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Pressure Dependent Quality Factor of Micron Scale Energy Harvesters

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Overview

- Problem statement
- Approach
- Experimentation
- Computational Model
- Validation
- Conclusion

Problem Statement

- Fluidic damping in piezoelectric based MEMs energy harvesters causes the device to loss harvested energy
- Fluidic damping is a function of cavity pressure
- Reducing cavity pressure comes at a cost
- Designers of micro cantilever energy harvesters (EH) need a tool which can demonstrate the effect of pressure levels on the degree of harvested energy (Q-factor) in an expedient manner.
- The explicit FSI approach (Navier Stokes – Structural mechanics coupling) of modeling MEMs damping is very time intensive.

Approach

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- To minimize result’s turn-over time, Reynolds Equation (Lubrication theory) is coupled with the Structural Mechanics equations to model the effect of pressure on fluidic damping
- Two experimental setups (simple cantilever and complex structured magnetometer) are used to validate the model’s accuracy
- A single mass cantilever EH model is used to compare results and computational time using COMSOL and ANSYS implicit and explicit FSI simulations

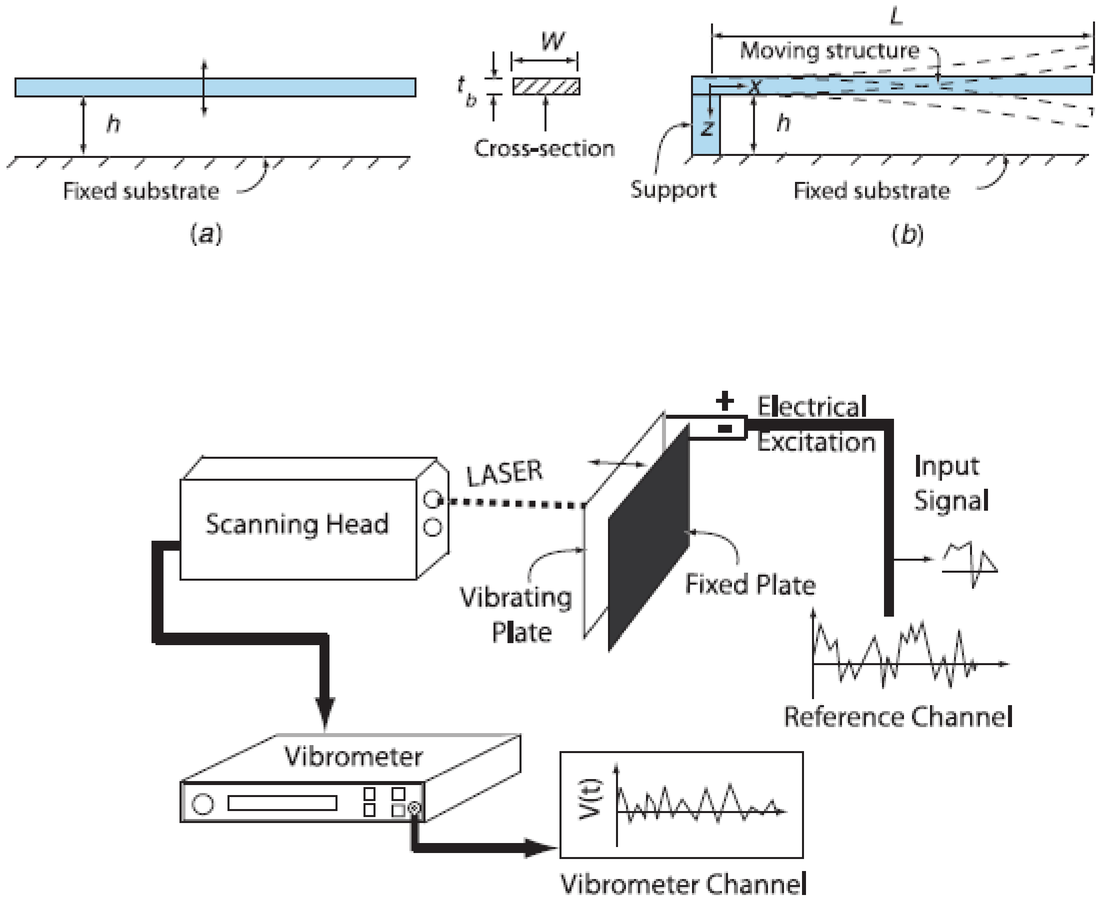
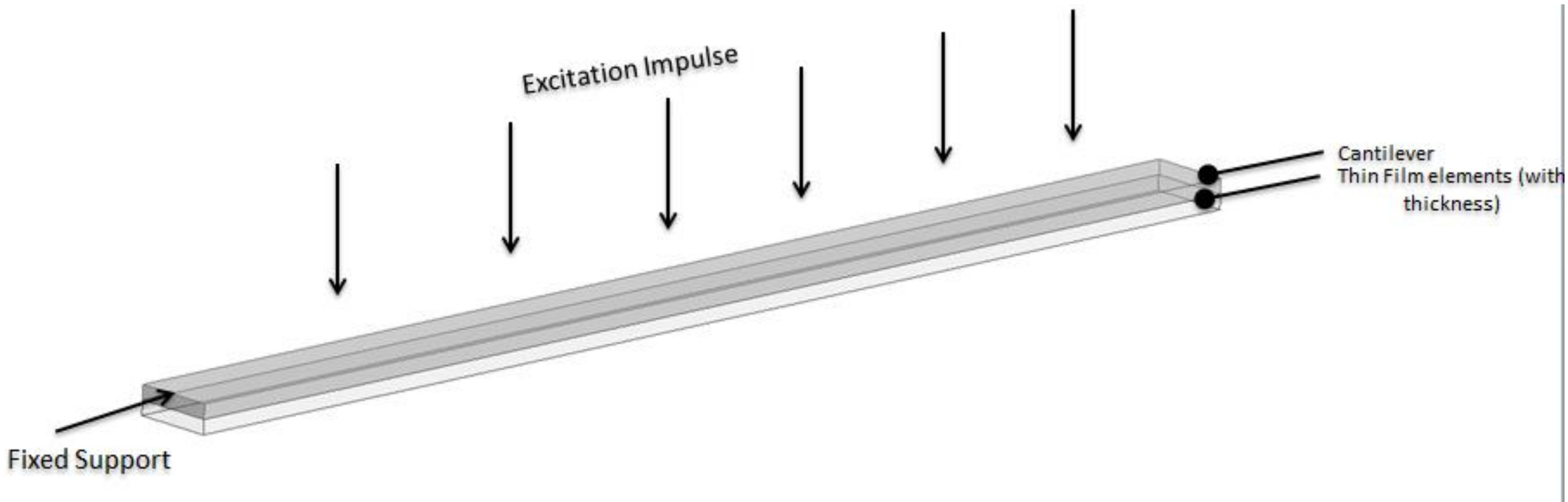


