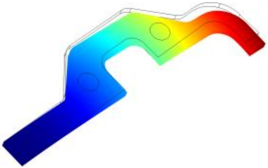
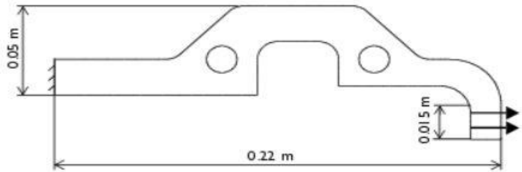


SOLID MECHANICS
A mechanical component

Tomasz Stręk
Institute of Applied Mechanics, Poznan University of Technology
ul. Jana Pawla II 24, 60-965 Poznan, Poland

DATE: 2020.04.20



Some key parameters for the model:

Material

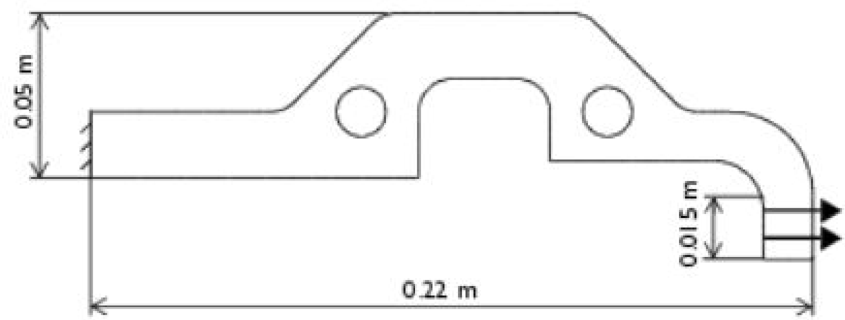
- Structural steel as taken from the material library
- Thickness of 4 mm

Load

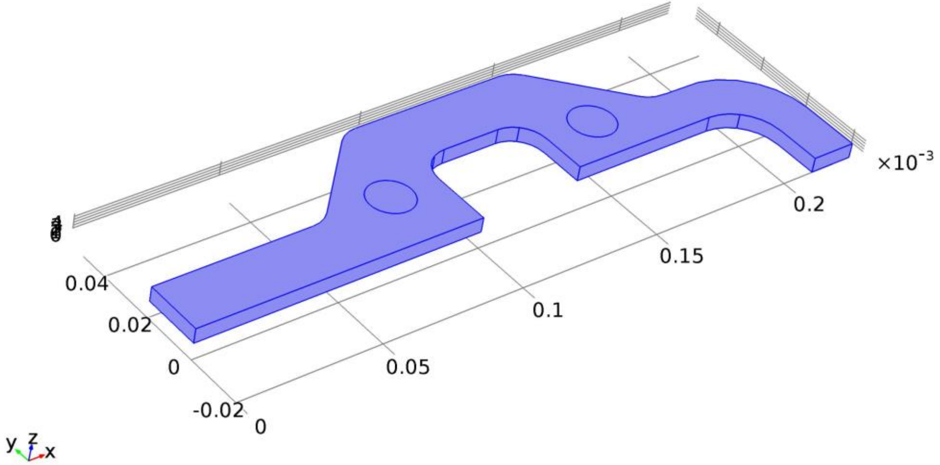
A 900 N force in the x direction on the inside of the right end

Constraints

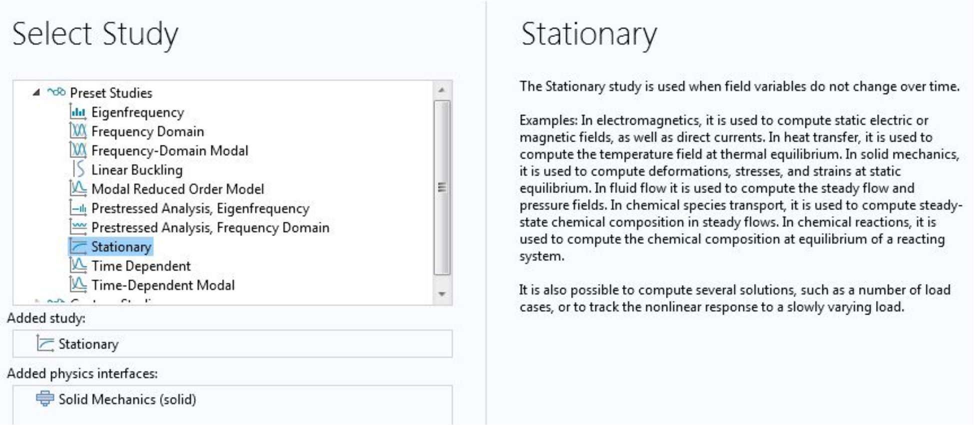
The left edge is fixed.

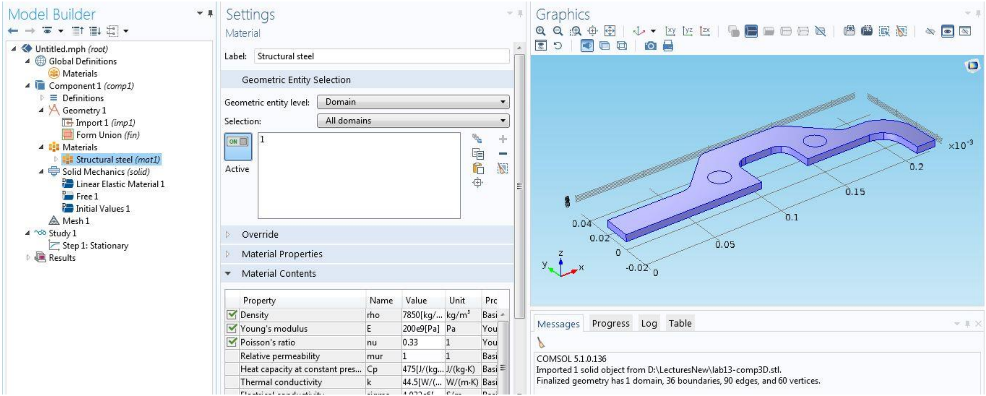


Thickness - 5 mm, Load – 1000 N


×10⁻³
0.2
0.15
0.1
0.05
0
0.04
0.02
0
-0.02
y
z
x

STATIONARY STUDY

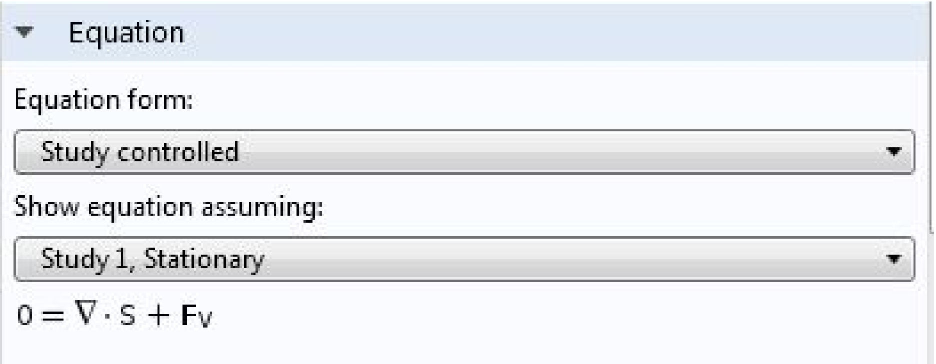




Model Builder
Untitled.mph (root)
Global Definitions
Materials
Component 1 (comp1)
Definitions
Geometry 1
Import 1 (imp1)
Form Union (fin)
Materials
Structural steel (mat1)
Solid Mechanics (solid)
Linear Elastic Material 1
Free 1
Initial Values 1
Mesh 1
Study 1
Step 1: Stationary
Results
Settings
Material
Label: Structural steel
Geometric Entity Selection
Geometric entity level: Domain
Selection: All domains
1
Active
Override
Material Properties
Material Contents
Property Name Value Unit
Density rho 7850[kg/... kg/m³
Young's modulus E 200e9[Pa] Pa
Poisson's ratio nu 0.33 1
Relative permeability mur 1 1
Heat capacity at constant pres... Cp 475[J/(kg... J/(kg·K)
Thermal conductivity k 44.5[W/(... W/(m·K)
Graphics
×10⁻³
0.2
0.15
0.1
0.05
0.04
0.02
0
-0.02
Messages Progress Log Table
COMSOL 5.1.0.136
Imported 1 solid object from D:\LecturesNew\lab13-comp3D.stl.
Finalized geometry has 1 domain, 36 boundaries, 90 edges, and 60 vertices.

