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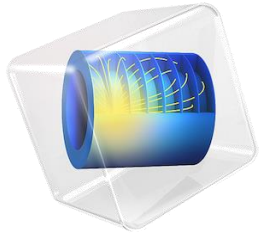

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Modeling History Dependent Heating of Viscoelastic Polymers under Harmonic Excitation

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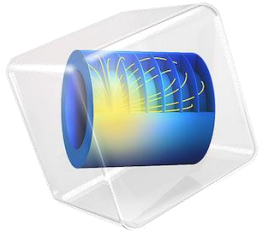
Introduction

- Viscoelastic polymers can dissipate significant amounts of energy in the form of heat when subjected to dynamic mechanical stimuli.
- Structures comprised of such lossy materials may heat up considerably when excited by loads at a frequency that approaches one of the structure's natural frequencies.
- A viscoelastic polymer tends to heat up significantly more when exposed to a loading history in which the excitation frequency ramps down, as opposed to a loading history in which the excitation frequency ramps up within the same bounds.
- The history dependence cannot be resolved by a transient thermal analysis if the coupled harmonic analysis assumes the mean storage and loss moduli.
- COMSOL Multiphysics ® allows for the seamless coupling of a transient thermal analysis with a harmonic analysis and enables us to predict this interesting phenomenon.



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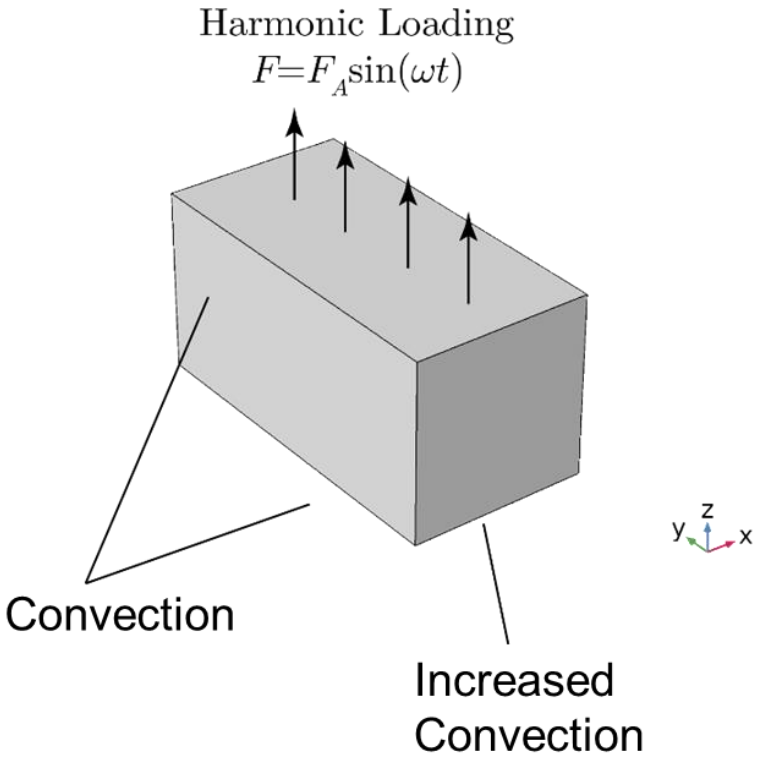
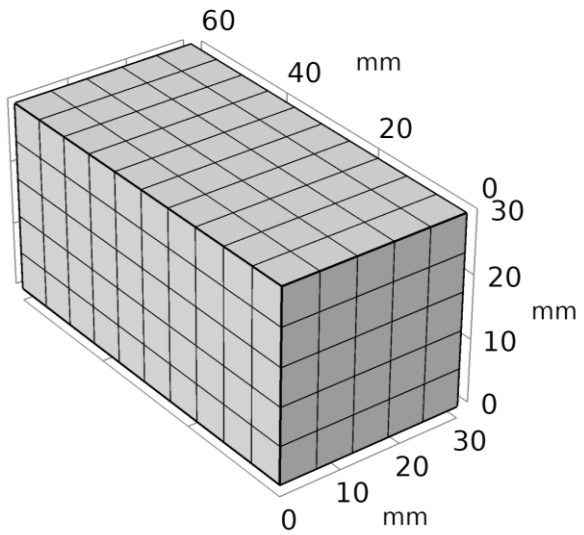
Viscoelastic Rectangular Block