Figure 1: Experimental setup for simple cantilever EH (Pandey et al.)

Simple Cantilever Resonator Model



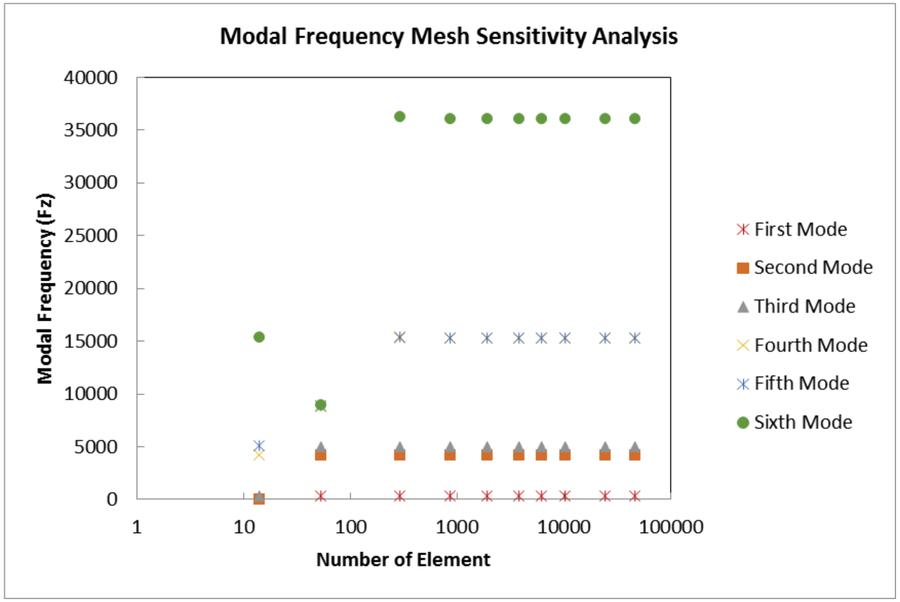
Reynolds Equation: $\frac{\partial}{\partial t}(\rho h) + \nabla_t . (h\rho v_{av}) = 0$

$v_{av} = \frac{1}{2}\left(v_{w,t} + v_{b,t}\right) - \left(\frac{h^2}{12\mu_{eff}}\right) \nabla_t . P_f$

$\mu_{eff} = \frac{\mu}{1+9.638 Kn^{1.159}}$ - Low pressure Regime (Kn (λ_0 / h) >0.1)

Figure 2: Model setup for simple cantilever EH (Pandey et al.)

