

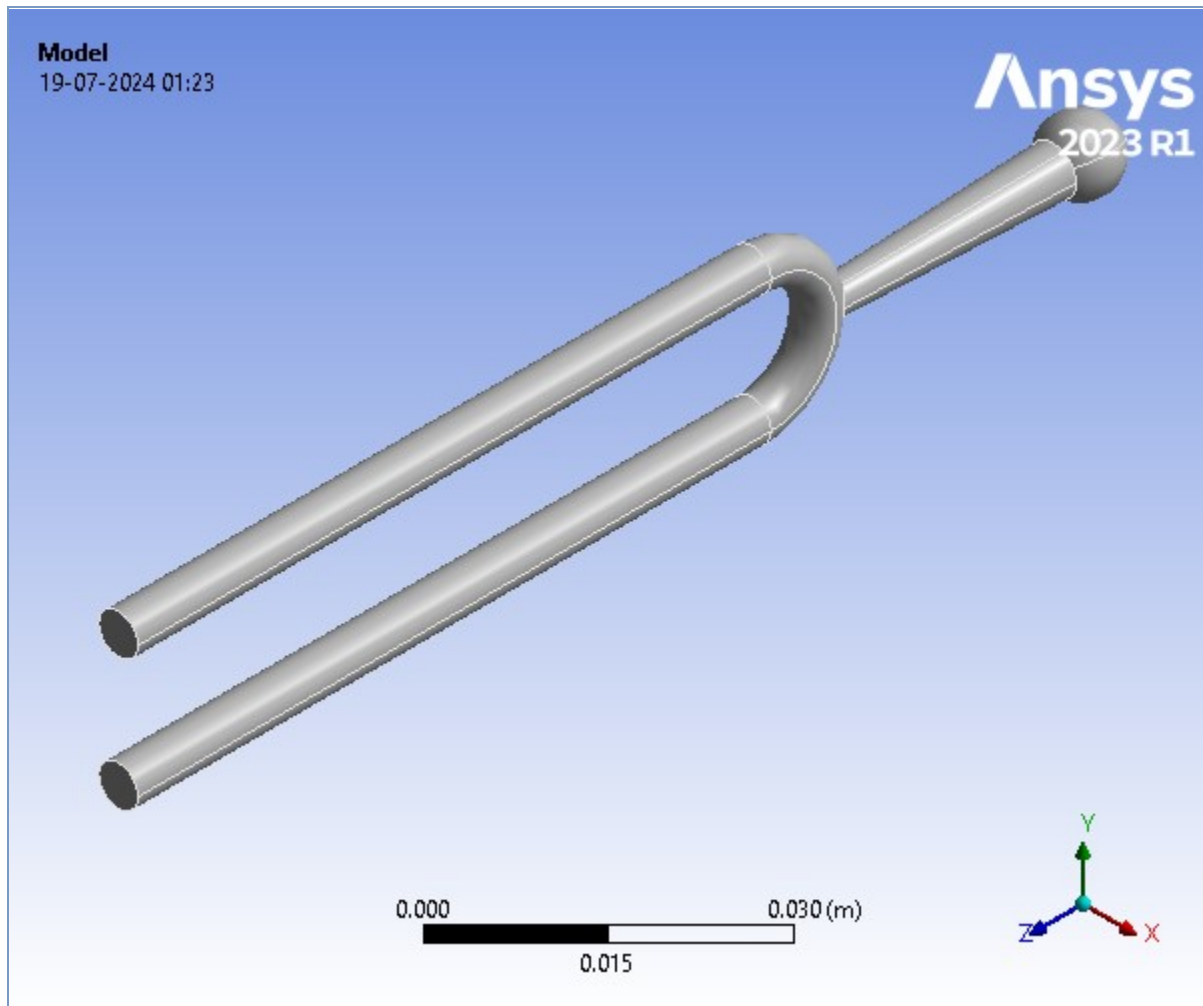


ANALYSIS BY: PEBBLE NARAYANAN	PROJECT 1: TUNING FORK - MODAL ANALYSIS
GUIDED BY: SOURAV SANGEETH	
SOFTWARE: ANSYS	PROJECT 2: SPANNER - TRANSIENT THERMAL & STATIC STRUCTURAL ANALYSIS
DATE: 19/07/2024	



Tuning Fork

First Saved	Thursday, July 18, 2024
Last Saved	Friday, July 19, 2024
Product Version	2023 R1
Save Project Before Solution	No
Save Project After Solution	No



Contents

- [Units](#)
- [Model \(A4\)](#)
 - [Geometry Imports](#)
 - [Geometry Import \(A3\)](#)
 - [Geometry](#)
 - [Tuning Fork-FreeParts|PartBody](#)
 - [Materials](#)
 - [Coordinate Systems](#)
 - [Mesh](#)
 - [Patch Conforming Method](#)
 - [Modal \(A5\)](#)
 - [Pre-Stress \(None\)](#)
 - [Analysis Settings](#)
 - [Fixed Support](#)
 - [Solution \(A6\)](#)
 - [Solution Information](#)
 - [Results](#)
- [Material Data](#)
 - [Aluminum Alloy](#)

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

TABLE 2

Model (A4) > Geometry Imports

Object Name	Geometry Imports
State	Solved

TABLE 3

Model (A4) > Geometry Imports > Geometry Import (A3)

Object Name	Geometry Import (A3)
State	Solved
Definition	
Source	D:\Pebble Narayanan\Mechanical Design Engineering\IP3 - TUNING FORK & SPANNER\Analysis\Tuning Fork.igs
Type	Iges
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes

Line Bodies	No
Parameters	Independent
Parameter Key	ANS;DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Analysis Type	3-D
Mixed Import Resolution	None
Import Facet Quality	Source
Clean Bodies On Import	No
Stitch Surfaces On Import	Program Tolerance
Stitch Tolerance	0.0000001
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

Geometry

TABLE 4
Model (A4) > Geometry

Object Name	Geometry
State	Fully Defined
Definition	
Source	D:\Pebble Narayanan\Mechanical Design Engineering\P3 - TUNING FORK & SPANNER\Analysis\Tuning Fork.igs
Type	Iges
Length Unit	Millimeters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	8.e-003 m
Length Y	1.95e-002 m
Length Z	0.114 m
Properties	
Volume	3.2855e-006 m ³
Mass	9.1007e-003 kg
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	52327
Elements	29084
Mesh Metric	None
Update Options	

Assign Default Material	No
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Independent
Parameter Key	ANS;DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Analysis Type	3-D
Mixed Import Resolution	None
Import Facet Quality	Source
Clean Bodies On Import	No
Stitch Surfaces On Import	Program Tolerance
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 5
Model (A4) > Geometry > Parts

Object Name	<i>Tuning Fork-FreeParts PartBody</i>
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Treatment	None
Material	
Assignment	Aluminum Alloy
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	8.e-003 m
Length Y	1.95e-002 m
Length Z	0.114 m
Properties	
Volume	3.2855e-006 m ³
Mass	9.1007e-003 kg
Centroid X	5.1561e-007 m

Centroid Y	-1.5537e-006 m
Centroid Z	-1.332e-002 m
Moment of Inertia Ip1	9.8039e-006 kg·m ²
Moment of Inertia Ip2	9.4187e-006 kg·m ²
Moment of Inertia Ip3	4.1061e-007 kg·m ²
Statistics	
Nodes	52327
Elements	29084
Mesh Metric	None

TABLE 6
Model (A4) > Materials

Object Name	<i>Materials</i>
State	Fully Defined
Statistics	
Materials	2
Material Assignments	0

Coordinate Systems

TABLE 7
Model (A4) > Coordinate Systems > Coordinate System

Object Name	<i>Global Coordinate System</i>
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Mesh

TABLE 8
Model (A4) > Mesh

Object Name	<i>Mesh</i>
State	Solved
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	4.e-004 m
Sizing	
Use Adaptive Sizing	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes

Defeature Size	Default
Transition	Fast
Span Angle Center	Coarse
Initial Size Seed	Assembly
Bounding Box Diagonal	0.11593 m
Average Surface Area	2.2455e-004 m ²
Minimum Edge Length	1.3249e-003 m
Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Aggressive Mechanical
Target Element Quality	Default (5.e-002)
Smoothing	Medium
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	No
Rigid Body Behavior	Dimensionally Reduced
Triangle Surface Mesher	Program Controlled
Topology Checking	Yes
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Statistics	
Nodes	52327
Elements	29084
Show Detailed Statistics	No

TABLE 9
Model (A4) > Mesh > Mesh Controls

Object Name	<i>Patch Conforming Method</i>
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Method	Tetrahedrons
Algorithm	Patch Conforming
Element Order	Use Global Setting

Modal (A5)

TABLE 10
Model (A4) > Analysis

Object Name	<i>Modal (A5)</i>
-------------	-------------------

State	Solved
Definition	
Physics Type	Structural
Analysis Type	Modal
Solver Target	Mechanical APDL
Options	
Environment Temperature	28. °C
Generate Input Only	No

TABLE 11
Model (A4) > Modal (A5) > Initial Condition

Object Name	<i>Pre-Stress (None)</i>
State	Fully Defined
Definition	
Pre-Stress Environment	None Available

TABLE 12
Model (A4) > Modal (A5) > Analysis Settings

Object Name	<i>Analysis Settings</i>
State	Fully Defined
Options	
Max Modes to Find	5
Limit Search to Range	No
On Demand Expansion Option	Program Controlled
-- On Demand Expansion	No
Solver Controls	
Damped	No
Solver Type	Program Controlled
Rotordynamics Controls	
Coriolis Effect	Off
Campbell Diagram	Off
Advanced	
Contact Split (DMP)	Off
Output Controls	
Stress	No
Back Stress	No
Strain	No
Contact Data	No
Nodal Forces	No
Volume and Energy	No
Euler Angles	No
Calculate Reactions	No
General Miscellaneous	No
Result File Compression	Program Controlled
Analysis Data Management	
Solver Files Directory	D:\Pebble Narayanan\Mechanical Design Engineering\IP3 - TUNING FORK & SPANNER\Analysis\Tuning Fork_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	

Save MAPDL db	No
Contact Summary	Program Controlled
Delete Unneeded Files	Yes
Solver Units	Active System
Solver Unit System	mks

TABLE 13
Model (A4) > Modal (A5) > Loads

Object Name	<i>Fixed Support</i>
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	5 Faces
Definition	
Type	Fixed Support
Suppressed	No

Solution (A6)

TABLE 14
Model (A4) > Modal (A5) > Solution

Object Name	<i>Solution (A6)</i>
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.
Information	
Status	Done
MAPDL Elapsed Time	6. s
MAPDL Memory Used	1.709 GB
MAPDL Result File Size	14.563 MB
Post Processing	
Beam Section Results	No

The following bar chart indicates the frequency at each calculated mode.

FIGURE 1
Model (A4) > Modal (A5) > Solution (A6)

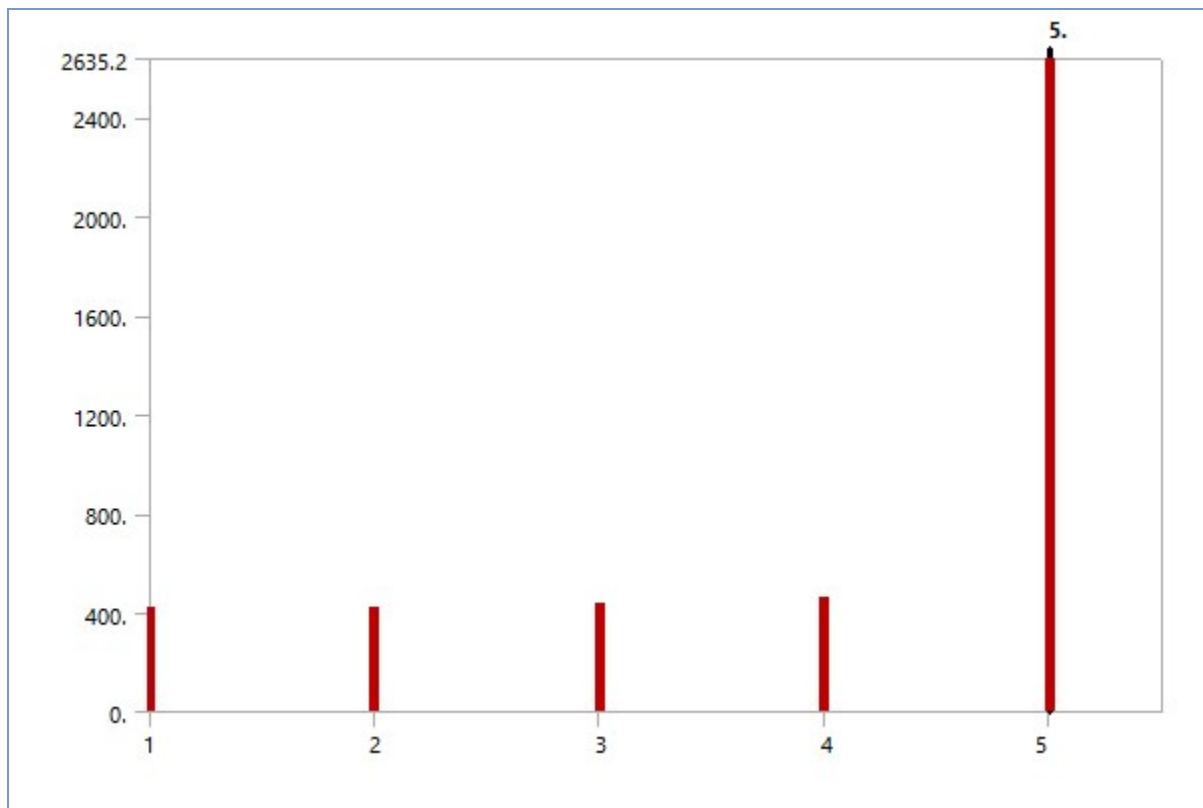


TABLE 15
Model (A4) > Modal (A5) > Solution (A6)

