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Experimental investigation and modeling of dynamic performance of wave springs

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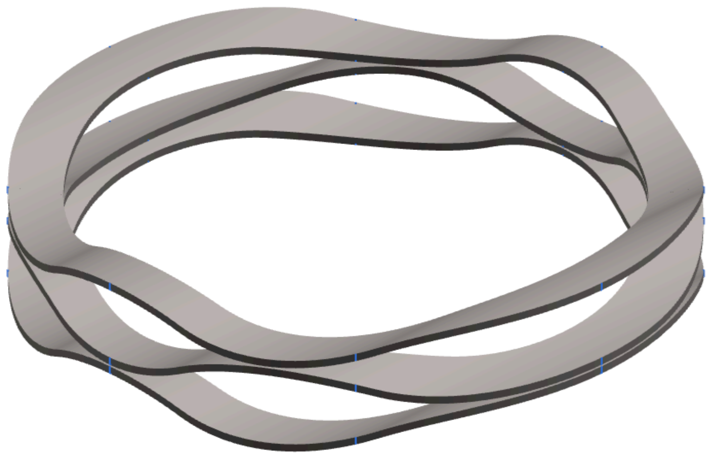
What is wave spring?



Crest-to-crest wave spring

Nested wave spring

- Flat wire compressive springs
- Construct from fixed-width metal strip
- Local shape – sinusoidal wave
- Many contact regions

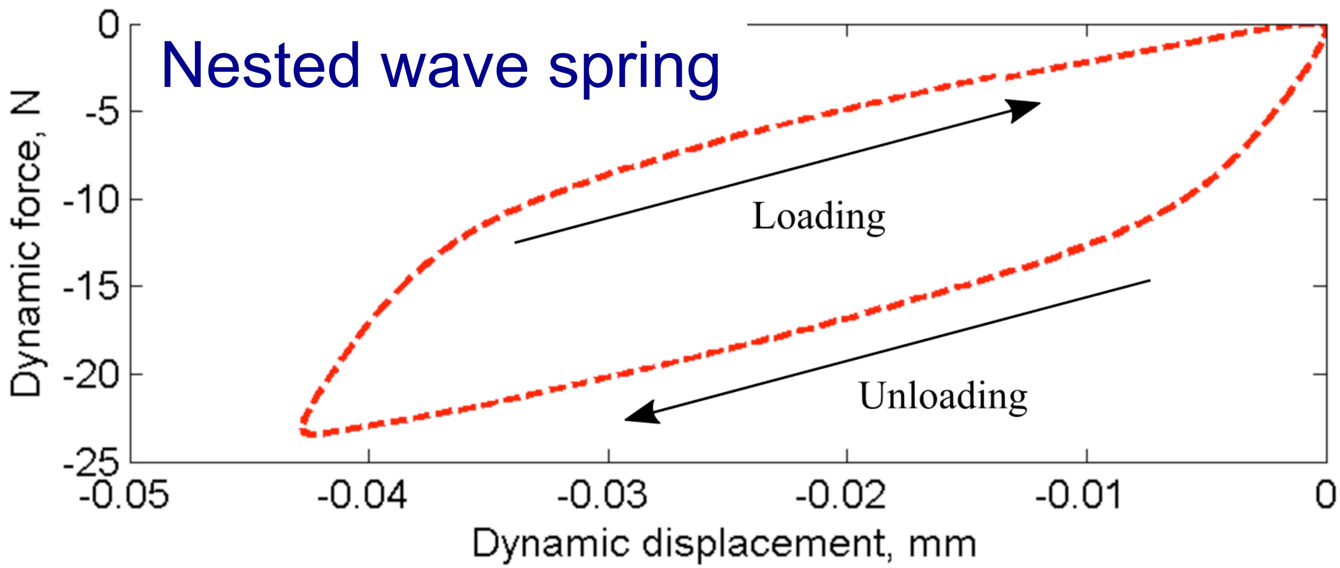
Why use wave spring?

- Coil spring
  - ✓ Reduce overall height
  - ✓ Nonlinear stiffness
  - ✓ Increase damping capability
- Viscoelastic material
  - ✓ Insensitive to temperature
- Application
  - ✓ Stiffness and damping element of Tuned Mass Damper.