Mesh Sensitivity



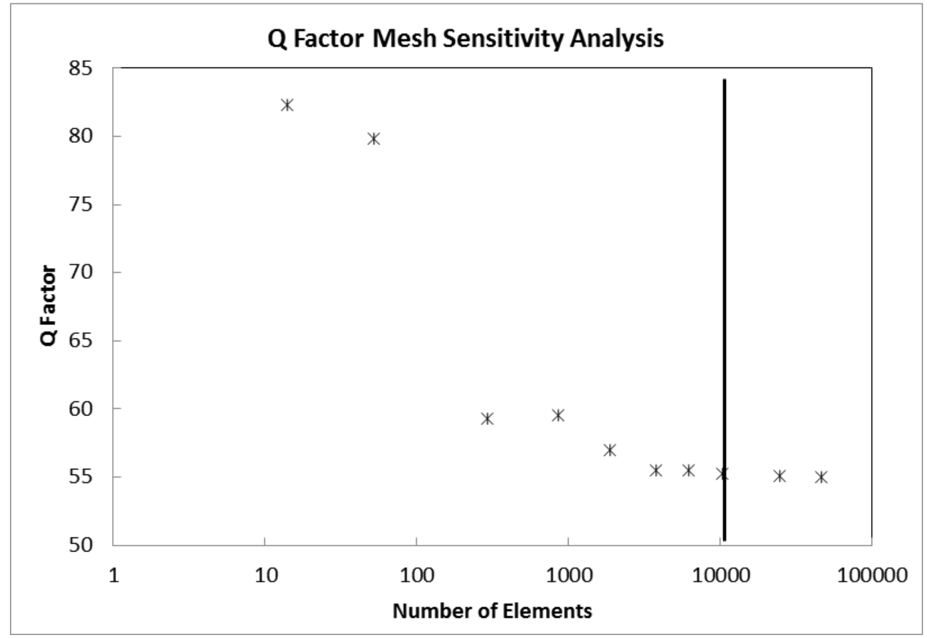
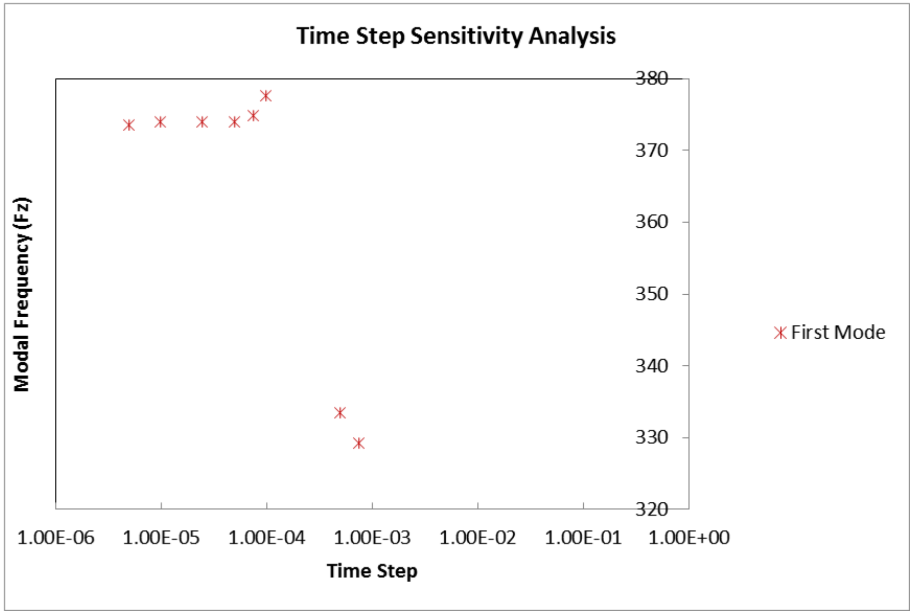