- Block Dimensions: 3 cm x 3 cm x 6 cm
- Harmonic Excitation: Pressure with magnitude 50 kPa and variable cyclic frequency ω

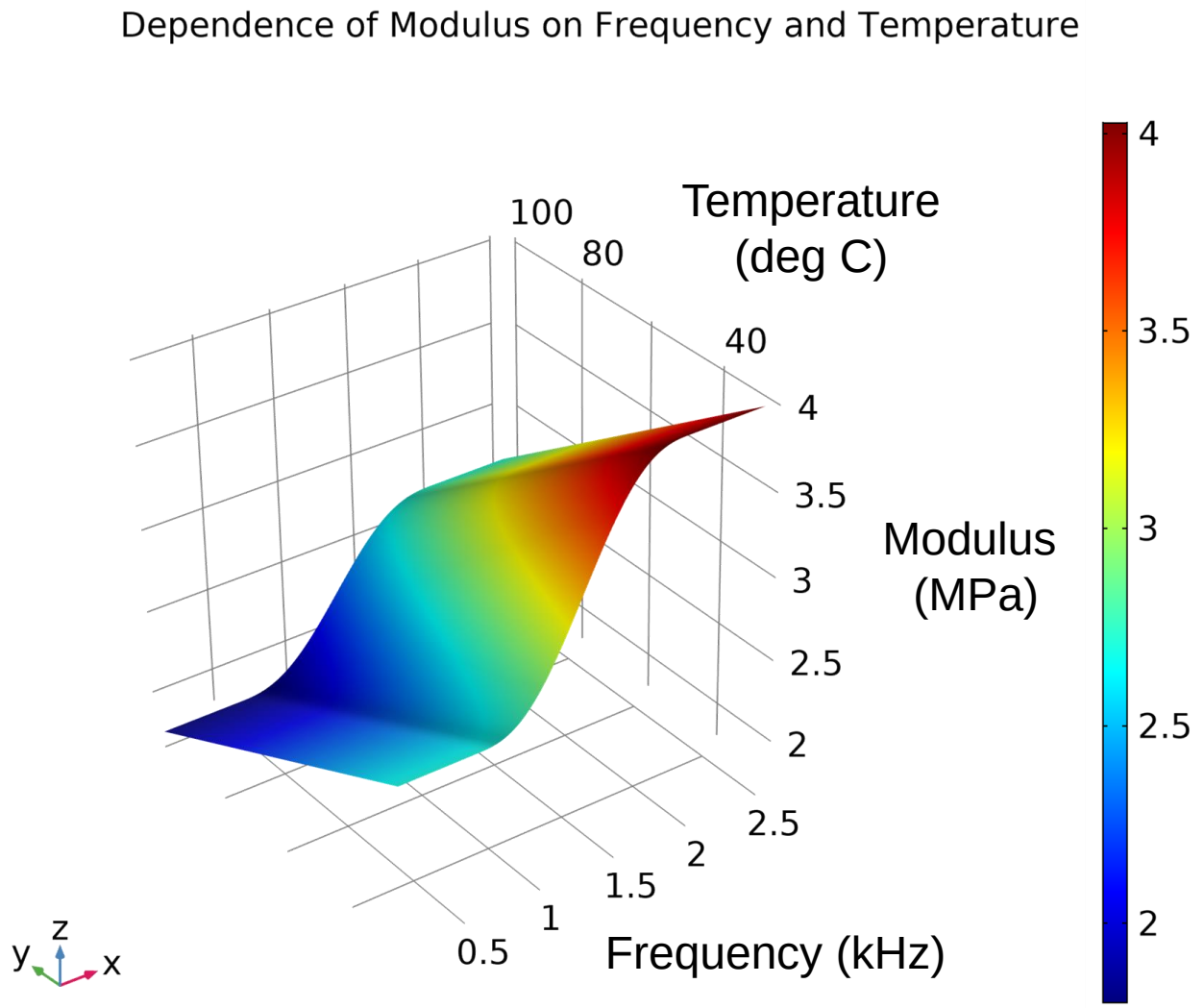




Linear Viscoelastic Solid – Mechanical Properties

Mechanical Properties

- Storage Modulus $G' = 2.6\ MPa$
- Loss Modulus $G'' = 0.5 \cdot G'$
- Storage and Loss moduli linearly decrease by 33% with temperature up to 100 degC
- Storage and Loss moduli increase with excitation frequency by up to 50% in the frequency range 0.6-2 kHz