How to use wave springs

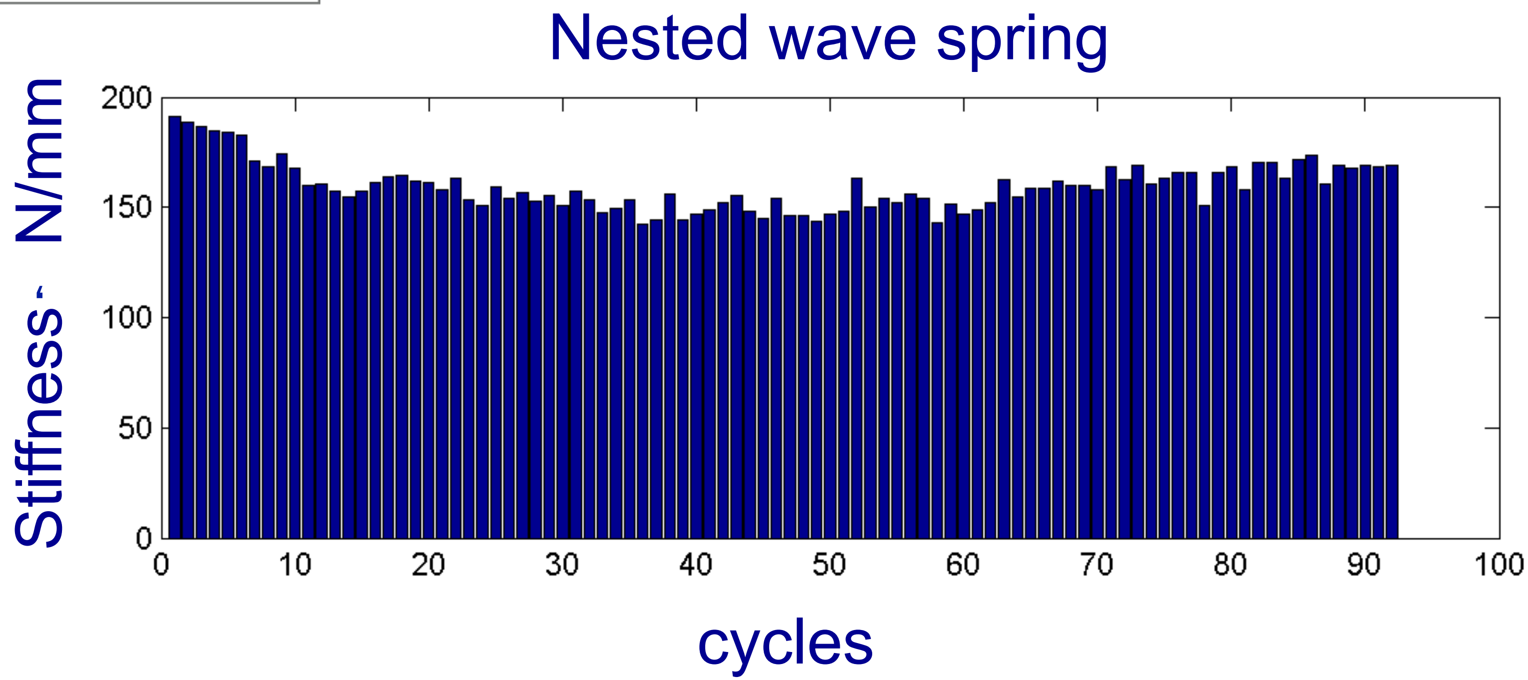
- Experimental investigations of stiffness and damping of wave springs
  - ✓ Effect of temperature
  - ✓ Effect of static compression
  - ✓ Repeatability
- Finite element modeling to predict performance of wave springs
  - ✓ Investigation of source of stiffness and damping
- Tuned mass damper using wave spring

Hysteresis loop of wave spring



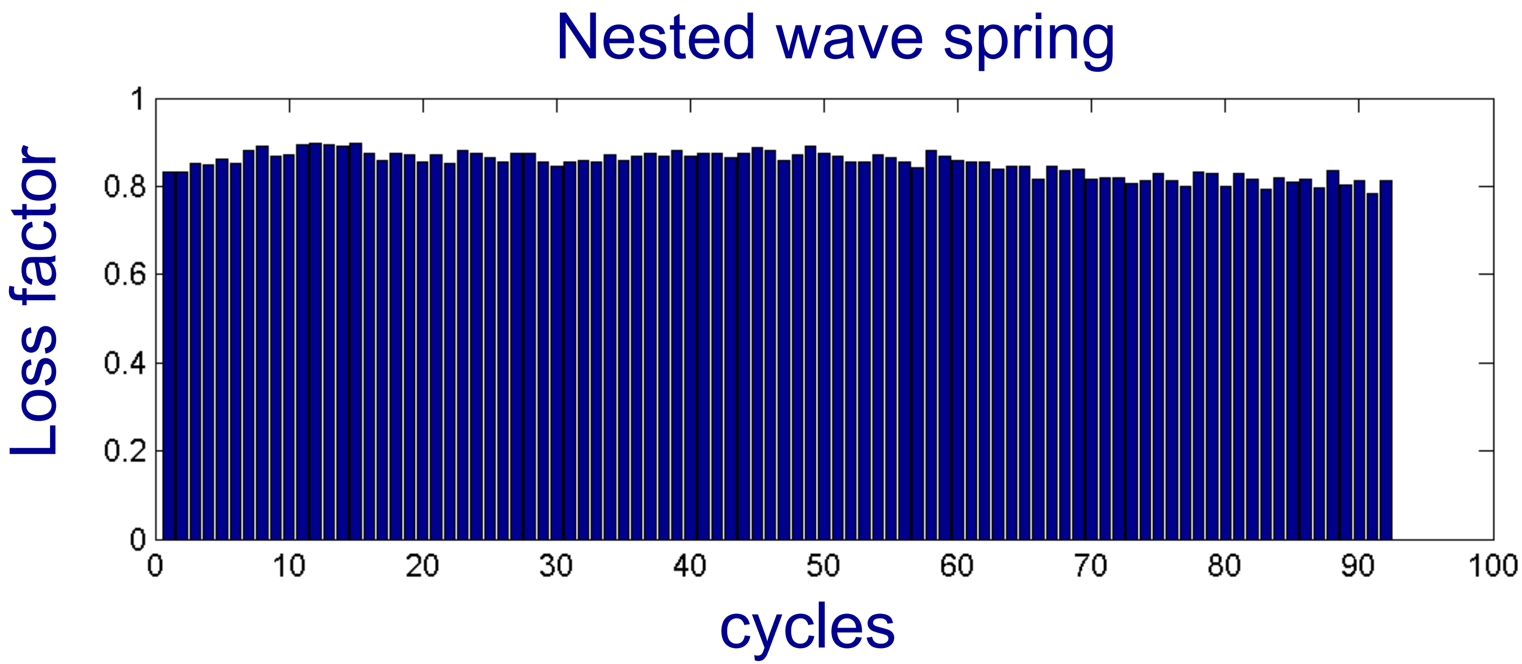
- Typical hysteresis loop for wave springs
  - ✓ Frictional damping behaviour is observed
  - ✓ Obvious damping can be obtained from wave spring