Mode	Frequency [Hz]
1.	416.38
2.	422.51
3.	440.25
4.	457.88
5.	2635.2

TABLE 16
Model (A4) > Modal (A5) > Solution (A6) > Solution Information

Object Name	<i>Solution Information</i>
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Identify Element Violations	0
Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 17
Model (A4) > Modal (A5) > Solution (A6) > Results

Object Name	Total Deformation 1	Total Deformation 2	Total Deformation 3	Total Deformation 4	Total Deformation 5
State	Solved				
Scope					
Scoping Method	Geometry Selection				
Geometry	All Bodies				
Definition					
Type	Total Deformation				
Mode	1.	2.	3.	4.	5.
Separate Data by Entity	No				
Identifier					
Suppressed	No				
Results					
Minimum	0. m				
Maximum	22.996 m	23.008 m	23.229 m	23.438 m	23.11 m
Average	7.4607 m	7.4842 m	7.4022 m	7.3479 m	8.3013 m
Minimum Occurs On	Tuning Fork-FreeParts PartBody				
Maximum Occurs On	Tuning Fork-FreeParts PartBody				
Information					
Frequency	416.38 Hz	422.51 Hz	440.25 Hz	457.88 Hz	2635.2 Hz

TABLE 18
Model (A4) > Modal (A5) > Solution (A6) > Total Deformation 1

Mode	Frequency [Hz]
1.	416.38
2.	422.51
3.	440.25
4.	457.88
5.	2635.2

FIGURE 2
Model (A4) > Modal (A5) > Solution (A6) > Total Deformation 1 > Figure

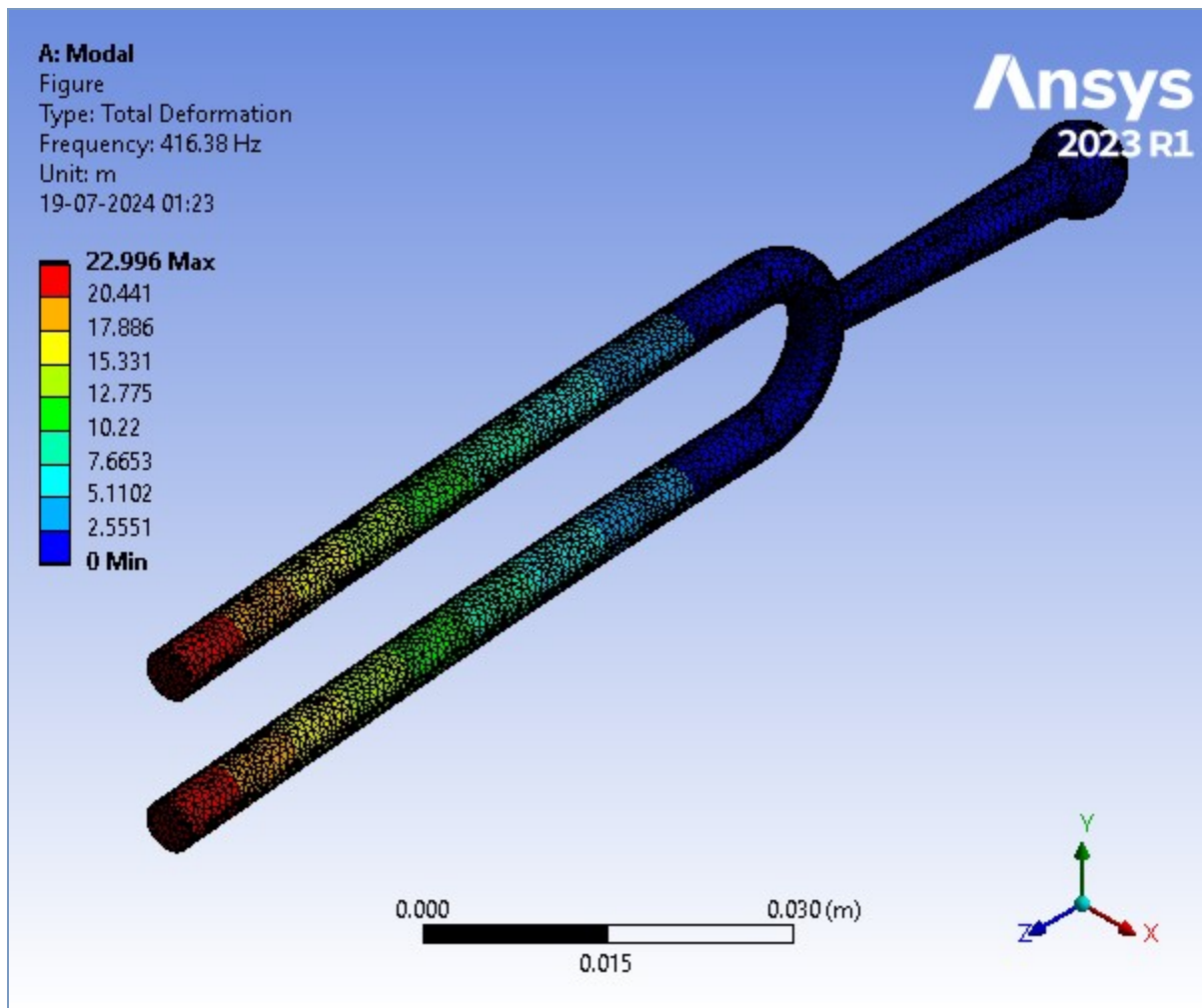


TABLE 19
 Model (A4) > Modal (A5) > Solution (A6) > Total Deformation 2

Mode	Frequency [Hz]
1.	416.38
2.	422.51
3.	440.25
4.	457.88
5.	2635.2

FIGURE 3
 Model (A4) > Modal (A5) > Solution (A6) > Total Deformation 2 > Figure

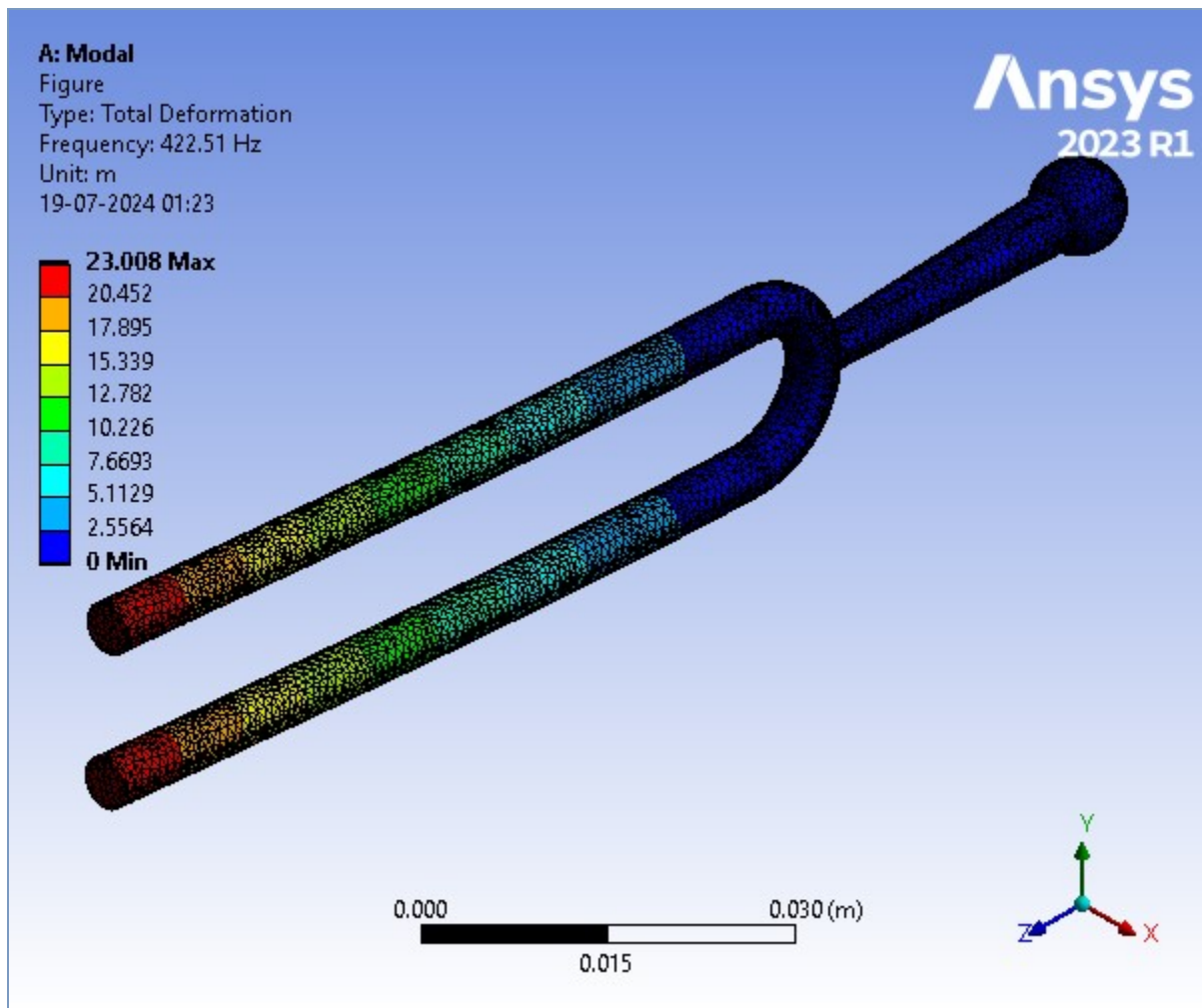


TABLE 20
Model (A4) > Modal (A5) > Solution (A6) > Total Deformation 3

Mode	Frequency [Hz]
1.	416.38
2.	422.51
3.	440.25
4.	457.88
5.	2635.2

FIGURE 4
Model (A4) > Modal (A5) > Solution (A6) > Total Deformation 3 > Figure

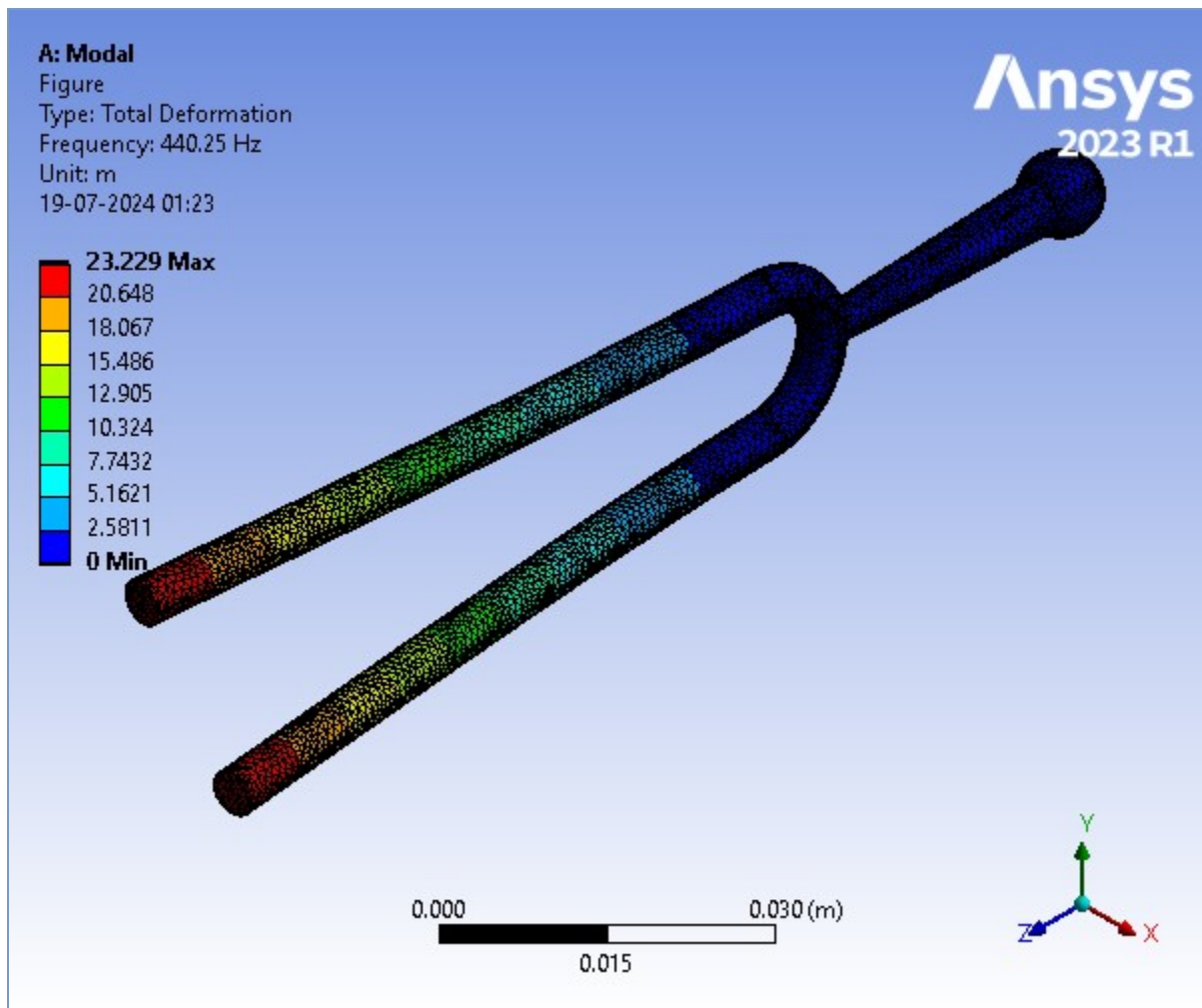


TABLE 21
Model (A4) > Modal (A5) > Solution (A6) > Total Deformation 4

Mode	Frequency [Hz]
1.	416.38
2.	422.51
3.	440.25
4.	457.88
5.	2635.2

FIGURE 5
Model (A4) > Modal (A5) > Solution (A6) > Total Deformation 4 > Figure