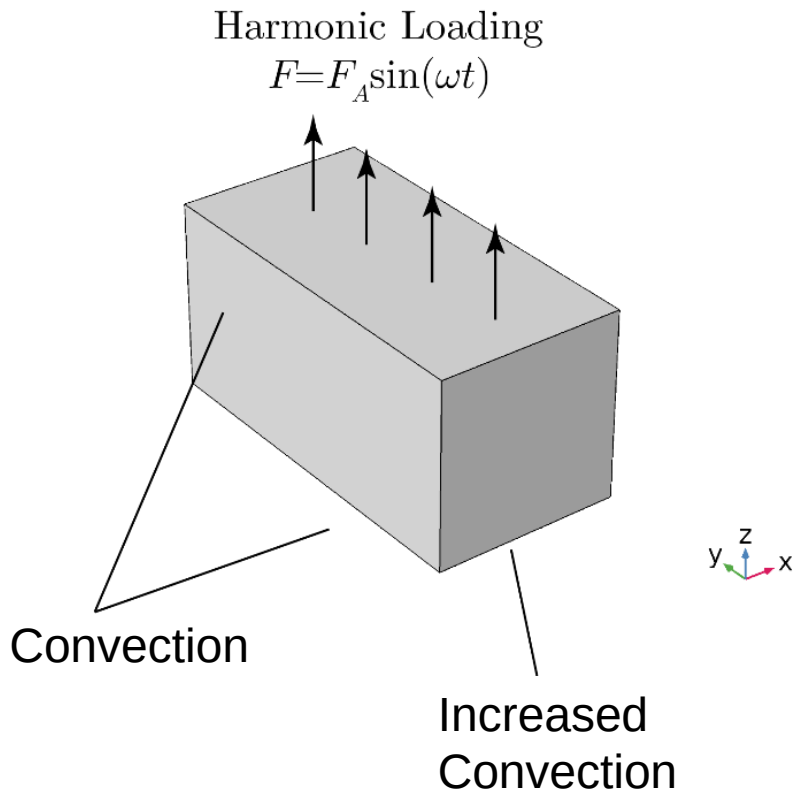
Linear Viscoelastic Solid – Thermal Properties

Thermal Properties

- Thermal Conductivity $k = 0.14\ W/m \cdot K$
- Heat Capacity at ct. pressure $k = 750\ J/kg \cdot K$