Material Contents

	Property	Name	Value	Unit
✓	Density	rho	7850[kg/…	kg/m³
✓	Young's modulus	E	200e9[Pa]	Pa
✓	Poisson's ratio	nu	0.33	1


Equation
Equation form:
Study controlled
Show equation assuming:
Study 1, Stationary
$0 = \nabla \cdot S + \mathbf{F}_V$

▾ Equation

Show equation assuming:

Study 1, Stationary ▾

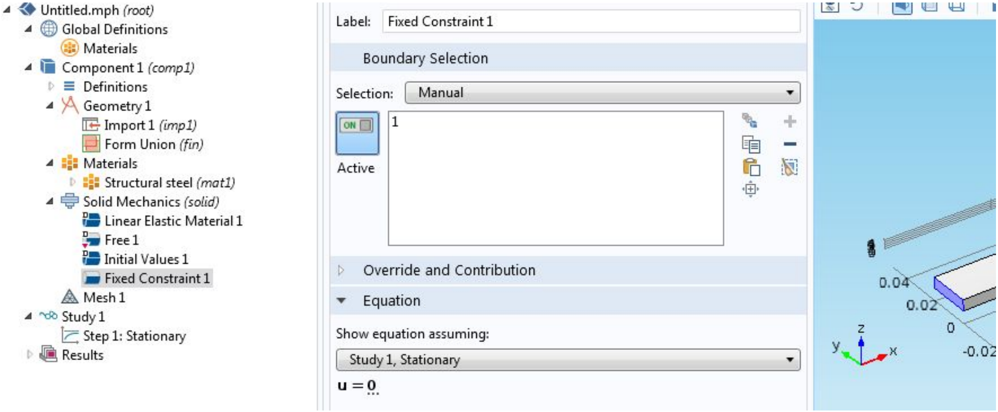
$$0 = \nabla \cdot S + \mathbf{F}_V$$

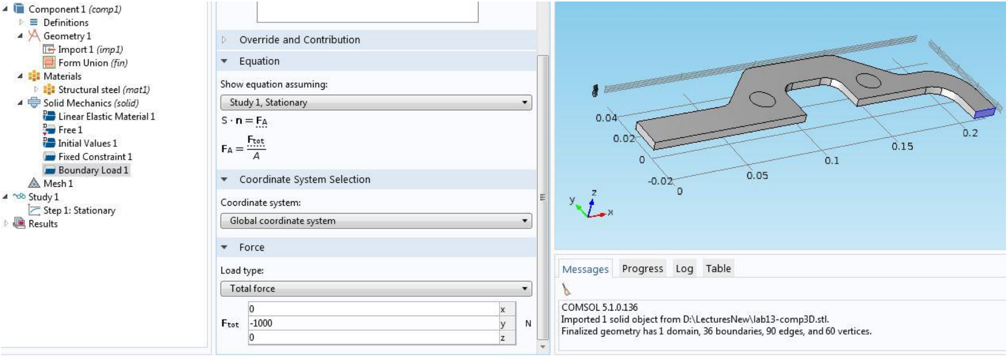
$$S = S_{ad} + \mathbf{C} : \epsilon_{el}, \quad \epsilon_{el} = \epsilon - \epsilon_{inel}$$

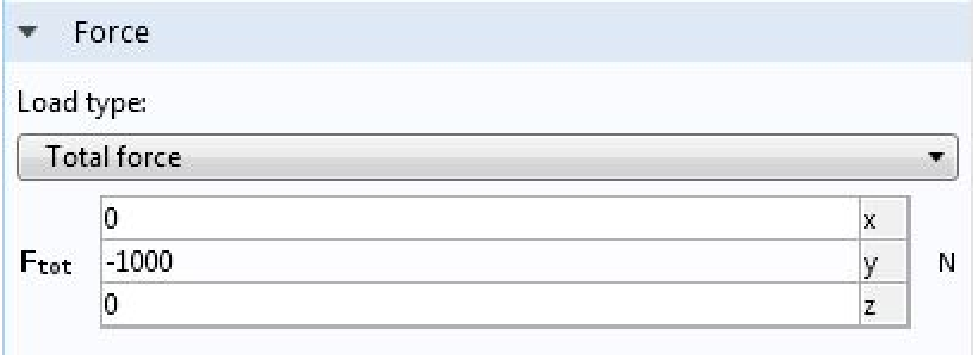
$$S_{ad} = S_0 + S_{ext} + S_q$$

$$\epsilon_{inel} = \epsilon_0 + \epsilon_{th} + \epsilon_{hs} + \epsilon_{pl} + \epsilon_{cr}$$

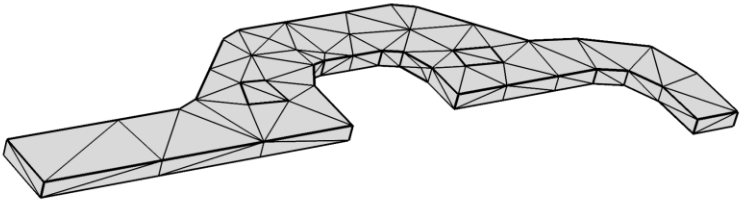
$$\epsilon = \frac{1}{2}\left[(\nabla \mathbf{u})^T + \nabla \mathbf{u}\right]$$

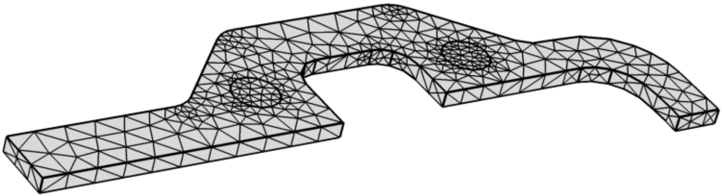

Untitled.mph (root)
Global Definitions
Materials
Component 1 (comp1)
Definitions
Geometry 1
Import 1 (imp1)
Form Union (fin)
Materials
Structural steel (mat1)
Solid Mechanics (solid)
Linear Elastic Material 1
Free 1
Initial Values 1
Fixed Constraint 1
Mesh 1
Study 1
Step 1: Stationary
Results
Label: Fixed Constraint 1
Boundary Selection
Selection: Manual
1
Active
Override and Contribution
Equation
Show equation assuming:
Study 1, Stationary
u = 0
0.04
0.02
0
-0.02
z
y
x


Component 1 (comp1)
Definitions
Geometry 1
Import 1 (imp1)
Form Union (fin)
Materials
Structural steel (mat1)
Solid Mechanics (solid)
Linear Elastic Material 1
Free 1
Initial Values 1
Fixed Constraint 1
Boundary Load 1
Mesh 1
Study 1
Step 1: Stationary
Results
Override and Contribution
Equation
Show equation assuming:
Study 1, Stationary
S · n = FA
FA = Ftot / A
Coordinate System Selection
Coordinate system:
Global coordinate system
Force
Load type:
Total force
Ftot
0 x
-1000 y
0 z
N
0.04
0.02
0
-0.02
0
0.05
0.1
0.15
0.2
y z x
Messages
Progress
Log
Table
COMSOL 5.1.0.136
Imported 1 solid object from D:\LecturesNew\lab13-comp3D.stl.
Finalized geometry has 1 domain, 36 boundaries, 90 edges, and 60 vertices.