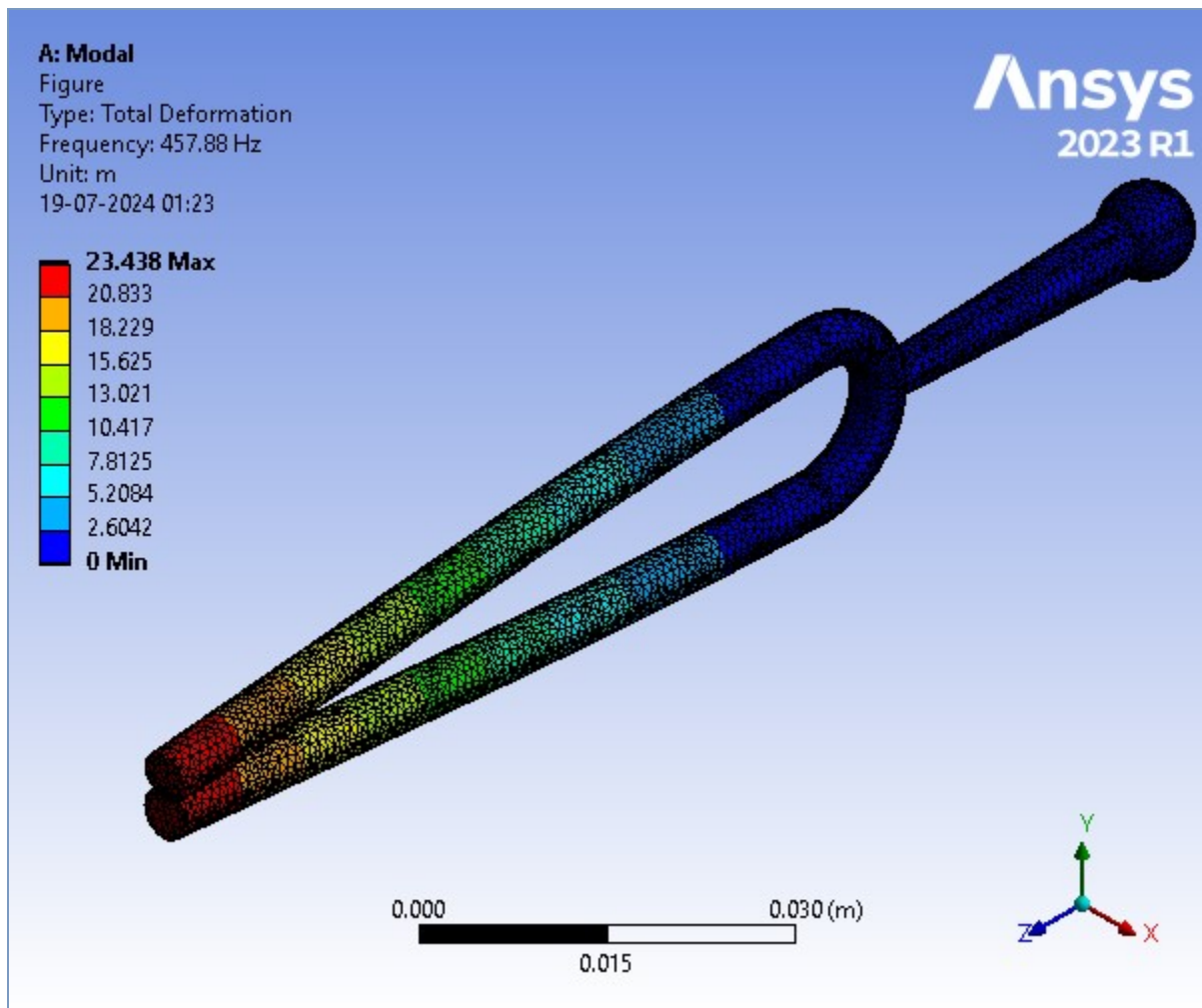
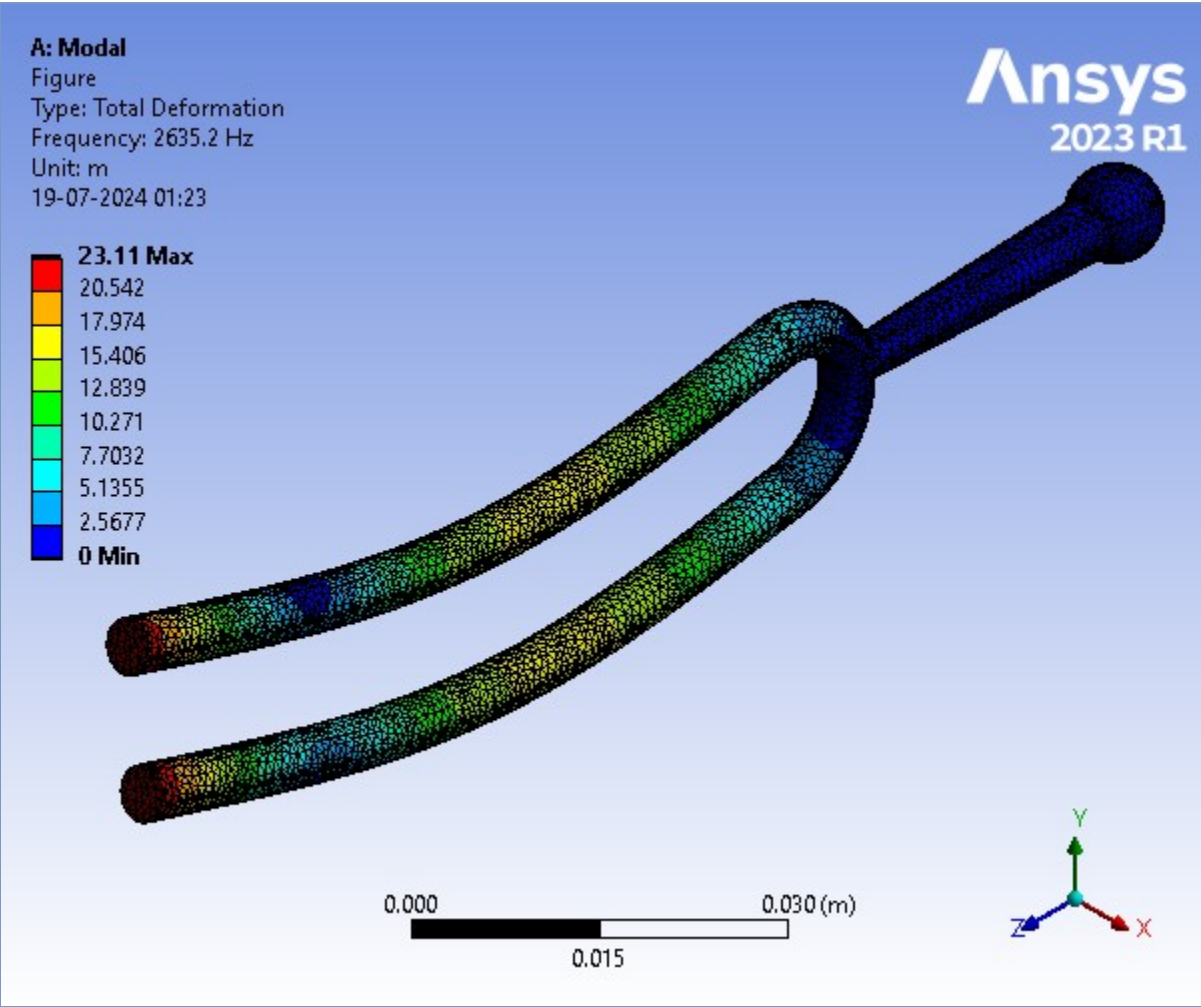


TABLE 22
Model (A4) > Modal (A5) > Solution (A6) > Total Deformation 5

Mode	Frequency [Hz]
1.	416.38
2.	422.51
3.	440.25
4.	457.88
5.	2635.2

FIGURE 6
Model (A4) > Modal (A5) > Solution (A6) > Total Deformation 5 > Figure



Material Data

Aluminum Alloy

TABLE 23
Aluminum Alloy > Constants

Density	2770 kg m ⁻³
Coefficient of Thermal Expansion	2.3e-005 C ⁻¹
Specific Heat	875 J kg ⁻¹ C ⁻¹

TABLE 24
Aluminum Alloy > Color

Red	Green	Blue
138	104	46

TABLE 25
Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 26
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength Pa
2.8e+008

TABLE 27
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength Pa
2.8e+008

TABLE 28
Aluminum Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
3.1e+008

TABLE 29
Aluminum Alloy > Isotropic Secant Coefficient of Thermal Expansion

Zero-Thermal-Strain Reference Temperature C
22

TABLE 30
Aluminum Alloy > Isotropic Thermal Conductivity

Thermal Conductivity W m ⁻¹ C ⁻¹	Temperature C
114	-100
144	0
165	100
175	200

TABLE 31
Aluminum Alloy > S-N Curve

Alternating Stress Pa	Cycles	R-Ratio
2.758e+008	1700	-1
2.413e+008	5000	-1
2.068e+008	34000	-1
1.724e+008	1.4e+005	-1
1.379e+008	8.e+005	-1
1.172e+008	2.4e+006	-1
8.963e+007	5.5e+007	-1
8.274e+007	1.e+008	-1
1.706e+008	50000	-0.5
1.396e+008	3.5e+005	-0.5
1.086e+008	3.7e+006	-0.5
8.791e+007	1.4e+007	-0.5
7.757e+007	5.e+007	-0.5
7.239e+007	1.e+008	-0.5
1.448e+008	50000	0
1.207e+008	1.9e+005	0
1.034e+008	1.3e+006	0
9.308e+007	4.4e+006	0
8.618e+007	1.2e+007	0
7.239e+007	1.e+008	0
7.412e+007	3.e+005	0.5
7.067e+007	1.5e+006	0.5
6.636e+007	1.2e+007	0.5
6.205e+007	1.e+008	0.5

TABLE 32
Aluminum Alloy > Isotropic Resistivity

Resistivity ohm m	Temperature C
2.43e-008	0
2.67e-008	20
3.63e-008	100

TABLE 33
Aluminum Alloy > Isotropic Elasticity

Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa	Temperature C
7.1e+010	0.33	6.9608e+010	2.6692e+010	

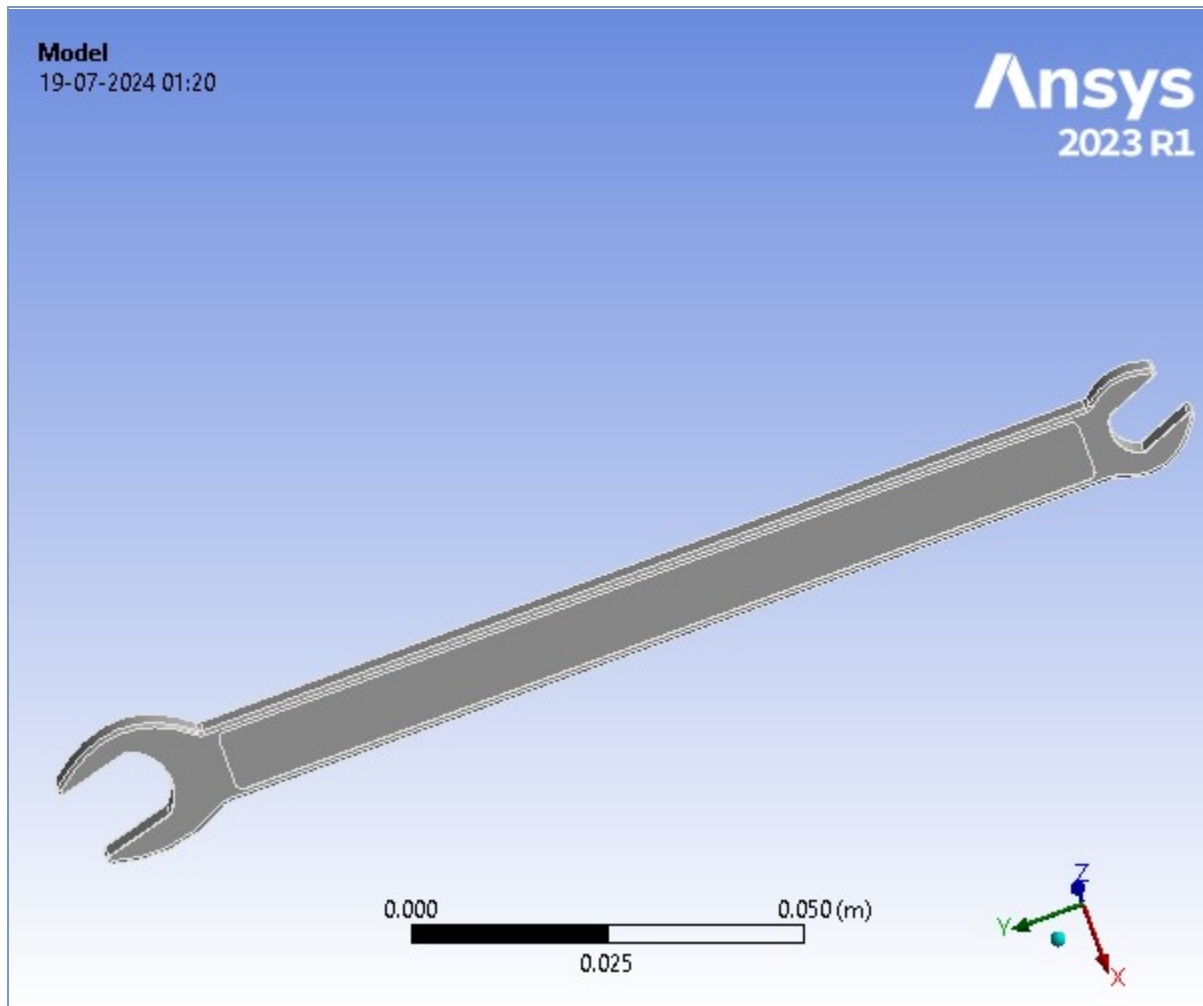
TABLE 34
Aluminum Alloy > Isotropic Relative Permeability