Figure 3: Mesh sensitivity analysis for (a) Modal Fq (b) Q factor

Time Step Sensitivity Analysis



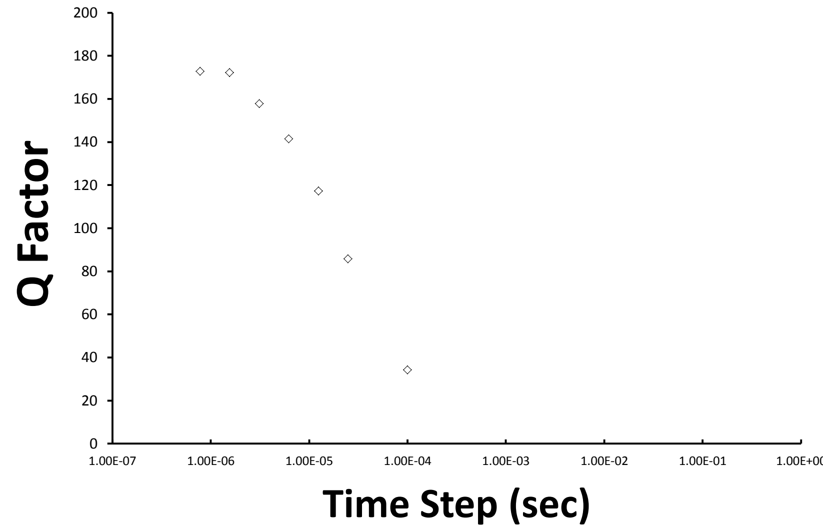


Figure 4: Mesh sensitivity analysis for (a) Modal Fq (b) Q factor

Model Time Stepping

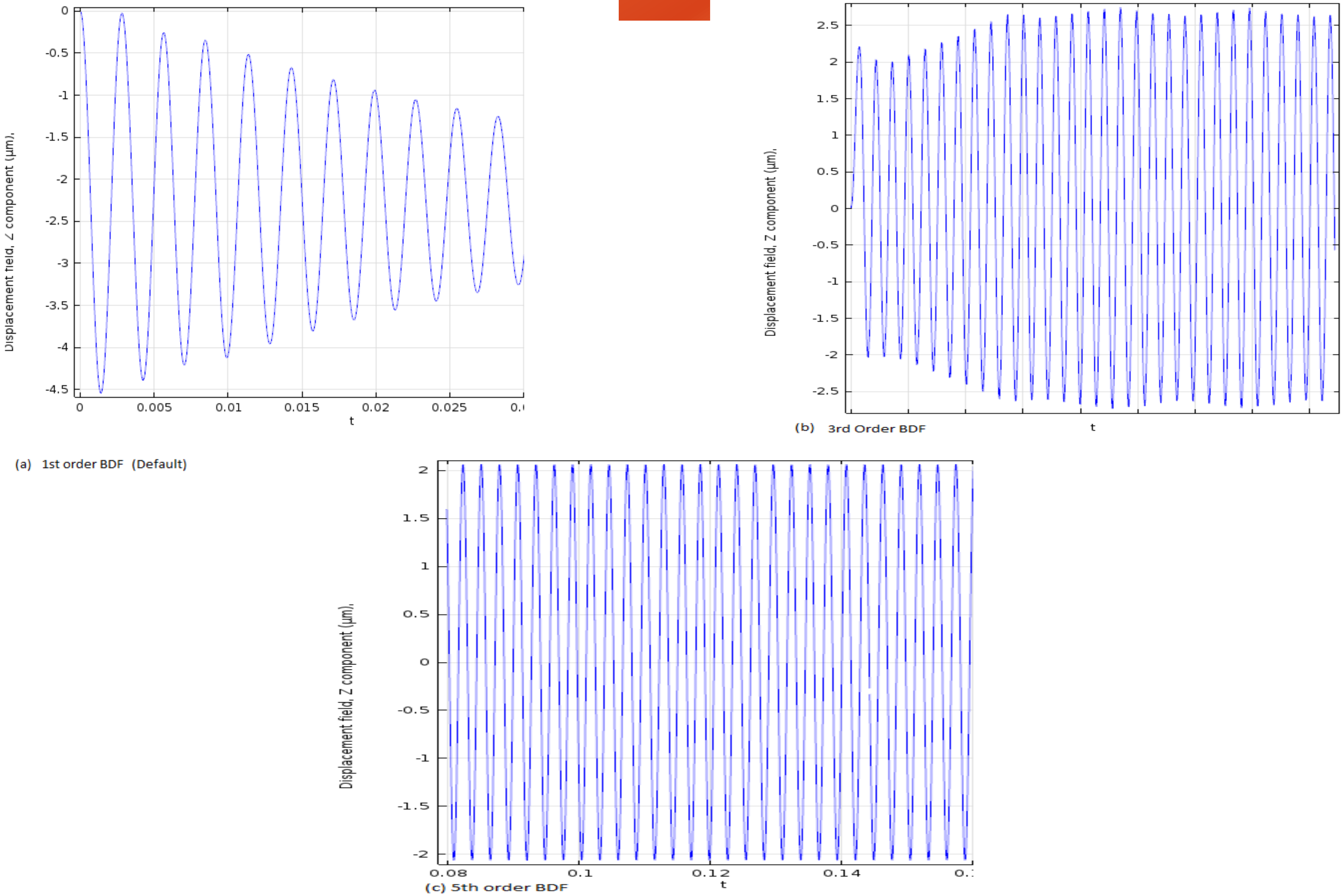
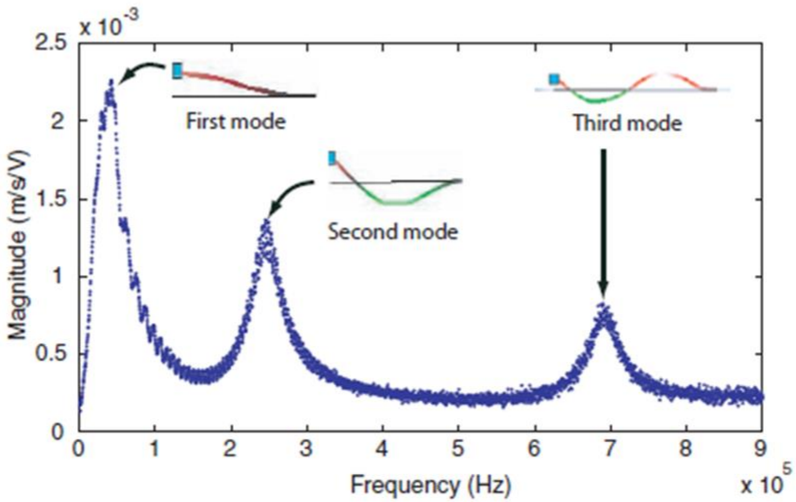


Figure 3: Effect of time step and time step formulation on dynamic response of un-damped resonator

Simple Cantilever Model Validation: Q factor as a function of mode frequency

- Pandey et al



- Thin Film-Structural Dynamics model

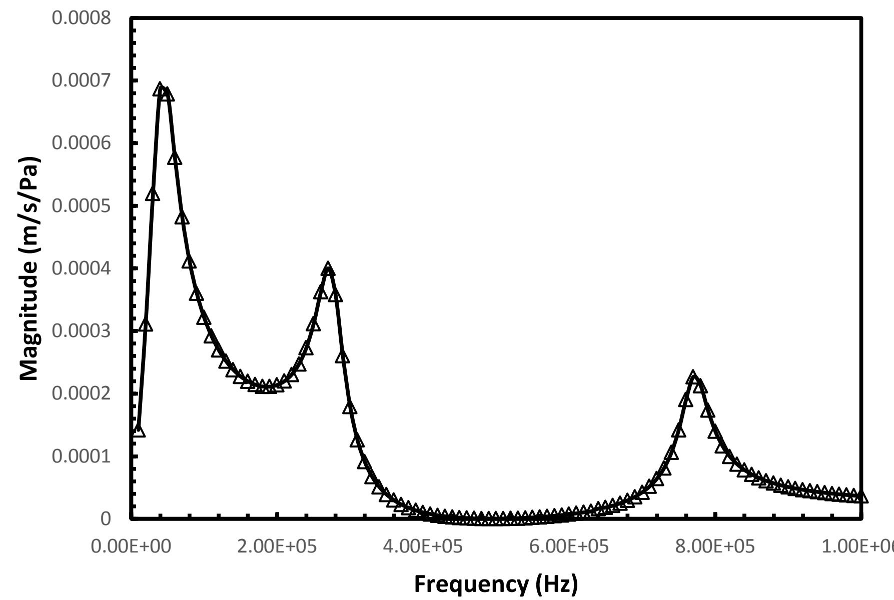


Figure 5: Simple cantilever resonator validation: Modal Q factors

	Model's Resonant Fq (Hz)	Measured Resonant Fq(Hz)	Frequency's Percentage error	Model's Q Factor	Measured Q Factor	Q Factor Error
First Mode	50000	43000	16%	1.21	1.20	**1%**
Second Mode	290000	245000	18%	7.92	7.58	**5%**
Third Mode	790000	690000	14%	19.55	18.52	**6%**

Simple Cantilever Model Validation: Q factor as a function of cantilever length

Length Microns	Experiment	Q Model	%error
350	1.204819277	1.195057	-1%
300	1.5625	1.513789	-3%
250	2.487562189	2.419897	-3%
200	4	3.892728	-3%
150	7.042253521	7.26456	3%

