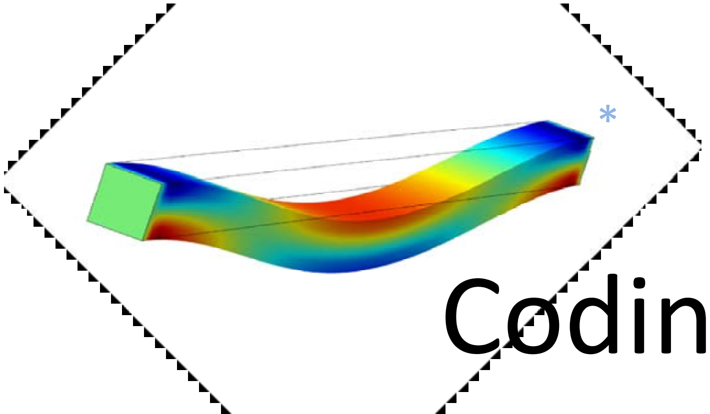

Coding of Effects of Thermoelastic Damping

NE211: Micro- Nano Mechanics
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**models.mems.thermoelastic_damping_3d*

Overview

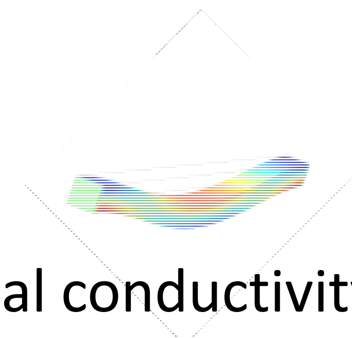
- Goal
- What is TED?
- Why TED is important in MEMS/ NEMS?
- Equations involved
- Effects of TED

Goal

- The aim of project is to have an idea about thermoelastic damping
- Understand its effect
- Use MATLAB to verify the effects