Relative Permeability
1



Spanner

First Saved	Friday, July 19, 2024
Last Saved	Friday, July 19, 2024
Product Version	2023 R1
Save Project Before Solution	No
Save Project After Solution	No



Contents

- [Units](#)
- [Model \(A4, B4\)](#)
 - [Geometry Imports](#)
 - [Geometry Import \(A3, B3\)](#)
 - [Geometry](#)
 - [Spanner-FreeParts|PartBody](#)
 - [Materials](#)
 - [Coordinate Systems](#)
 - [Mesh](#)
 - [Patch Conforming Method](#)
 - [Transient Thermal \(A5\)](#)
 - [Initial Temperature](#)
 - [Analysis Settings](#)
 - [Loads](#)
 - [Solution \(A6\)](#)
 - [Solution Information](#)
 - [Result Charts](#)
 - [Results](#)
 - [Static Structural \(B5\)](#)
 - [Analysis Settings](#)
 - [Loads](#)
 - [Imported Load \(A6\)](#)
 - [Imported Body Temperature](#)
 - [Solution \(B6\)](#)
 - [Solution Information](#)
 - [Results](#)
- [Material Data](#)
 - [Carbon steel, 1015, normalized](#)

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4, B4)

TABLE 2
Model (A4, B4) > Geometry Imports

Object Name	Geometry Imports
State	Solved

TABLE 3
Model (A4, B4) > Geometry Imports > Geometry Import (A3, B3)

Object Name	<i>Geometry Import (A3, B3)</i>
State	Solved
Definition	
Source	D:\Pebble Narayanan\Mechanical Design Engineering\P3 - TUNING FORK & SPANNER\Analysis\Spanner.igs
Type	Iges
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Independent
Parameter Key	ANS;DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Analysis Type	3-D
Mixed Import Resolution	None
Import Facet Quality	Source
Clean Bodies On Import	No
Stitch Surfaces On Import	Program Tolerance
Stitch Tolerance	0.0000001
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

Geometry

TABLE 4
Model (A4, B4) > Geometry

Object Name	<i>Geometry</i>
State	Fully Defined
Definition	
Source	D:\Pebble Narayanan\Mechanical Design Engineering\P3 - TUNING FORK & SPANNER\Analysis\Spanner.igs
Type	Iges
Length Unit	Millimeters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	1.8609e-002 m
Length Y	0.15243 m
Length Z	1.0304e-002 m
Properties	
Volume	6.6669e-006 m ³

Mass	5.2335e-002 kg
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	95712
Elements	53348
Mesh Metric	None
Update Options	
Assign Default Material	No
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Independent
Parameter Key	ANS;DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Analysis Type	3-D
Mixed Import Resolution	None
Import Facet Quality	Source
Clean Bodies On Import	No
Stitch Surfaces On Import	Program Tolerance
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 5
Model (A4, B4) > Geometry > Parts

Object Name	<i>Spanner-FreeParts PartBody</i>
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Treatment	None
Material	
Assignment	Carbon steel, 1015, normalized
Nonlinear Effects	Yes

Thermal Strain Effects	Yes
Bounding Box	
Length X	1.8609e-002 m
Length Y	0.15243 m
Length Z	1.0304e-002 m
Properties	
Volume	6.6669e-006 m ³
Mass	5.2335e-002 kg
Centroid X	-6.4681e-005 m
Centroid Y	4.171e-003 m
Centroid Z	-2.7915e-008 m
Moment of Inertia Ip1	9.142e-005 kg·m ²
Moment of Inertia Ip2	6.9001e-007 kg·m ²
Moment of Inertia Ip3	9.192e-005 kg·m ²
Statistics	
Nodes	95712
Elements	53348
Mesh Metric	None

TABLE 6
Model (A4, B4) > Materials

Object Name	<i>Materials</i>
State	Fully Defined
Statistics	
Materials	2
Material Assignments	0

Coordinate Systems

TABLE 7
Model (A4, B4) > Coordinate Systems > Coordinate System

Object Name	<i>Global Coordinate System</i>
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Mesh

TABLE 8
Model (A4, B4) > Mesh

Object Name	<i>Mesh</i>
State	Solved
Display	

Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	5.e-004 m
Sizing	
Use Adaptive Sizing	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Fast
Span Angle Center	Coarse
Initial Size Seed	Assembly
Bounding Box Diagonal	0.15391 m
Average Surface Area	4.1626e-005 m ²
Minimum Edge Length	6.5375e-006 m
Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Aggressive Mechanical
Target Element Quality	Default (5.e-002)
Smoothing	Medium
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	No
Rigid Body Behavior	Dimensionally Reduced
Triangle Surface Mesher	Program Controlled
Topology Checking	Yes
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Statistics	
Nodes	95712
Elements	53348
Show Detailed Statistics	No

TABLE 9
Model (A4, B4) > Mesh > Mesh Controls

Object Name	<i>Patch Conforming Method</i>
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No

Method	Tetrahedrons
Algorithm	Patch Conforming
Element Order	Use Global Setting

Transient Thermal (A5)

TABLE 10
Model (A4, B4) > Analysis

Object Name	<i>Transient Thermal (A5)</i>
State	Solved
Definition	
Physics Type	Thermal
Analysis Type	Transient
Solver Target	Mechanical APDL
Options	
Generate Input Only	No

TABLE 11
Model (A4, B4) > Transient Thermal (A5) > Initial Condition

Object Name	<i>Initial Temperature</i>
State	Fully Defined
Definition	
Initial Temperature	Uniform Temperature
Initial Temperature Value	28. °C

TABLE 12
Model (A4, B4) > Transient Thermal (A5) > Analysis Settings

Object Name	<i>Analysis Settings</i>
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Initial Time Step	1.e-002 s
Minimum Time Step	1.e-003 s
Maximum Time Step	0.1 s
Time Integration	On
Solver Controls	
Solver Type	Program Controlled
Radiosity Controls	
Radiosity Solver	Program Controlled
Flux Convergence	1.e-004
Maximum Iteration	1000.
Solver Tolerance	0.1 W/m ²
Over Relaxation	0.1
Hemicube Resolution	10.
Nonlinear Controls	
Heat Convergence	Program Controlled
Temperature Convergence	Program Controlled
Line Search	Program Controlled

Nonlinear Formulation	Program Controlled
Advanced	
Contact Split (DMP)	Off
Output Controls	
Calculate Thermal Flux	Yes
Contact Data	Yes
Nodal Forces	No
Volume and Energy	Yes
Euler Angles	Yes
General Miscellaneous	No
Contact Miscellaneous	No
Store Results At	All Time Points
Result File Compression	Program Controlled
Analysis Data Management	
Solver Files Directory	D:\Pebble Narayanan\Mechanical Design Engineering\IP3 - TUNING FORK & SPANNER\Analysis\Spanner_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Contact Summary	Program Controlled
Delete Unneeded Files	Yes
Nonlinear Solution	Yes
Solver Units	Active System
Solver Unit System	mks

TABLE 13
Model (A4, B4) > Transient Thermal (A5) > Loads

Model (A1, B4) - Transient Thermal (A6) - Loads		
Object Name	Temperature	Convection
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	3 Faces	109 Faces
Definition		
Type	Temperature	Convection
Magnitude	Tabular Data	
Suppressed	No	
Film Coefficient		5. W/m ² ·°C (step applied)
Coefficient Type		Average Film Temperature
Ambient Temperature		28. °C (step applied)
Convection Matrix		Program Controlled
Tabular Data		
Independent Variable	Time	

FIGURE 1
Model (A4, B4) > Transient Thermal (A5) > Temperature

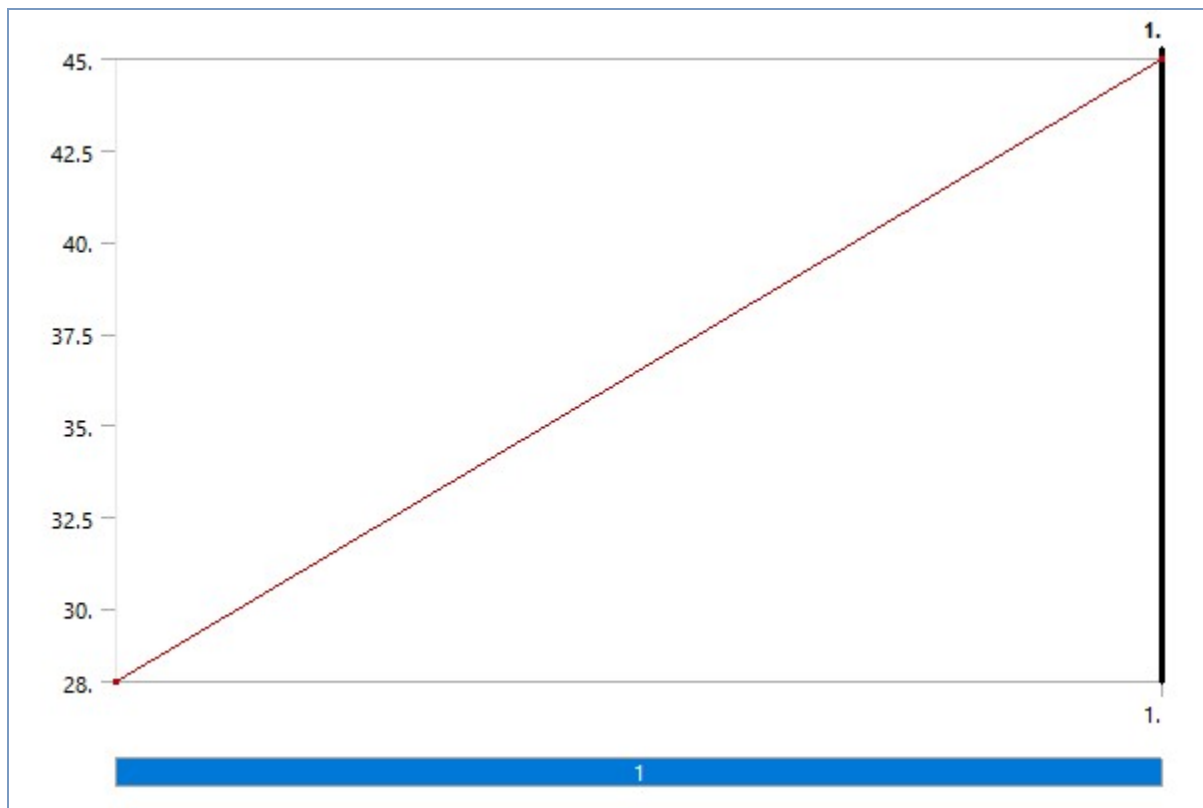


TABLE 14
Model (A4, B4) > Transient Thermal (A5) > Temperature

Steps	Time [s]	Temperature [°C]
1	0.	28.
	1.	45.

FIGURE 2
Model (A4, B4) > Transient Thermal (A5) > Convection



TABLE 15
Model (A4, B4) > Transient Thermal (A5) > Convection

Temperature [°C]	Convection Coefficient [W/m²·°C]
21.	5.