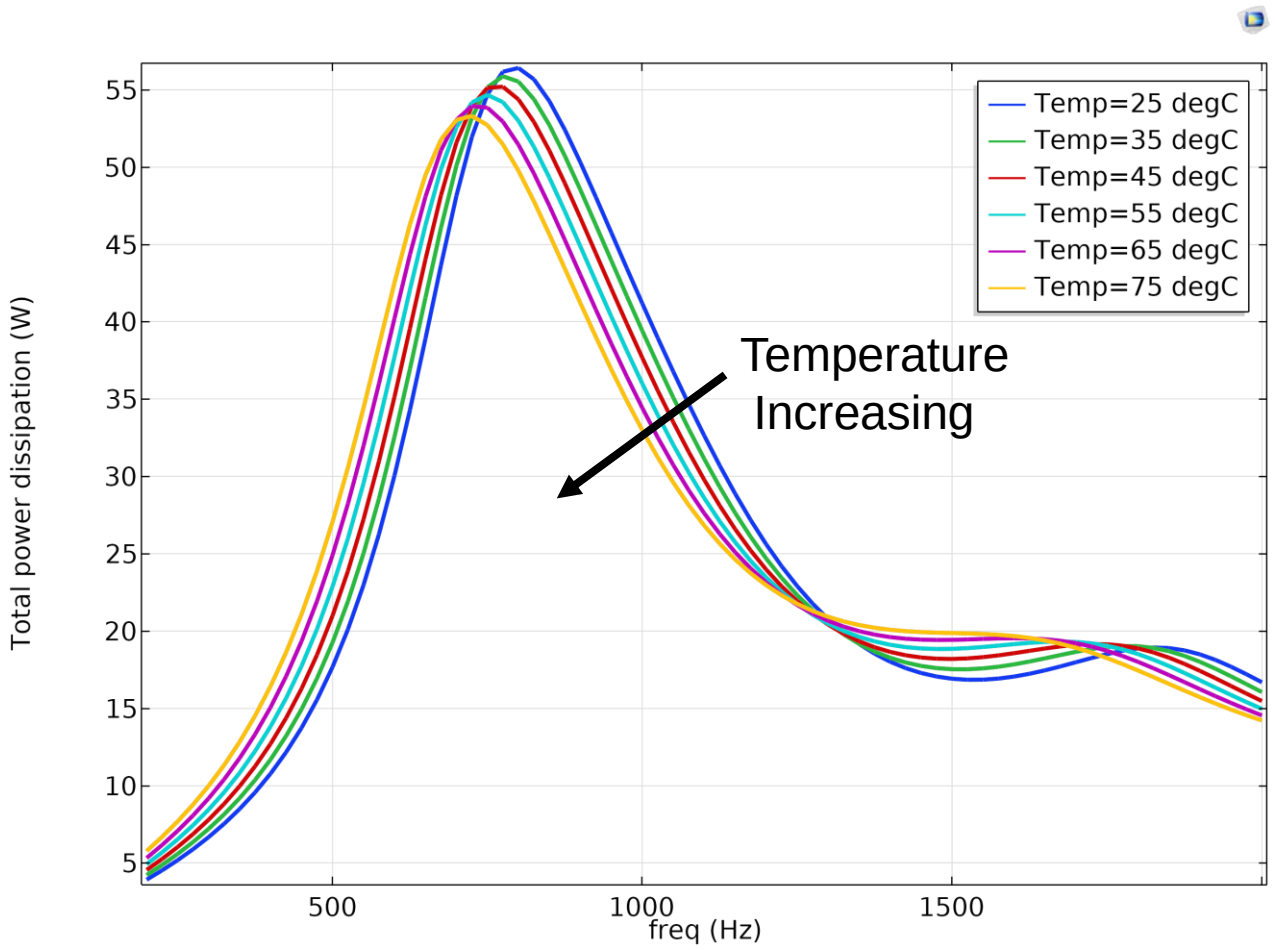
Thermal BCs

- All solid surfaces are exposed to natural convection with coefficient $h = 2\ W/m^2 \cdot K$
- The base of the solid has increased convection with coefficient $h = 4\ W/m^2 \cdot K$ due to being in contact with a better conductive surface
- A volumetric heat source is providing heat to the solid equal to the amount of energy lost due to viscous dissipation



