

Introduction to ANSYS Mechanical

Realize Your Product Promise®

ANSYS Chapter Overview

In this chapter, performing steady-state thermal analyses in Mechanical will be covered:

- A. Basics of Steady State Heat Transfer
- **B.** Geometry
- **C.** Material Properties
- **D.** Thermal Contact
- E. Thermal Boundary Conditions
- F. Solution Options
- **G.** Results and Postprocessing
- H. Workshop 9.1 Pump Housing

Note: advanced topics including thermal transient analyses are covered in the ANSYS Mechanical Heat Transfer training course.

ANSYS A. Basics of Steady-State Heat Transfer

The schematic setup for a steady-state (static) thermal analysis is shown here.

Later in this chapter we will shown the procedure for setting up a coupled thermal structural analysis.



ANSYS . . . Basics of Steady-State Heat Transfer

For a steady-state (static) thermal analysis in Mechanical, the temperatures {T} are solved for in the matrix below:

 $[K(T)]{T} = {Q(T)}$

Assumptions:

- No transient effects are considered in a steady-state analysis
- [K] can be constant or a function of temperature
- {Q} can be constant or a function of temperature
- Fixed temperatures represent constraints {T} on the system (like fixed displacements on structures).

It is important to remember these assumptions related to performing *thermal analyses* in Mechanical.

ANSYS B. Geometry

In thermal analyses all body types are supported:

- Solid, surface, and line bodies.
 - Line bodies cross-section and orientation is defined within DesignModeler or SpaceClaim.
 - A "Thermal Mass" feature is available for use in transient analysis (not covered in this course).

Shell and line body assumptions:

- Shells: temperatures may vary over the surface (no through-thickness temperature variation)
- Line bodies: temperature may vary along the length of the beam (no variation across the cross section).

ANSYS C. Material Properties

• The only required material property for steady state is thermal conductivity.

 Thermal Conductivity is input in the Engineering Data application

 Temperature-dependent thermal conductivity is input as a table



If any temperature-dependent material properties exist, this will result in a *nonlinear* solution.

As with structural analyses, contact regions are automatically created to enable heat transfer between parts in assemblies.





When can heat flow across a contact region?

Contact Turno	Heat Transfe	r Between Parts in Cor	ntact Region?
contact Type	Initially Touching	Inside Pinball Region	Outside Pinball Region
Bonded	Yes	Yes	No
No Separation	Yes	Yes	No
Rough	Yes	No	No
Frictionless	Yes	No	No
Frictional	Yes	No	No

- Thermal Contact Behavior:
 - If parts are in contact heat transfer can occur between them.
 - If parts are out of contact no heat transfer takes place.
 - For bonded and no separation the pinball can be expanded to allow heat transfer across a gap.

If the contact is bonded or no separation, then heat transfer will occur when the surfaces are within the pinball radius.



Details of "Bonded - Impeller To PumpHousing" л Scope Geometry Selection Scoping Method Contact 1 Face Target 1 Face Contact Bodies Impeller Target Bodies PumpHousing Definition Bonded Type Scope Mode Automatic Behavior Program Controlled Trim Contact Program Controlled Trim Tolerance 0.79243 mm Suppressed No Advanced Formulation Program Controlled Detection Method Program Controlled Elastic Slip Tolerance Program Controlled Program Controlled Thermal Conductance inball Region Radius Pinball Radius 0. mm Geometric Modification Contact Geometry Correction None Target Geometry Correction None

Contact Region

In this figure, the gap between the two parts is larger than the pinball region, so no heat transfer will occur between the parts.

By default, perfect thermal contact is assumed, meaning no temperature drop occurs at the interface.

Numerous "real world" conditions can contribute to less than perfect contact conductance:

- Surface roughness
- surface finish
- Oxides
- trapped fluids
- contact pressure
- surface temperature
- lubricants
- Etc





The amount of heat flow across a contact interface is defined by the contact heat flux expression "q" shown here:

- *T_{contact}* is the temperature of the contact surface and
- *T_{target}* is the temperature of the target surface.

 $q = TCC \cdot \left(T_{target} - T_{contact}\right)$

- By default, TCC (<u>Thermal Contact Conductivity</u>) is set to a high value based on the size and material conductivities in the model. This essentially provides 'perfect' conductance between parts.
- A lower TCC value can be set in the contact details to provide a thermal resistance.