Solution (A6)

TABLE 16
Model (A4, B4) > Transient Thermal (A5) > Solution

Object Name	<i>Solution (A6)</i>
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.
Information	
Status	Done
MAPDL Elapsed Time	22. s
MAPDL Memory Used	1.2148 GB
MAPDL Result File Size	208.5 MB
Post Processing	
Beam Section Results	No

TABLE 17
Model (A4, B4) > Transient Thermal (A5) > Solution (A6) > Solution Information

Object Name	<i>Solution Information</i>
State	Solved
Solution Information	
Solution Output	Solver Output

Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 18
Model (A4, B4) > Transient Thermal (A5) > Solution (A6) > Solution Information > Result Charts

Object Name	Temperature - Global Maximum	Temperature - Global Minimum
State	Solved	
Scope		
Scoping Method	Global Maximum	Global Minimum
Definition		
Type	Temperature	
Suppressed	No	
Results		
Minimum	28.17 °C	28. °C
Maximum	45. °C	28. °C

FIGURE 3
Model (A4, B4) > Transient Thermal (A5) > Solution (A6) > Solution Information > Temperature - Global Maximum

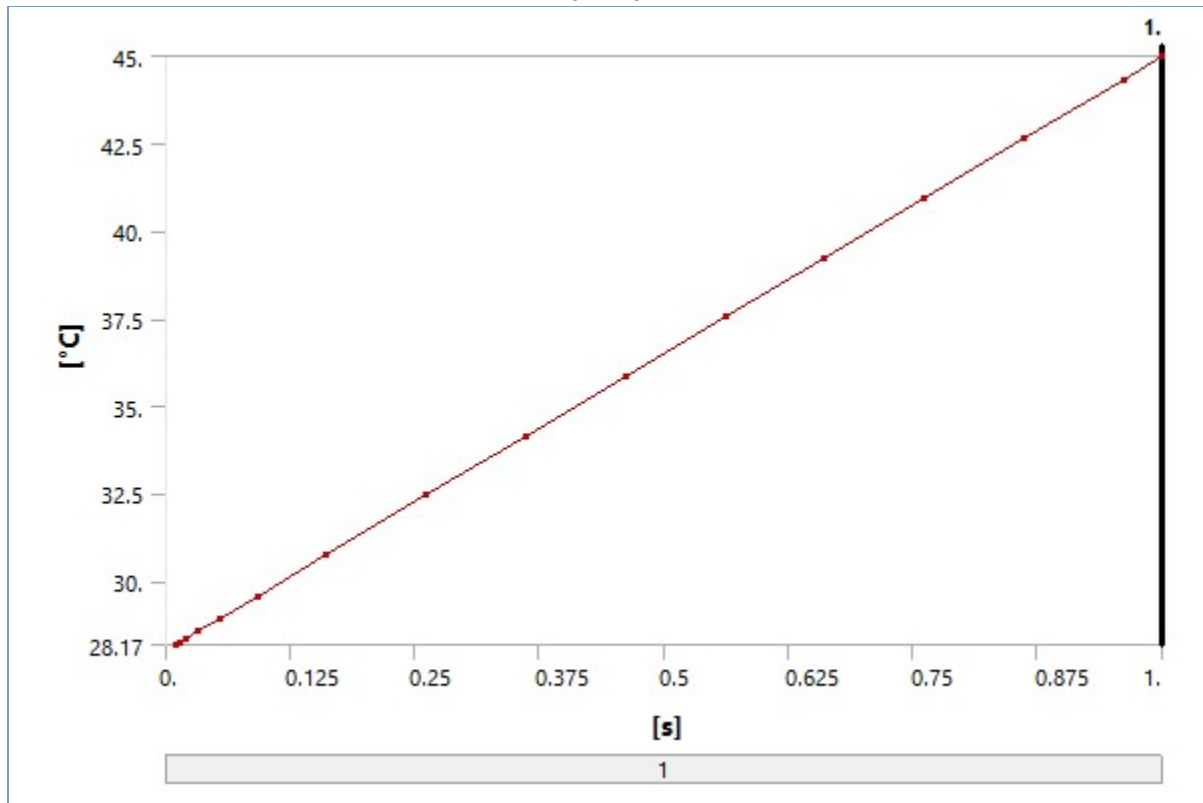


FIGURE 4
Model (A4, B4) > Transient Thermal (A5) > Solution (A6) > Solution Information > Temperature - Global

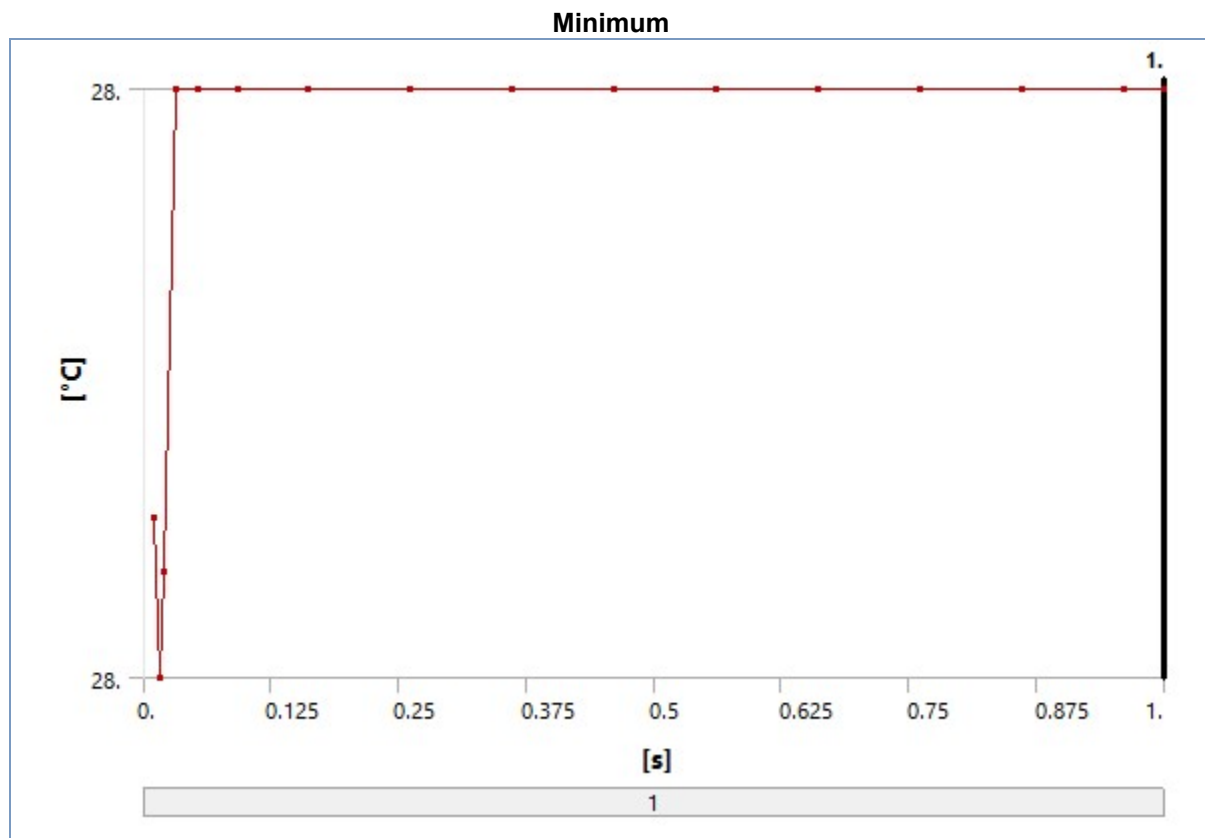


TABLE 19
Model (A4, B4) > Transient Thermal (A5) > Solution (A6) > Results

Object Name	Temperature	Total Heat Flux
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Temperature	Total Heat Flux
By	Time	
Display Time	Last	
Separate Data by Entity	No	
Calculate Time History	Yes	
Identifier		
Suppressed	No	
Results		
Minimum	28. °C	6.6755e-011 W/m²
Maximum	45. °C	7.126e+005 W/m²
Average	30.687 °C	32729 W/m²
Minimum Occurs On	Spanner-FreeParts PartBody	
Maximum Occurs On	Spanner-FreeParts PartBody	
Minimum Value Over Time		
Minimum	28. °C	1.0625e-011 W/m²
Maximum	28. °C	6.8522e-011 W/m²
Maximum Value Over Time		
Minimum	28.17 °C	54820 W/m²
Maximum	45. °C	7.126e+005 W/m²

Information		
Time	1. s	
Load Step	1	
Substep	16	
Iteration Number	16	
Integration Point Results		
Display Option		Averaged
Average Across Bodies		No

FIGURE 5
Model (A4, B4) > Transient Thermal (A5) > Solution (A6) > Temperature

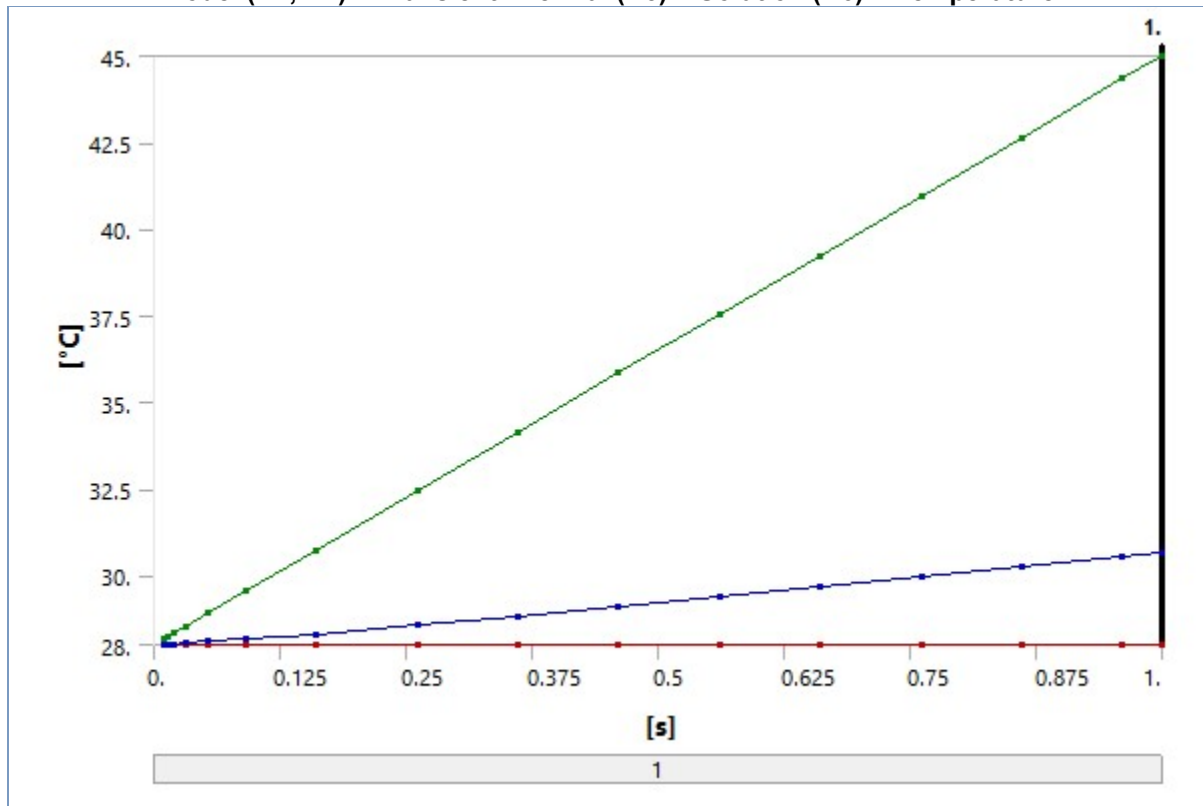
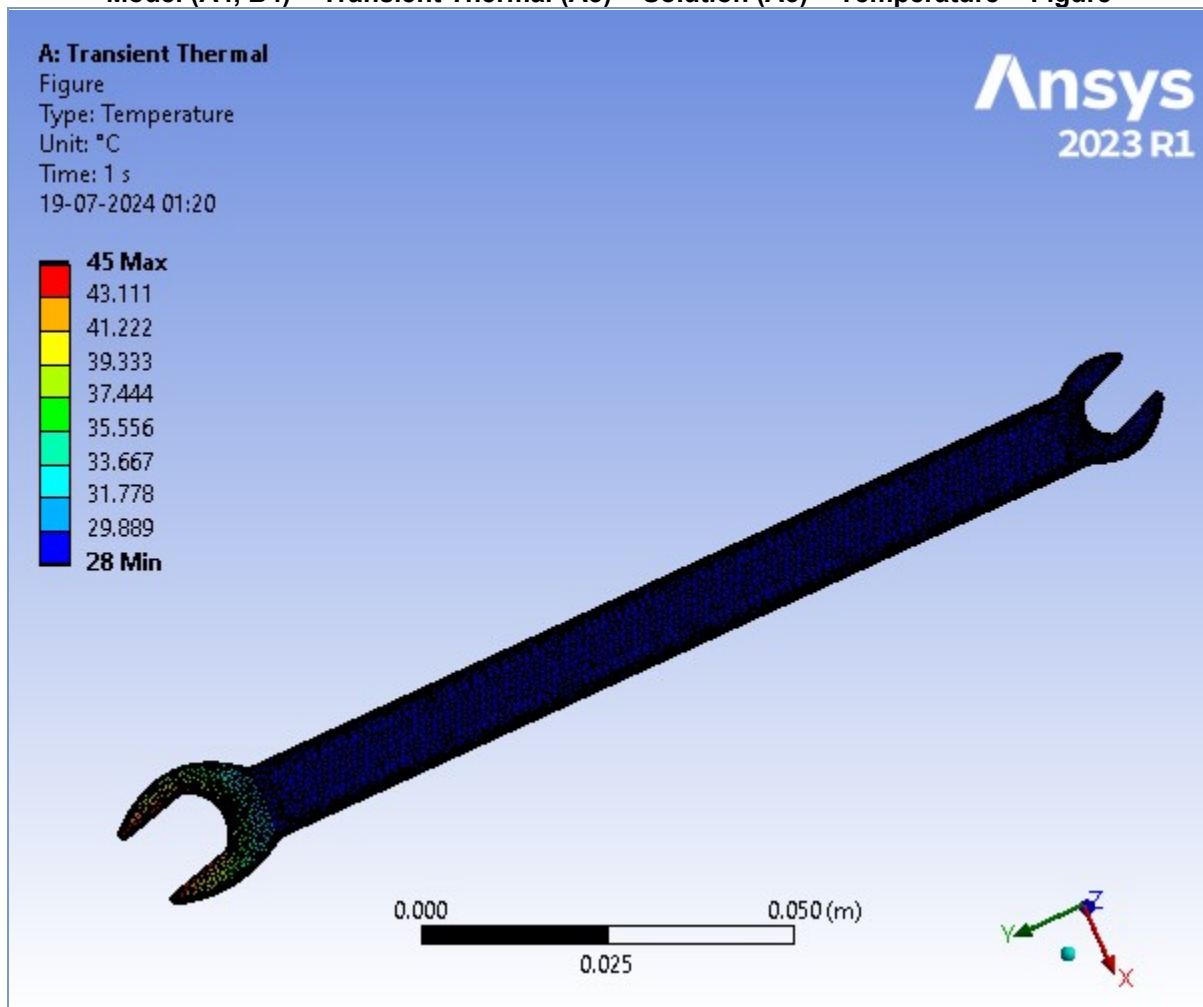


