Beta Contact Features at 5.6/5.6.1

Fluid Pressure & Thermal Contact

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Updates to this Document

- 11/17/99 - First started this document
- 12/20/99 - Added pressure on contact elems
- 01/05/00 - Added some changes from 5.5 to 5.6
- 03/12/00 - Fixed up typos, etc. Modified examples.
- 04/22/00 - Added corrections from developer Yongyi Zhu
  - press-dependent thermal conductance
  - pressure on asymmetric contact outside/inside pinball
  - Reran input files to produce better quality images
  - Need to get rid of some examples since not useful.
- 04/29/00 - Changed wordings, including occurrences of "fluid pressure"
  - Changed all examples to symmetric contact
  - Got rid of all OLD "example 2" (not very useful)
- 06/08/00 - Fixed typo (thanks, Greg!)

- Sheldon's to-do list:
  - Rigid-flexible contact, too?
  - Frictional heating examples (transient), pres-dependent TCR examples
  - Heat flux on surfaces?
  - Add better postprocessing info
  - Pressure-, Temp- table. Gap distance table examples. Temp-depend HF

Undocumented Beta Features

- It is important to note that beta features are *untested* (not fully QA'd) and *unsupported*, so it is up to the discretion of the user to implement beta capabilities. Please report any potential problems/difficulties to CSI.
- The thermal contact and the fluid pressure loading features are planned to be included as "full" features in 5.7, but these are tentative plans, and no expressed guarantee is made to this effect.

Overview

- Two beta features at 5.6 for the new surface-to-surface contact elements (TARGE169-170 and CONTA171-174) will be described.
- Thermal contact features include thermal contact conductance, near- and far-field radiation and convection capabilities, and heat dissipation effects.
- Fluid pressure loading effects involve having a pressure load which is negligible when contact pairs are closed but have a given value as the surfaces separate (to mimic internal fluid pressure in a vessel).

Overview (cont.)

- Use of symmetric contact pairs assumed throughout this document
  - See Ch. 9.4.6 “Asymmetric Contact vs. Symmetric Contact” in the ANSYS 5.6 Structural Analysis Guide for more details on defining symmetric contact pairs
- Note that since these features are beta, options may change in future releases, so be sure to verify procedure for thermal contact and fluid pressure loading when these features are “fully” documented
- Files “therm_cond.inp” and “fluid_pres.inp” are files showing examples covered in this memo

Activation of Beta Features

- Beta features generally are “active” all the time, but there is a special way to activate them in the GUI.
- Add the line:

  ```
  keyw,beta,1
  ```

  to the `start56.ans` file located in:

  ```
  /ansys56/docu/start56.ans          (UNIX)
  C:\ansys56\docu\start56.ans        (Windows)
  ```

  prior to launching ANSYS 5.6.
- *Throughout this document, it is assumed that the reader is familiar with the* <u>*general*</u> *capabilities of the surface-to-surface contact elements.*

Thermal Contact

Section 1

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List of Thermal Features

- Thermal contact conductance
  - Function of Temperature and/or Contact Pressure
- Radiation
  - Near-field radiation between target and contact surface
  - Far-field radiation between contact and "environment"
- Convection
  - Near-field convection between target and contact surface
  - Far-field convection between contact and "ambient"
- Frictional heat dissipation
  - Percent of friction converted to heat flux at interface
  - This is for transient analyses only

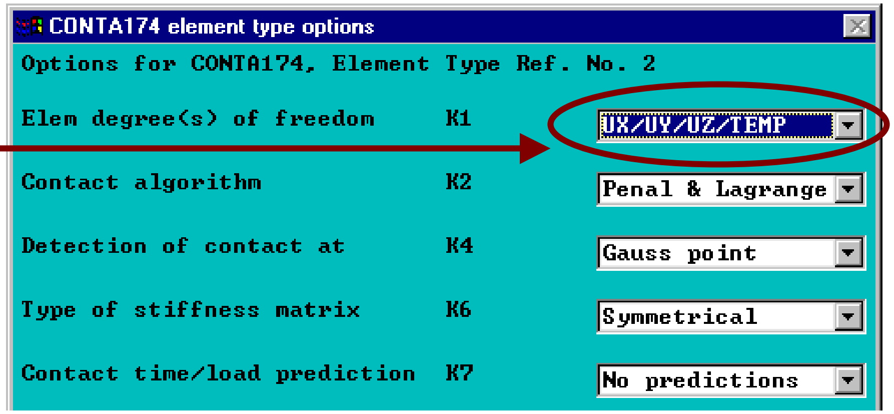
Applicability

- Used on all 2D/3D, lower- and higher-order elements: TARGE169-170 and CONTAC171-174
- Surface-to-surface conduction, radiation, and convection act upon elements directly normal to each other.
  - Radiation view factor is input via real constant
  - For more complex radiation (w/ view factor calculation), use /AUX12 Radiation matrix or Radiosity solver
  - This assumption is valid for near-field radiation and/or convection since, in PINB, gap is usually very small.

Adding TEMP DOF

- KEYOPT(1) controls structural or structural/thermal option.
  - KEYOPT(1)=0 (default) uses UX, UY, (and UZ)
  - KEYOPT(1)=1 uses UX, UY, (UZ), and TEMP
  - There is currently no TEMP DOF only option, so constrain UX, UY, (and UZ) on contact elements for thermal-only problem.

Activate Thermal option by changing this KEYOPT



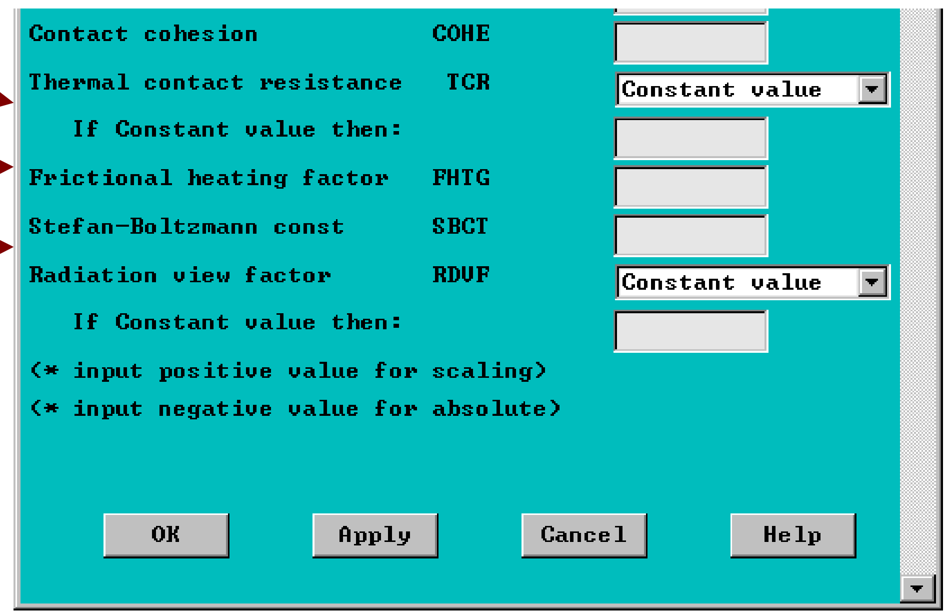
Adding Real Constants

- After KEYOPT(1) is changed, when adding real constants, new options will appear.