Load – 1000 N





Statistics

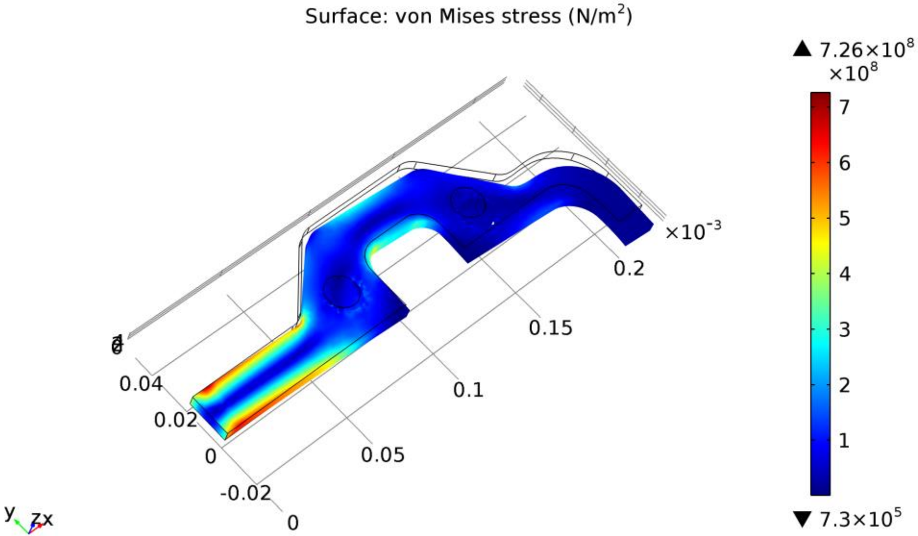
Mesh

Build All

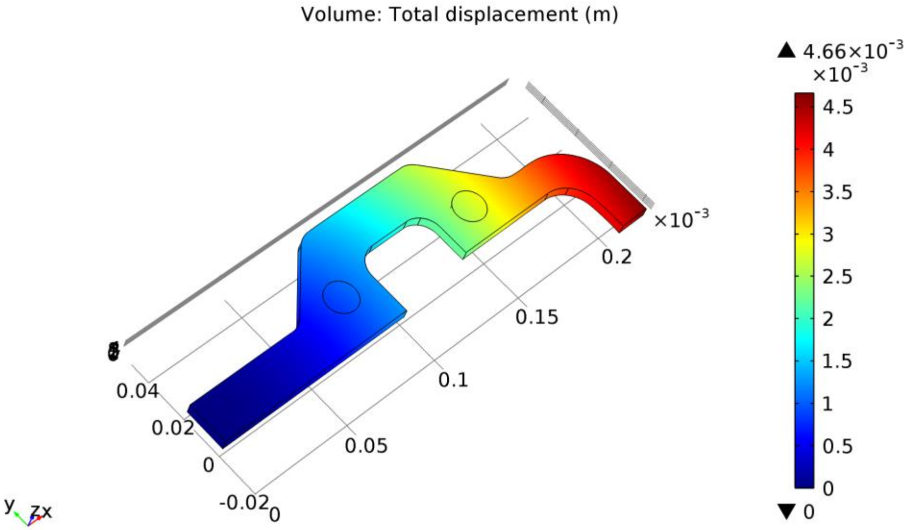
Tetrahedral elements:	2276
Triangular elements:	1530
Edge elements:	299
Vertex elements:	60

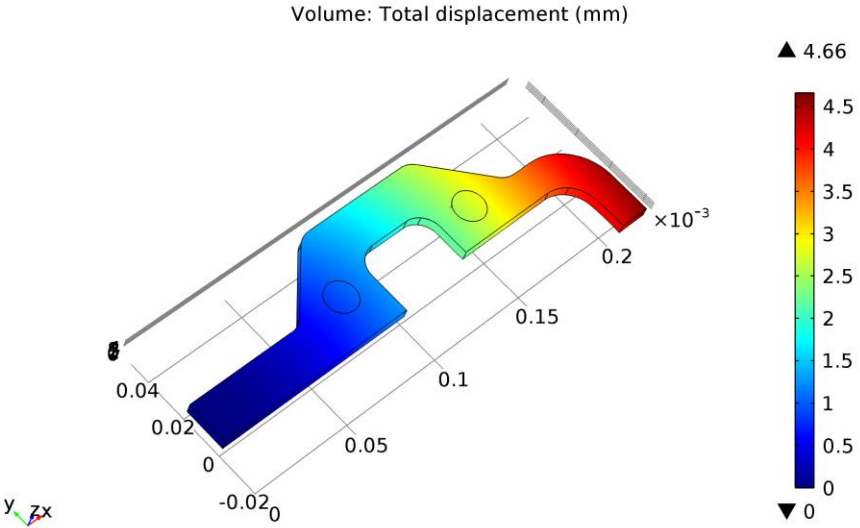
Domain element statistics

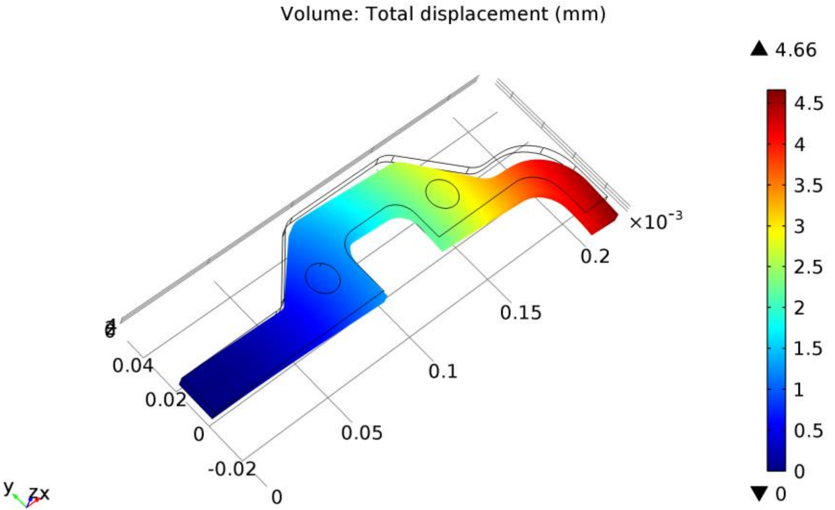
Number of elements:	2276
Minimum element quality:	0.0128
Average element quality:	0.5954
Element volume ratio:	0.01023
Mesh volume:	2.947E-5 m^3
Maximum growth rate:	3.967
Average growth rate:	2.16



Surface: von Mises stress (N/m²)
▲ 7.26×10⁸
×10⁸
7
6
5
4
3
2
1
▼ 7.3×10⁵
×10⁻³
0.2
0.15
0.1
0.05
0
0.04
0.02
0
-0.02
y
z
x


Volume: Total displacement (m)
4.66×10^-3
×10^-3
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
×10^-3
0.2
0.15
0.1
0.05
0.04
0.02
0
-0.02
0
y
z
x


Volume: Total displacement (mm)
▲ 4.66
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
▼ 0
×10^-3
0.2
0.15
0.1
0.05
0
0.04
0.02
0
-0.02
y
z
x



Volume: Total displacement (mm)
▲ 4.66
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
▼ 0
×10⁻³
0.2
0.15
0.1
0.05
0
0.04
0.02
0
-0.02
y
z
x

NON-STATIONARY STUDY

or

TIME-DEPENDENT STUDY

Equation

Equation form:

Study controlled

Show equation assuming:

Study 2, Time Dependent

$$\rho \frac{\partial^2 \mathbf{u}}{\partial t^2} = \nabla \cdot S + \mathbf{F}\mathrm{v}$$

Equation

Show equation assuming:

Study 2, Time Dependent

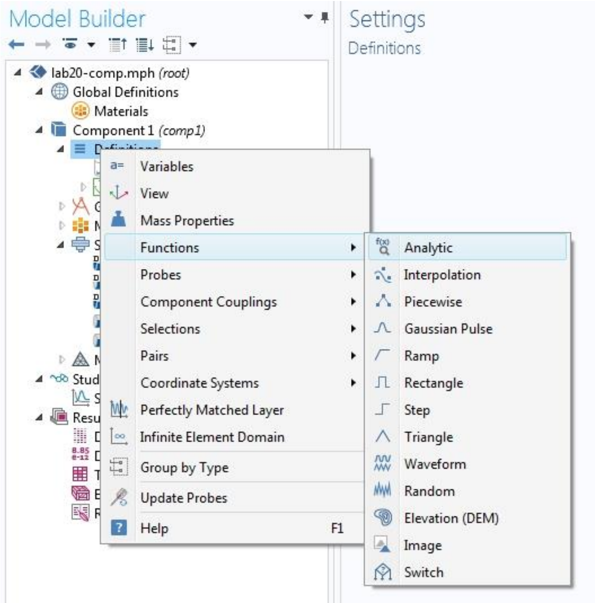
$$\rho \frac{\partial^2 \mathbf{u}}{\partial t^2} = \nabla \cdot S + \mathbf{F}_V$$

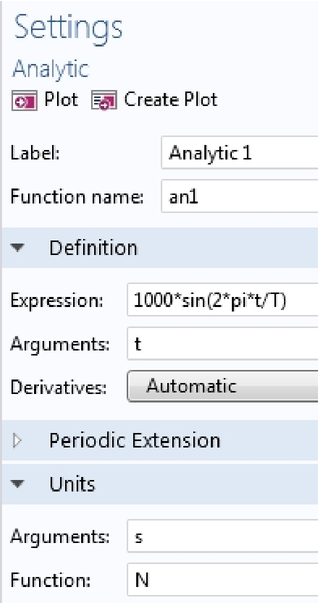
$$S = S_{ad} + \mathbf{C} : \epsilon_{el}, \quad \epsilon_{el} = \epsilon - \epsilon_{inel}$$

