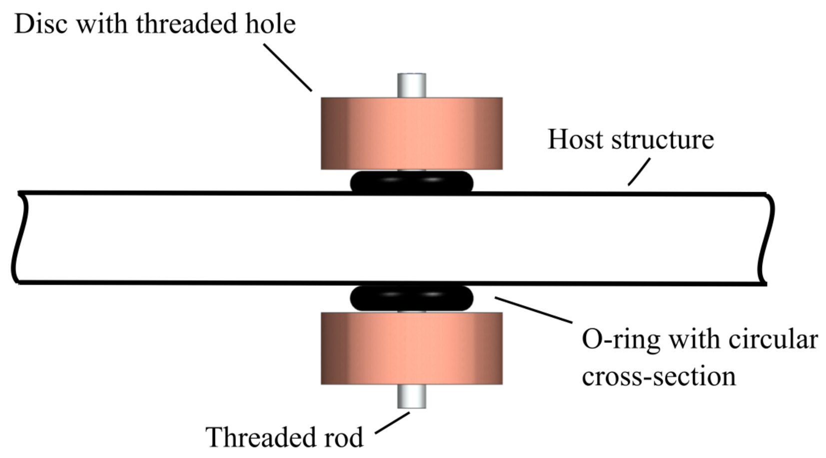
Aim & Objectives

Aim:

Develop a ***DESIGN PROCEDURE*** for elastomeric O-ring TMDs, considering how the stiffness can be tuned in-situ

Objectives:

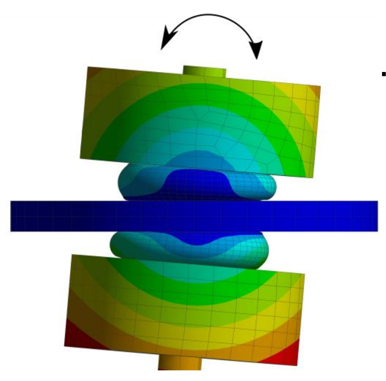
- Illustrate the proposed TMD design and its behaviour
- Investigate the dynamic stiffness and damping characteristics experimentally and analytically.
- Demonstrate a practical application of the approach on an engineering structure



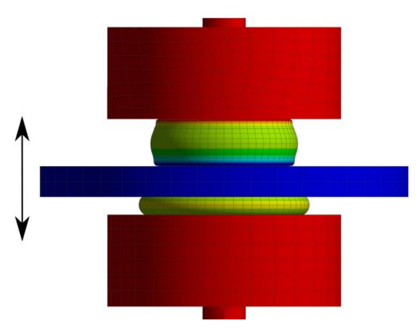
Initial evaluation

Design methodology:

- Selection of the threaded rod and attached discs based on the desired TMD mass;
- Choice of O-ring material, diameter, and wire diameter (i.e. diameter of the O-ring's solid section), in order to achieve desired damping and stiffness;
- Final adjustment of the pre-compression to optimise the stiffness.



Rocking mode



Tensile-compressive mode

Working modes:

- Excluding twisting and shear motion;
- Neglecting the modes including local resonance within the O-rings
- Two effective working modes – tension-compression and rocking modes .

Effect of pre-compression of the O-rings:

Static compression	Rocking mode	Compression mode
0.05 mm	113 Hz	274 Hz
2.1 mm	413 Hz	639 Hz
Frequency ratio	3.66	2.12