Repeatability of dynamic excitation



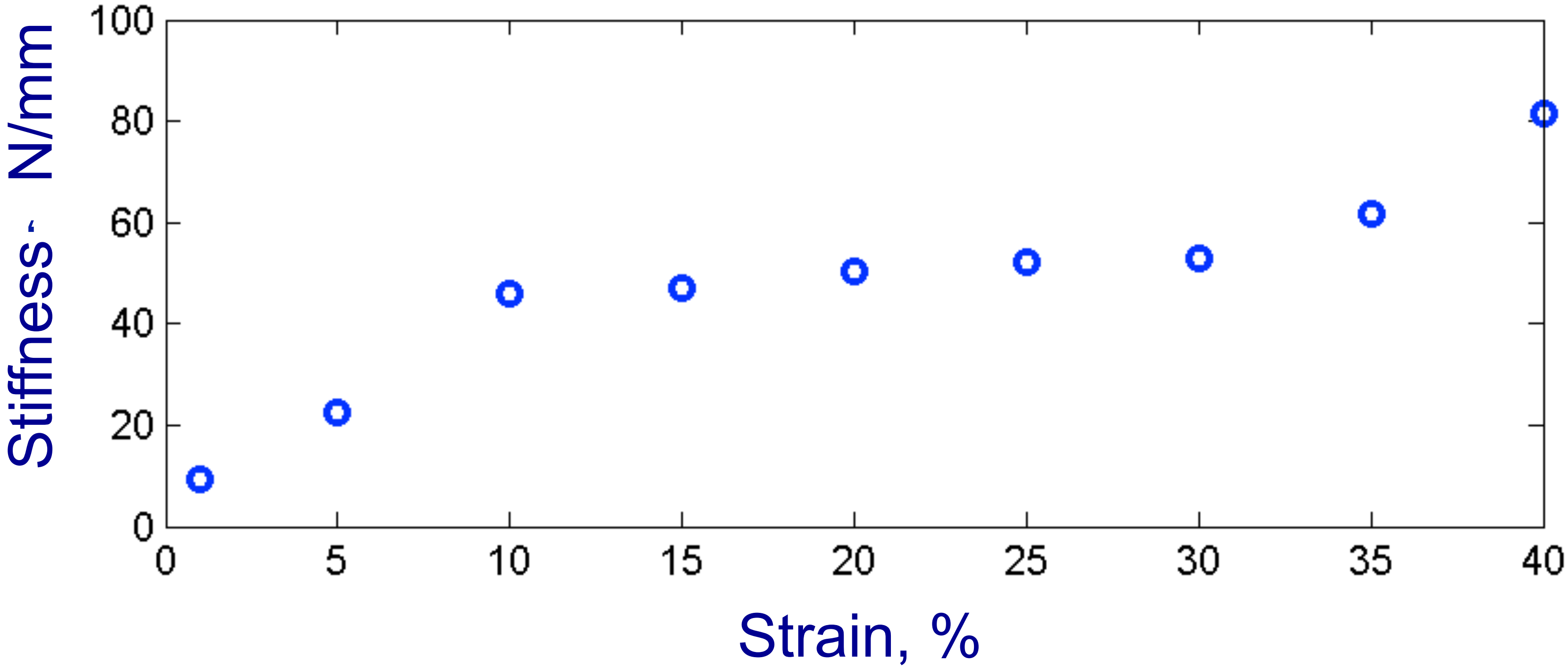
- 96 cycles used to estimate dynamic performance
- Stiffness varies with different cycles
- may be caused by sliding and rotation from wave spring

Repeatability of dynamic excitation



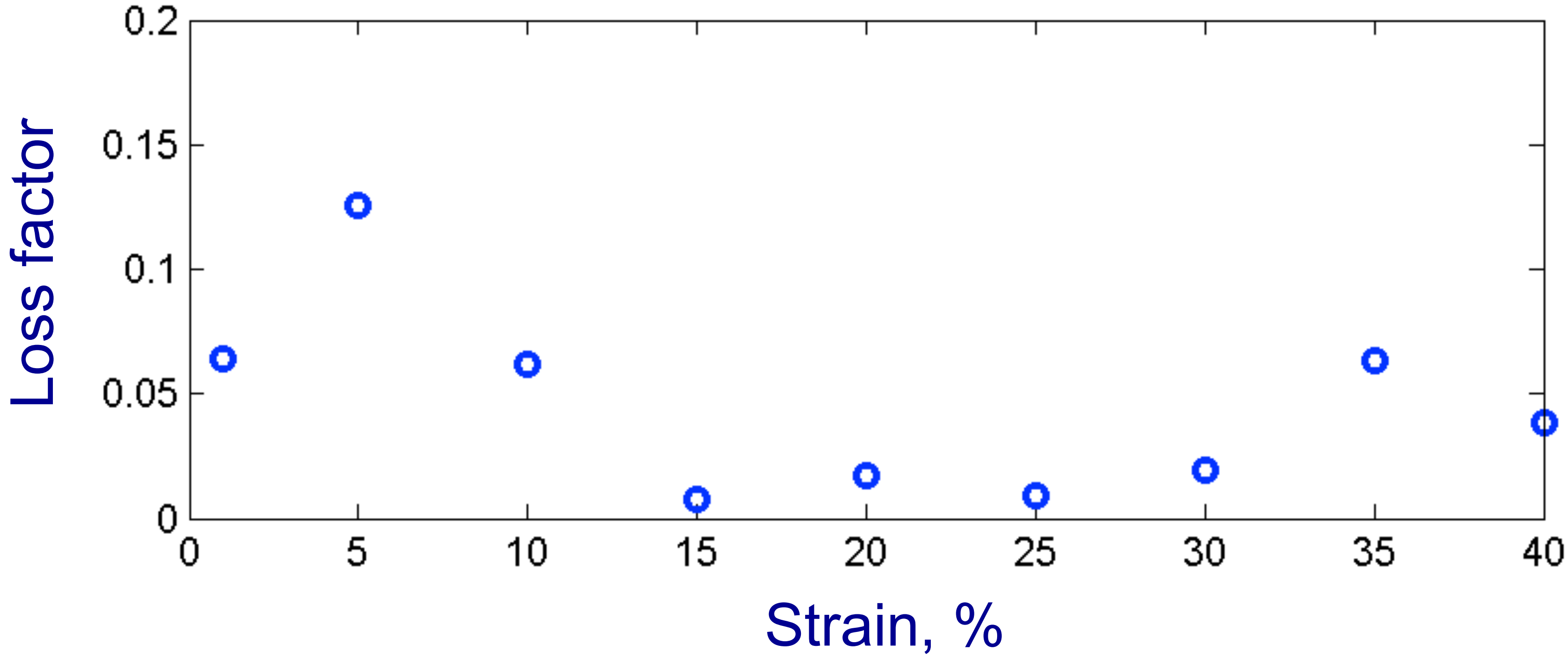
- 96 cycles used to estimate dynamic performance
- Energy loss factor is almost same
- average contact area and force vary slightly