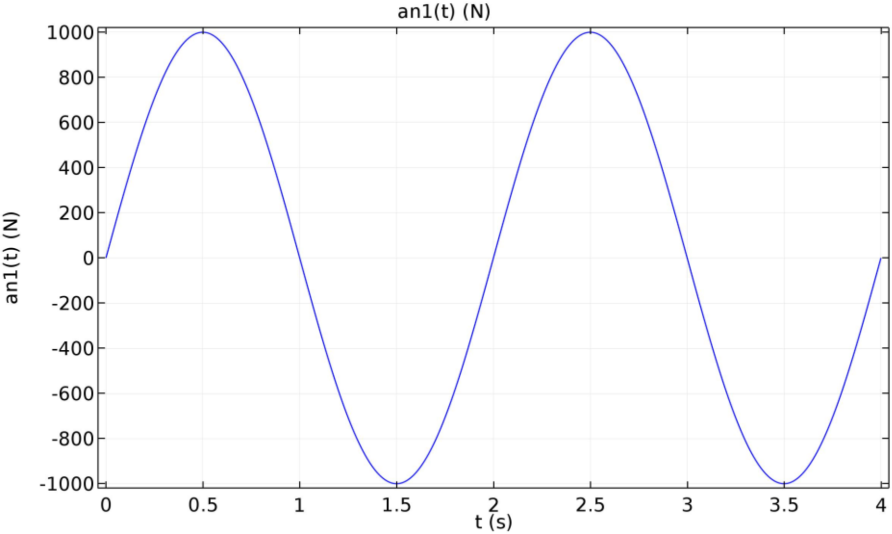
$$S_{ad} = S_0 + S_{ext} + S_q$$

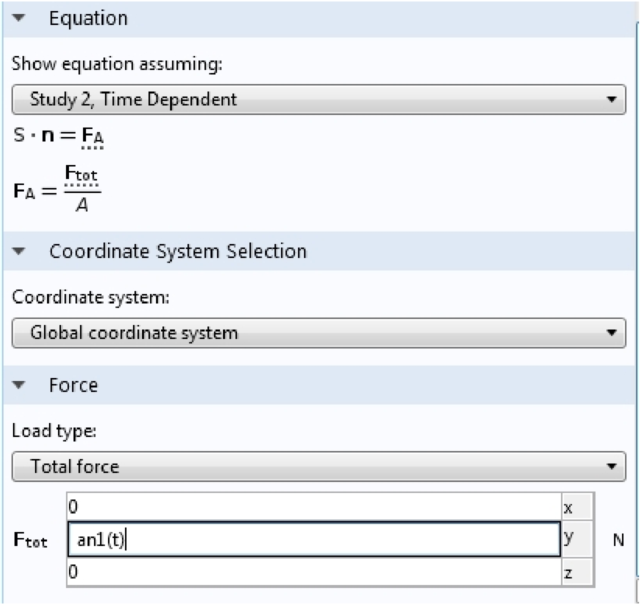
$$\epsilon_{inel} = \epsilon_0 + \epsilon_{th} + \epsilon_{hs} + \epsilon_{pl} + \epsilon_{cr}$$

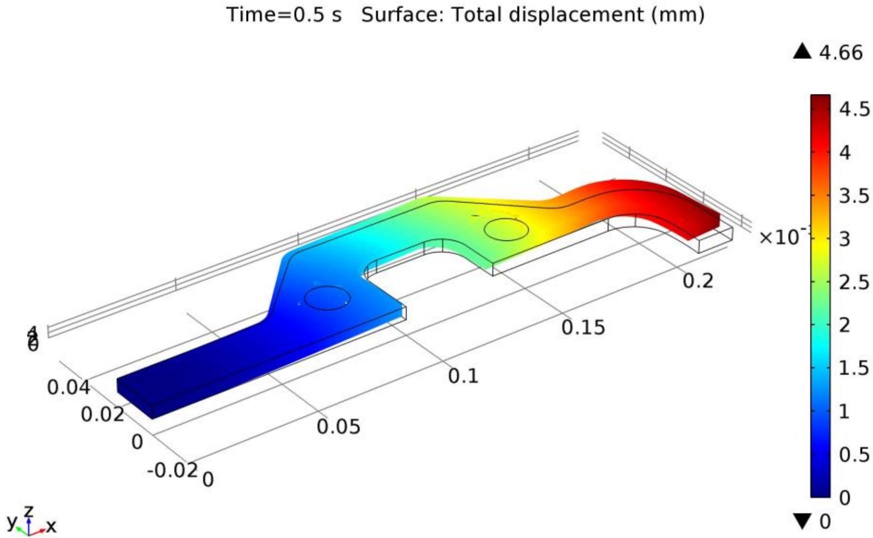
$$\epsilon = \frac{1}{2}\left[(\nabla \mathbf{u})^T + \nabla \mathbf{u}\right]$$


Model Builder
Settings
Definitions
lab20-comp.mph (root)
Global Definitions
Materials
Component 1 (comp1)
Variables
View
Mass Properties
Functions
Probes
Component Couplings
Selections
Pairs
Coordinate Systems
Perfectly Matched Layer
Infinite Element Domain
Group by Type
Update Probes
Help
F1
Analytic
Interpolation
Piecewise
Gaussian Pulse
Ramp
Rectangle
Step
Triangle
Waveform
Random
Elevation (DEM)
Image
Switch

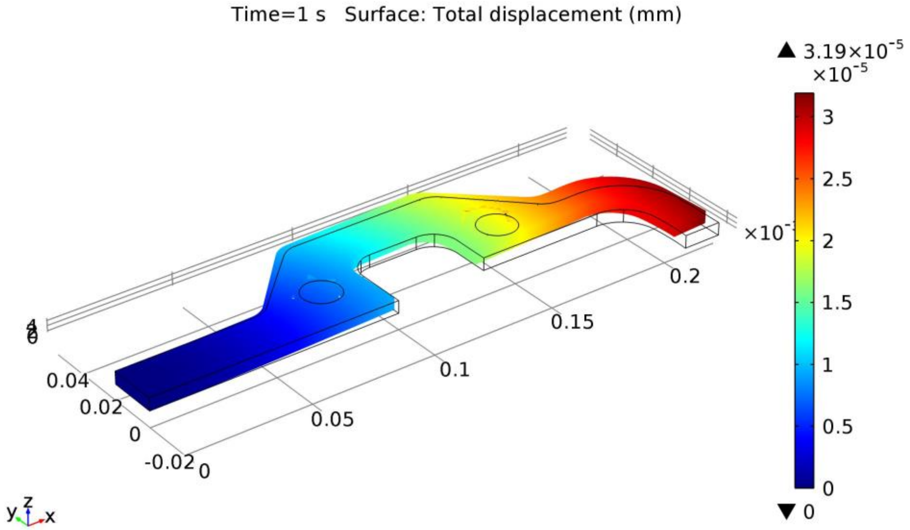

Settings
Analytic
Plot
Create Plot
Label:
Analytic 1
Function name:
an1
Definition
Expression:
1000*sin(2*pi*t/T)
Arguments:
t
Derivatives:
Automatic
Periodic Extension
Units
Arguments:
s
Function:
N


an1(t) (N)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
an1(t) (N)
0
0.5
1
1.5
2
2.5
3
3.5
4
t (s)

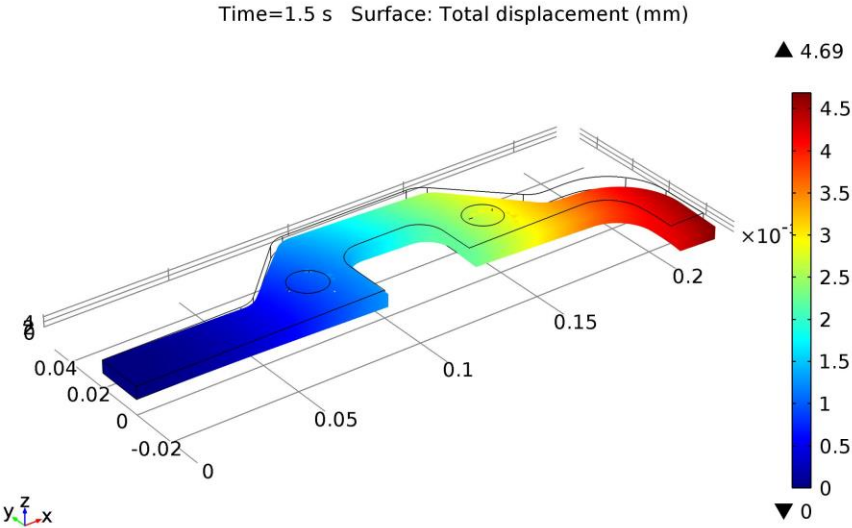

Equation
Show equation assuming:
Study 2, Time Dependent
S · n = FA
FA = Ftot / A
Coordinate System Selection
Coordinate system:
Global coordinate system
Force
Load type:
Total force
Ftot
0 x
an1(t) y
0 z
N