Scope Scoping Method Geometry Selection Contact 1 Face Target 1 Face Contact Bodies Impeller Target Bodies PumpHousing Definition Type Type Bonded Scope Mode Automatic Behavior Program Controlled Trim Contact Program Controlled Trim Tolerance 0.79243 mm Suppressed No Advanced Frogram Controlled Formulation Program Controlled Thermal Conductance Manual Thermal Conductance Manual Thermal Conductance Value 0. W/mm².*C Pinball Region Program Controlled Geometric Modification Contact Geometry Correction Contact Geometry Correction None None	etails of "Bonded - Impeller To	PumpHousing"
Scoping Method Geometry Selection Contact 1 Face Target 1 Face Contact Bodies Impeller Target Bodies PumpHousing Definition	Scope	
Contact 1 Face Target 1 Face Contact Bodies Impeller Target Bodies PumpHousing Definition Program Controlled Type Bonded Scope Mode Automatic Behavior Program Controlled Trim Contact Program Controlled Trim Tolerance 0.79243 mm Suppressed No Advanced - Formulation Program Controlled Detection Method Program Controlled Thermal Conductance Manual Thermal Conductance Nual Geometric Modification Program Controlled Contact Geometry Correction None	Scoping Method	Geometry Selection
Target 1 Face Contact Bodies Impeller Target Bodies PumpHousing Definition Type Type Bonded Scope Mode Automatic Behavior Program Controlled Trim Contact Program Controlled Trim Tolerance 0.79243 mm Suppressed No Advanced Forguam Controlled Formulation Program Controlled Detection Method Program Controlled Thermal Conductance Manual Thermal Conductance Manual Thermal Conductance Program Controlled Geometric Modification Program Controlled Contact Geometry Correction None	Contact	1 Face
Contact Bodies Impeller Target Bodies PumpHousing Definition Type Definition Bonded Scope Mode Automatic Behavior Program Controlled Trim Contact Program Controlled Trim Tolerance 0.79243 mm Suppressed No Advanced Formulation Formulation Program Controlled Detection Method Program Controlled Thermal Conductance Manual Thermal Conductance Value 0. W/mm ² · ^C C Pinball Region Program Controlled Geometric Modification Contact Geometry Correction Contact Geometry Correction None	Target	1 Face
Target Bodies PumpHousing Definition Figure Bonded Type Bonded Scope Mode Automatic Behavior Program Controlled Trim Contact Program Controlled Trim Tolerance 0.79243 mm Suppressed No Advanced Program Controlled Elastic Slip Tolerance Program Controlled Thermal Conductance Manual Thermal Conductance Nowal Geometric Modification Program Controlled Contact Geometry Correction None	Contact Bodies	Impeller
Definition Type Bonded Scope Mode Automatic Scope Mode Automatic Behavior Program Controlled Trim Contact Program Controlled Trim Tolerance 0.79243 mm Suppressed No Advanced - Formulation Program Controlled Detection Method Program Controlled Elastic Slip Tolerance Manual Thermal Conductance Manual Thermal Conductance O.W/mm ² ·C Pinball Region Program Controlled Geometric Modification Contact Geometry Correction Contact Geometry Correction None	Target Bodies	PumpHousing
Type Bonded Scope Mode Automatic Behavior Program Controlled Trim Contact Program Controlled Trim Tolerance 0.79243 mm Suppressed No Advanced Forgram Controlled Formulation Program Controlled Detection Method Program Controlled Elastic Slip Tolerance Manual Thermal Conductance Manual Thermal Conductance Value 0. W/mm ¹ ·°C Pinball Region Program Controlled Geometric Modification Contact Geometry Correction Contact Geometry Correction None	Definition	
Scope Mode Automatic Behavior Program Controlled Trim Contact Program Controlled Trim Tolerance 0.79243 mm Suppressed No Advanced Formulation Formulation Program Controlled Elastic Slip Tolerance Program Controlled Thermal Conductance Manual Thermal Conductance Value 0. W/mm³.*C Pinball Region Program Controlled Geometric Modification Contact Geometry Correction Target Geometry Correction None	Туре	Bonded
Behavior Program Controlled Trim Contact Program Controlled Trim Tolerance 0.79243 mm Suppressed No Advanced Program Controlled Formulation Program Controlled Detection Method Program Controlled Elastic Slip Tolerance Program Controlled Thermal Conductance Manual Thermal Conductance No Geometric Modification Contact Geometry Correction Target Geometry Correction None	Scope Mode	Automatic
Trim Contact Program Controlled Trim Tolerance 0.79243 mm Suppressed No Advanced Porgram Controlled Petection Method Program Controlled Elastic Slip Tolerance Manual Thermal Conductance Manual Thermal Conductance No Geometric Modification Program Controlled Contact Geometry Correction None	Behavior	Program Controlled
Trim Tolerance 0.79243 mm Suppressed No Advanced Formulation Program Controlled Detection Method Detection Method Program Controlled Elastic Slip Tolerance Program Controlled Thermal Conductance Manual Thermal Conductance Value 0. W/mm ² ·°C Pinball Region Program Controlled Geometric Modification Contact Geometry Correction Target Geometry Correction None	Trim Contact	Program Controlled
Suppressed No Advanced Formulation Formulation Program Controlled Detection Method Program Controlled Elastic Slip Tolerance Program Controlled Thermal Conductance Manual Thermal Conductance Value 0. W/mm ² .*C Pinball Region Program Controlled Geometric Modification Contact Geometry Correction Target Geometry Correction None	Trim Tolerance	0.79243 mm
Advanced Formulation Program Controlled Detection Method Program Controlled Elastic Slip Tolerance Program Controlled Thermal Conductance Manual Thermal Conductance Value 0. W/mm²*C Pinball Region Program Controlled Geometric Modification Contact Geometry Correction Target Geometry Correction None	Suppressed	No
Formulation Program Controlled Detection Method Program Controlled Elastic Slip Tolerance Program Controlled Thermal Conductance Manual Thermal Conductance 0. W/mm ² ·*C Pinball Region Program Controlled Geometric Modification Contact Geometry Correction Target Geometry Correction None	Advanced	
Detection Method Program Controlled Elastic Slip Tolerance Program Controlled Thermal Conductance Manual Thermal Conductance Value 0. W/mm ¹ ·°C Pinball Region Program Controlled Geometric Modification Forgram Controlled Contact Geometry Correction None	Formulation	Program Controlled
Elastic Slip Tolerance Program Controlled Thermal Conductance Manual Thermal Conductance Value 0. W/mm ² ·*C Pinball Region Program Controlled Geometric Modification Contact Geometry Correction None Target Geometry Correction None	Detection Method	Program Controlled
Thermal Conductance Manual Thermal Conductance Value 0. W/mm².*C Pinball Region Program Controlled Geometric Modification Contact Geometry Correction Target Geometry Correction None	Elastic Slip Tolerance	Program Controlled
Thermal Conductance Value 0. W/mm³·*C Pinball Region Program Controlled Geometric Modification Contact Geometry Correction None Target Geometry Correction None	Thermal Conductance	Manual
Pinball Region Program Controlled Geometric Modification Contact Geometry Correction None Target Geometry Correction None	Thermal Conductance Value	0. W/mm²⋅°C
Geometric Modification Contact Geometry Correction None Target Geometry Correction None	Pinball Region	Program Controlled
Contact Geometry Correction None Target Geometry Correction None	Geometric Modification	
Target Geometry Correction None	Contact Geometry Correction	None
	Target Geometry Correction	None