Effect of static compression



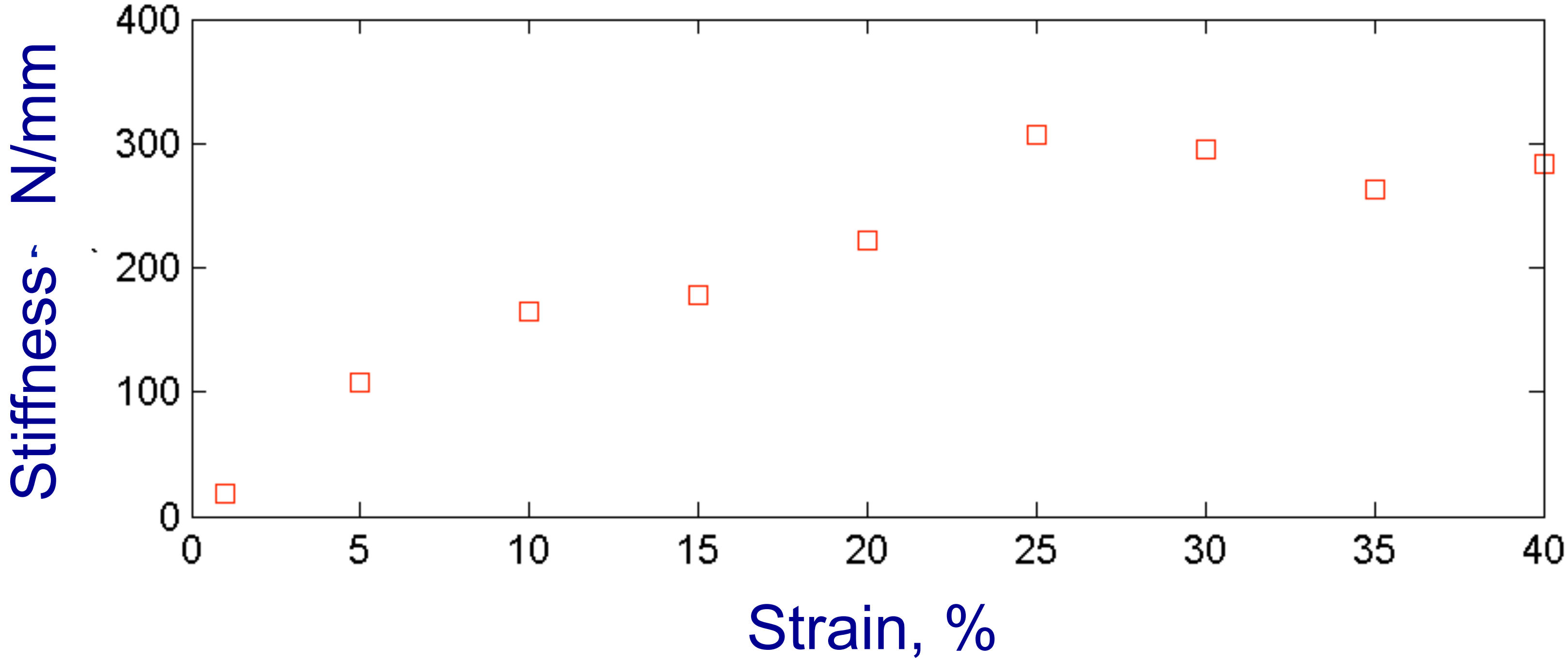
- Crest-to-crest wave springs
  - ✓ Stiffness can vary from 10 to 90 N/mm

Effect of static compression



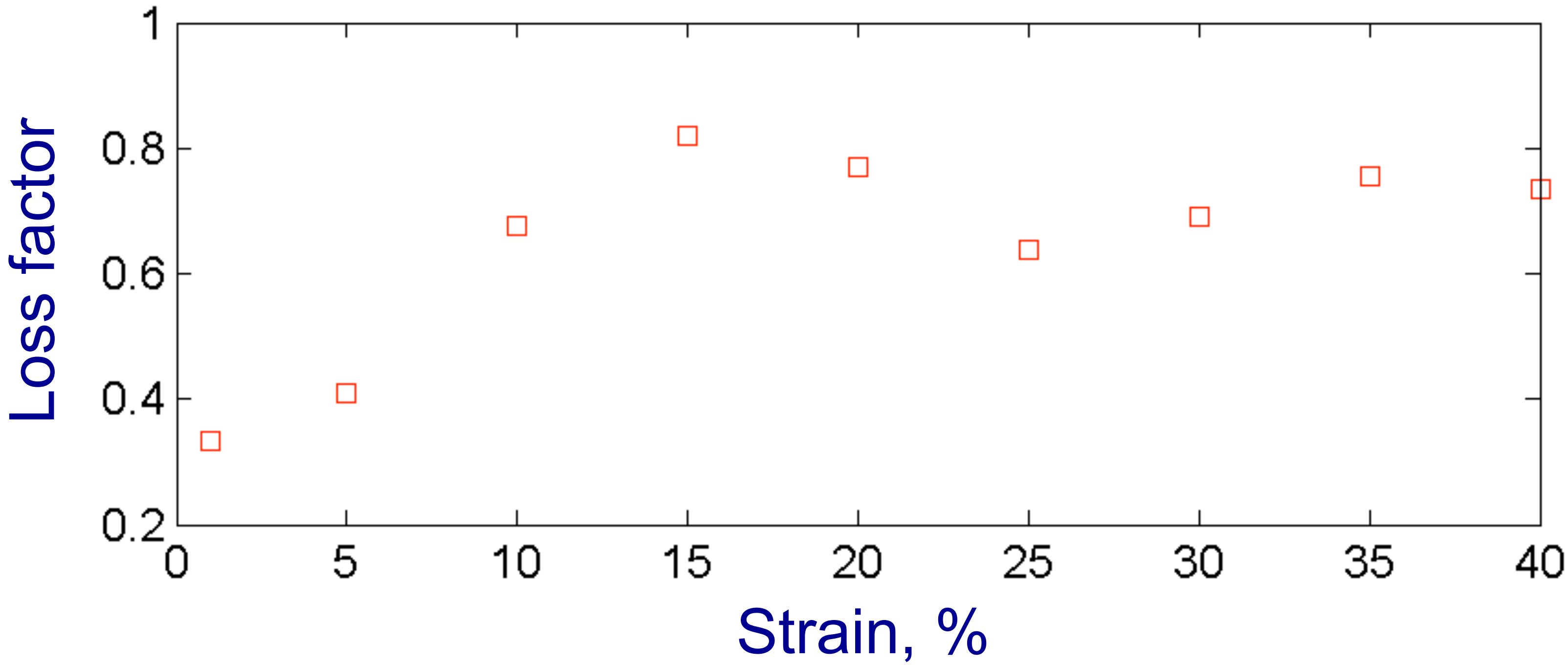
- Crest-to-crest wave springs
  - ✓ Negligible damping was observed from 15%-25% strain
  - ✓ Relative high damping occur in extreme low/high strain