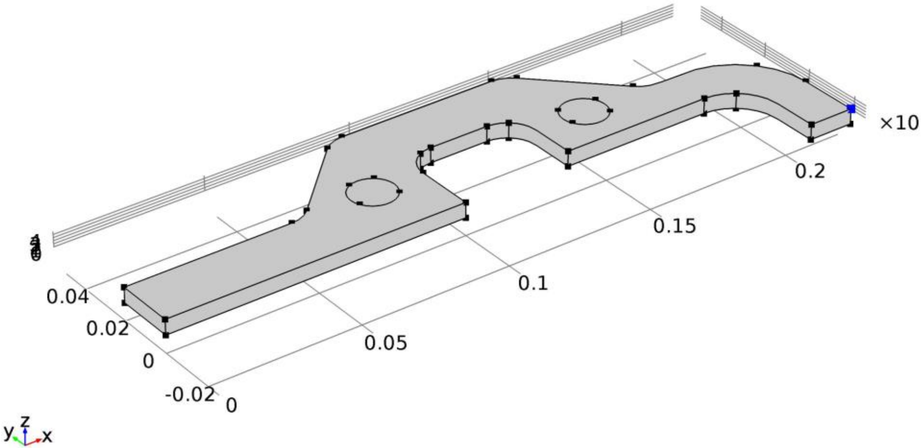
Time=0.5 s Surface: Total displacement (mm)
▲ 4.66
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
▼ 0
0.2
0.15
0.1
0.05
0
0.04
0.02
0
-0.02
y
z
x



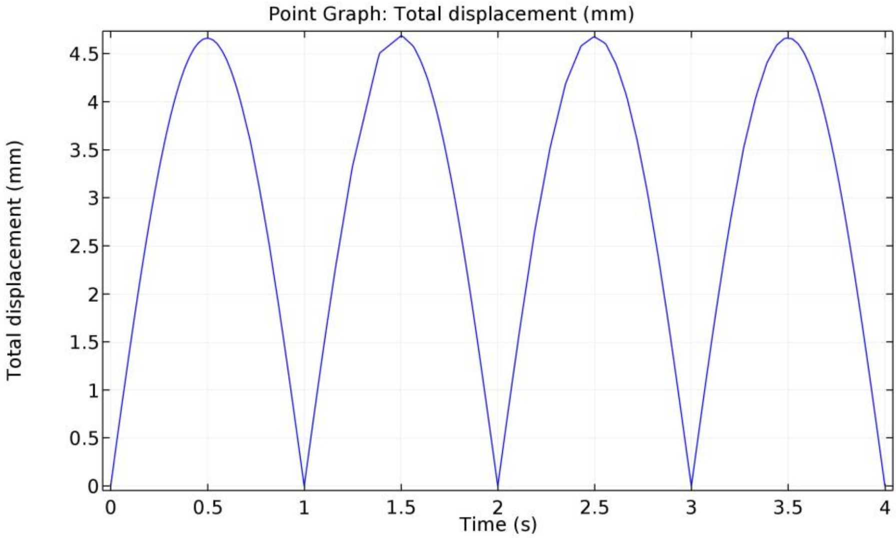
Time=1 s Surface: Total displacement (mm)
▲ 3.19×10^-5
×10^-5
3
2.5
2
1.5
1
0.5
0
▼ 0
0.04
0.02
0
-0.02
0
0.05
0.1
0.15
0.2
y z x



Time=1.5 s   Surface: Total displacement (mm)
▲ 4.69
4.5
4
3.5
×10⁻³
3
2.5
2
1.5
1
0.5
0
▼ 0
0.2
0.15
0.1
0.05
0
0.04
0.02
0
-0.02
y z x



×10
0.2
0.15
0.1
0.05
0.04
0.02
0
-0.02
0
y
z
x


Point Graph: Total displacement (mm)
Total displacement (mm)
Time (s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

EIGENFREQUENCY

STUDY

Equation

Show equation assuming:

Study 2, Eigenfrequency

$$-\rho\omega^2\mathbf{u} = \nabla\cdot S + \mathbf{F}_V, \quad -i\omega = \lambda$$

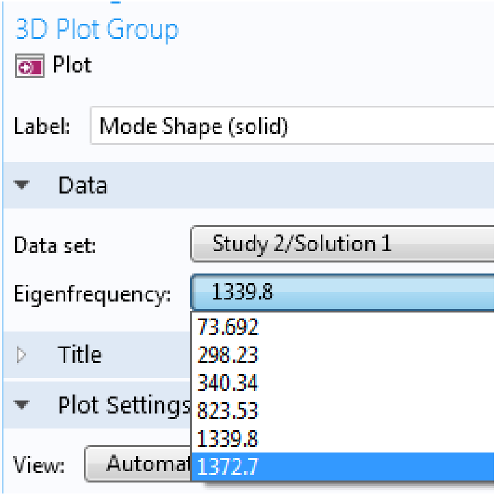
$$S = S_{ad} + \mathbf{C}:\epsilon_{el}, \quad \epsilon_{el} = \epsilon - \epsilon_{inel}$$

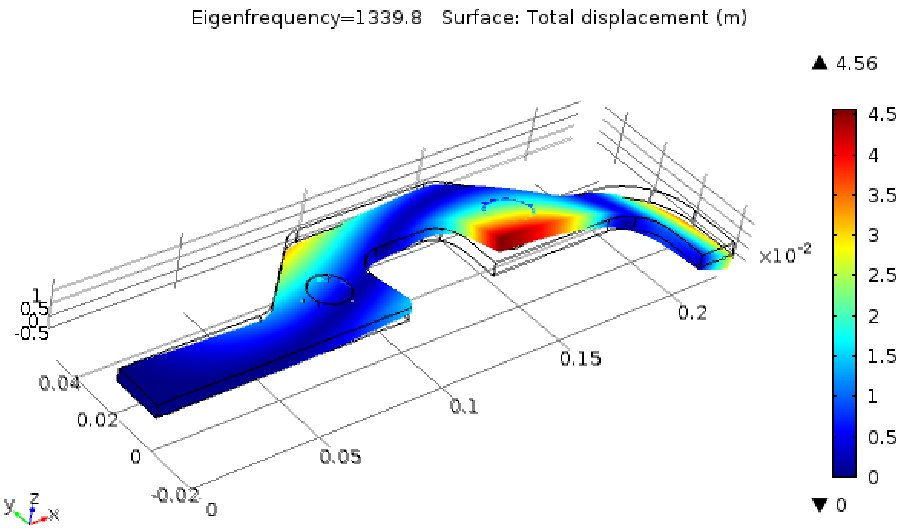
$$S_{ad} = S_0 + S_{ext} + S_q$$

$$\epsilon_{inel} = \epsilon_0 + \epsilon_{th} + \epsilon_{hs} + \epsilon_{pl} + \epsilon_{cr}$$

$$\epsilon = \frac{1}{2}\left[(\nabla\mathbf{u})^T + \nabla\mathbf{u}\right]$$

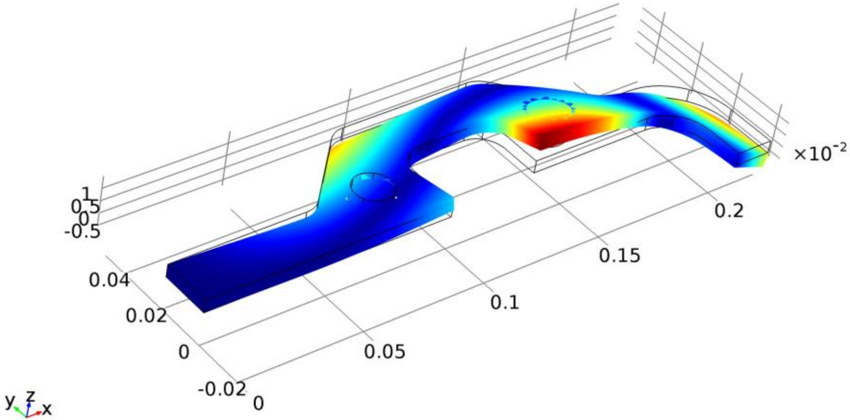
RESULTS

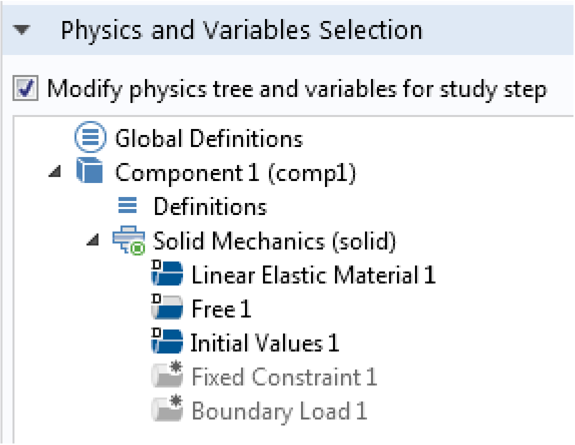

3D Plot Group
Plot
Label:
Mode Shape (solid)
Data
Data set:
Study 2/Solution 1
Eigenfrequency:
1339.8
73.692
298.23
340.34
823.53
1339.8
1372.7
Title
Plot Settings
View:
Automat