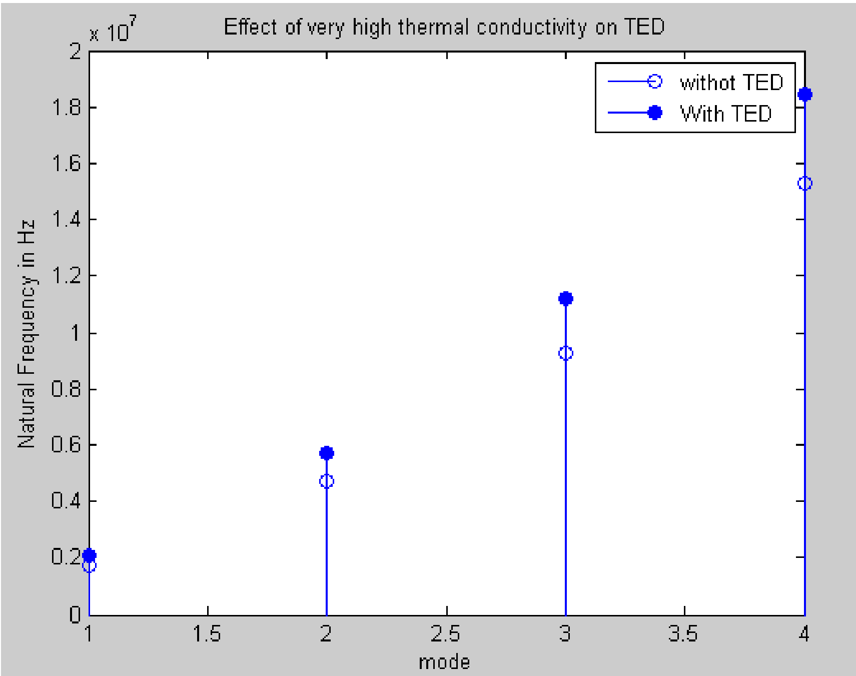
What is TED?
Thermoelastic Damping

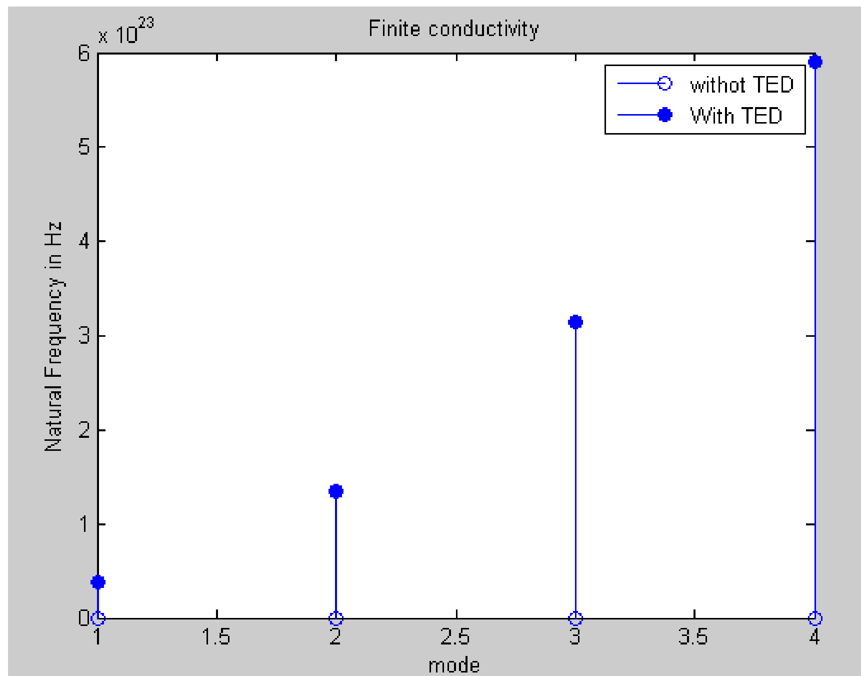
Strain Field ⟷ Coupling ⟷ Temperature field



- Stress field in vibrating body is non-uniform
- Some region become hotter relative to others
- Heat flows within the body, if it has finite thermal conductivity
- Temperature field is set up which intern affects strain

Finite Thermal Conductivity …





Why TED is important in MEMS/NEMS?

- Flexural-mode micromechanical and nanomechanical beam resonators are critical components in many areas
- Consequences of coupling of elastic and thermal energy domains are -

1. Attenuation of amplitude of vibration
2. Shift of isothermal frequency

- It is intrinsic and hence imposes an upper limit on the Quality factor

Equations involved

Equation of motion of the beam

$$\rho A \frac{\delta^2 W}{\delta t^2} + \frac{\delta^2}{\delta x^2}\left(EI\frac{\delta^2 W}{\delta x^2} + E\alpha I_t\right) = 0 \quad *$$

Heat equation : 1D

$$\frac{\delta\theta}{\delta t} = \chi\frac{\delta^2\theta}{\delta y^2} + \gamma\frac{\Delta E}{\alpha}\frac{\delta}{\delta t}\left(\frac{\delta^2 W}{\delta x^2}\right) \quad *$$

To calculate the effect of thermoelastic damping on the vibration of a thin beam, the above coupled thermoelastic equations are solved for the case of harmonic vibrations.

** Thermoelastic damping in micro- and nanomechanical systems*
- Ron Liftshitz and M.L. Roukes
- Physical review B, volume 61. number 8, 2000

New eigen frequencies of beam

The beam equation takes the following form

$$\omega^2 W_o = \frac{EI}{\rho A}\{1 + \Delta E[1 + f(\omega)]\}\frac{\delta^4 W_o}{\delta x^4} \quad *$$

$f(\omega)$ is complex function of k(ω)