Excitation Frequency Sweep

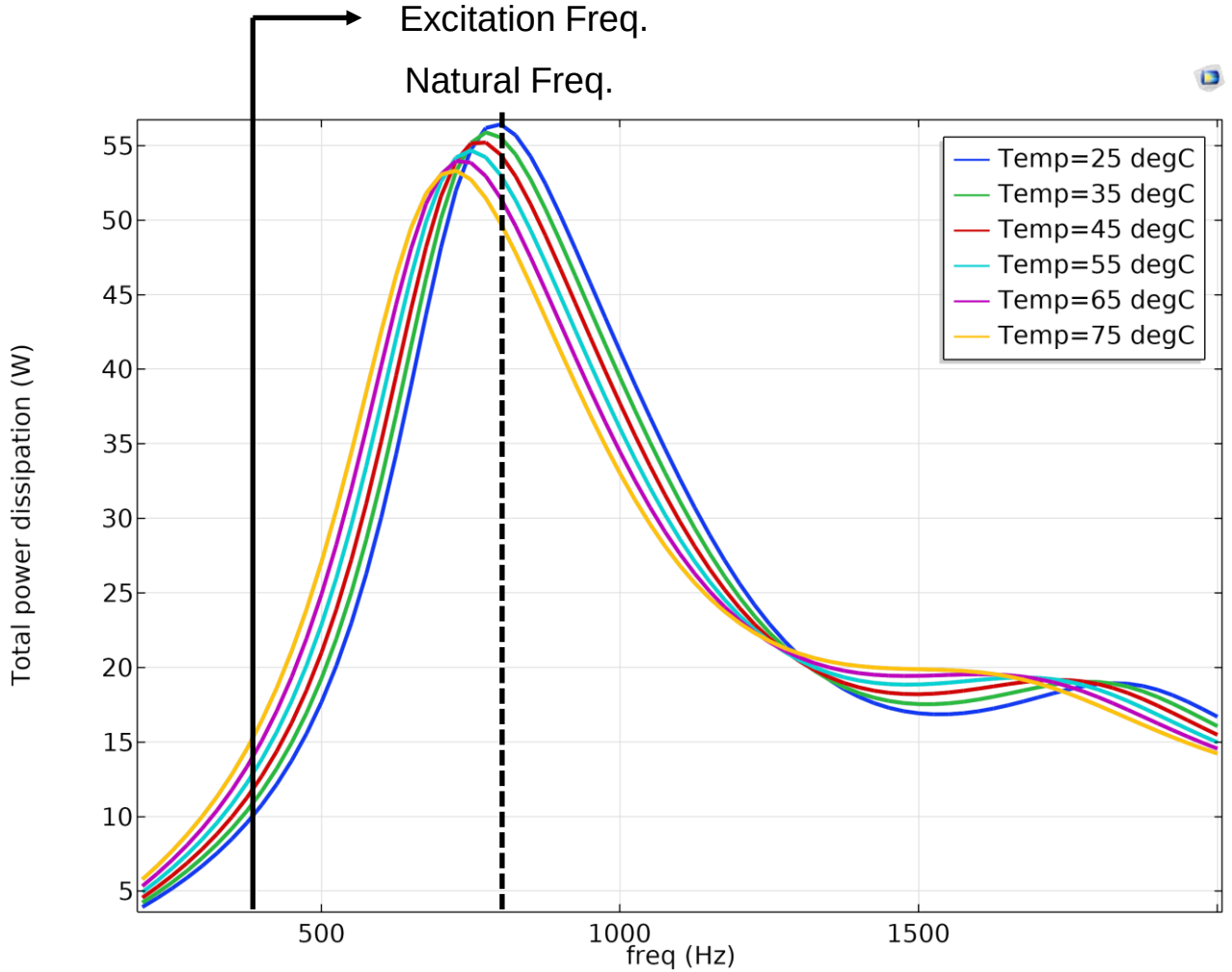
- The solid is subjected to a harmonic excitation, the frequency of which varies slowly from 400 to 1600 Hz over 60 s.
- The range of frequencies includes a natural frequency which decreases with increasing temperature.
- The temperature dependence of the natural frequency coupled with the slowly varying excitation frequency result in a history dependent thermal response for the solid.



History Dependent Heating Under Harmonic Excitation

When the excitation frequency ramps-up, the solid is heating up and therefore the natural frequency decreases.