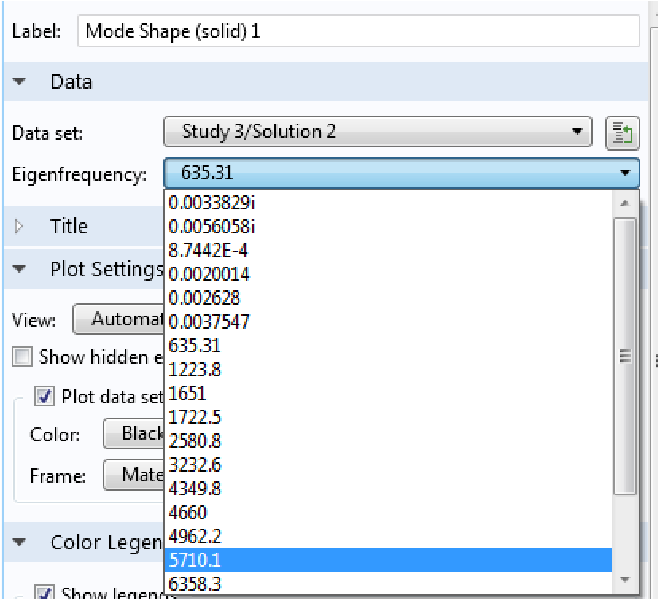


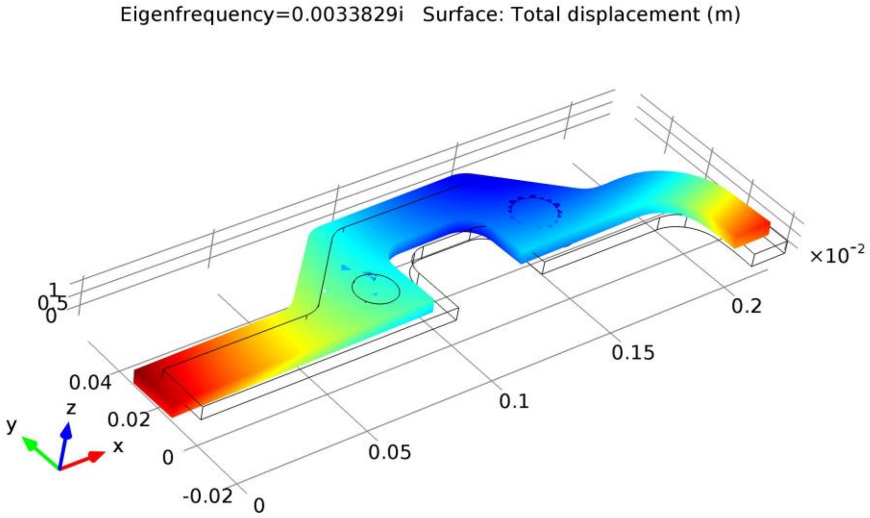
Eigenfrequency=1339.8 Surface: Total displacement (m)
▲ 4.56
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
▼ 0
×10^-2
1
0.5
0
-0.5
0.04
0.02
0
-0.02
0
0.05
0.1
0.15
0.2
y z x

Eigenfrequency=1339.8   Surface: Total displacement (m)




Physics and Variables Selection
Modify physics tree and variables for study step
Global Definitions
Component 1 (comp1)
Definitions
Solid Mechanics (solid)
Linear Elastic Material 1
Free 1
Initial Values 1
Fixed Constraint 1
Boundary Load 1

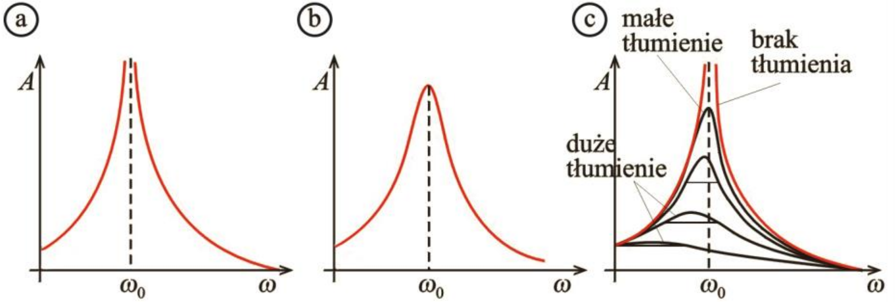

Label: Mode Shape (solid) 1
Data
Data set: Study 3/Solution 2
Eigenfrequency: 635.31
0.0033829i
0.0056058i
8.7442E-4
0.0020014
0.002628
0.0037547
635.31
1223.8
1651
1722.5
2580.8
3232.6
4349.8
4660
4962.2
5710.1
6358.3
Title
Plot Settings
View: Automat
Show hidden e
Plot data set
Color: Black
Frame: Mate
Color Legen


Eigenfrequency=0.0033829i Surface: Total displacement (m)
1
0.5
0
×10⁻²
0.04
0.02
0
-0.02
0
0.05
0.1
0.15
0.2
y
z
x