Young's modulus E is replaced by a frequency dependent modulus

$$E_\omega = E\{1 + \Delta E[1 + f(\omega)]\} \quad *$$

- In general the new frequencies are complex
- The real part gives new eigen frequencies
- The imaginary part gives the attenuation

$$^{*}\omega\_TED = \omega\left\{1 + \frac{\Delta E}{2}[1 + f(\omega)]\right\}$$

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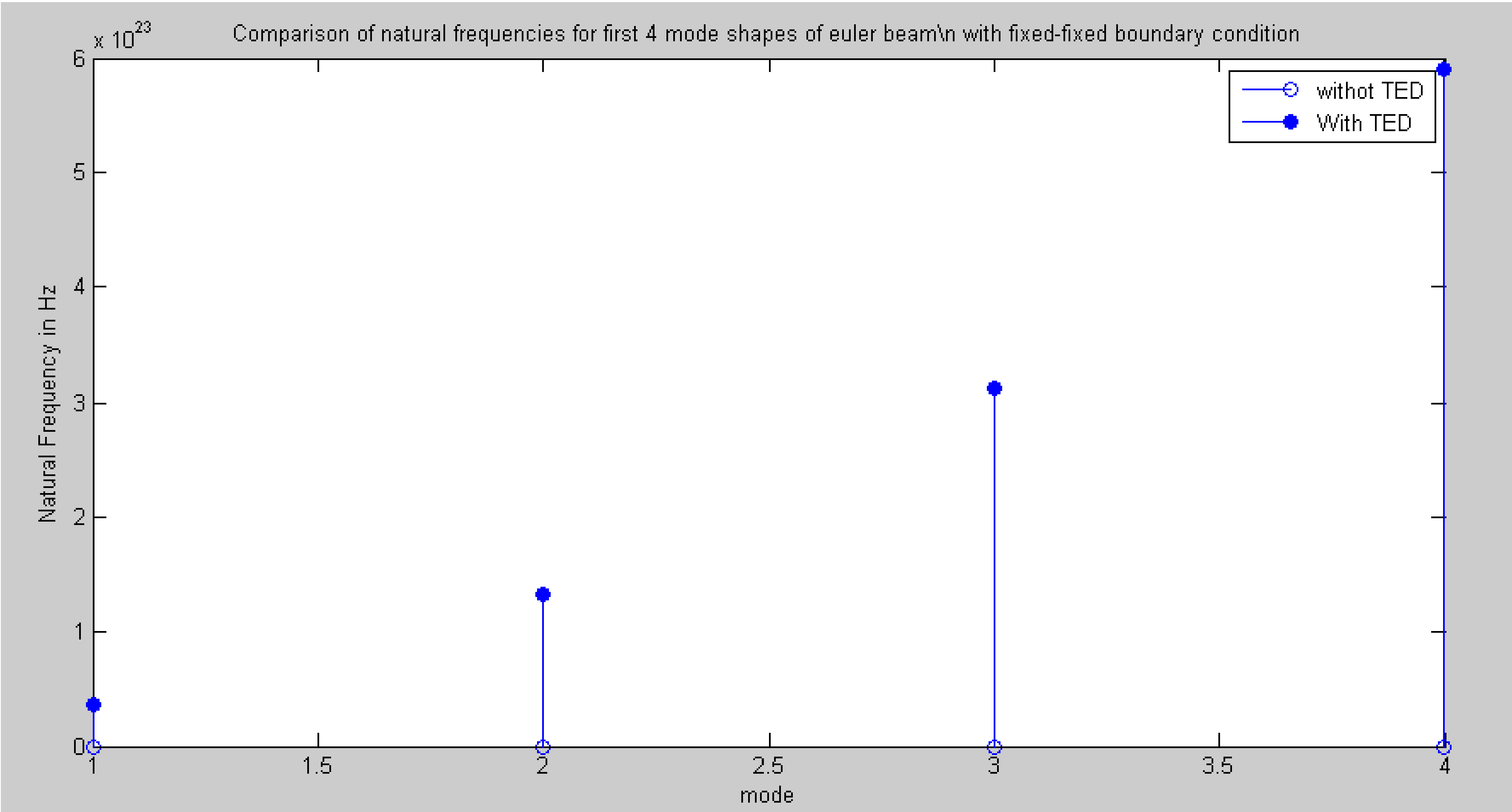
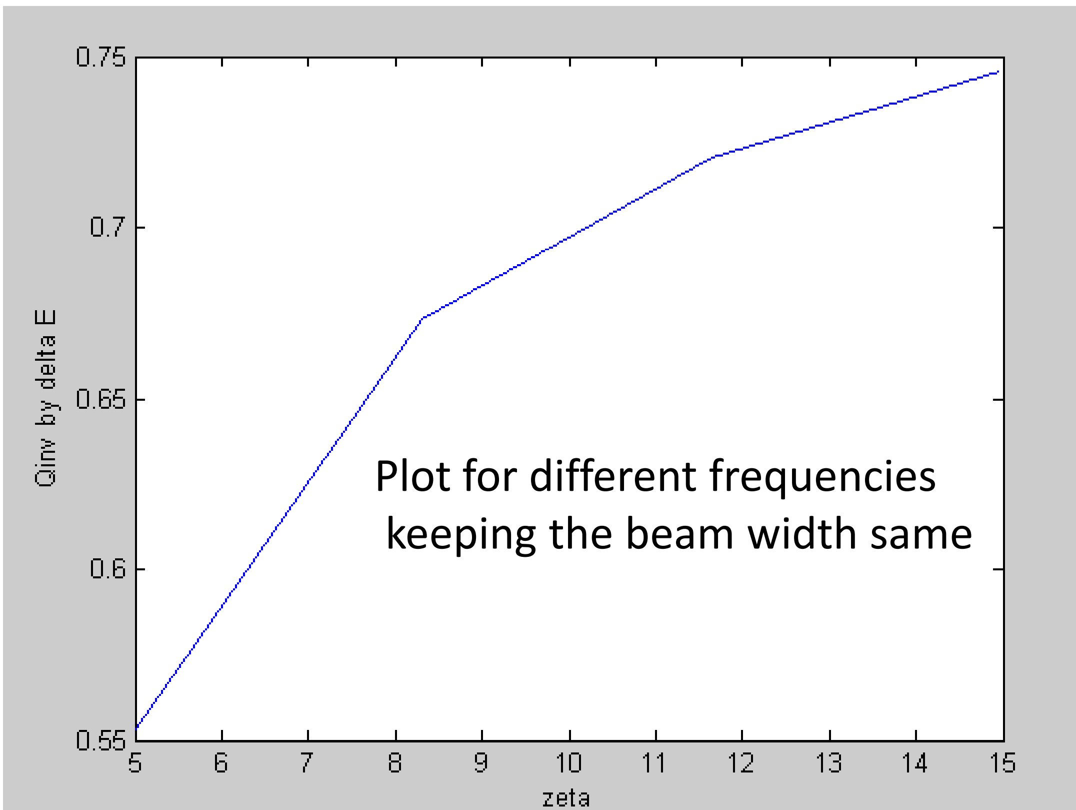
Effect Of TED on Eigen-frequency