TABLE 20
Model (A4, B4) > Transient Thermal (A5) > Solution (A6) > Temperature

Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1.e-002	28.	28.17	28.013
1.4738e-002		28.251	28.02
1.9475e-002		28.331	28.027
3.2046e-002		28.545	28.048
5.3719e-002		28.913	28.088
9.1673e-002		29.558	28.163
0.16126		30.741	28.317
0.26126		32.441	28.56
0.36126		34.141	28.818
0.46126		35.841	29.089
0.56126		37.541	29.369
0.66126		39.241	29.659
0.76126		40.941	29.955
0.86126		42.641	30.259

0.96126		44.341	30.567
1.		45.	30.687

FIGURE 6**Model (A4, B4) > Transient Thermal (A5) > Solution (A6) > Temperature > Figure****FIGURE 7****Model (A4, B4) > Transient Thermal (A5) > Solution (A6) > Total Heat Flux**

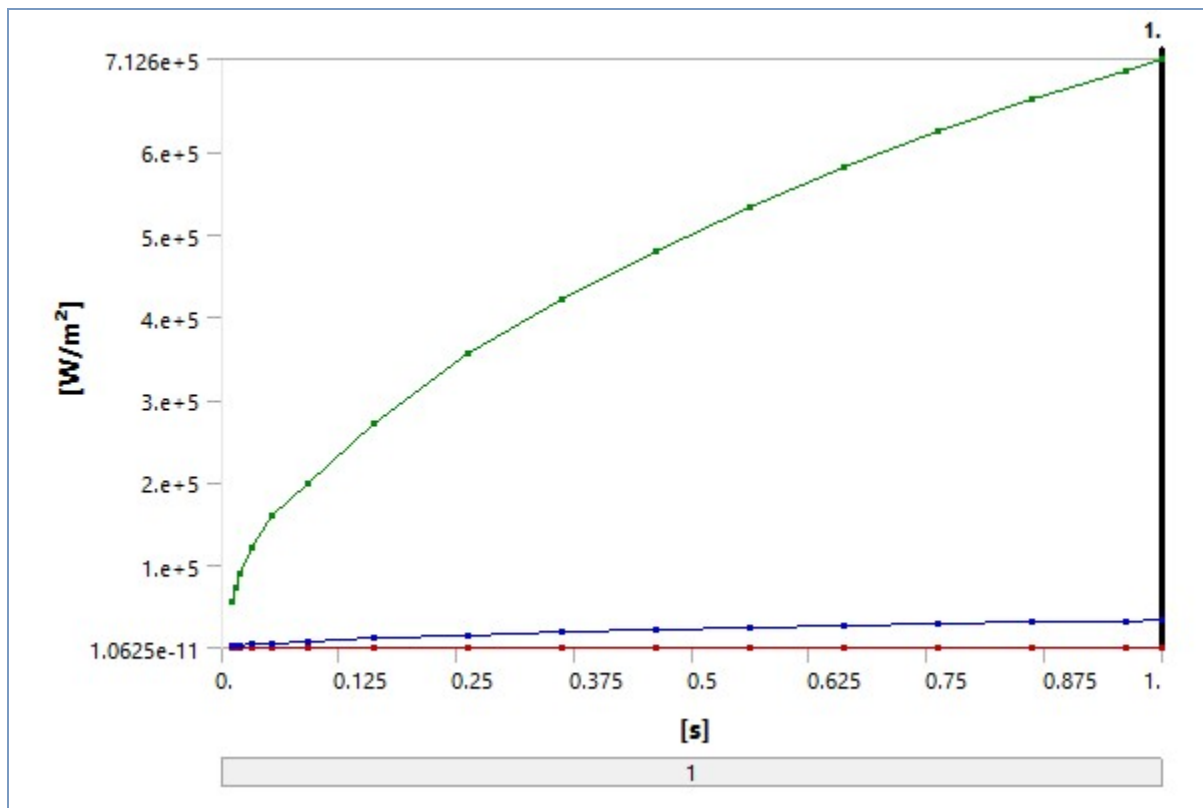


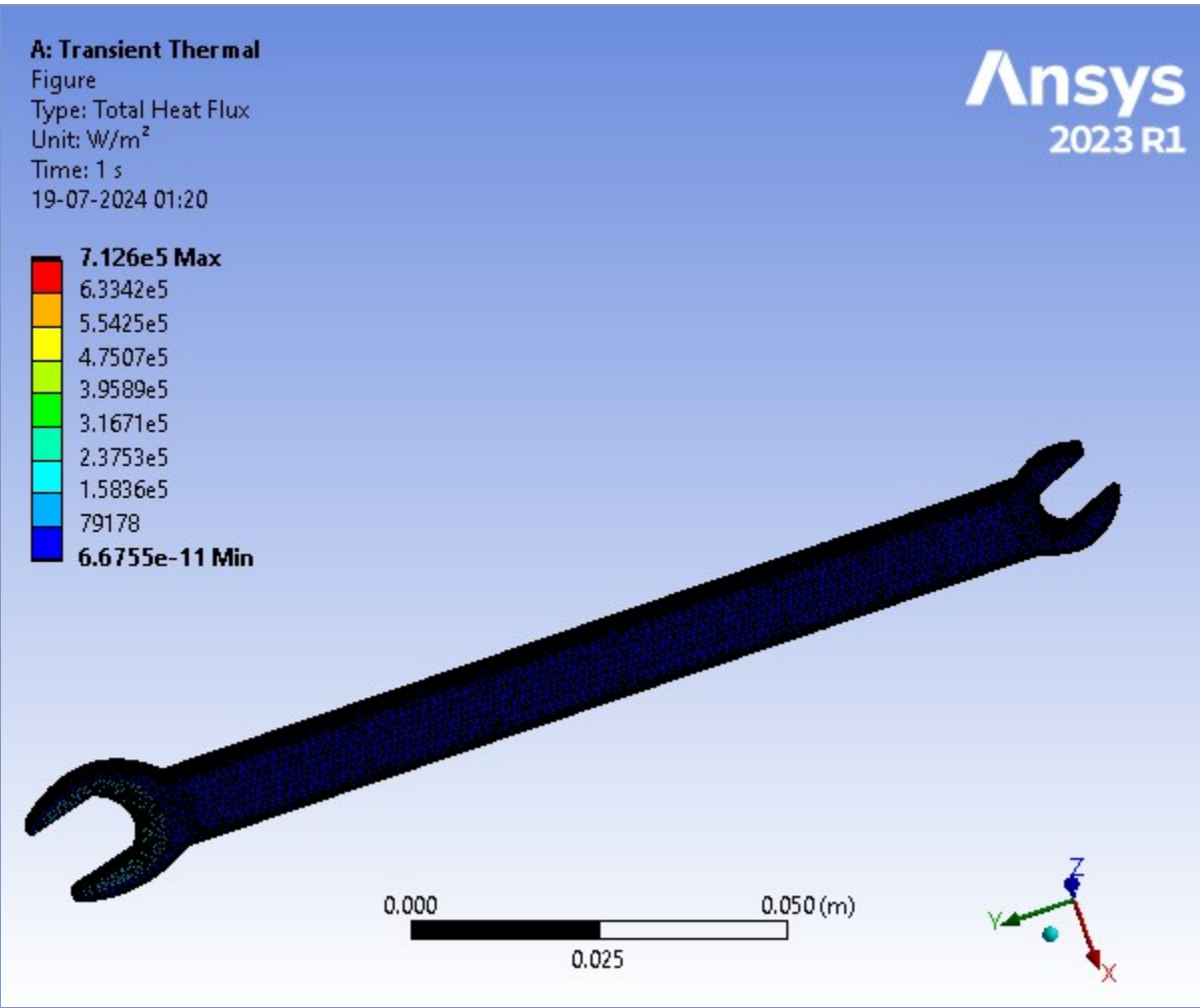
TABLE 21

Model (A4, B4) > Transient Thermal (A5) > Solution (A6) > Total Heat Flux

Time [s]	Minimum [W/m ²]	Maximum [W/m ²]	Average [W/m ²]
1.e-002	3.5282e-011	54820	1764.9
1.4738e-002	2.0998e-011	73806	2413.4
1.9475e-002	3.1043e-011	89668	2972.5
3.2046e-002	3.0262e-011	1.2116e+005	4182.2
5.3719e-002	2.5809e-011	1.5885e+005	5887.7
9.1673e-002	3.8083e-011	1.9934e+005	8301.5
0.16126	6.0843e-011	2.7238e+005	11774
0.26126	4.0141e-011	3.5557e+005	15701
0.36126	6.8522e-011	4.2079e+005	18957
0.46126	3.333e-011	4.7884e+005	21749
0.56126	5.9558e-011	5.3418e+005	24243
0.66126	1.0625e-011	5.8259e+005	26459
0.76126	4.1751e-011	6.2559e+005	28471
0.86126	4.3116e-011	6.641e+005	30322
0.96126	5.8581e-011	6.9884e+005	32043
1.	6.6755e-011	7.126e+005	32729

FIGURE 8

Model (A4, B4) > Transient Thermal (A5) > Solution (A6) > Total Heat Flux > Figure



Static Structural (B5)

TABLE 22	
Model (A4, B4) > Analysis	
Object Name	Static Structural (B5)
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	28. °C
Generate Input Only	No

TABLE 23	
Model (A4, B4) > Static Structural (B5) > Analysis Settings	
Object Name	Analysis Settings
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s

Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Off
Solver Pivot Checking	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Quasi-Static Solution	Off
Rotordynamics Controls	
Coriolis Effect	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Combine Restart Files	Program Controlled
Nonlinear Controls	
Newton-Raphson Option	Program Controlled
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Program Controlled
Advanced	
Inverse Option	No
Contact Split (DMP)	Off
Output Controls	
Stress	Yes
Back Stress	No
Strain	Yes
Contact Data	Yes
Nonlinear Data	No
Nodal Forces	No
Volume and Energy	Yes
Euler Angles	Yes
General Miscellaneous	No
Contact Miscellaneous	No
Store Results At	All Time Points
Result File Compression	Program Controlled
Analysis Data Management	
Solver Files Directory	D:\Pebble Narayanan\Mechanical Design Engineering\P3 - TUNING FORK & SPANNER\Analysis\Spanner_files\dp0\SYS-1\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Contact Summary	Program Controlled
Delete Unneeded	

Files	Yes
Nonlinear Solution	Yes
Solver Units	Active System
Solver Unit System	mks

TABLE 24
Model (A4, B4) > Static Structural (B5) > Loads

Object Name	Fixed Support	Force
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	3 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Applied By		Surface Effect
Coordinate System		Global Coordinate System
X Component		300. N (ramped)
Y Component		0. N (ramped)
Z Component		0. N (ramped)

FIGURE 9
Model (A4, B4) > Static Structural (B5) > Force

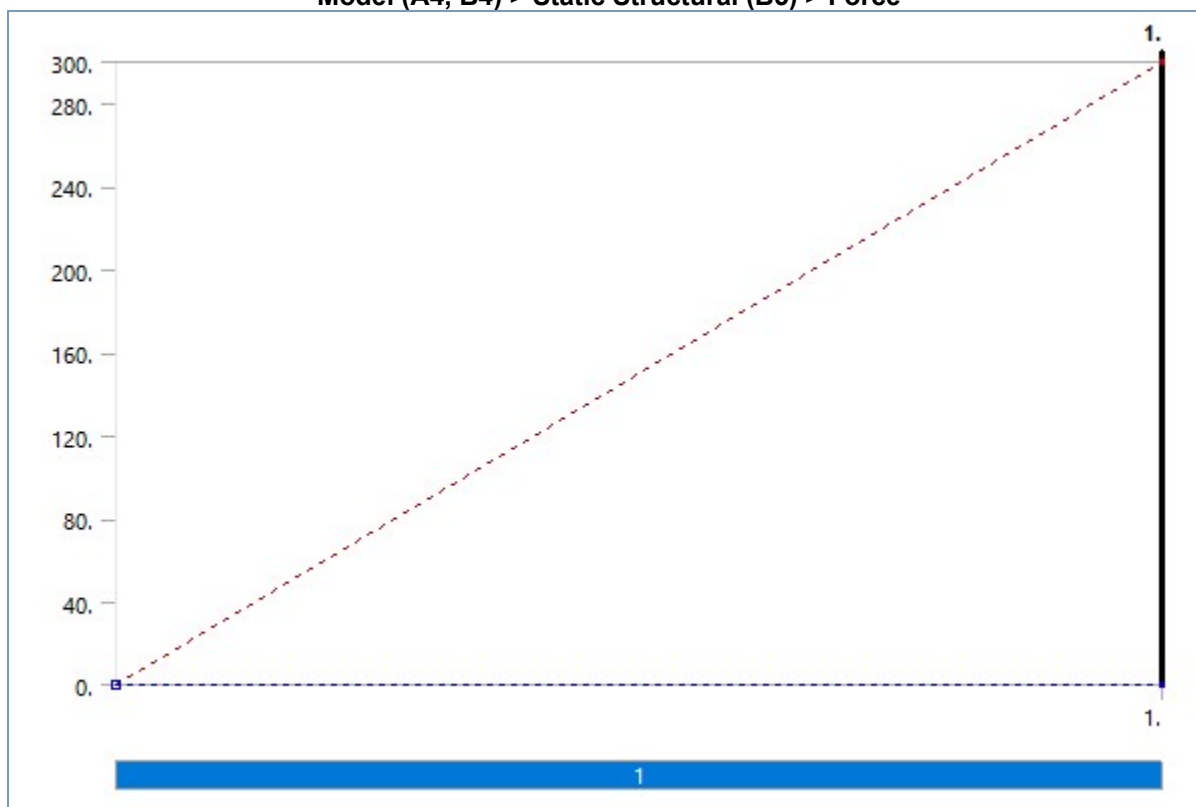


TABLE 25
Model (A4, B4) > Static Structural (B5) > Imported Load (A6)