Effect of static compression



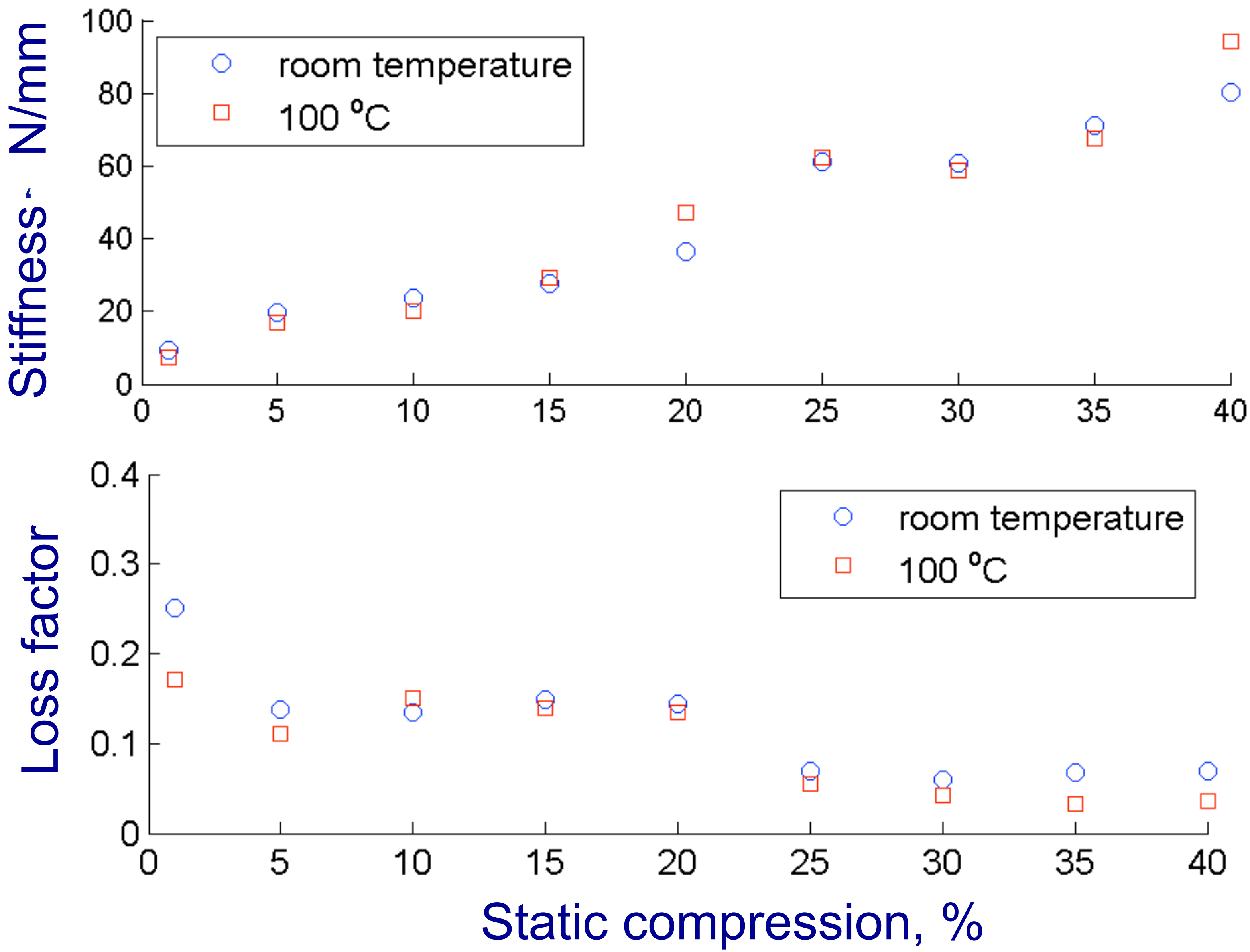
- Nested wave springs
  - ✓ limited stiffness variation is achieved
  - ✓ Stiffness could increase approx. 3 times with pre-strain

Effect of static compression



- Nested wave springs
  - ✓ Energy dissipation is high
  - ✓ Less variation occurs when static compression is larger than 10%