The plot shows that eigen frequency increases significantly because of thermoelastic damping

Inverse of Quality factor

- The amount of thermoelastic damping is expressed in terms of inverse of Quality factor.



$$Q^{-1} = 2\left|\frac{Im(\omega)}{Re(\omega)}\right| \quad *$$

$$\xi = b\sqrt{\frac{\omega_o}{2\chi}} \quad *$$

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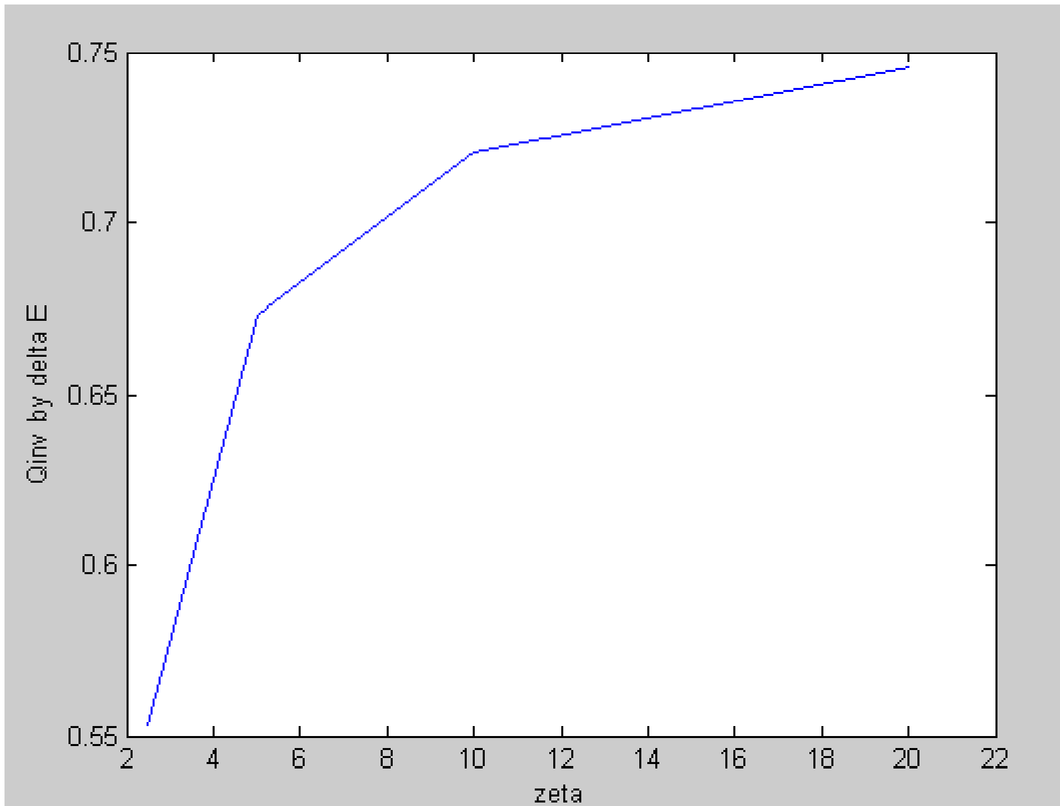
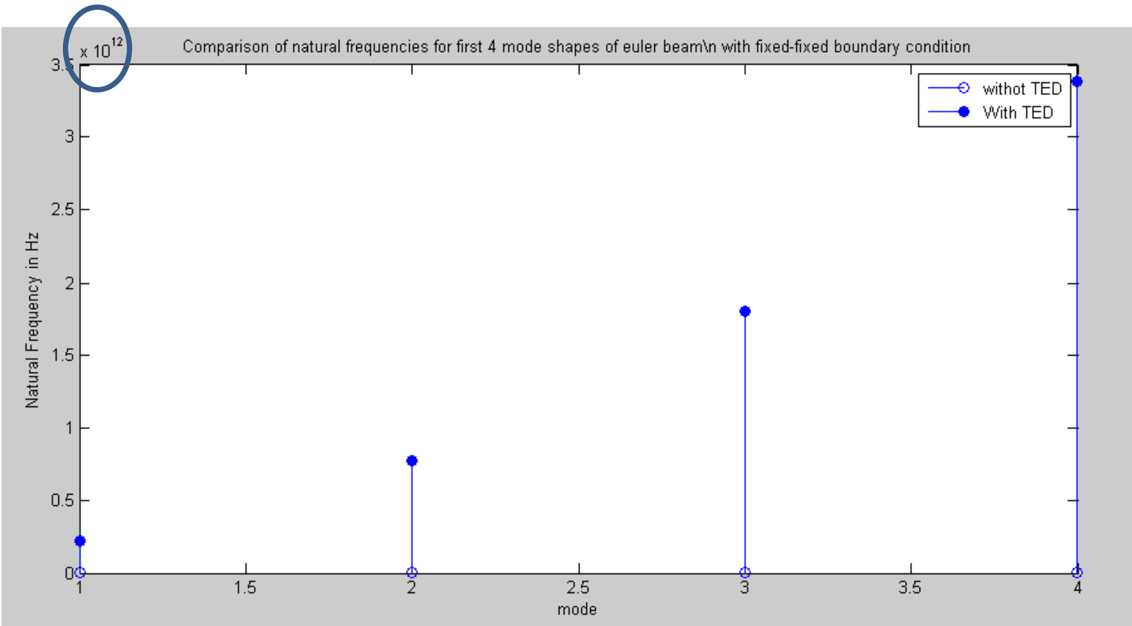
Inverse of quality factor