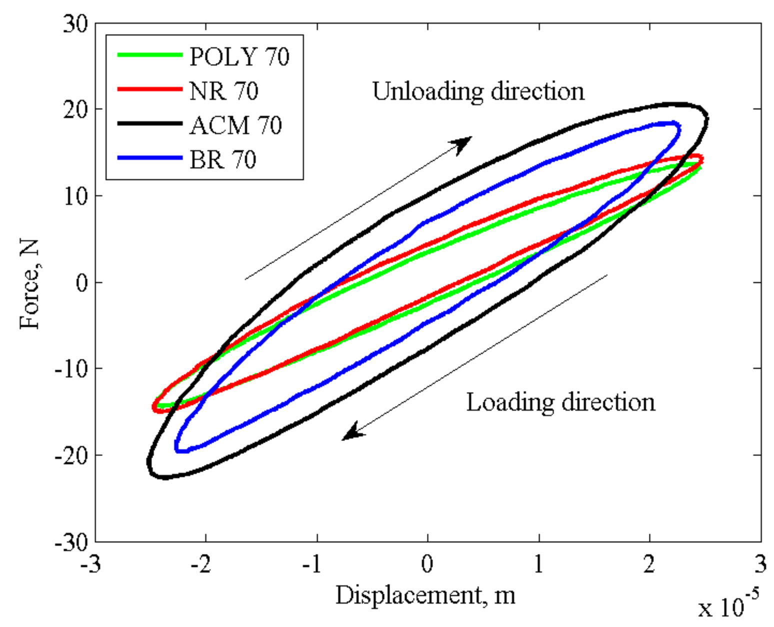
Characterisations – O-ring

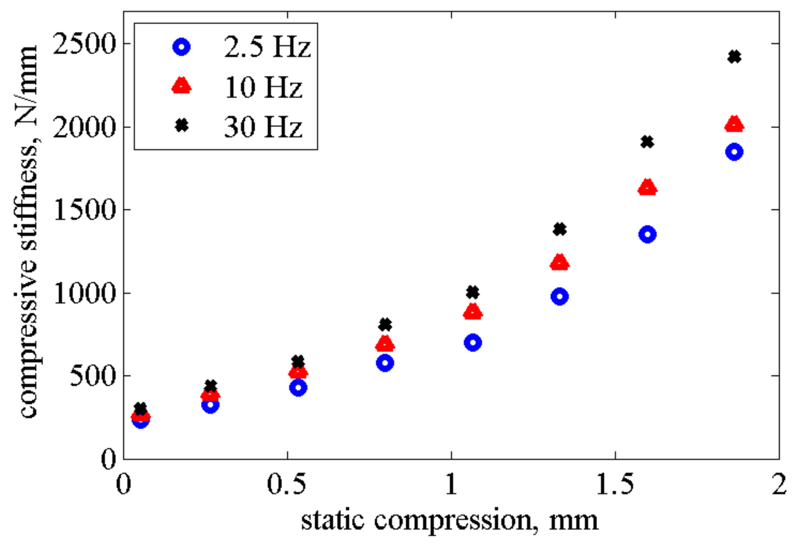
Choice of elastomer - requirements:

- Relatively low loss factor (approximately 0.2);
- Working far away from glass transition zone.
- Short stabilisation time for the Mullins effect

Choice of elastomer – Nitrile rubber:

- Low cost.
- Useful level of damping





Nonlinear stiffness – O-ring:

- Stiffness increases dramatically with compression.
- Increase of stiffness with frequency – viscoelasticity.
- Loss factor remains unchanged.
- At low dynamic displacement (up to 0.025 mm), dynamic-strain dependent nonlinearity is not activated

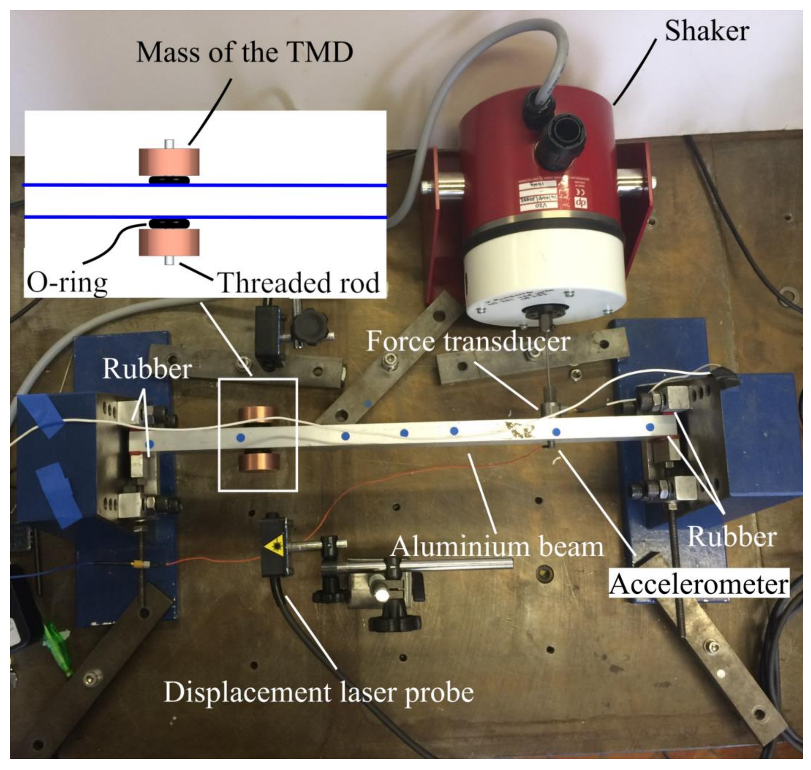
Case study

Choice of the static compressions:

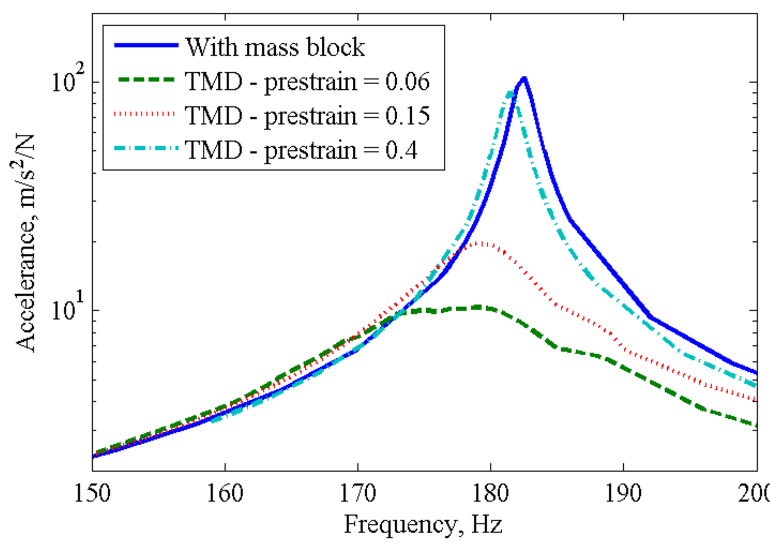
- Only the motion of the TMD in ***COMPRESSION-EXTENSION*** were selected as targeted modes.
- Influences of the mode shape variations were ***NOT*** considered.
- Optimal stiffness:

Performance of the TMD:

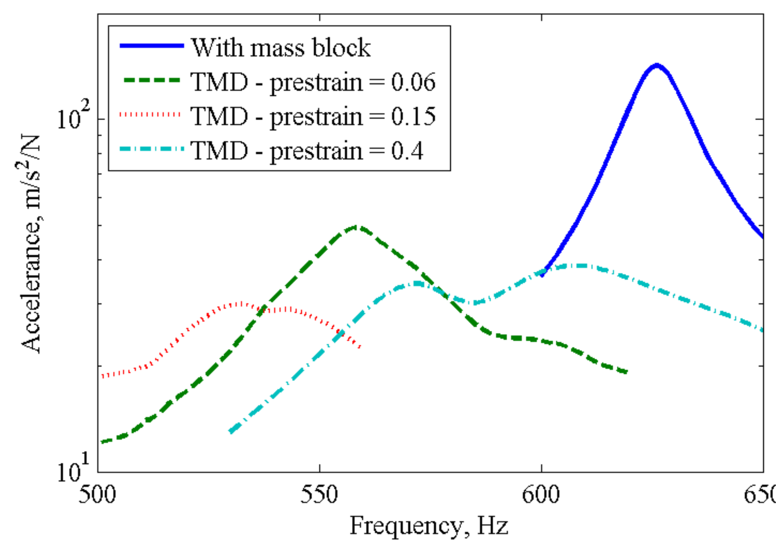
- The lateral vibrations were ***SUPPRESSED BY A FACTOR OF 8-10*** at selected frequencies.
- ***BOTH*** resonance peaks can be suppressed when the O-rings have a static compression of ***15%***. -> Rocking and compressive modes work simultaneously?
- Other ***NONLINEAR*** behaviours (e.g. interface friction) can be observed as well.



Test-rig for the rubber-end hollow beam.