Effect of temperature

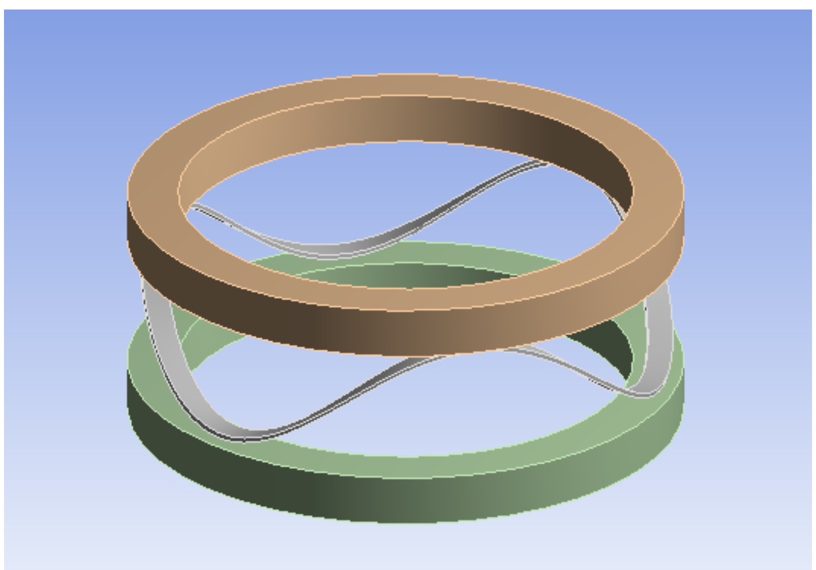


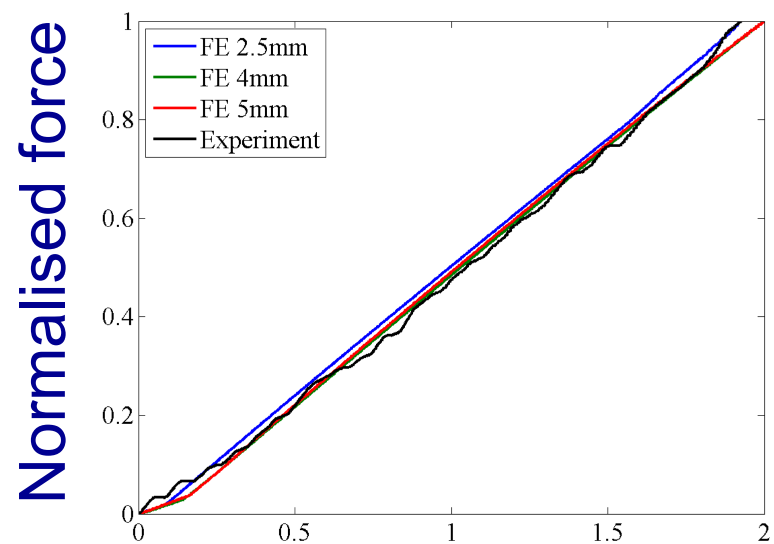
Finite element modelling

- Identify stiffness of wave springs – design tool
- Uncertainty of modelling of wave springs
  - ✓ Local amplitudes for sinusoidal wave – NOT correct
  - ✓ Shape of waves – NOT sinusoidal curve

Finite element modelling

- Single layer metal strip
  - ✓ Use to identify whether FE code can estimate stiffness of curved structure
  - ✓ Investigate uncertainties of waveform