Thermal Conductance

Frictional Heat Dissipation

Radiation options



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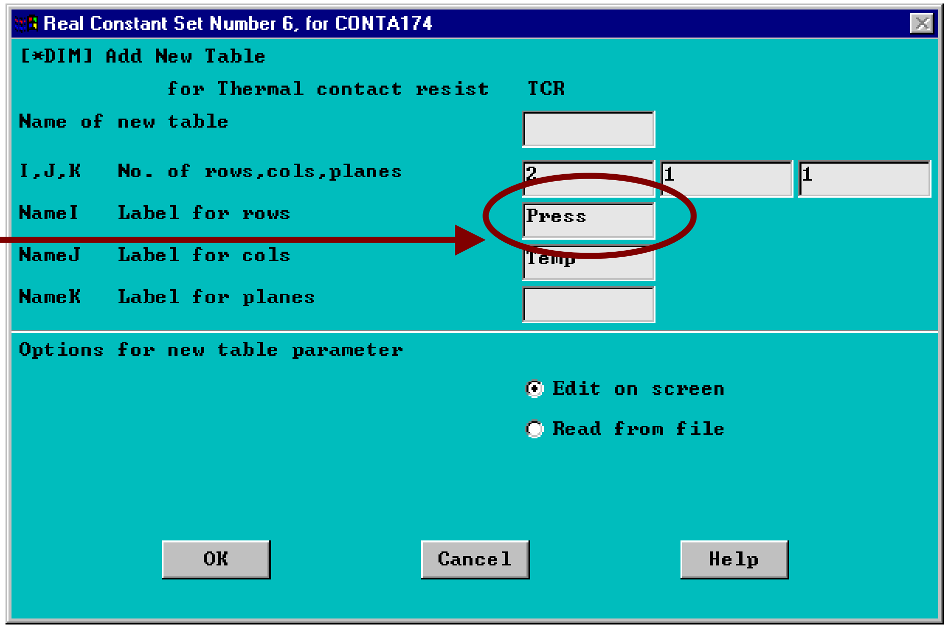
GUI Note

- When using GUI to add new temperature- or pressure-dependent TCR, note that table label is incorrect at 5.6/5.6.1

Change “Press” to “Pressure”
“Press” is not recognized as a valid index variable.



Thermal Contact Conductance

Section 2

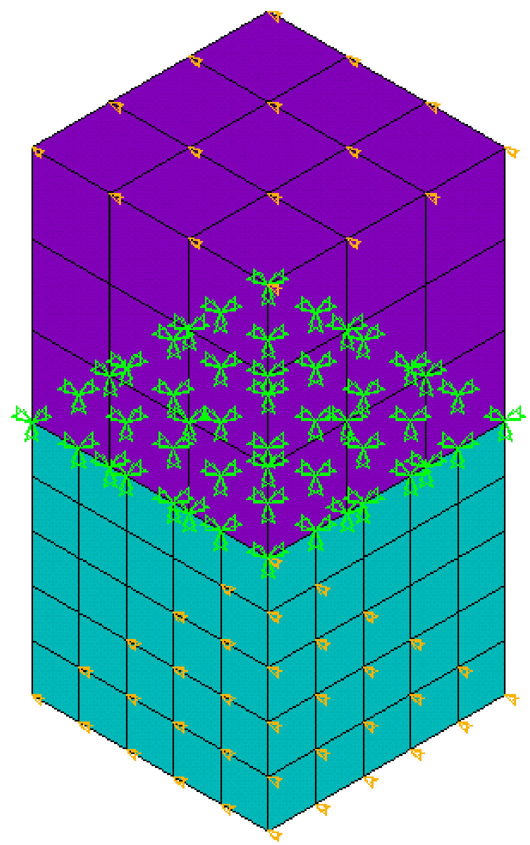
Thermal Contact Conductance

$$\dot{q} = TCR \cdot \left(T_T - T_C\right)$$

- Conduction heat flux rate at interface is a function of TCR (thermal contact conductance, real constant 14) and difference in temperature between target and contact surfaces.
- TCR can be a function of temperature and/or pressure by using %TABLE% option (TEMP and PRESSURE). TCR has units of heat/time/length^2/temp

Simple Block Example 1

- Two blocks connected with bonded contact, KEYOPT(12)=5
  - Bottom surface TEMP=20
  - Top surface TEMP=500
  - UX, UY, UZ of contact constrained
  - KXX = 167
- Note different mesh densities on both parts
- Use of "bonded" option is not needed, just used to illustrate that it *can* be used.



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Example 1A: Perfect Contact

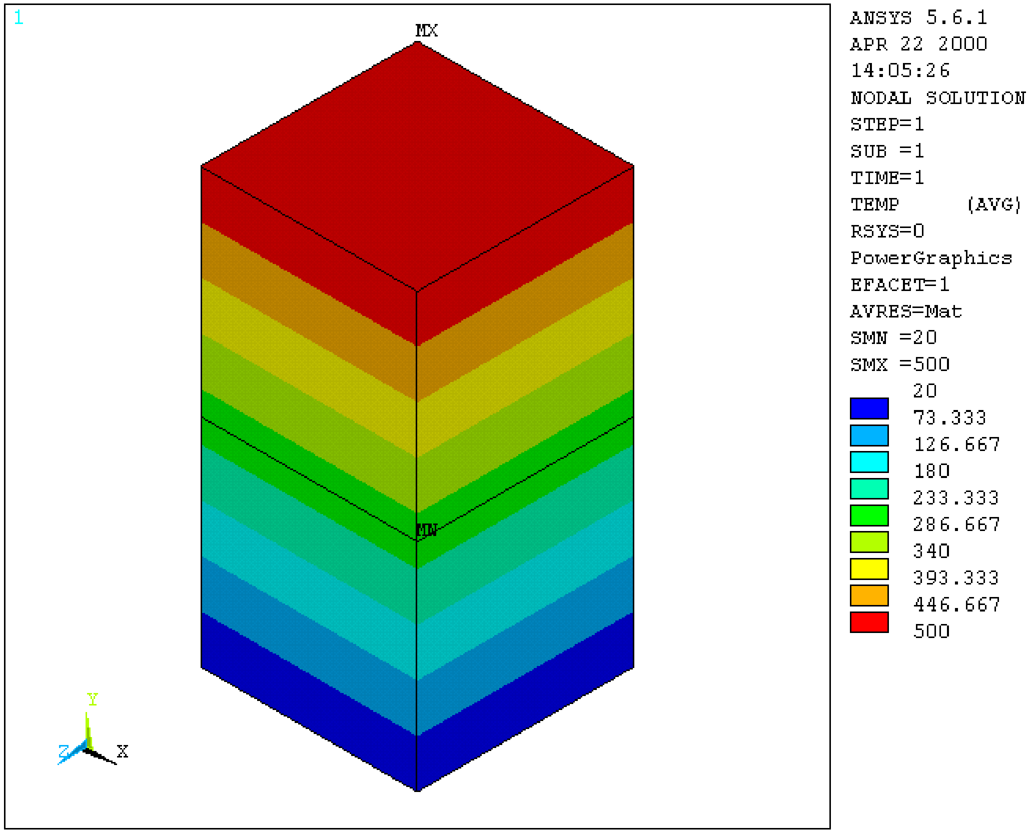
Set TCR=1e10

Basically, this is perfect thermal contact between two blocks.

Temperature profile results shown on right.

Note uniform variation of temperature as expected.

Asymmetric contact pairs used.