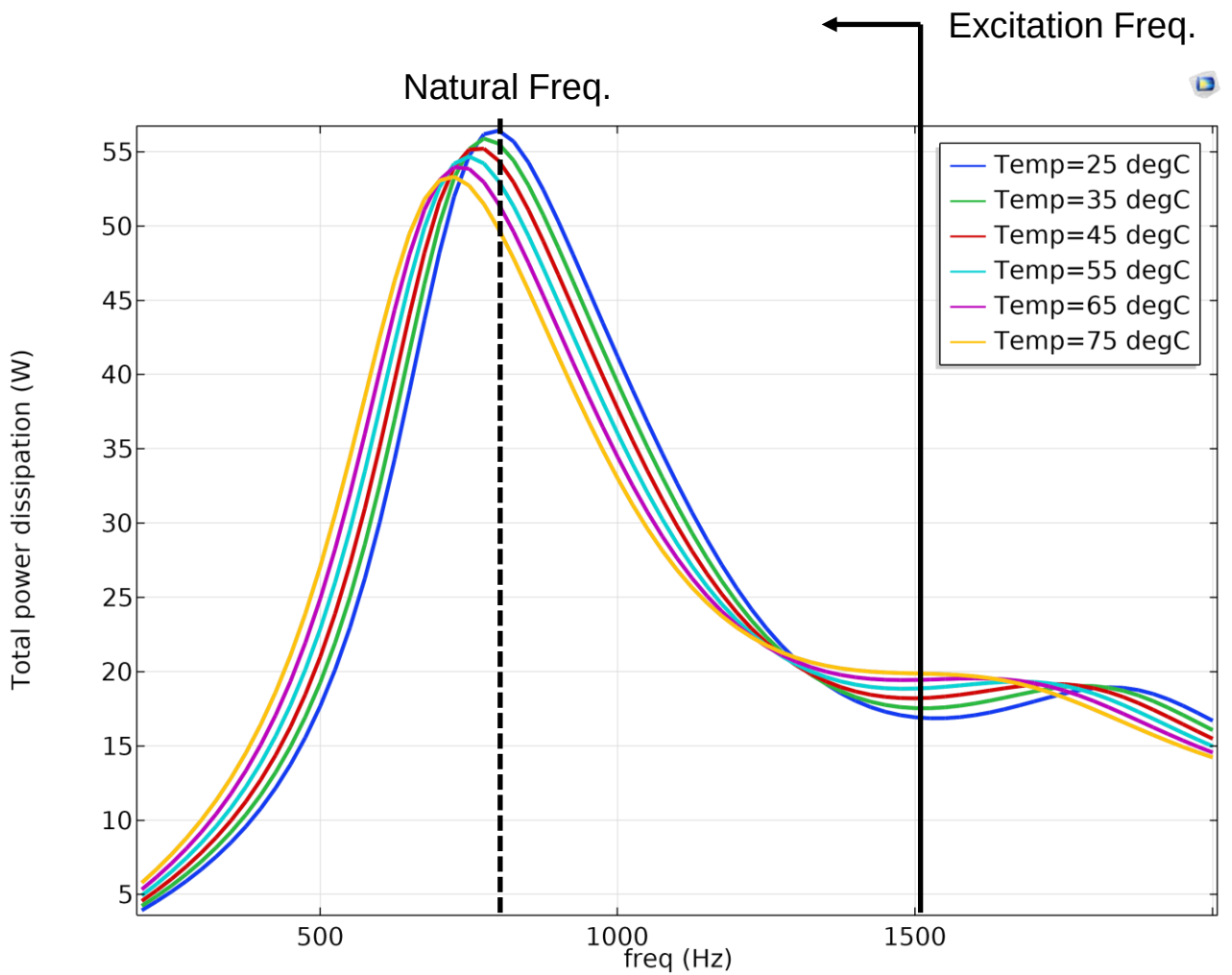
The overlap between the excitation frequency and natural frequency is causing the solid to heat up by dissipating energy.