Spot welds provide discrete contact locations where heat transfer can take place.





Heat Flow: Heat Flow

- A heat flow rate can be applied to a vertex, edge, or surface.
- Heat flow has units of energy/time.

Heat Flux: Meat Flux

- Heat flux can be applied to surfaces only (edges in 2D).
- Heat flux has units of energy/time/area.

Internal Heat Generation: 🥄 🧟 Internal Heat Generation

- An internal heat generation rate can be applied to bodies only.
- Heat generation has units of energy/time/volume.

A positive value for heat load will add energy to the system.

Perfectly insulated (heat flow = 0): 🔍 Perfectly Insulated

Remove part of an applied boundary condition.



<u>NOTE</u>: adiabatic (perfectly insulated) is the default condition where no boundary condition is applied. Therefore, Perfectly Insulated is <u>ONLY</u> necessary to remove part of a previously applied BC or to define a symmetry region.

Temperature, Convection and Radiation:

 At least one type of thermal condition containing temperature {T} should be present to bound the problem (prevent the thermal equivalent of rigid body motion).



Imposes a temperature on vertices, edges, surfaces or bodies.

$$q_c = hA(T_{surface} - T_{ambient})$$

Convection:

• Ambient temperature

$$q_R = \sigma \varepsilon FA \left(T_{surface}^4 - T_{ambient}^4 \right)$$

Radiation: Radiation

- Ambient temperature
- 15 © 2015 ANSYS, Inc. February 27, 2015

Convection: Convection

- Applied to surfaces only (edges in 2D analyses).
- Convection q is defined by a film coefficient h, the surface area A, and the difference in the surface temperature $T_{surface}$ & ambient temperature $T_{ambient}$ $q_c = hA(T_{surface} - T_{ambient})$

Ic **Surface** and

- "h" and "T_{ambient}" are user input values.
- The film coefficient *h* can be constant, temperature or spatially dependent (only temperature dependent is covered in this course).