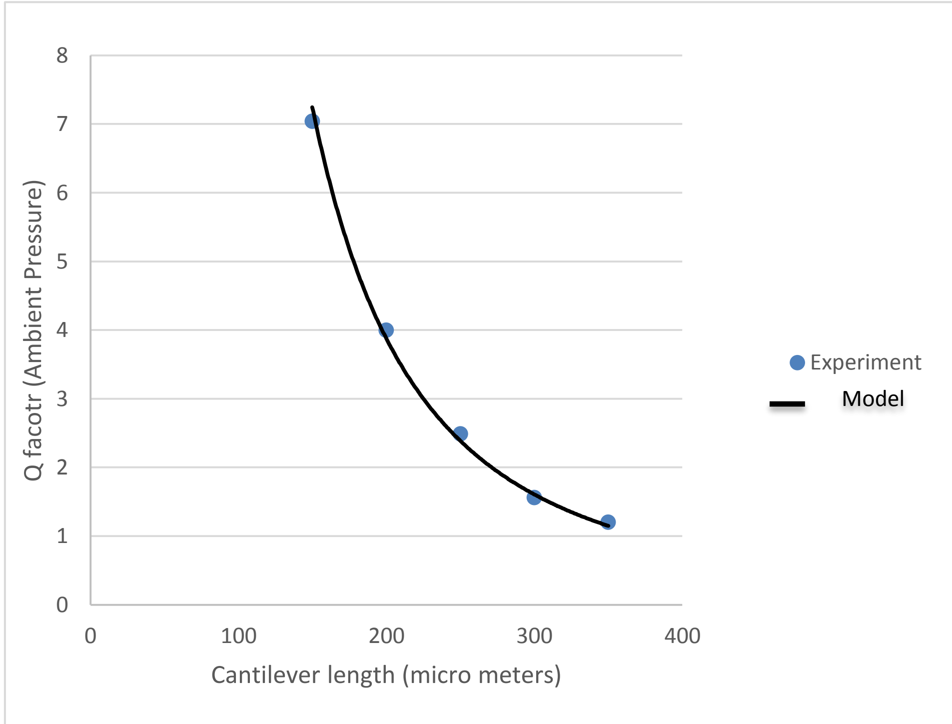


Figure 6: Simple cantilever resonator validation (cantilever length)