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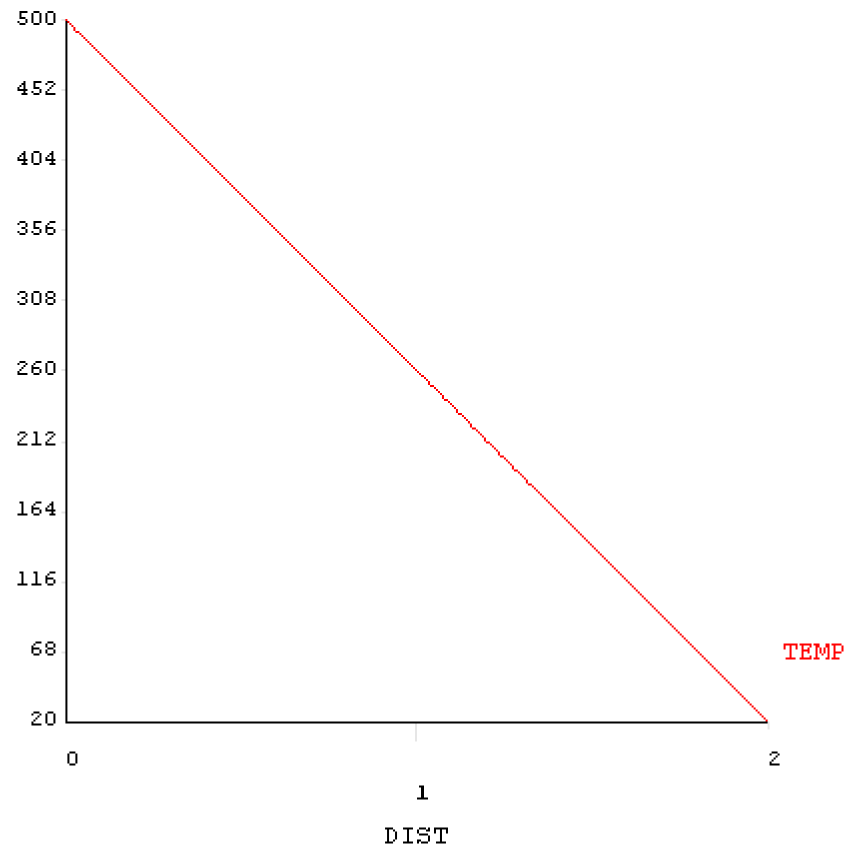
Example 1A: Perfect Contact

Plot of temperature from top to bottom.

Since heat flow is 1-D and TCR is set to high number, we expect it to follow Fourier's Law, which this graph illustrates (linear variation of temperature w/ distance)



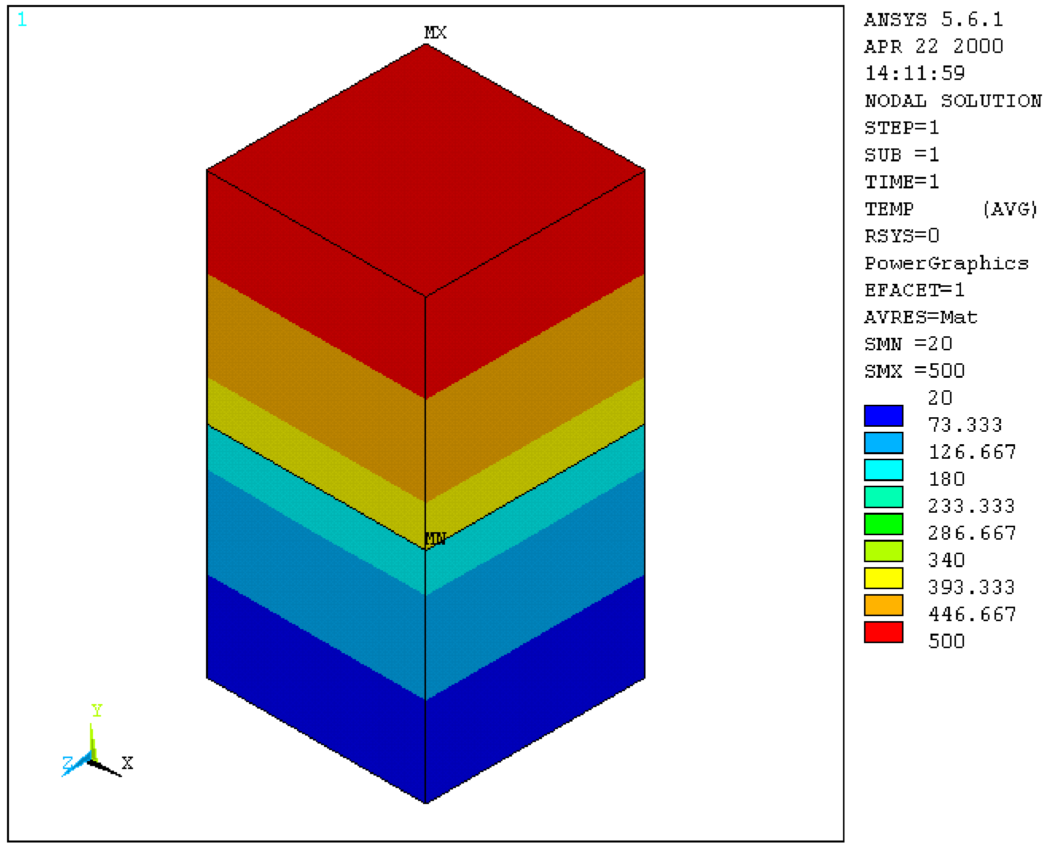
Example 1B: Conductance=100

Set TCR=100

Now, we have a thermal resistance between interface

Temperature profile results shown on right.

Note the "step" change of temperature, as expected



Example 1B: Conductance=100

Plot of temperature from top to bottom.

Thermal resistances in series. Solve equation and get:

T_{top}=369.2

T_{bot}=150.8

ANSYS results:

T_{top}=369.47

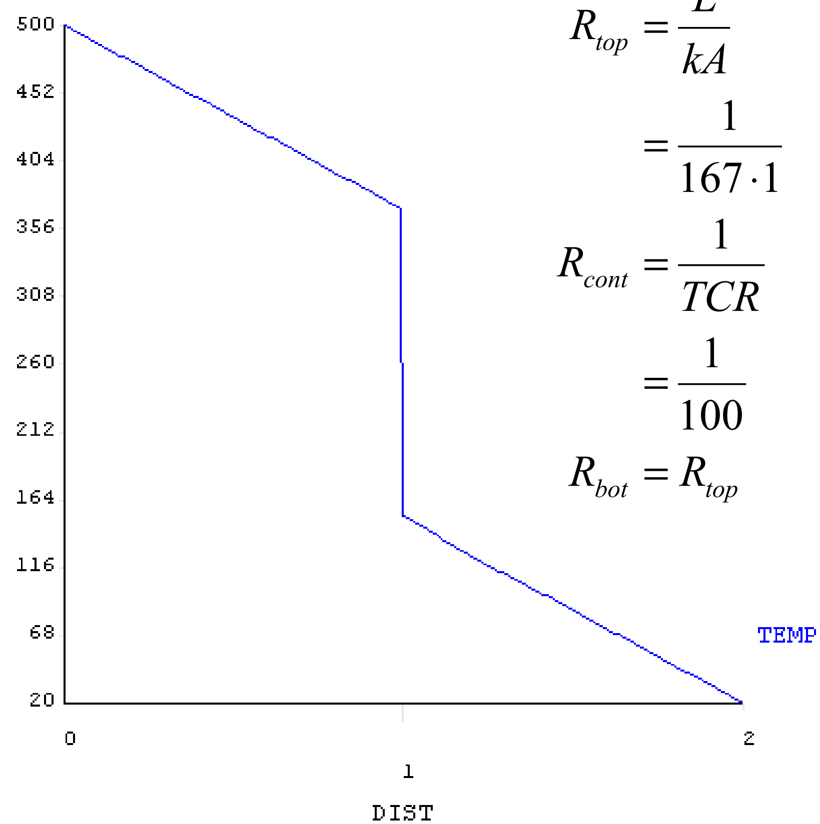
T_{bot}=150.02

With matching mesh (5x5x5):