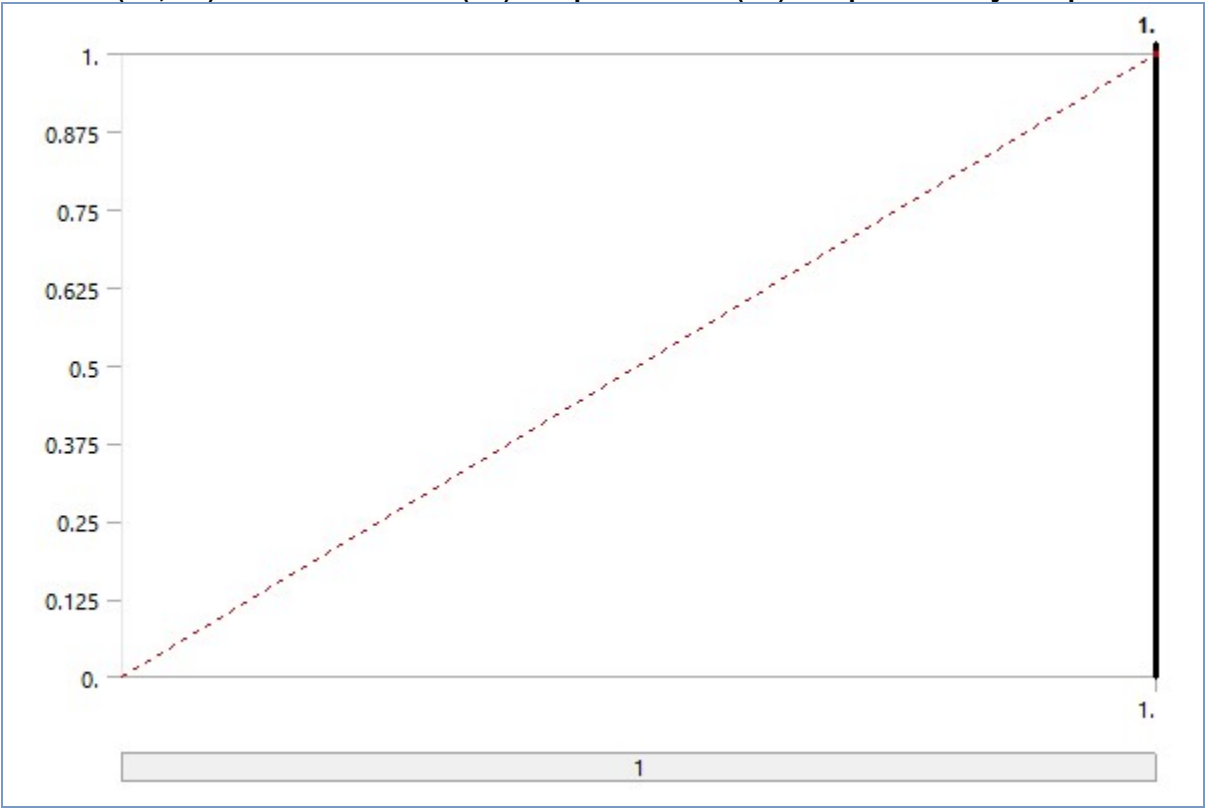
Object Name	<i>Imported Load (A6)</i>
State	Fully Defined

Definition	
Type	Imported Data
Interpolation Type	Mechanical Results Transfer
Suppressed	No
Source	A6::Solution
Data Management	
Delete Mapped Data Files	Yes

TABLE 26
Model (A4, B4) > Static Structural (B5) > Imported Load (A6) > Imported Body Temperature

Object Name	<i>Imported Body Temperature</i>
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Type	Imported Body Temperature
Tabular Loading	Program Controlled
Suppressed	No
Source Environment	Transient Thermal (A5)
Source Time	Worksheet

FIGURE 10
Model (A4, B4) > Static Structural (B5) > Imported Load (A6) > Imported Body Temperature



Model (A4, B4) > Static Structural (B5) > Imported Load (A6) > Imported Body Temperature

	Source Time (s)	Analysis Time (s)
1	End Time	1
*		

Solution (B6)

TABLE 27
Model (A4, B4) > Static Structural (B5) > Solution

Object Name	<i>Solution (B6)</i>
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.
Information	
Status	Done
MAPDL Elapsed Time	28. s
MAPDL Memory Used	673. MB
MAPDL Result File Size	104.44 MB
Post Processing	
Beam Section Results	No
On Demand Stress/Strain	No

TABLE 28
Model (A4, B4) > Static Structural (B5) > Solution (B6) > Solution Information

Object Name	<i>Solution Information</i>
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Identify Element Violations	0
Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 29
Model (A4, B4) > Static Structural (B5) > Solution (B6) > Results

Object Name	Total Deformation	Directional Deformation
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Total Deformation	Directional Deformation
By	Time	
Display Time	Last	
Separate Data by Entity	No	
Calculate Time History	Yes	
Identifier		
Suppressed	No	
Orientation		X Axis

Coordinate System	Global Coordinate System	
Results		
Minimum	0. m	-7.302e-007 m
Maximum	1.01e-003 m	
Average	3.5444e-004 m	3.5314e-004 m
Minimum Occurs On	Spanner-FreeParts PartBody	
Maximum Occurs On	Spanner-FreeParts PartBody	
Minimum Value Over Time		
Minimum	0. m	-7.302e-007 m
Maximum	0. m	-1.451e-007 m
Maximum Value Over Time		
Minimum	2.0197e-004 m	
Maximum	1.01e-003 m	
Information		
Time	1. s	
Load Step	1	
Substep	4	
Iteration Number	5	

FIGURE 11
Model (A4, B4) > Static Structural (B5) > Solution (B6) > Total Deformation

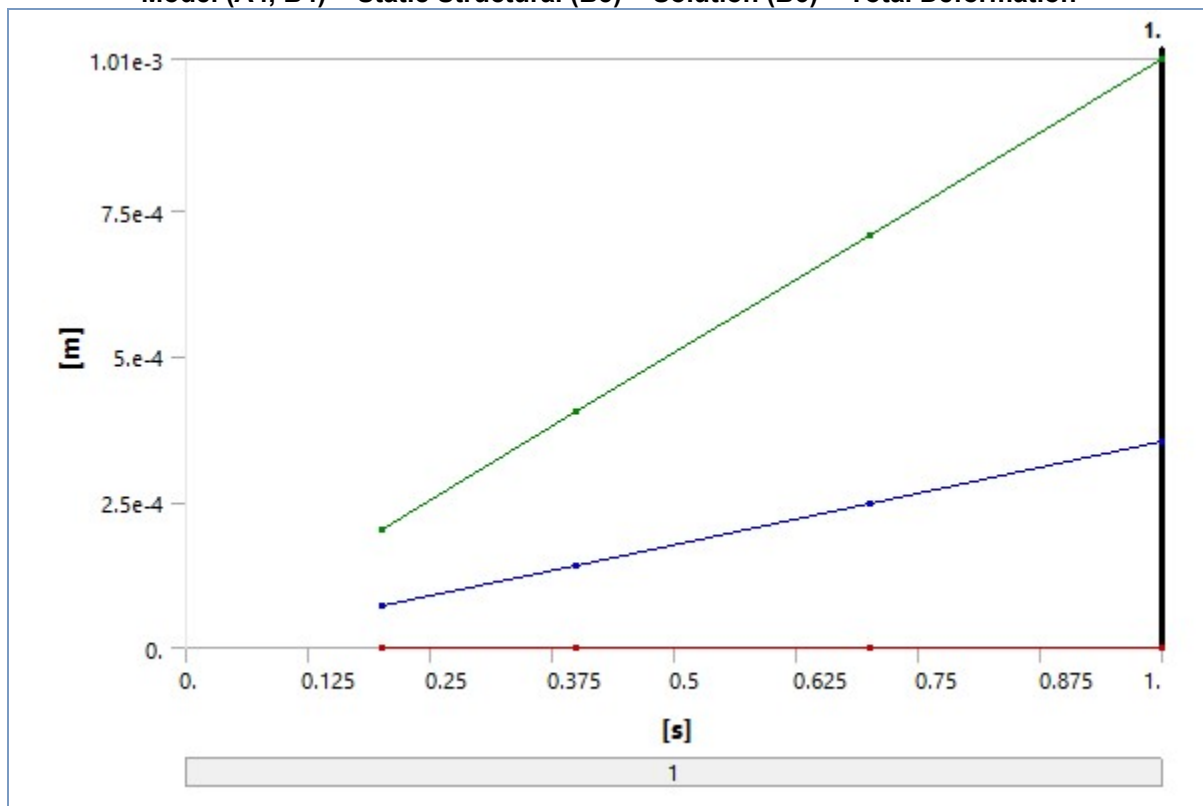


TABLE 30
Model (A4, B4) > Static Structural (B5) > Solution (B6) > Total Deformation

Time [s]	Minimum [m]	Maximum [m]	Average [m]
0.2	0.	2.0197e-004	7.0879e-005
0.4		4.0396e-004	1.4176e-004
0.7		7.0695e-004	2.481e-004
1.		1.01e-003	3.5444e-004

FIGURE 12

Model (A4, B4) > Static Structural (B5) > Solution (B6) > Total Deformation > Figure

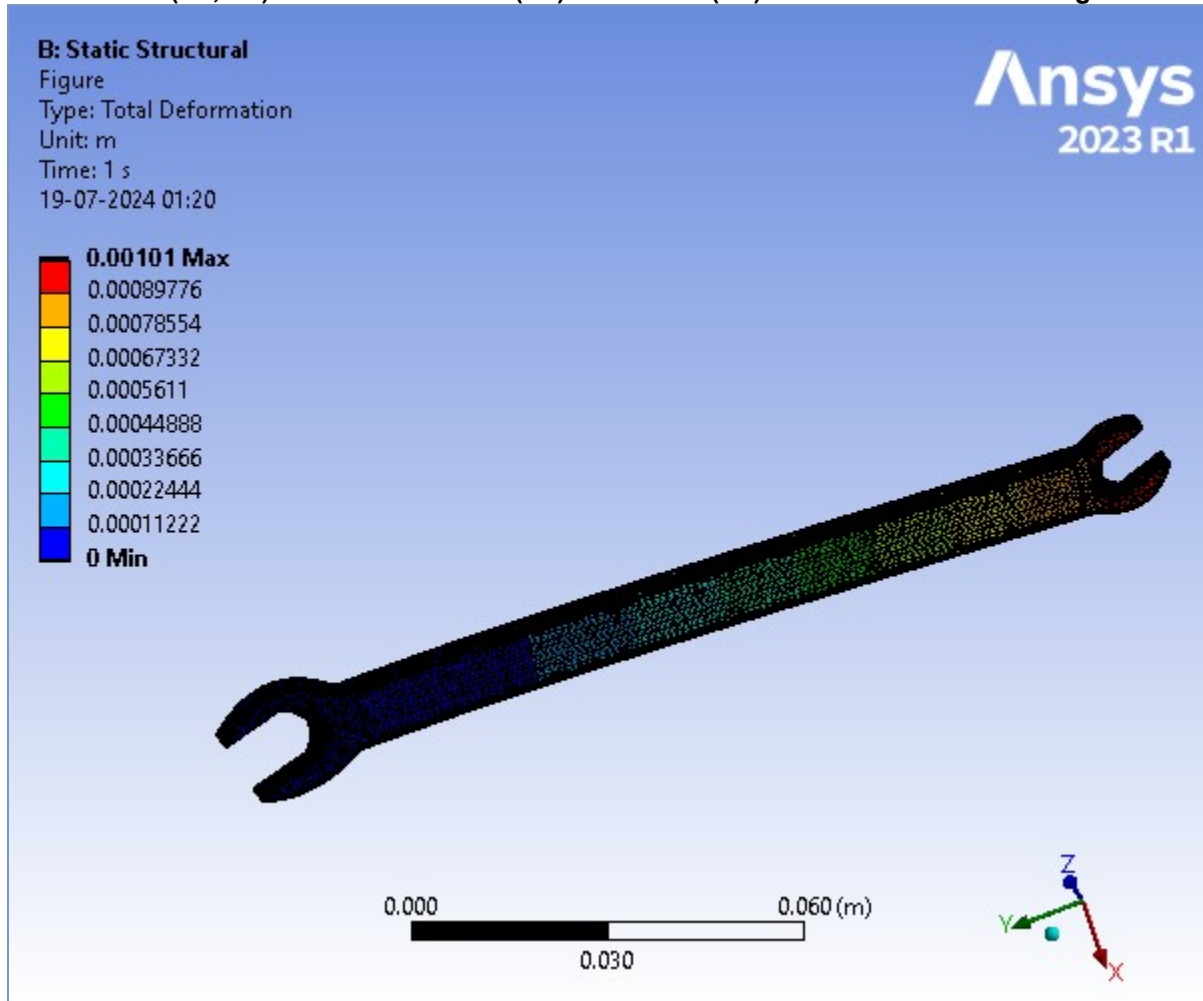


FIGURE 13

Model (A4, B4) > Static Structural (B5) > Solution (B6) > Directional Deformation