Magnetometer Resonator Model

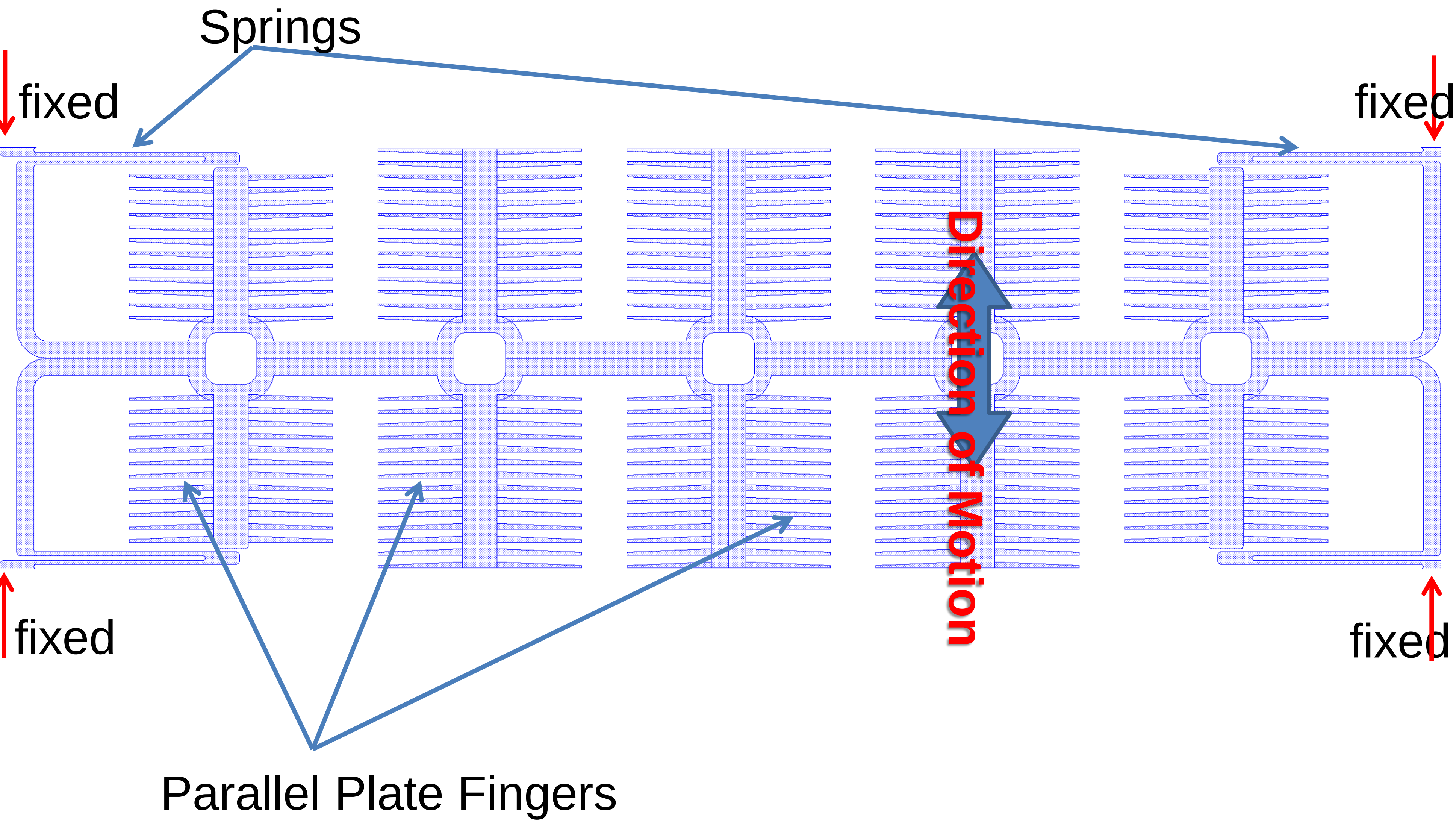


Figure 7: Magnetometer resonator model boundary conditions

MAGNETOMETER RESONATOR MODAL MODEL

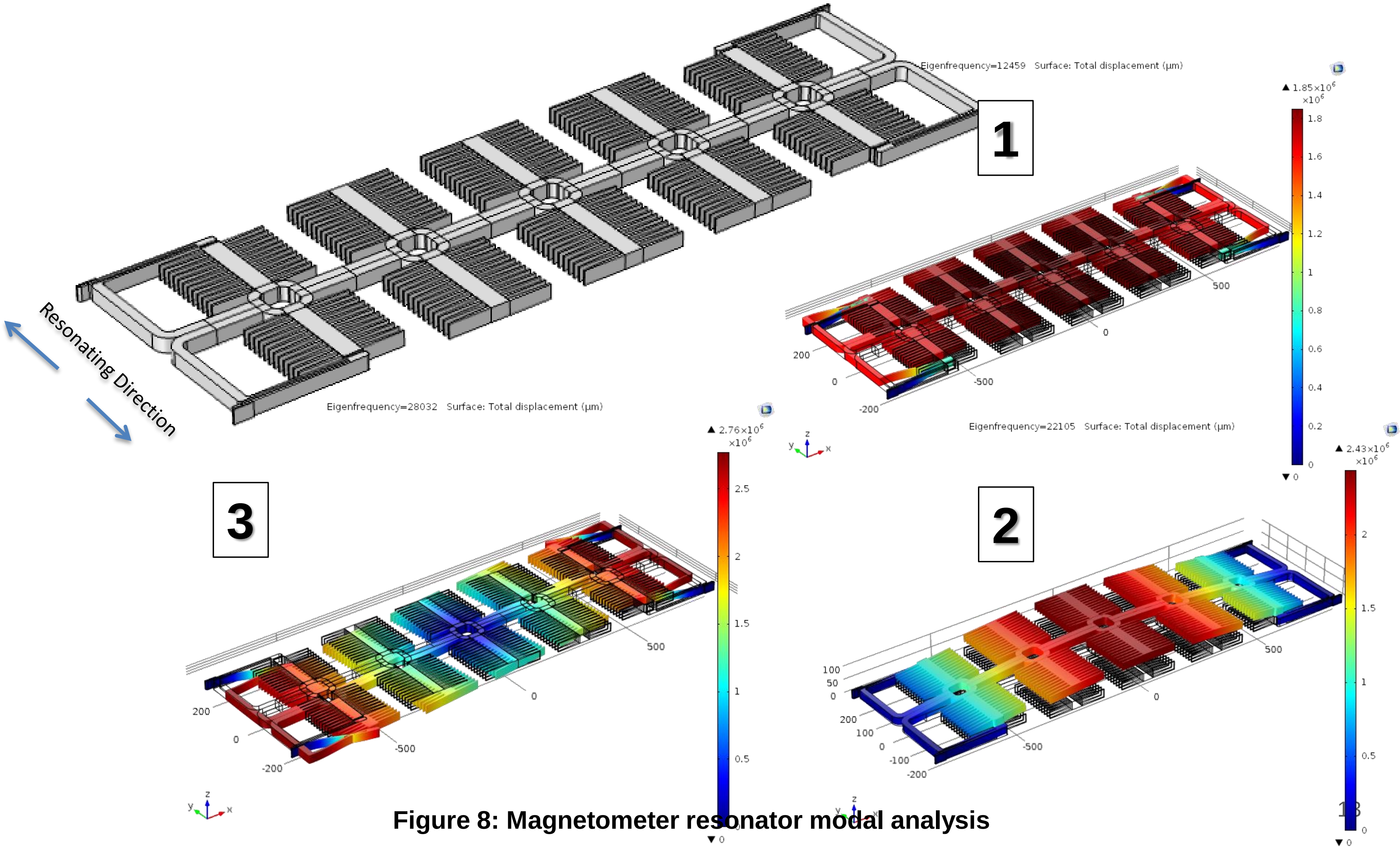


Figure 8: Magnetometer resonator modal analysis

Magnetometer Model Validation: Q factor as a function of Cavity pressure

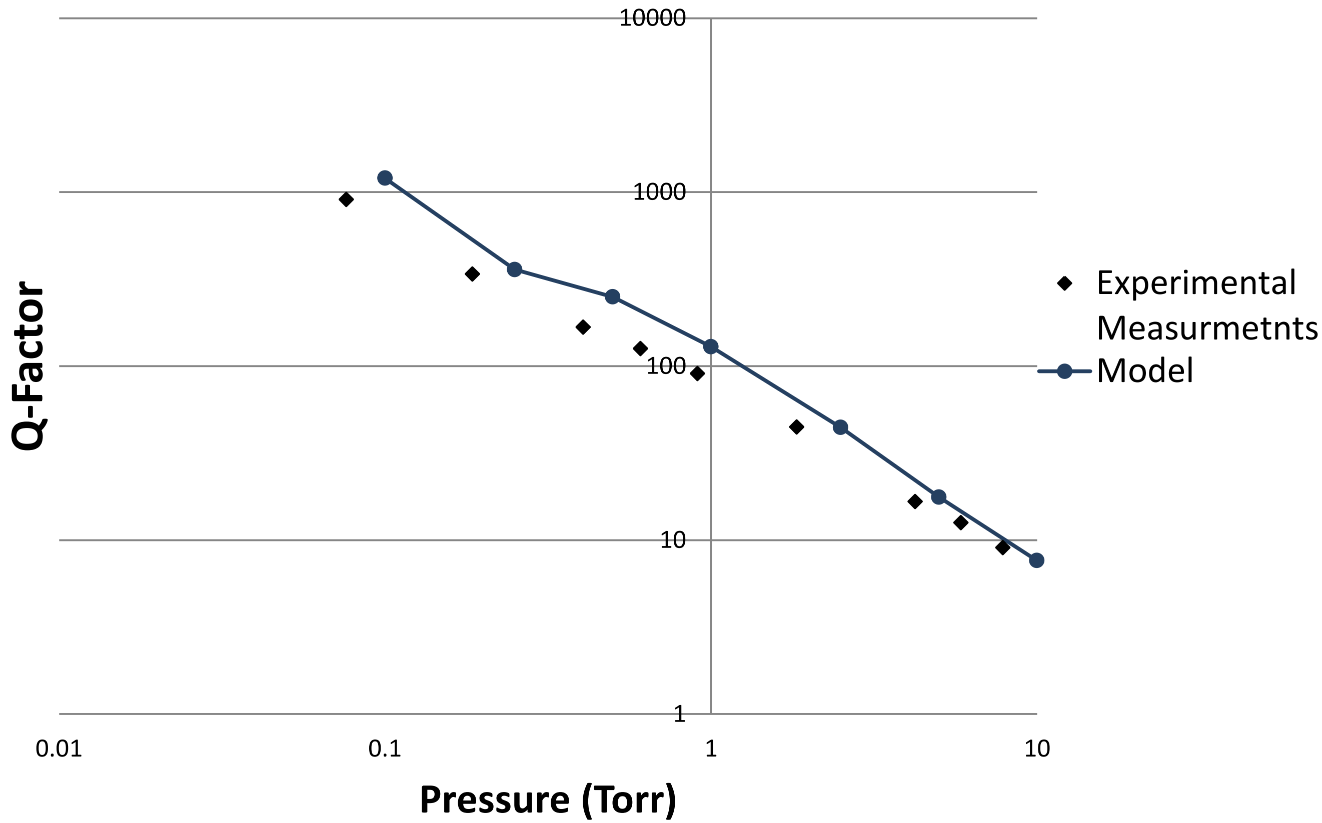


Figure 9: Magnetometer resonator Q factor Validation

Single mass resonator model