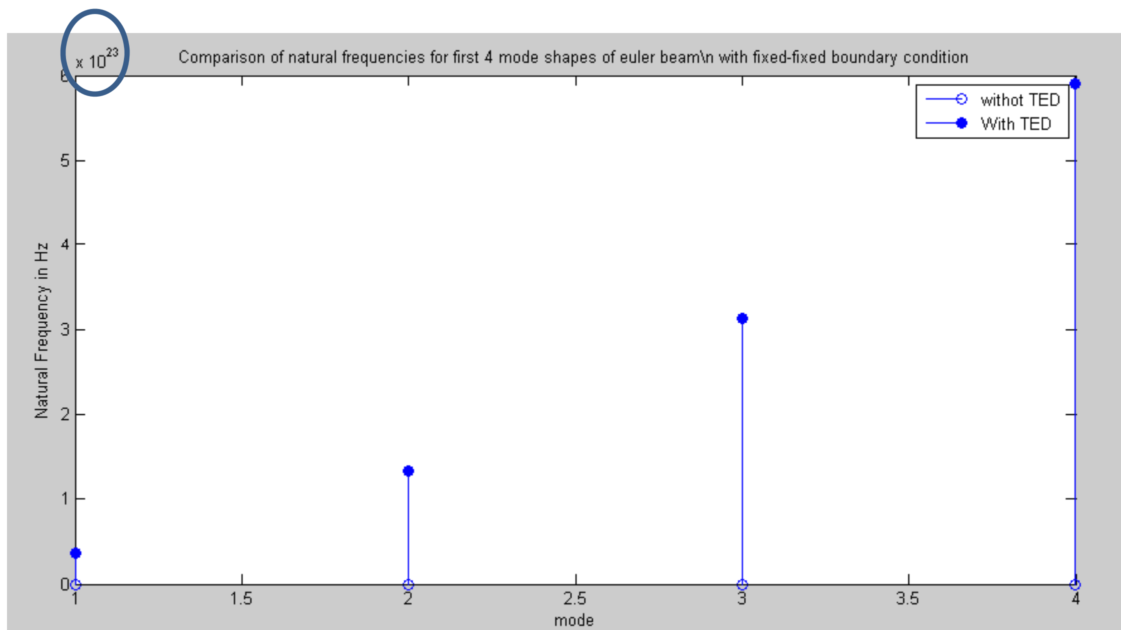


Plot for same frequency
but with different beam width

Scaling Effect



L = 100000e-6 m
b = 20000e-6m
c = 2000e-6m



L = 100e-6 m
b = 20e-6m
c = 2e-6m

Conclusion

1. There is frequency shift due to thermoelastic damping

2. This effect is dominently observed in micro and nano scale

3. Quality factor decreases because of thermoelastic damping

Future work

- Studying the effect for electrostatically actuated forced vibration

References

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Thermoelastic damping in micro- and nanomechanical systems

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Thank You