De	etails of "Convection"	д
	Scope	
	Scoping Method	Geometry Selection
	Geometry	1 Face
	Definition	
Г	Туре	Convection
	Film Coefficient	3. W/m ² .°C (ramped)
	Ambient Temperature	22.°C (ramped)
L	Ambient Temperature Convection Matrix	22. °C (ramped) Program Controlled

De	etails of "Convection"		д
-	Scope		
	Scoping Method	Geometry Selection	
	Geometry	1 Face	
-	Definition		
	Туре	Convection	
	Film Coefficient	Tabular Data	
	Coefficient Type	Average Film Temperature	
	Ambient Temperature	22. °C (ramped)	
	Convection Matrix	Program Controlled	· · · · ·
	Suppressed	No	
	Edit Data For	Film Coefficient	
-	Tabular Data		
	Independent Variable	Temperature	
-	Graph Controls		
	X-Axis	Temperature	

To define temperature dependent convection:

- Select "Tabular" for the film coefficient.
- Set the independent variable to "temperature".
- Enter coefficient vs temperature tabular data.
- In the "Coefficient Type" field, specify how temperature from the table is to be interpreted.

		1.7.1.777			
-	Definition				
	Туре	Convection			
	Film Coefficient	Tabular Data			
	Coefficient Type	Average Film Temperature 🛛 💌			
	Ambient Temperature	Bulk Temperature			
	Suppressed	-Surface Temperature			
	Edit Data For	Difference of Surface and Bulk Temp			

Note: as shown (above right), other independent variables are available for tabular data. These are not covered in this course.



-	Scope		•
	Scoping Method	Geometry Selection	
1	Geometry	1 Face	
]	Definition	÷	-
	Туре	Convection	
	Film Coefficient	Tabular Data	
	Coefficient Type	Average Film Temperature	S Import
	Ambient Temperature	200. °⊂ (ramped)	😼 Import
	Suppressed	No	The second
	Edit Data For	Film Coefficient	Export
	Tabular Data	1	Constant
	Independent Variabk	Temperature	
1	Graph Controls	Time	🖌 Tabular
2	X-Axis	18	Function



• Once defined convection correlations can be exported to a convection library for reuse.

 Several common "text book" correlations are available to import from a Workbench sample library.

🔊 Import...

Export...

Constant Tabular Function



ata Source:		20.2
Convection_Samples C:\Program Files\ANSYS In	:\v140\aisol/CommonFiles/Language/en-i	us/EngineeringDal
∢ [
	Add	Remove
Convection Data to Import:		
Filter		
C Stagnant Air - Horizontal Cyl		
C Stagnant Air - Simplified Case		
C Stagnant Air - Vertical Planes1		
C Stagnant Air - Vertical Planes2		
C Stagnant Air - Vertical Planes2 C Stagnant Air - Vertical Planes		
C Stagnant Air - Vertical Planes2 C Stagnant Air - Vertical Planes C Stagnant Water - Simplified Case		
C Stagnant Air - Vertical Planes2 C Stagnant Air - Vertical Planes C Stagnant Water - Simplified Case		
C Stagnant Air - Vertical Planes2 C Stagnant Air - Vertical Planes C Stagnant Water - Simplified Case		
C Stagnant Air - Vertical Planes2 C Stagnant Air - Vertical Planes C Stagnant Water - Simplified Case		

Radiation:

Radiation

Applied to surfaces (edges in 2D analyses)

 $q_{R} = \sigma \varepsilon FA \left(T_{surface}^{4} - T_{ambient}^{4} \right)$

- Where:
 - $-\sigma$ = Stefan-Boltzman constant
 - ε = Emissivity
 - A = Area of radiating surface
 - F = Form factor
- Correlations:
 - <u>To ambient</u> (form factor assumed to be 1)
 OR
 - <u>Surface to surface</u> (view factors calculated).
- Stefan Boltzman constant is set automatically based on the active unit system
- 19 © 2015 ANSYS, Inc. February 27, 2015

-	Scope				
	icoping Method Named Selec	Named Selection	on		
	Named Selection	NS_RadSurf_1			
	Definition				
	Туре	Padiation			
	Correlation	To Ambient			
	Emissivity	0.7			
1	Ambient Temperature	25. °C (ramped)			
	Suppressed	No			

De	tails of "Radiation 2"	
Ξ	Scope	
	Scoping Method	Geometry Selection
	Geometry	5 Faces
	Definition	1
-	Type	Radiation
	Correlation	Surface to Surface
	Emissivity	1. (step applied)
	Ambient Temperature	22. °C (ramped)
	Enclosure	1.
	Suppressed	No

Surface to Surface radiation is related by "Enclosure" number.