FREQUECY DOMAIN

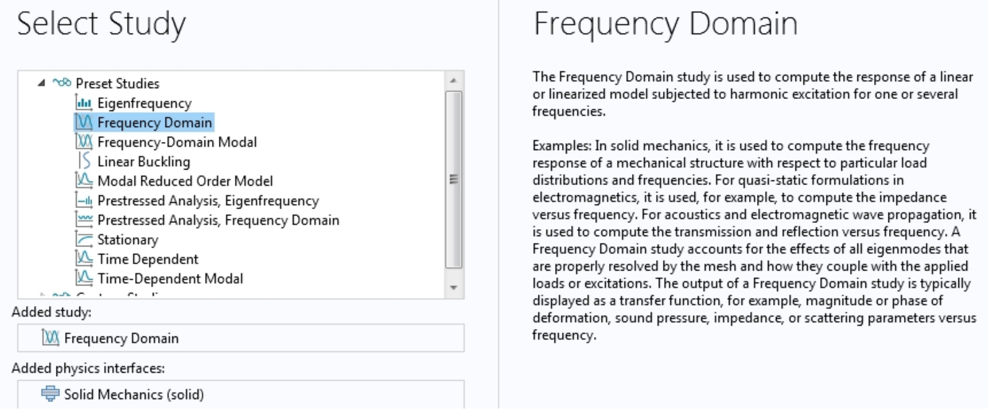
STUDY

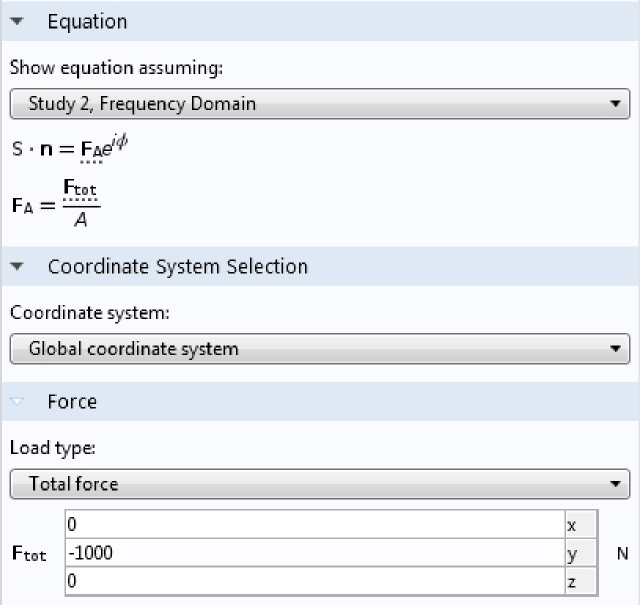
FREQUENCY RESPONSE


a
A
ω_0
ω
b
A
ω_0
ω
c
małe
tłumienie
brak
tłumienia
A
duże
tłumienie
ω_0
ω

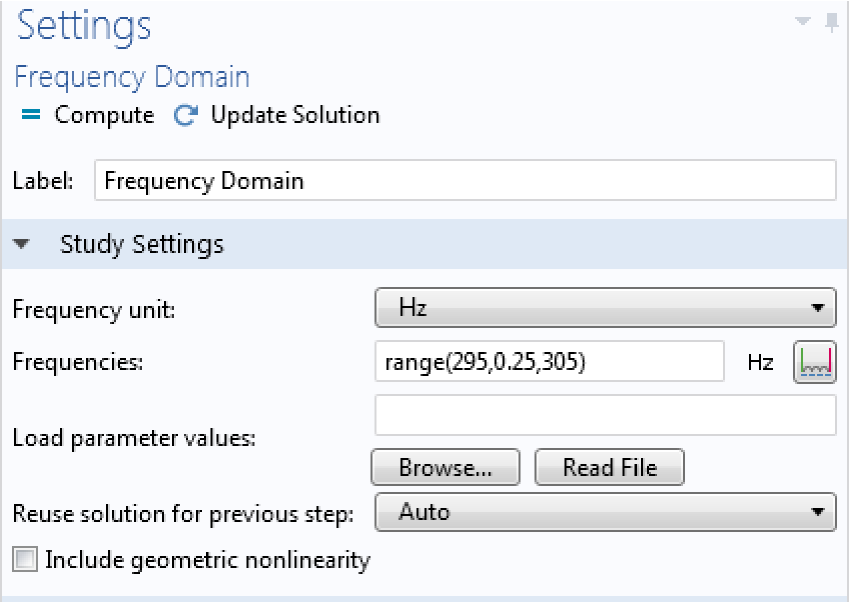
a)

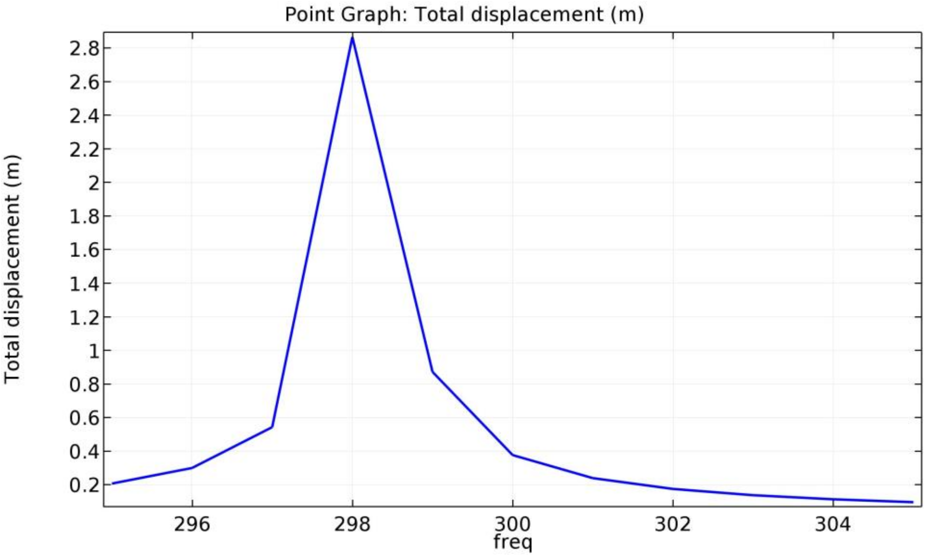
b)

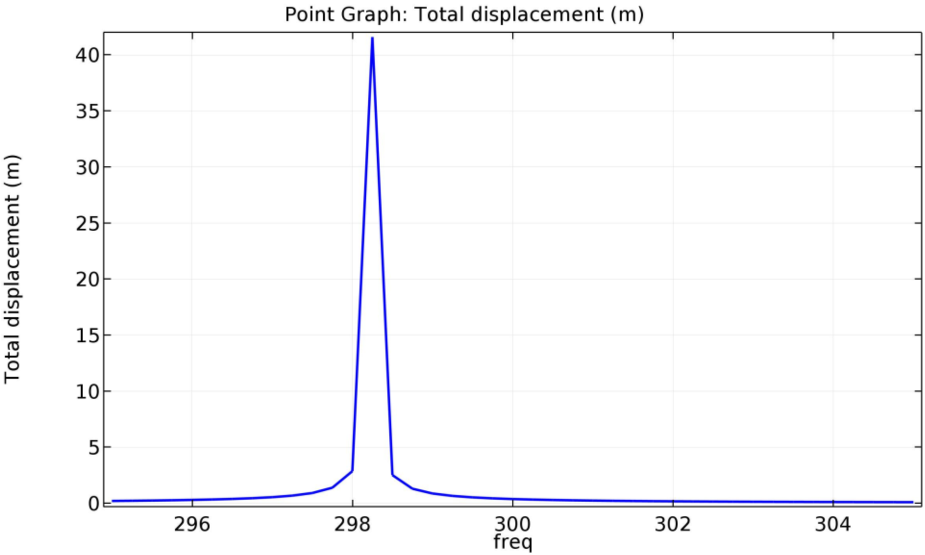

Select Study
Preset Studies
Eigenfrequency
Frequency Domain
Frequency-Domain Modal
Linear Buckling
Modal Reduced Order Model
Prestressed Analysis, Eigenfrequency
Prestressed Analysis, Frequency Domain
Stationary
Time Dependent
Time-Dependent Modal
Added study:
Frequency Domain
Added physics interfaces:
Solid Mechanics (solid)
Frequency Domain
The Frequency Domain study is used to compute the response of a linear or linearized model subjected to harmonic excitation for one or several frequencies.
Examples: In solid mechanics, it is used to compute the frequency response of a mechanical structure with respect to particular load distributions and frequencies. For quasi-static formulations in electromagnetics, it is used, for example, to compute the impedance versus frequency. For acoustics and electromagnetic wave propagation, it is used to compute the transmission and reflection versus frequency. A Frequency Domain study accounts for the effects of all eigenmodes that are properly resolved by the mesh and how they couple with the applied loads or excitations. The output of a Frequency Domain study is typically displayed as a transfer function, for example, magnitude or phase of deformation, sound pressure, impedance, or scattering parameters versus frequency.



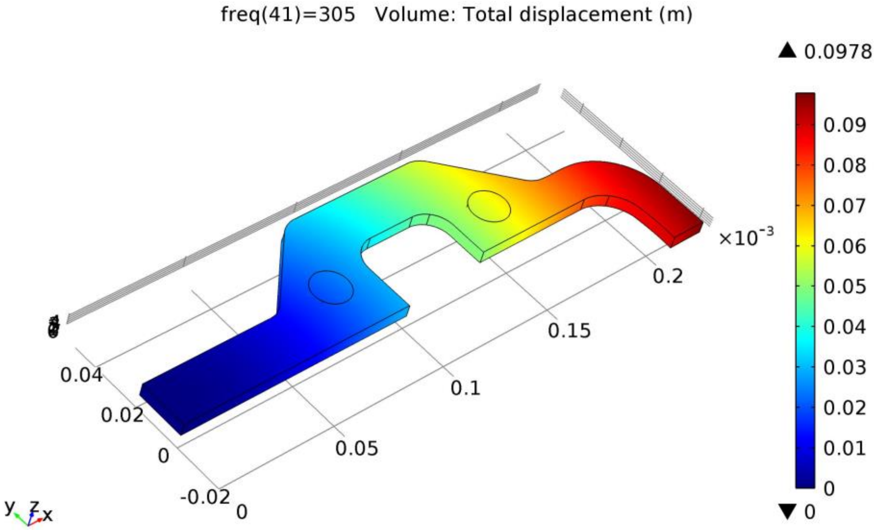
Equation
Show equation assuming:
Study 2, Frequency Domain
$S \cdot \mathbf{n} = \mathbf{F}_A e^{i\phi}$
$\mathbf{F}_A = \frac{\mathbf{F}_{tot}}{A}$
Coordinate System Selection
Coordinate system:
Global coordinate system
Force
Load type:
Total force
$\mathbf{F}_{tot}$
0
-1000
0
x
y
z
N