T_{top}=369.21

T_{bot}=150.79

Very good agreement



$$R_{top} = \frac{L}{kA} = \frac{1}{167 \cdot 1}$$

$$R_{cont} = \frac{1}{TCR} = \frac{1}{100}$$

$$R_{bot} = R_{top}$$

Radiation Between Contact Surfaces

Section 3

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Radiation Overview

$$\dot{q} = RDVF \cdot EMIS \cdot SBCT \cdot \left(T_T^4 - T_C^4\right)$$

- Radiation heat flux rate is based RDVF (view factor, real constant 17) and SBCT (Stefan-Boltzmann constant, real constant 16). EMIS input as material property.
- Temperatures based on absolute temperature, so TOFFSET is needed as well.
- RDVF can be a function of temperature and/or gap distance by using %TABLE% option.

Radiation Overview (cont.)

- In near-field contact (within pinball region), temperatures are contact and target surface temperatures, respectively.
- In far-field contact, T_T becomes “ambient” temperature defined by “bulk temperature” command:

```
SFE,all,1,conv,2,temp_value
```

- Consequently, for far-field radiation, symmetric contact pairs are needed.

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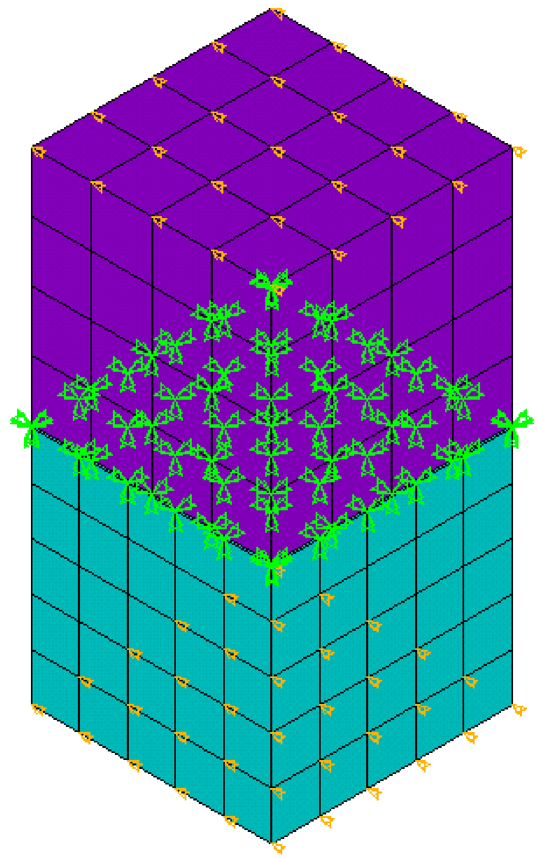
Simple Example 1

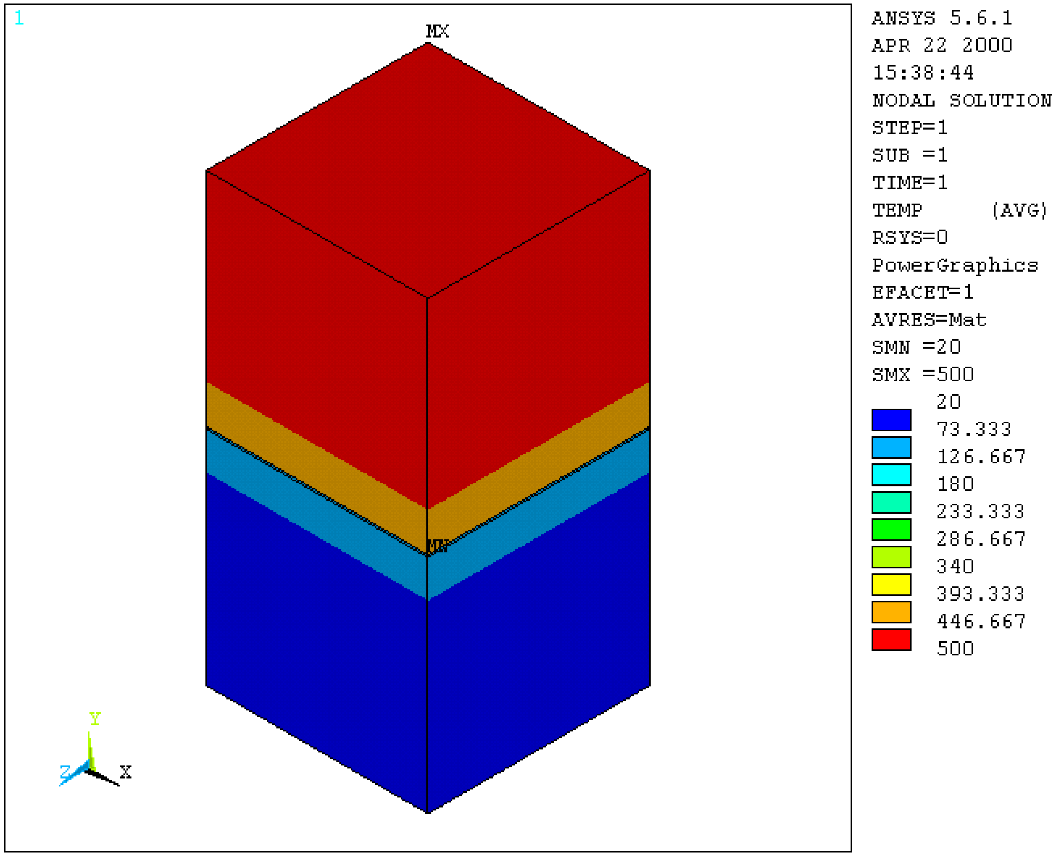
- Two blocks connected with standard contact, KEYOPT(12)=0
  - Bottom surface TEMP=20
  - Top surface TEMP=500
  - UX, UY, UZ of contact constrained
  - KXX = 167
  - RDVF = 1.0, EMIS = 0.8
  - Environment temp is 1000
- Radiation applied on symmetric contact pairs
- Note non-uniform mesh density



Example 1A: Near-field Radiation

OFFST distance set to 0.01 (OFFST < PINB).

Note temperature distribution on left.



Example 1A: Near-field Radiation

Problem, though modeled 3D, is essentially 1D in nature.