• In the example shown, 2 radiation boundaries are defined with different emissivity. By sharing a common enclosure number, view factors will be calculated for all surfaces.



ANSYS F. Solution Options

As with all analysis types in Mechanical the "Analysis Settings" can be used to set solution options.

• Note, the same Analysis Data Management options discussed in chapter 4 regarding static analyses are available in thermal analysis.



	E Steady-	State Thermal (D5) al Temperature ysis Settings vection
De	tails of "Analysis Setti	ngs" P
	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
+	Radiosity Controls	
+	Nonlinear Controls	
+	Output Controls	
Ξ	Analysis Data Manage	ement
	Solver Files Directory	E:\TEST\WS4a-bolt_files\dp0\SYS-5\MECH\
	Future Analysis	None
	Scratch Solver Files	
	Save MAPDL db	No
	Delete Unneeded Fi	Yes
	Nonlinear Solution	Yes
	Solver Units	Active System
	Solver Unit System	mks
+	Visibility	

ANSYS ... Solution Options

To perform a thermal-stress solution link a structural analysis to the thermal model at the Solution level.

An "imported load" branch is inserted in the Static Structural branch along with any applied structural loads and supports

-	4			-		В		
1	Steady-State Thermal (ANSYS)	i.		1	777	Static Structural (ANSYS)		
2	Engineering Data	× .		2	9	Engineering Data	~	
3	P Geometry	1	-	3	P	Geometry	~	
4	🎯 Model	4		4	0	Model	4	
5	🍓 Setup	7	-	5	1	Setup	2	
6	🕼 Solution	4	/	6	1	Solution	4	
7	🥪 Results	4		7	1	Results	4	



ANSYS G. Results and Postprocessing

Various results are available for postprocessing:

- Temperature
- Heat Flux
- "Reaction" Heat Flow Rate
- User defined results







In Mechanical, results can be requested before or after solving.

- A new solution is not required when retrieving new results from a solved model.
- 23 © 2015 ANSYS, Inc. February 27, 2015



Temperature:

• Temperature is a scalar quantity and has no direction associated with it.





ANSYS ... Heat Flux

Heat flux contour or vector plots are available:

- Heat flux *q* is defined as:
- $q = -KXX \cdot \nabla T$



- "Total Heat Flux" and "Directional Heat Flux" can be requested
 - The magnitude & direction can be plotted as vectors by activating vector mode
 A: Steady-State Thermal (ANSYS)





ANSYS ... Reaction Heat Flow Rate

Reaction heat flow rates are available for Temperature, convection or radiation boundary conditions:

- Reaction heat flow rate is requested by inserting a reaction probe.
- A short cut is to drag and drop a boundary condition onto the Solution branch.





=	Definition					
	Туре	Reaction				
	Location Method	Boundary Condition				
	Boundary Condition	on Temperature				
	Options					
	Display Time	End Time				
-	Results					
	Heat	3083.1 W				
J	Maximum value u	ver time				
]	Minimum ¥alue O	ver Time				
i	Information					

ANSYS ... Thermal equilibrium

When the solution is finished it's good practice to check the validity of the solution. Thermal equilibrium can be checked.

From the First Law of Thermodynamics, the steady-state heat balance can be expressed simply as:

Energy in - Energy out = 0

Reaction probes are used to check heat transfer induced by each boundary condition.

Example next slide ...

27 © 2015 ANSYS, Inc. February 27, 2015

ANSYS ... Thermal equilibrium

Example:



Heat balance:

- Heat generation load 0.001: W/mm^3. Total heat generated : + 44.698 W
- Reaction of temperature load: -34.382 W
- Reaction of convection BC: -10.316 W



By summing the probe results we find good agreement:

 $H_{gen} - R_{temp} - R_{conv} = 0$

```
44.698 - 10.316 - 34.382 = 0.000
```

Having verified an energy balance we can proceed to postprocess other results.

28 © 2015 ANSYS, Inc. February 27, 2015

ANSYS H. Workshop 9.1

- Workshop 9.1 Steady State Thermal Analysis
- Goal:
 - Analyze the pump housing shown below for its heat transfer characteristics.