Settings
Frequency Domain
Compute
Update Solution
Label:
Frequency Domain
Study Settings
Frequency unit:
Hz
Frequencies:
range(295,0.25,305)
Hz
Load parameter values:
Browse...
Read File
Reuse solution for previous step:
Auto
Include geometric nonlinearity


Point Graph: Total displacement (m)
Total displacement (m)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
296
298
300
302
304
freq

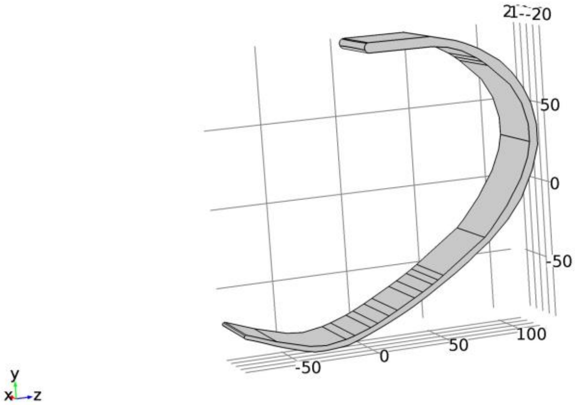


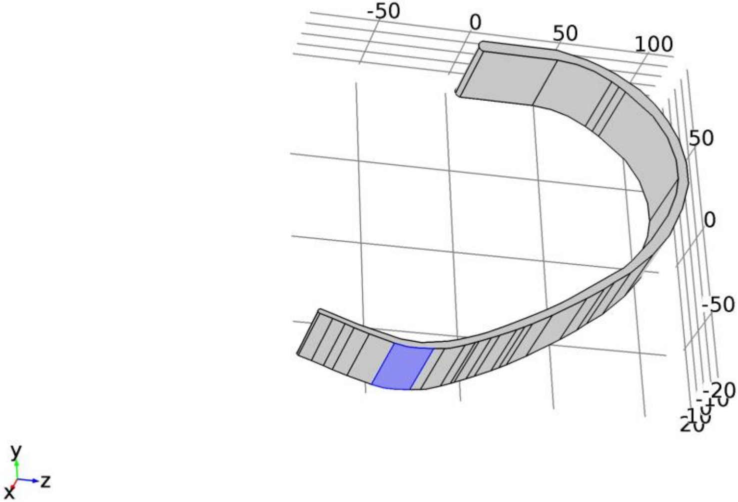
Point Graph: Total displacement (m)
Total displacement (m)
0
5
10
15
20
25
30
35
40
296
298
300
302
304
freq



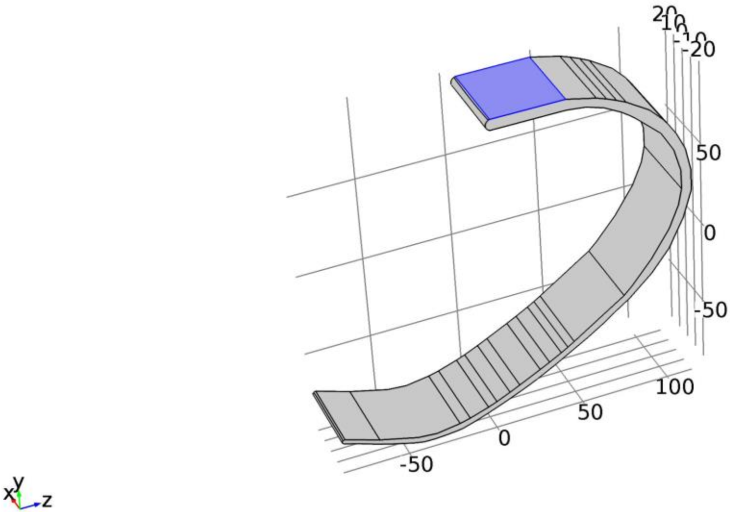
freq(41)=305 Volume: Total displacement (m)
▲ 0.0978
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
▼ 0
×10^-3
0.2
0.15
0.1
0.05
0
0.04
0.02
0
-0.02
y z x

STATIONARY STUDY – PROSTHESIS NITRO

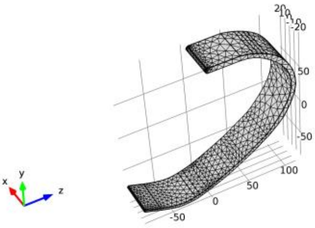




-50
0
50
100
50
0
-50
-20
-10
10
20
y
z
x



20
10
0
-10
-20
50
0
-50
100
50
0
-50
x
y
z



Statistics

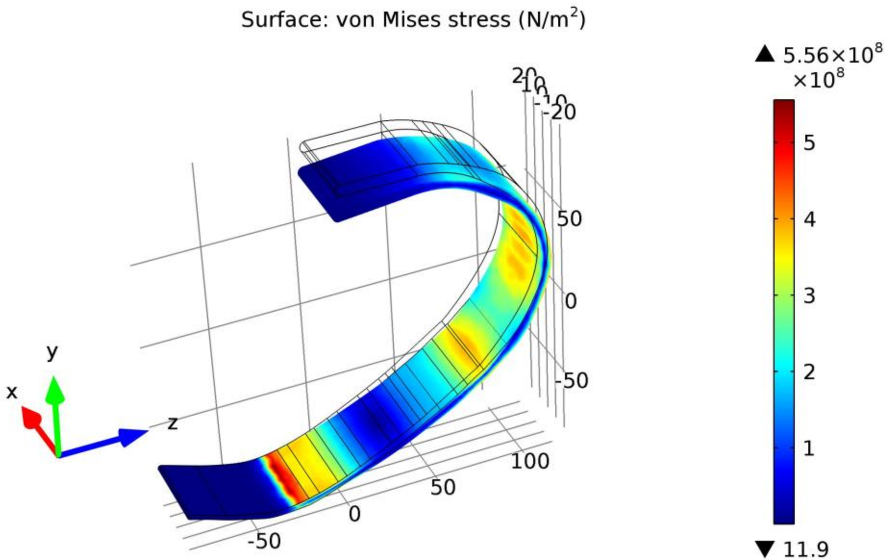
Complete mesh

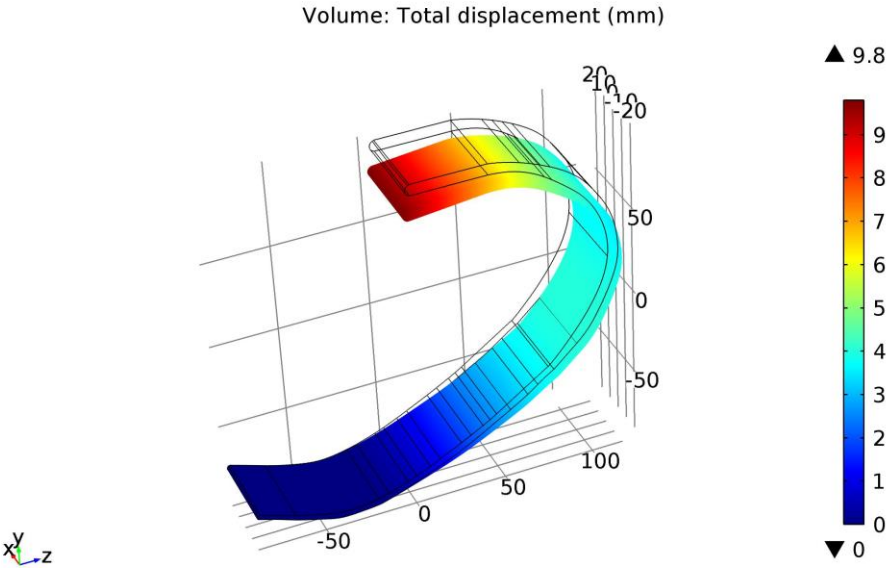
Element type: All elements

Tetrahedral elements:	3412
Triangular elements:	2504
Edge elements:	707
Vertex elements:	110

Domain element statistics

Number of elements:	3412
Minimum element quality:	0.05009
Average element quality:	0.6376
Element volume ratio:	6.459E-4
Mesh volume:	88090.0 mm^3
Maximum growth rate:	4.468
Average growth rate:	2.053


Surface: von Mises stress (N/m^2)
▲ 5.56×10^8
×10^8
5
4
3
2
1
▼ 11.9
20
10
0
-10
-20
50
0
-50
100
50
0
-50
x
y
z



Volume: Total displacement (mm)
▲ 9.8
9
8
7
6
5
4
3
2
1
0
▼ 0
20
-20
50
0
-50
100
50
0
-50
x
y
z