Solve for temperature:

T_{top}=435.8

T_{low} = 84.2

ANSYS results:

T_{top}=435.9

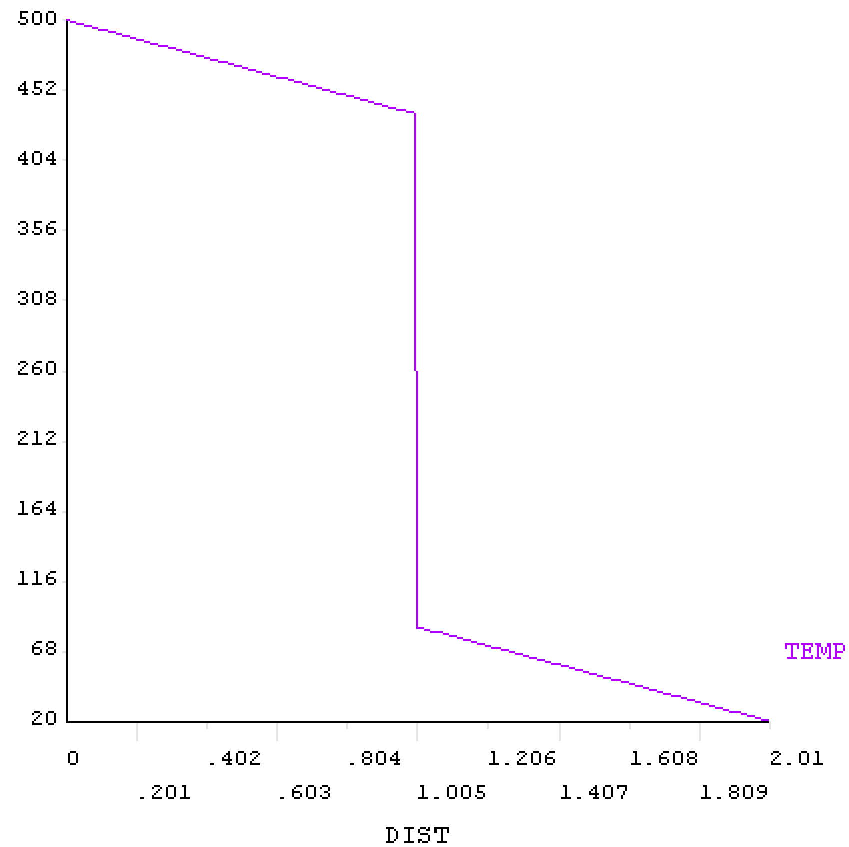
T_{low} = 83.8

With matching mesh (5x5x5):

T_{top}=435.8

T_{low} = 84.2

Very good agreement.



Example 1B: Far-field Radiation

OFFST distance set to 1 (OFFST > PINB).

Environ. temp = 1000

Let's look at Top block:

Solve for temperature:

T_{top}=822.4

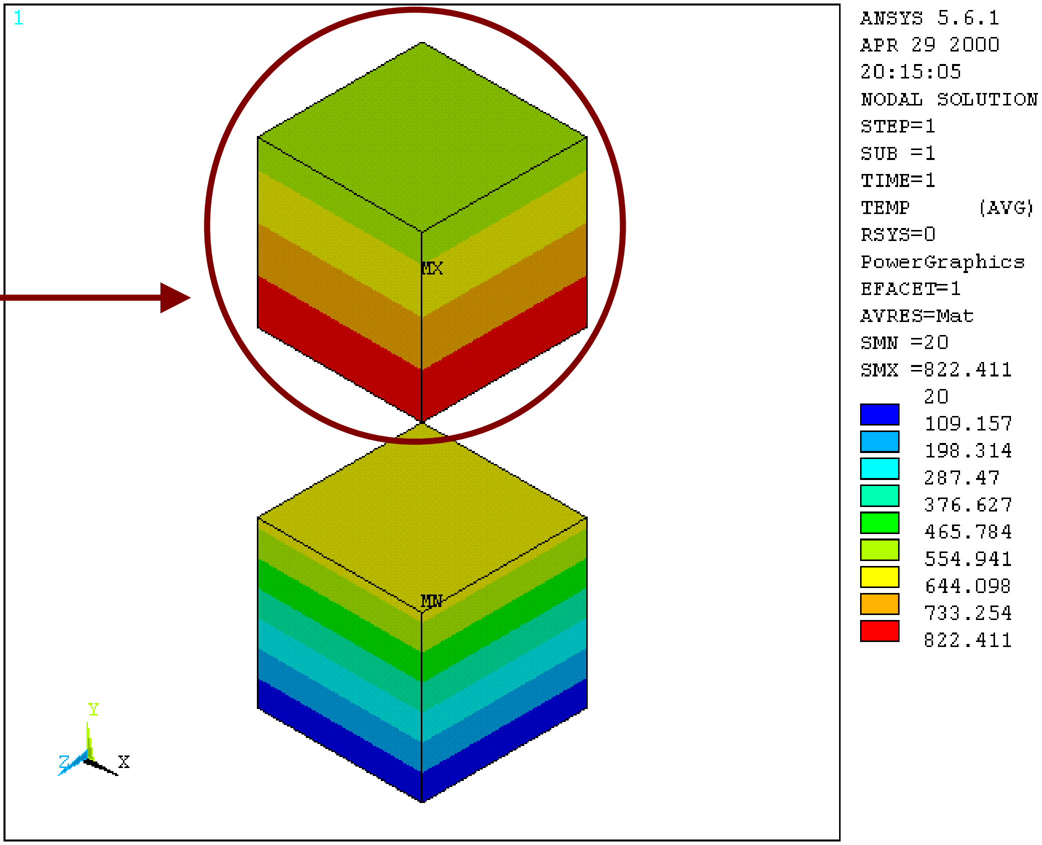
H = 53837.7

ANSYS results:

T_{top}=822.4

H = 53842.6

Very good agreement



Example 1B: Far-field Radiation

OFFST distance set to 1 (OFFST > PINB).

Environ. temp = 1000

Let's look at Bottom Block:

Solve for temperature:

T_{top}=585.8

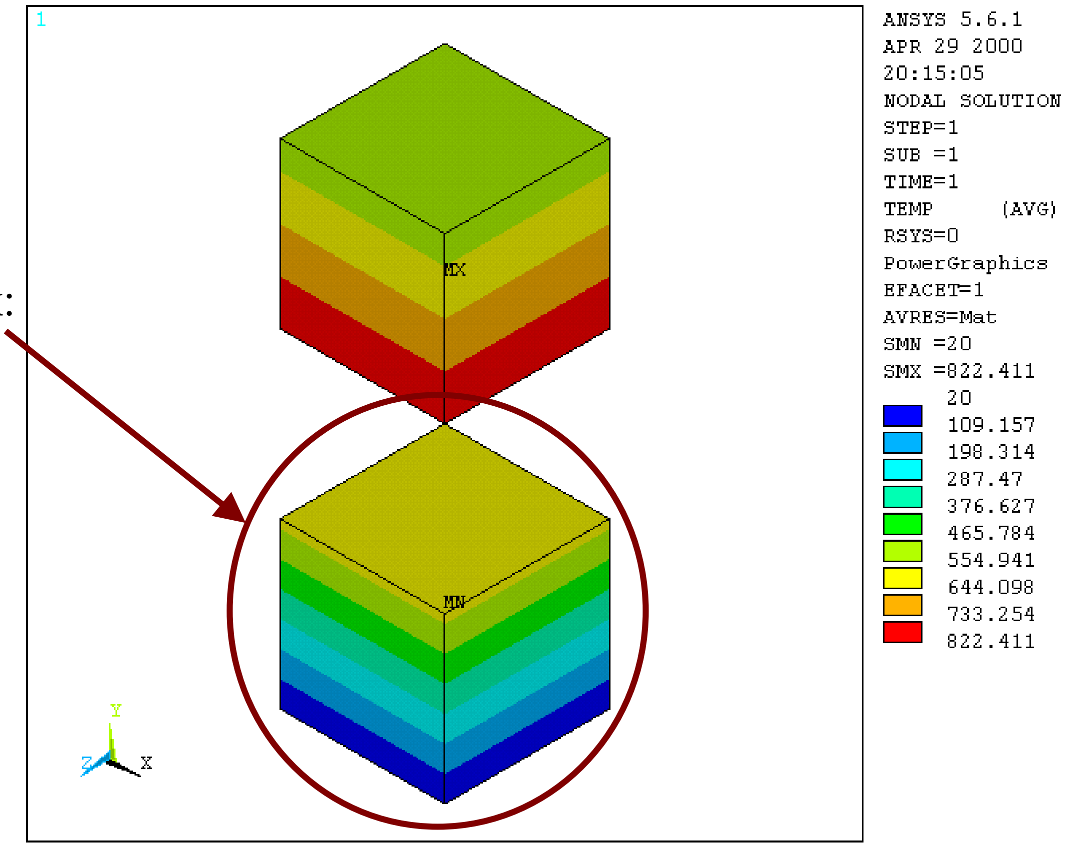
H = 94486.7

ANSYS results:

T_{top}=585.8

H = 94486.68

Very good agreement



Convection Between Contact Surfaces

Section 4

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Convection Overview

$$\dot{q} = HTC \cdot \left(T_T - T_C\right)$$

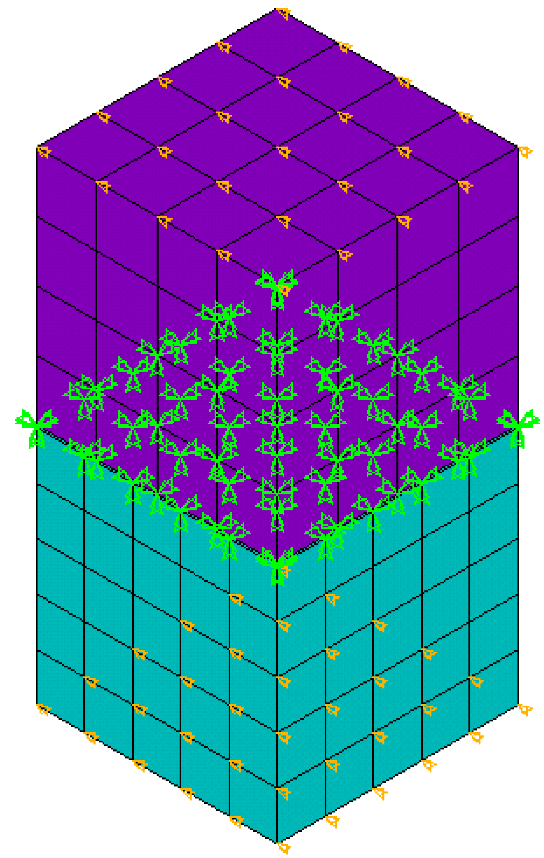
- Conv. heat flux rate is based on HTC (heat transfer coefficient) input via `SFE,all,1,conv,1,htc_value`
- In near-field contact, ΔT is based on difference of target and contact surfaces.
- In far-field contact, target temperature is based on "ambient" temperature defined by:

```
SFE,all,1,conv,2,temp_value
```

- For far-field conv, symmetric contact pairs are required.

Simple Example 1

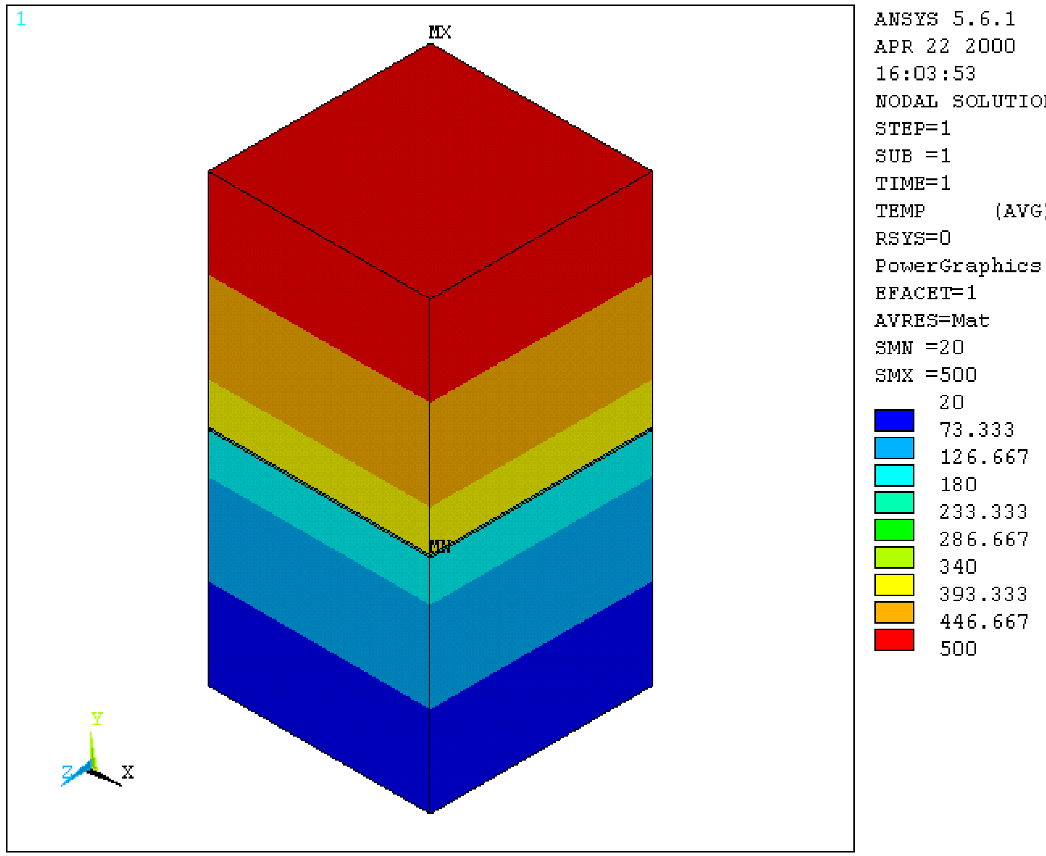
- Two blocks connected with standard contact, KEYOPT(12)=0
  - Bottom surface TEMP=20
  - Top surface TEMP=500
  - UX, UY, UZ of contact constrained
  - KXX = 167
  - Film Coeff = 100
  - Ambient temp is 1000
- Convection applied on symmetric contact pairs
- Note non-uniform mesh density



Example 1A: Near-field Convection

OFFST distance set to 0.01 (OFFST < PINB).

SFE commands applied to contact surfaces only.



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Example 1A: Near-field Convection

Profile from top to bottom shown.