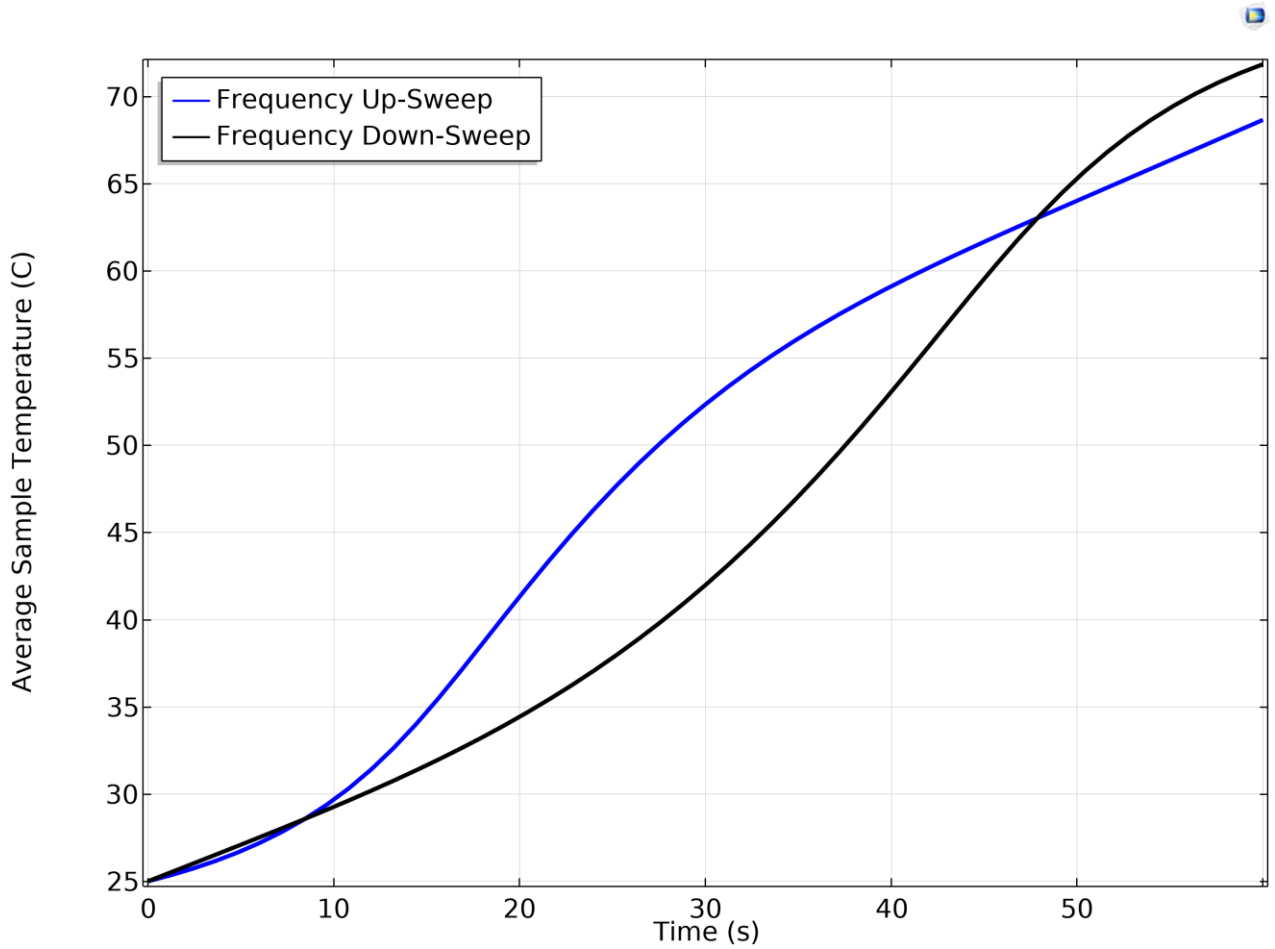
History Dependent Heating Under Harmonic Excitation

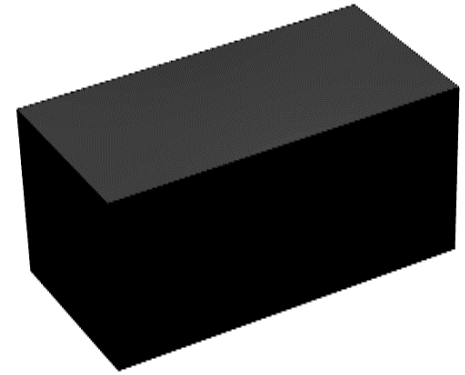
When the excitation frequency ramps-down, the solid is, once again, heating up and therefore the natural frequency decreases.

The overlap between the excitation frequency and natural frequency is now extended since both frequencies are moving in the same direction, causing the solid to heat up more than before by dissipating energy.