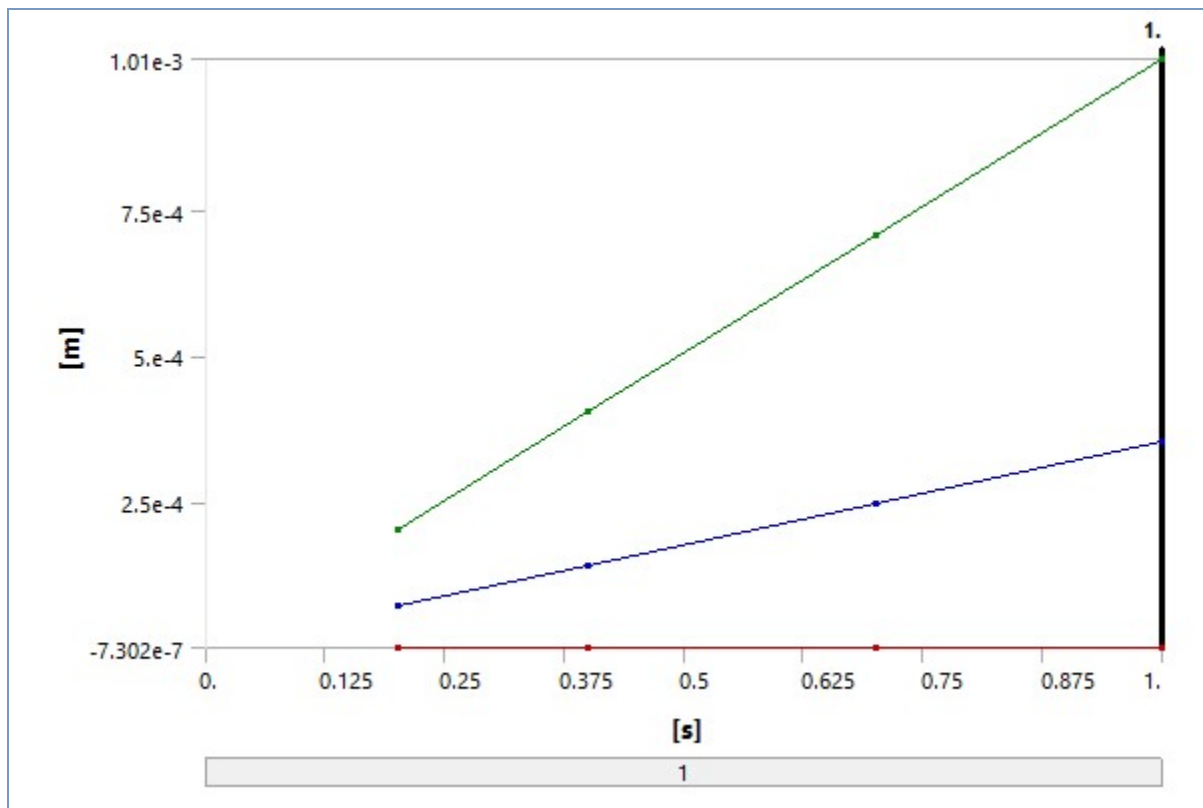
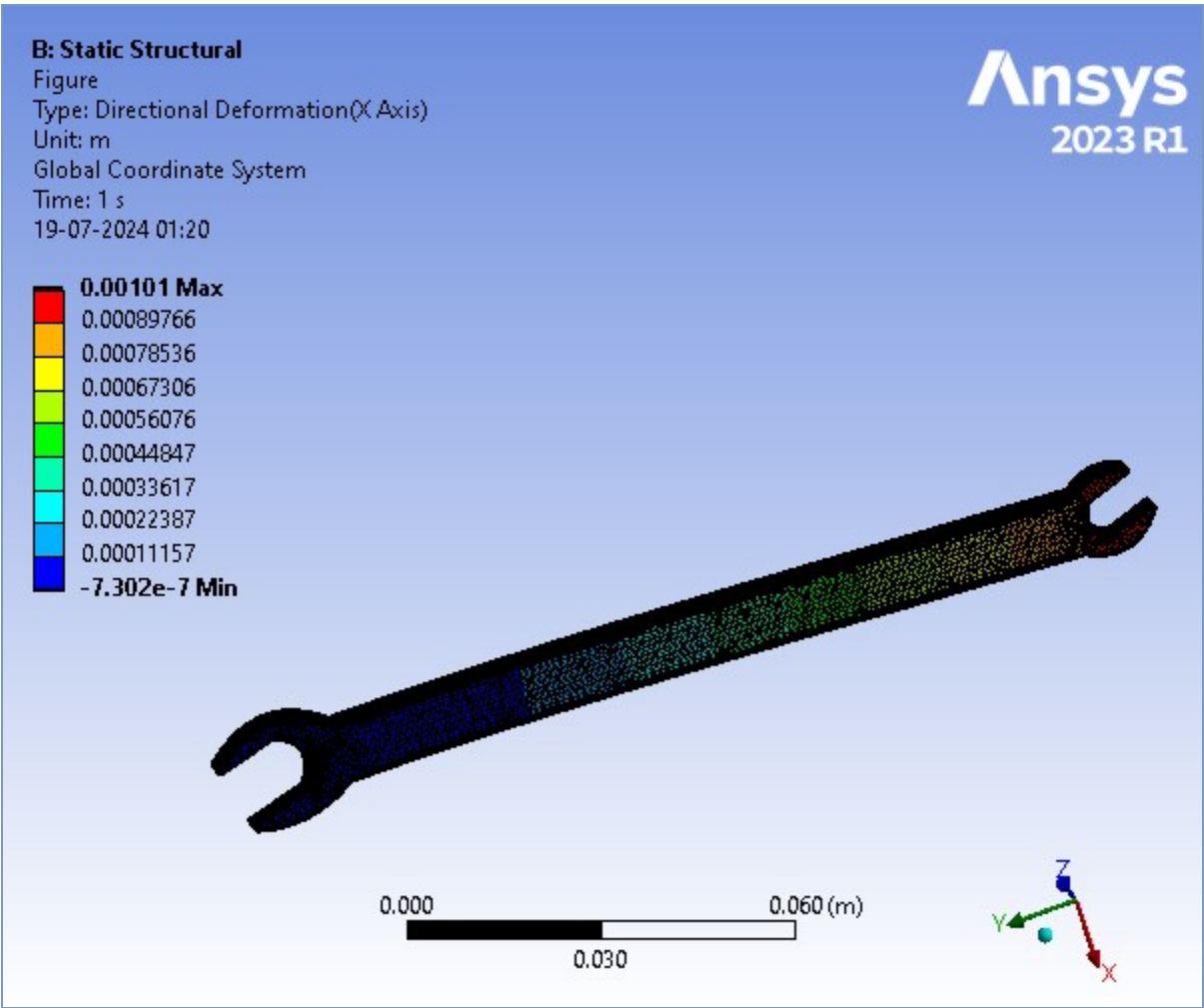


TABLE 31
Model (A4, B4) > Static Structural (B5) > Solution (B6) > Directional Deformation

Time [s]	Minimum [m]	Maximum [m]	Average [m]
0.2	-1.451e-07	2.0197e-04	7.0619e-05
0.4	-2.9068e-07	4.0395e-04	1.4124e-04
0.7	-5.0991e-07	7.0694e-04	2.4719e-04
1.	-7.302e-07	1.01e-003	3.5314e-004

FIGURE 14
Model (A4, B4) > Static Structural (B5) > Solution (B6) > Directional Deformation > Figure



Material Data

Carbon steel, 1015, normalized

TABLE 32
Carbon steel, 1015, normalized > Constants

Density	7850 kg m ⁻³
Tensile Yield Strength	3.263e+008 Pa
Tensile Ultimate Strength	4.226e+008 Pa
Resistivity	1.697e-007 ohm m

TABLE 33
Carbon steel, 1015, normalized > Opacity

Red	Green	Blue
128	128	128
Opacity		
1		
Metallic Finish		
1		

TABLE 34
Carbon steel, 1015, normalized > Isotropic Elasticity

Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa	Temperature C
2.218e+011	0.29	1.7603e+011	8.5969e+010	-260.2
2.203e+011	0.29	1.7484e+011	8.5388e+010	-182.3
2.174e+011	0.29	1.7254e+011	8.4264e+010	-104.4
2.141e+011	0.29	1.6992e+011	8.2984e+010	-26.47
2.114e+011	0.29	1.6778e+011	8.1938e+010	51.43
2.081e+011	0.29	1.6516e+011	8.0659e+010	129.3
2.036e+011	0.29	1.6159e+011	7.8915e+010	207.2
1.978e+011	0.29	1.5698e+011	7.6667e+010	285.1
1.907e+011	0.29	1.5135e+011	7.3915e+010	363
1.823e+011	0.29	1.4468e+011	7.0659e+010	440.9
1.726e+011	0.29	1.3698e+011	6.6899e+010	518.8
1.616e+011	0.29	1.2825e+011	6.2636e+010	596.7
1.493e+011	0.29	1.1849e+011	5.7868e+010	674.6
1.358e+011	0.29	1.0778e+011	5.2636e+010	752.5
1.277e+011	0.29	1.0135e+011	4.9496e+010	830.4
1.224e+011	0.29	9.7143e+010	4.7442e+010	908.3
1.171e+011	0.29	9.2937e+010	4.5388e+010	986.2
1.118e+011	0.29	8.873e+010	4.3333e+010	1064
1.066e+011	0.29	8.4603e+010	4.1318e+010	1142
1.013e+011	0.29	8.0397e+010	3.9264e+010	1220

TABLE 35
Carbon steel, 1015, normalized > Multilinear Isotropic Hardening

Stress Pa	Plastic Strain m m ⁻¹	Temperature C
3.584e+008	0	20
4.069e+008	3.333e-003	20
4.327e+008	6.667e-003	20
4.503e+008	1.e-002	20
4.652e+008	1.333e-002	20
4.778e+008	1.667e-002	20
4.89e+008	2.e-002	20
4.991e+008	2.333e-002	20
5.083e+008	2.667e-002	20
5.161e+008	3.e-002	20

TABLE 36
Carbon steel, 1015, normalized > S-N Curve

Alternating Stress Pa	Cycles	R-Ratio
3.887e+008	1000	-1
3.645e+008	3162	-1
3.423e+008	10000	-1
3.217e+008	31620	-1
3.025e+008	1.e+005	-1
2.845e+008	3.162e+005	-1
2.676e+008	1.e+006	-1
2.517e+008	3.162e+006	-1
2.367e+008	1.e+007	-1
2.227e+008	3.162e+007	-1
2.095e+008	1.e+008	-1
2.018e+008	1000	0
1.951e+008	3162	0
1.885e+008	10000	0

1.821e+008	31620	0
1.757e+008	1.e+005	0
1.695e+008	3.162e+005	0
1.633e+008	1.e+006	0
1.573e+008	3.162e+006	0
1.513e+008	1.e+007	0
1.454e+008	3.162e+007	0
1.397e+008	1.e+008	0
1.031e+008	1000	0.5
1.013e+008	3162	0.5
9.953e+007	10000	0.5
9.77e+007	31620	0.5
9.584e+007	1.e+005	0.5
9.394e+007	3.162e+005	0.5
9.201e+007	1.e+006	0.5
9.005e+007	3.162e+006	0.5
8.805e+007	1.e+007	0.5
8.602e+007	3.162e+007	0.5
8.397e+007	1.e+008	0.5

TABLE 37
Carbon steel, 1015, normalized > Isotropic Secant Coefficient of Thermal Expansion

Coefficient of Thermal Expansion C^{-1}	Temperature C
6.847e-006	-270.1
8.218e-006	-227.9
9.196e-006	-185.7
9.896e-006	-143.5
1.041e-005	-101.3
1.081e-005	-59.04
1.114e-005	-16.82
1.145e-005	25.41
1.175e-005	67.63
1.205e-005	109.9
1.236e-005	152.1
1.267e-005	194.3
1.298e-005	236.5
1.327e-005	278.7
1.353e-005	321
1.376e-005	363.2
1.396e-005	405.4
1.416e-005	447.6
1.433e-005	489.9
1.449e-005	532.1
1.462e-005	574.3
1.474e-005	616.5
1.483e-005	658.7
1.486e-005	701
1.296e-005	743.2
1.095e-005	785.4
1.123e-005	827.6
1.172e-005	869.9
Zero-Thermal-Strain Reference Temperature C	
20	

TABLE 38
Carbon steel, 1015, normalized > Isotropic Thermal Conductivity

Thermal Conductivity W m ⁻¹ C ⁻¹	Temperature C
46.72	-150.2
50.31	-73.48
51.99	3.183
52.1	79.85
50.96	156.5
48.92	233.2
46.31	309.9
43.45	386.5
40.7	463.2
38.37	539.9

TABLE 39
Carbon steel, 1015, normalized > Specific Heat Constant Pressure

Specific Heat J kg ⁻¹ C ⁻¹	Temperature C
222.6	-200.2
265.4	-168.4
303.7	-136.7
337.9	-105
368.4	-73.25
395.5	-41.53
419.5	-9.805
440.8	21.92
459.6	53.64
476.5	85.37
491.6	117.1
505.4	148.8
518.1	180.5
530.1	212.3
541.8	244
553.4	275.7
565.4	307.4
578	339.2
591.7	370.9
606.6	402.6
623.3	434.3
641.9	466.1
662.9	497.8
686.6	529.5
713.3	561.2
743.4	593
777.2	624.7
815.1	656.4
857.3	688.1
1025	719.9