1st mode of the beam



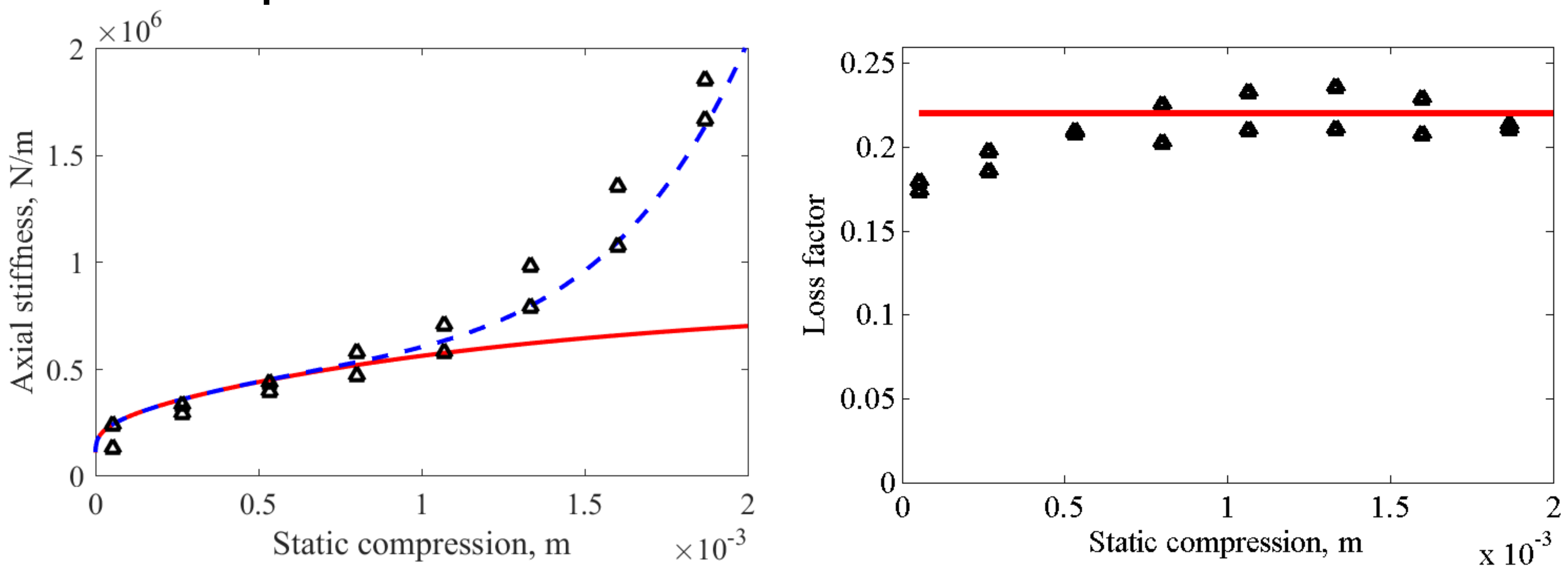
2nd mode of the beam

Analytical models

Assumptions:

- The ***PLAIN STRAIN MODEL*** is used. A ***RECTANGULAR RING*** with deformed height and contact length is used to represent the load-carrying behaviour at given compressions
- Frequency and temperature dependent properties of the O-ring are explained by the ***COMPLEX MODULUS***.
- The damping of O-ring is assumed ***LINEAR VISCOUS***.
- Dynamic displacement is far less than the static compression; the stiffness is uniform through the cross-section of O-ring .

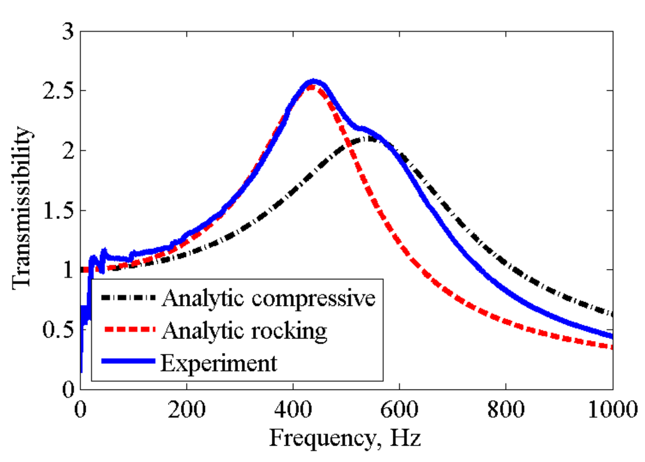
Tensile-compressive behaviour



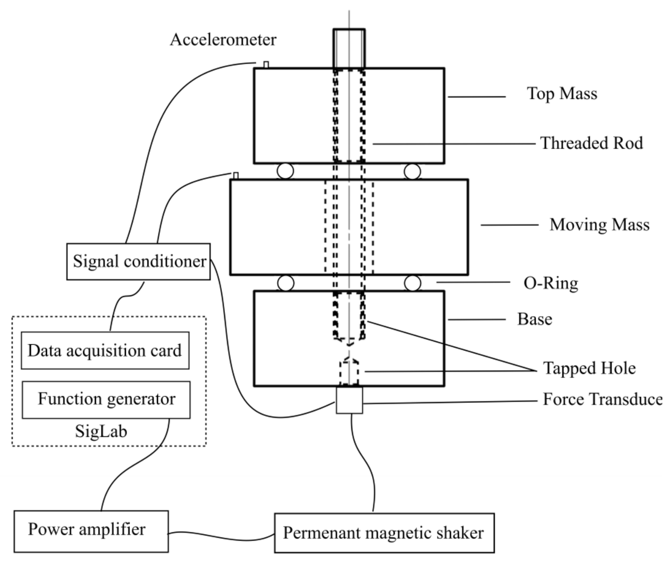
Δ: experimental results; **—**: developed model; **— —**: semi-empirical model

- Errors (stiffness):
  The proposed model does not account for the expansion of the nominal diameter of the O-ring.

Rocking behaviour



Transmissibility



Validation rig

Concluding remarks

- The geometrical nonlinearity of the O-rings allows adjustment of the TMD stiffness, enabling simple in-situ tuning of the device
- Analytical and semi-empirical formulae can be used to size the O-ring, and the TMD, for a given practical application
- Off-axis vibrations that link with the rocking mode of the TMD need to be considered as they can influence the motion of the host structure, and therefore can be used in the overall vibration control strategy.