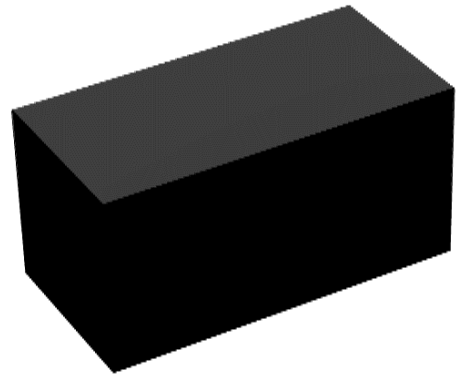


Average Temperature During Excitation



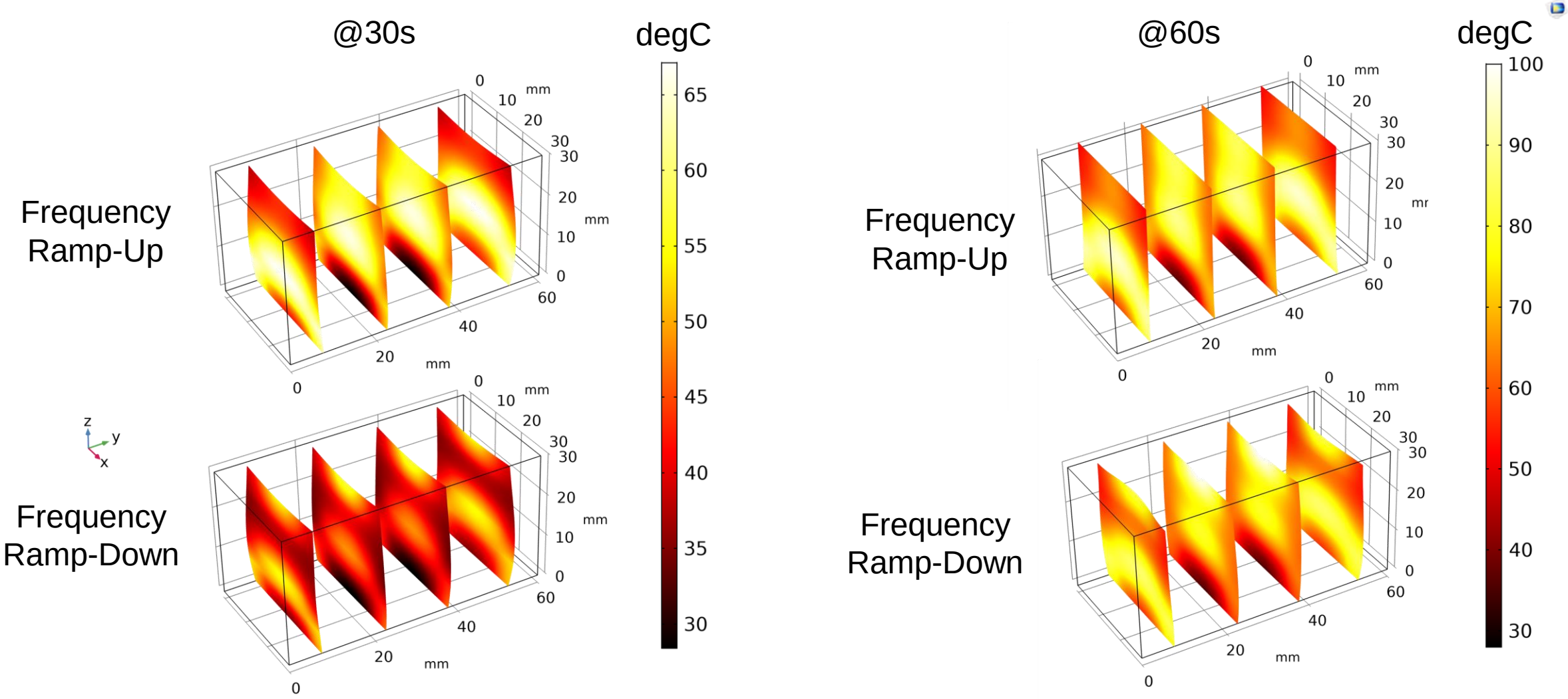


Ramp-up



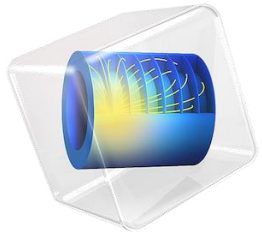
Ramp-down

Temperature Slices



Conclusions

- Resonant frequencies tend to decrease with increasing temperature.
- Viscoelastic polymers subjected to harmonic loading heat up over time.
- Heating of viscoelastic polymers under harmonic loading is history dependent.
- The history dependence cannot be resolved by a transient thermal analysis if the coupled harmonic analysis assumes the mean storage and loss moduli.
- COMSOL Multiphysics can resolve the physics that lead to this behavior by coupling the transient thermal analysis to harmonic analysis for each timestep and therefore accurately predict the dissipated heat and the history dependent heating of viscous polymers.



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