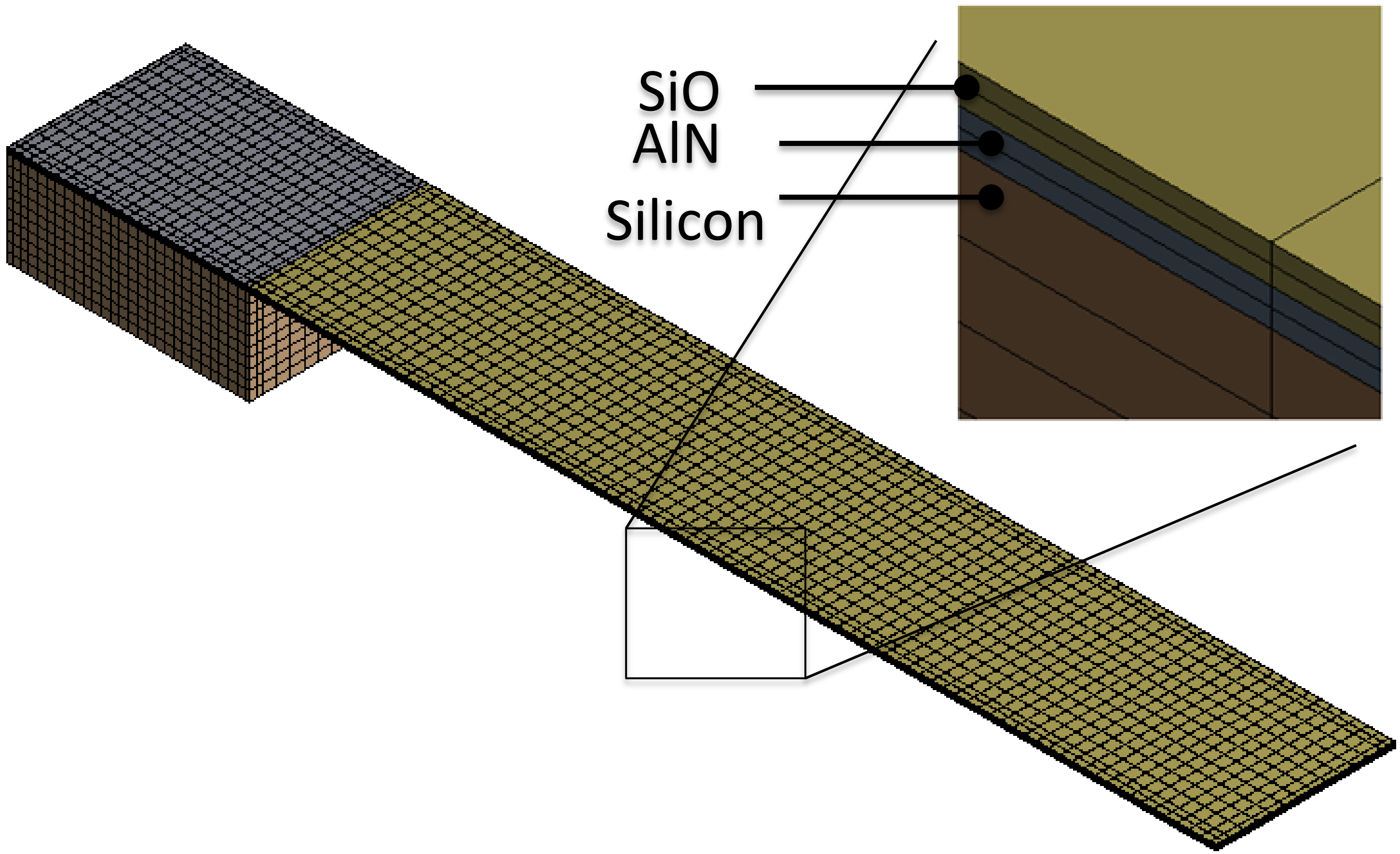


Figure 10: Single Mass Cantilever Model

Single Mass Cantilever Models' Comparisons

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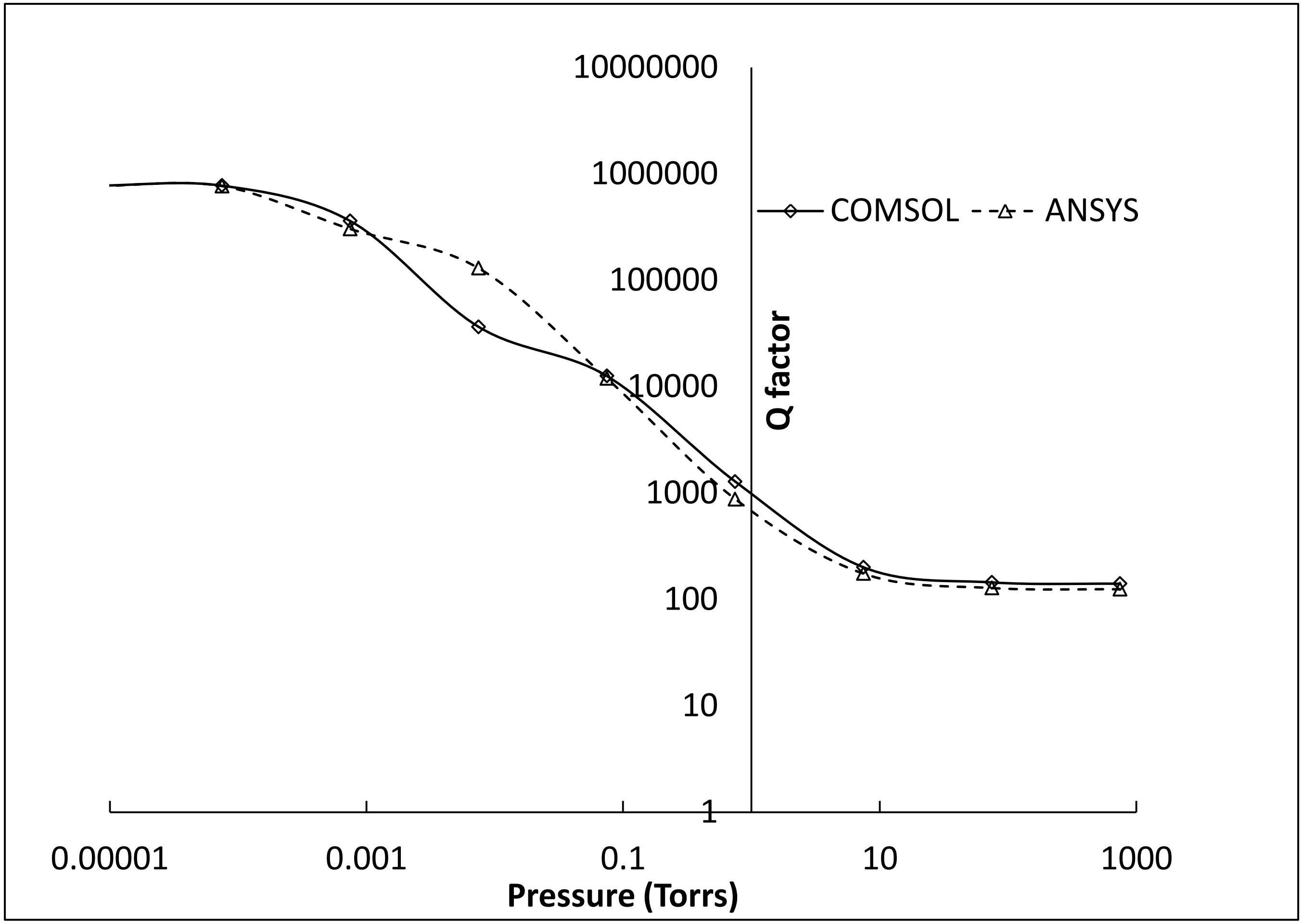

Figure 11: Single Mass Cantilever Q factor Model

CONCLUSION

- Pressure dependent damping characteristics of MEMs resonator have been modeled using the Structural mechanics - thin Film models coupling.
- The models were validated for modal, geometry and pressure dependent Q factor estimates
- These solutions are 15 times faster than explicit FSI simulations with only 7% deviation in Q factor calculations
- Care must be taken to ensure time stepping formulations are adequate and time step selections are strict to avoid numerical damping
- COMSOL and ANSYS estimates are identical but the COMSOL modeling approach presents many advantages for this type of model

Thank you!