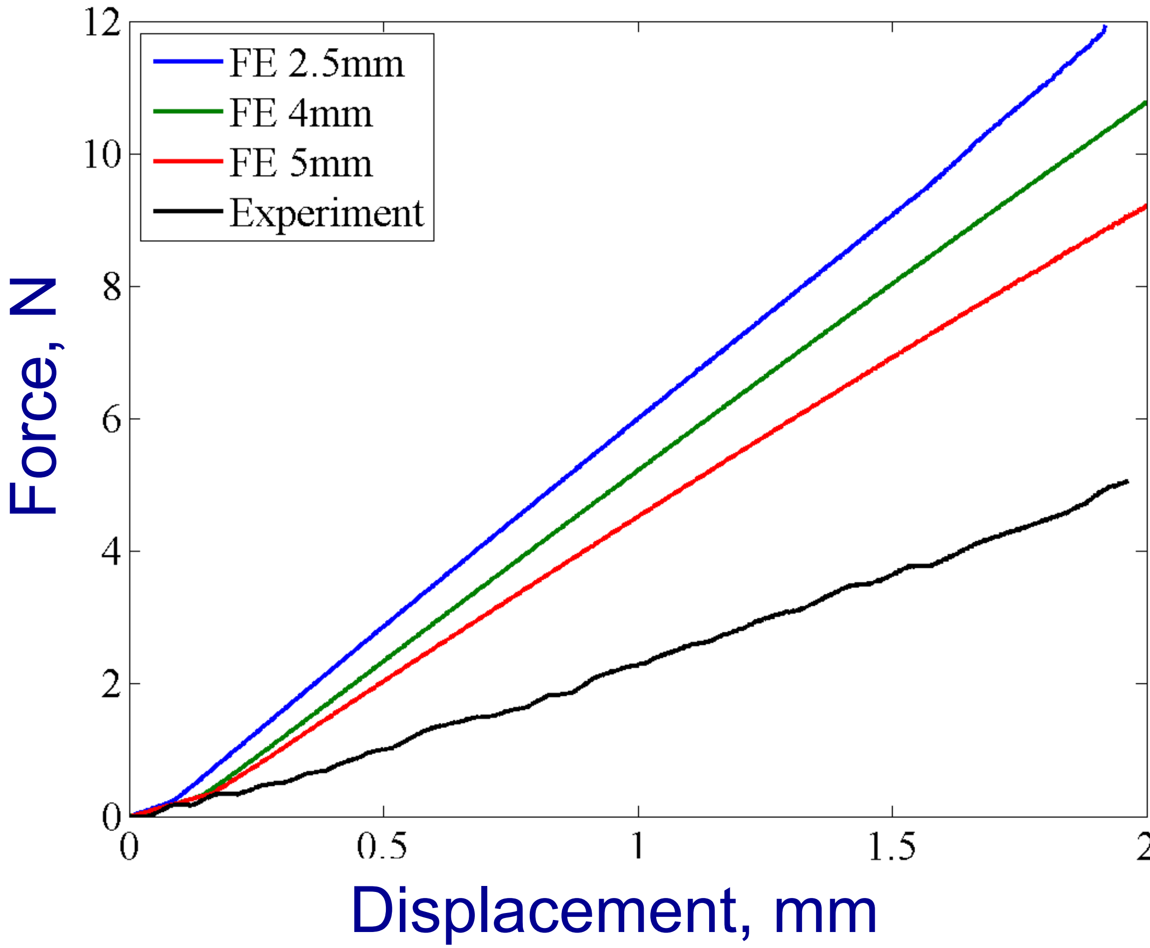




Displacement, mm

Finite element modelling

Single layer metal strip



Stiffness from FE model is much higher

May cause by misestimation of shape of wave spring

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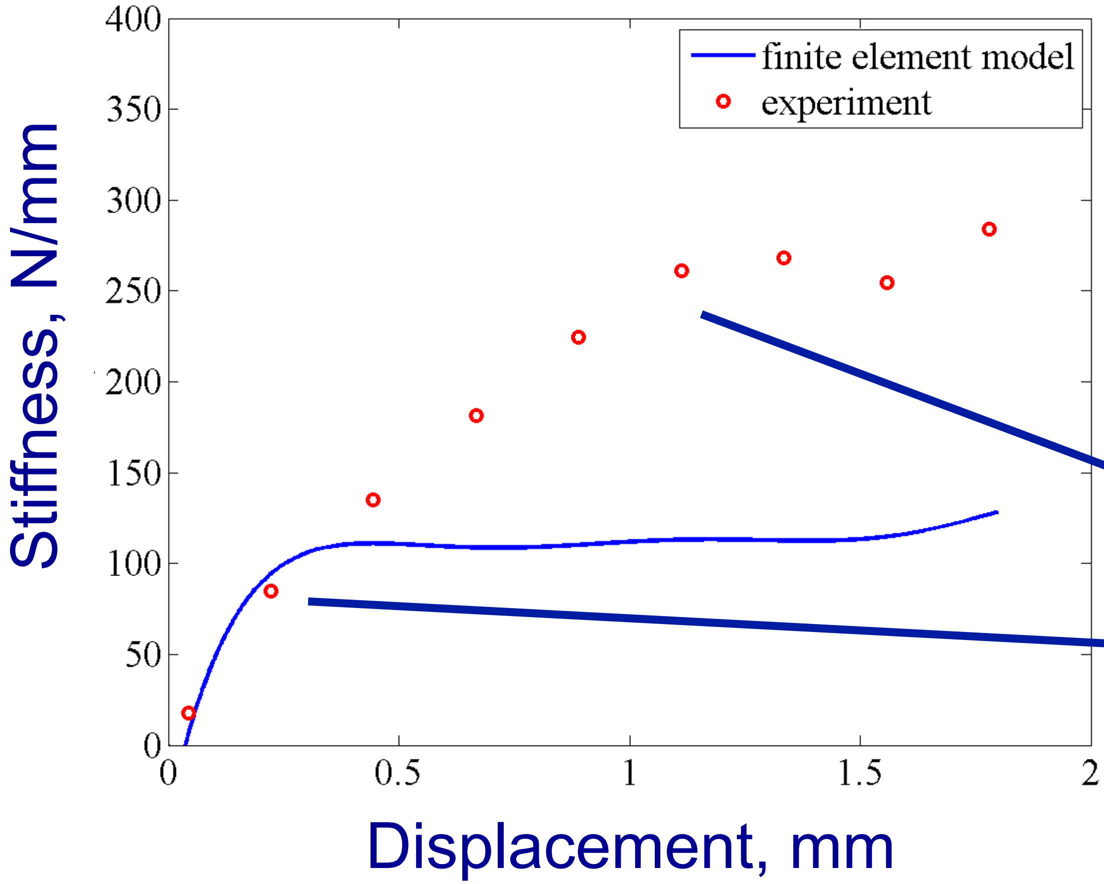
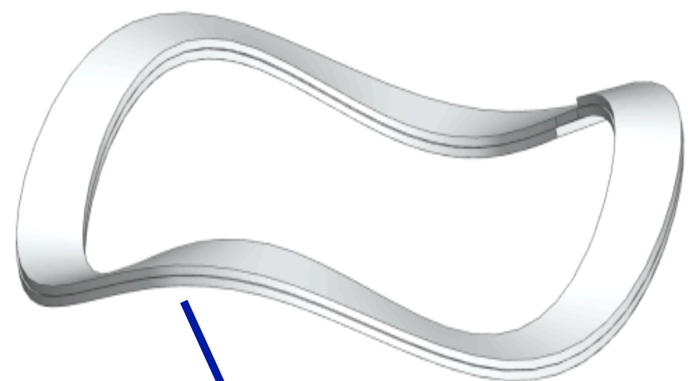
Finite element modelling

Nested wave spring

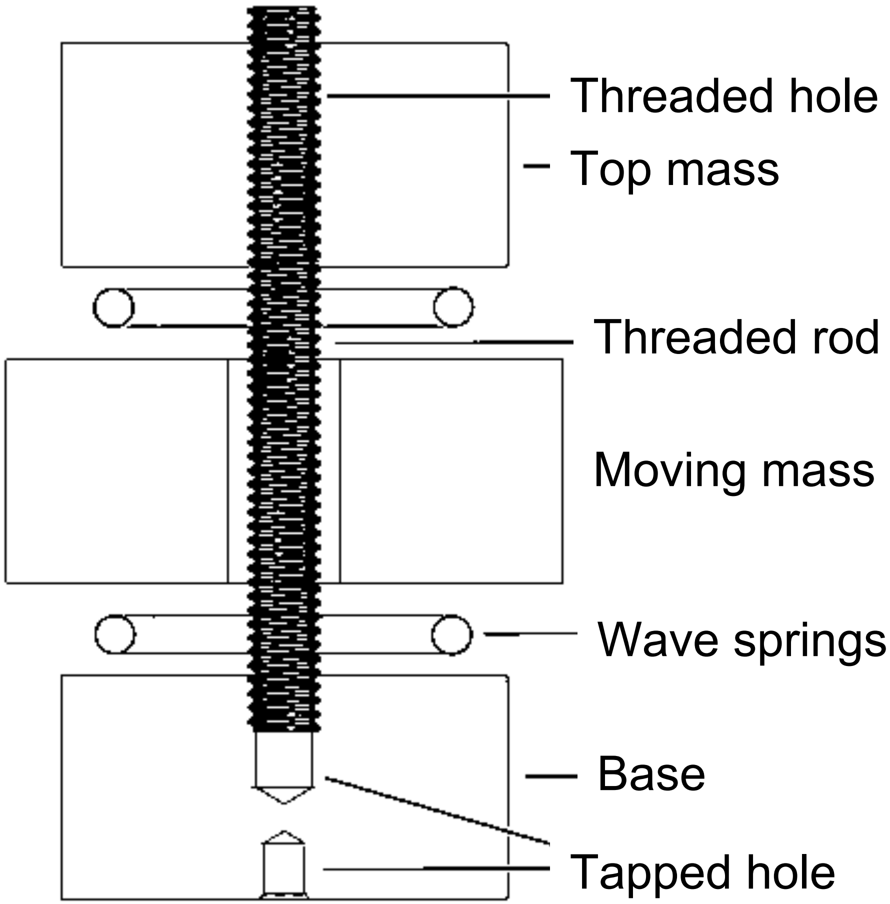




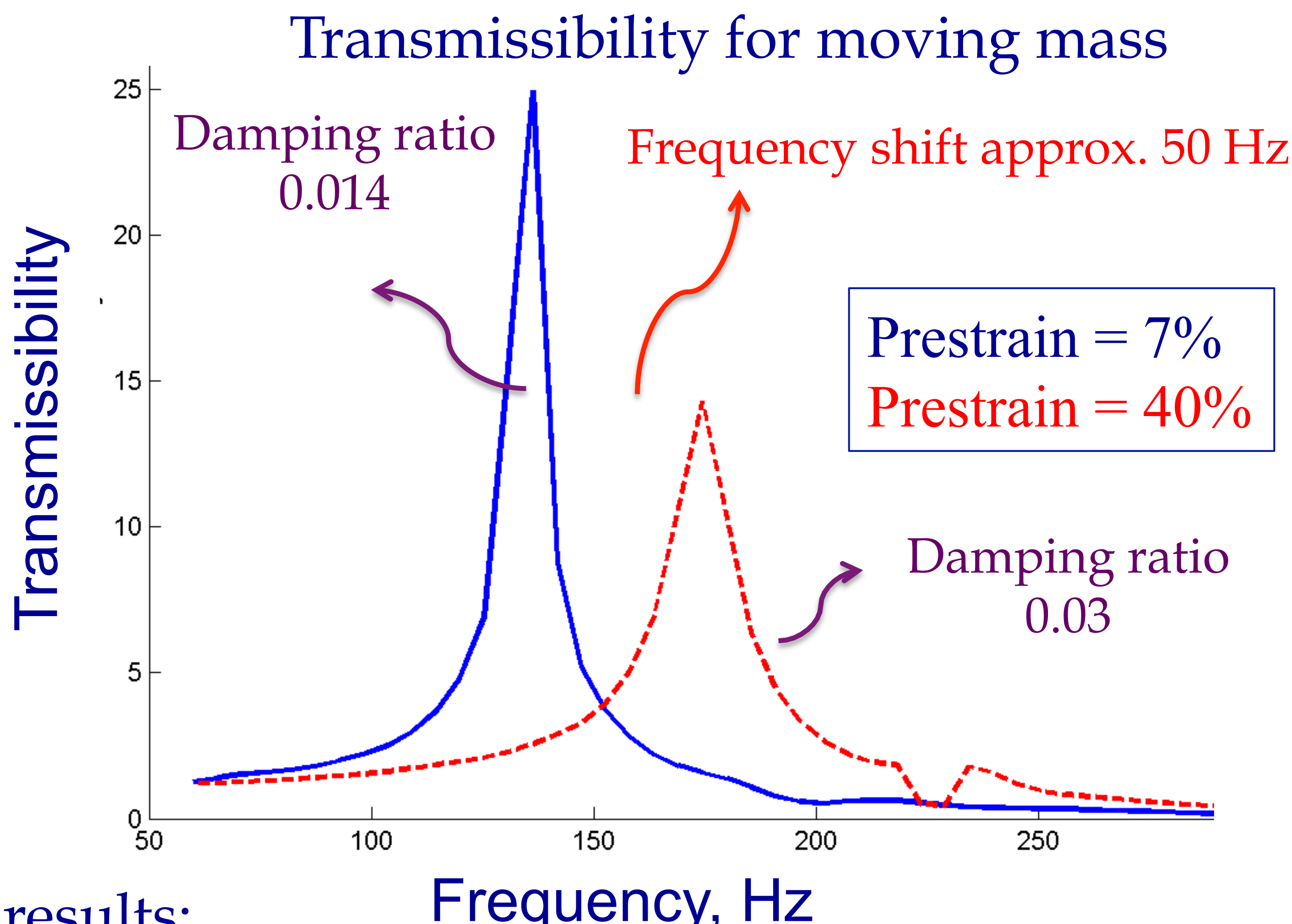
May cause by gaps between wave springs in the CAD model

Application: Stand alone TMD

- Key features
  - Ease to adjust static compression
  - Ease to modify limitation of tuning frequencies
- Challenges
  - Additional unnecessary weight
  - Initial static compression



Performance for stand alone TMD



Key results:

- ✓ Resonance shift with static compressions
- ✓ Damping increases significantly.

Conclusion

- Wave springs are shown as a kind of temperature insensitive elastic and damping elements
- Finite element modelling can predict the stiffness of wave spring while local waveform need to be modelled accurately.
- TMDs using wave springs are shown to be effective, especially in high temperature.

Thanks for your attention.
Any questions?

Mesh convergence