Calculated:

T_{top}=369.2

T_{bot}=150.8

ANSYS values:

T_{top}=369.5

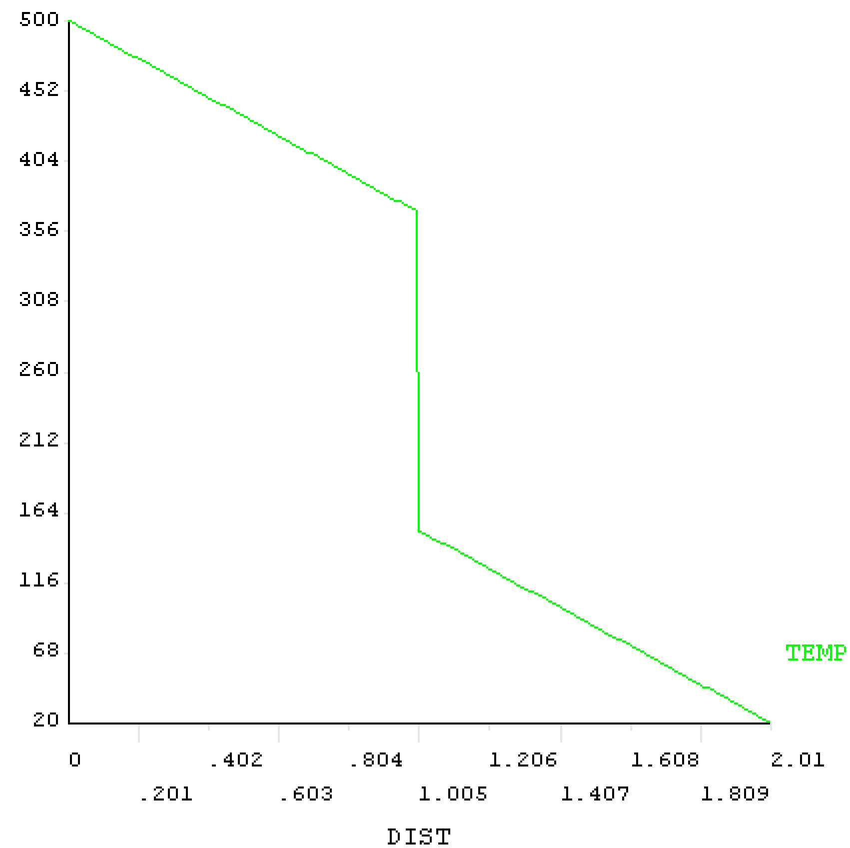
T_{bot}=150.0

With matching mesh (5x5x5):

T_{top}=369.2

T_{bot}=150.8

Very good agreement.



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Example 1B: Far-field Convection

OFFST distance set to 1 (OFFST > PINB).

Ambient temp = 1000

Let's look at Top block:

Solve for temperature:

T_{top}=687.3

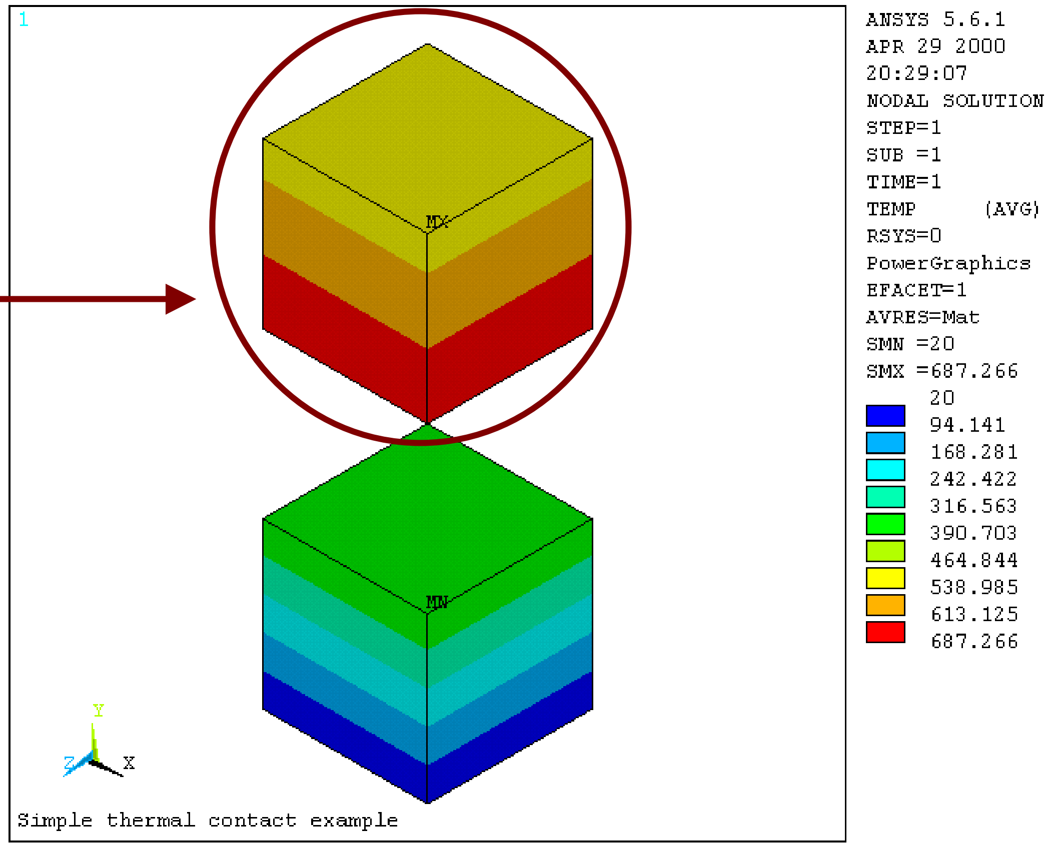
H = 31273.4

ANSYS results:

T_{top}=687.3

H = 31273.4

Very good agreement



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Example 1B: Far-field Convection

OFFST distance set to 1 (OFFST > PINB).

Ambient temp = 1000

Let's look at Bottom block:

Solve for temperature:

T_{top}=387.0

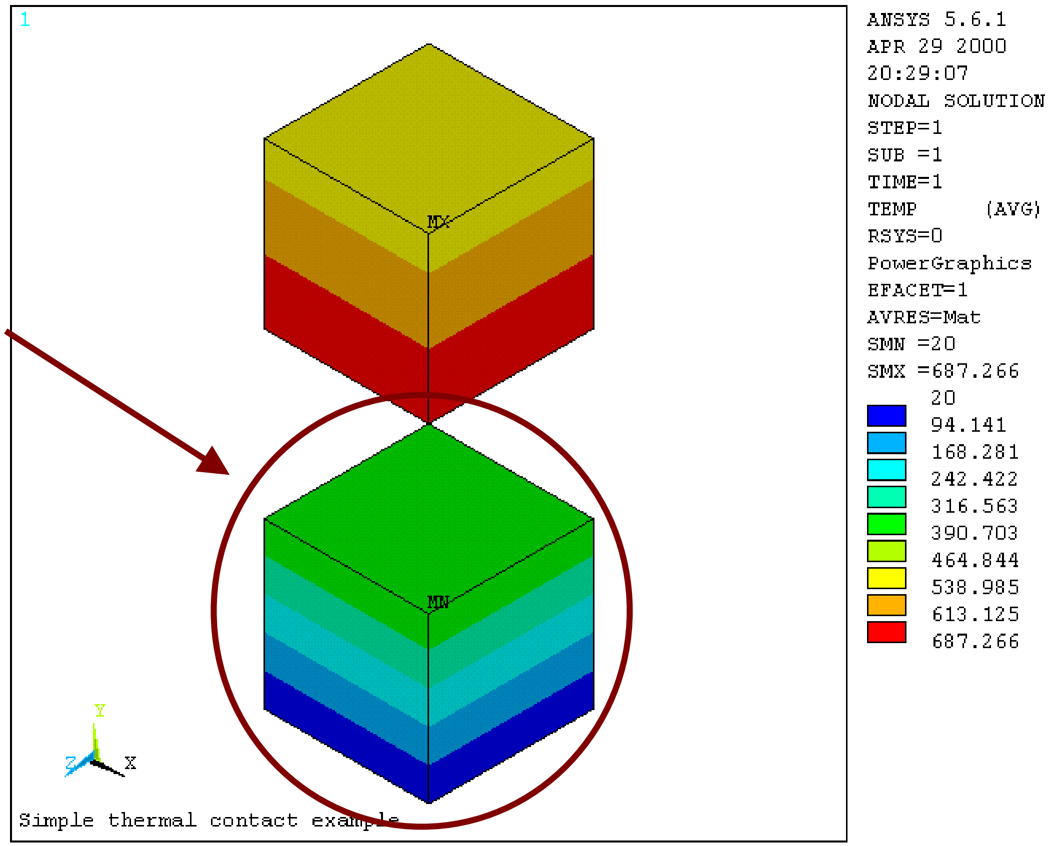
H = 61295.9

ANSYS results:

T_{top}=387.0

H = 61295.9

Very good agreement



Heat Gen. Due to Frictional Dissipation

Section 5

Frictional Dissipation

$$\dot{q} = FHTG \cdot \tau_{surf} \cdot v$$

- Heat generation due to frictional energy dissipation input with FHTG (Frictional HeaT Generation fraction) which varies from 0.0 (no heat gen) to 1.0 (all frictional losses converted to heat), input as real constant 15.
- Dependent on shear stress τ_{surf} times sliding velocity v (relative velocity between contact surfaces). Inertial effects need to be included (transient phenomena).

(Currently no documented example; to be supplied later by author)

Fluid Pressure Load on Contact Surfaces

Section 6

Overview

- A fluid pressure load can be defined on the contact surfaces using SFE command (load key=1).
- When the contact pair is closed, no pressure is exerted on the contact elements (and underlying solid).
- When the contact pair is open (fully or partially), the fluid pressure is active for that portion of the contact and target surfaces which have opened.
- Useful when modeling seals which may partially open, internal pressure (fluid) will exert pressure on separating surfaces.

Apply SFE on Contact Elements

- Use SFE (not solid model loads) to apply pressure on contact elements only:

```
ESEL,S,ENAME,,171,174        ! or ESEL,S,TYPE,,3
SFE,ALL,1,PRES,,100          ! Apply value of 100
```

- At 5.6.1, the pressure arrows may look opposite in sign (`/PSF,PRES,,2`) but note that:
  - Positive pressure value acts into element
  - Negative pressure value “pulls” element
  - “Standard” definition of pressure. In almost all instances, positive value of pressure will always be applied.

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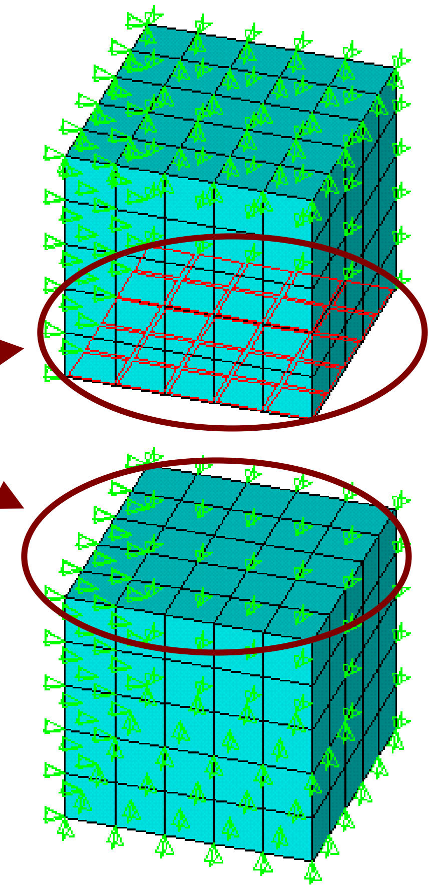
Simple Block Example 1

- The following is a simple example of two blocks separated by a distance OFFST & with symmetric contact pairs.
- Pressure of 100 applied to contact surfaces only (circled in red)
  - Pressure symbol is shown on bottom if blocks are rotated to view “underside”. Graphics will be resolved in future release.
- Symmetry constraints applied to sides and ends of block.
- Expect a constant state of stress

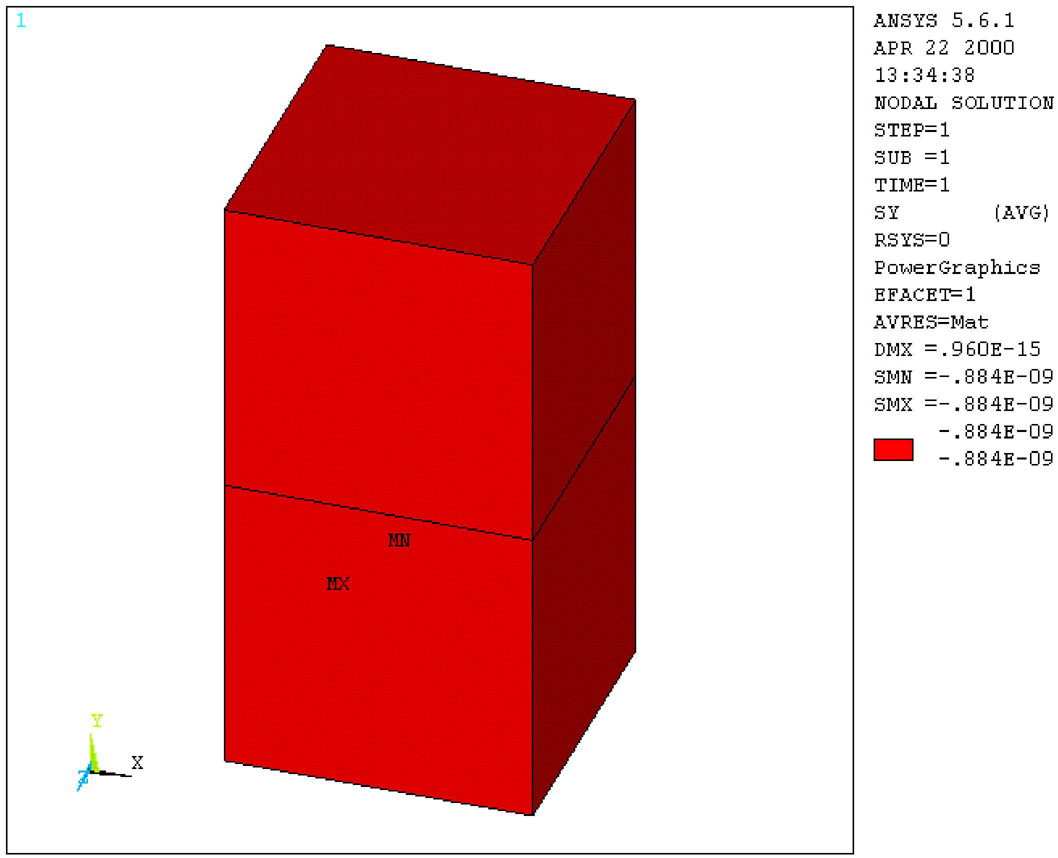


Example 1A: Blocks Touching

OFFST=0

Blocks are touching, so no pressure is applied to interface between blocks.

SY=1e-9, so basically no pressure

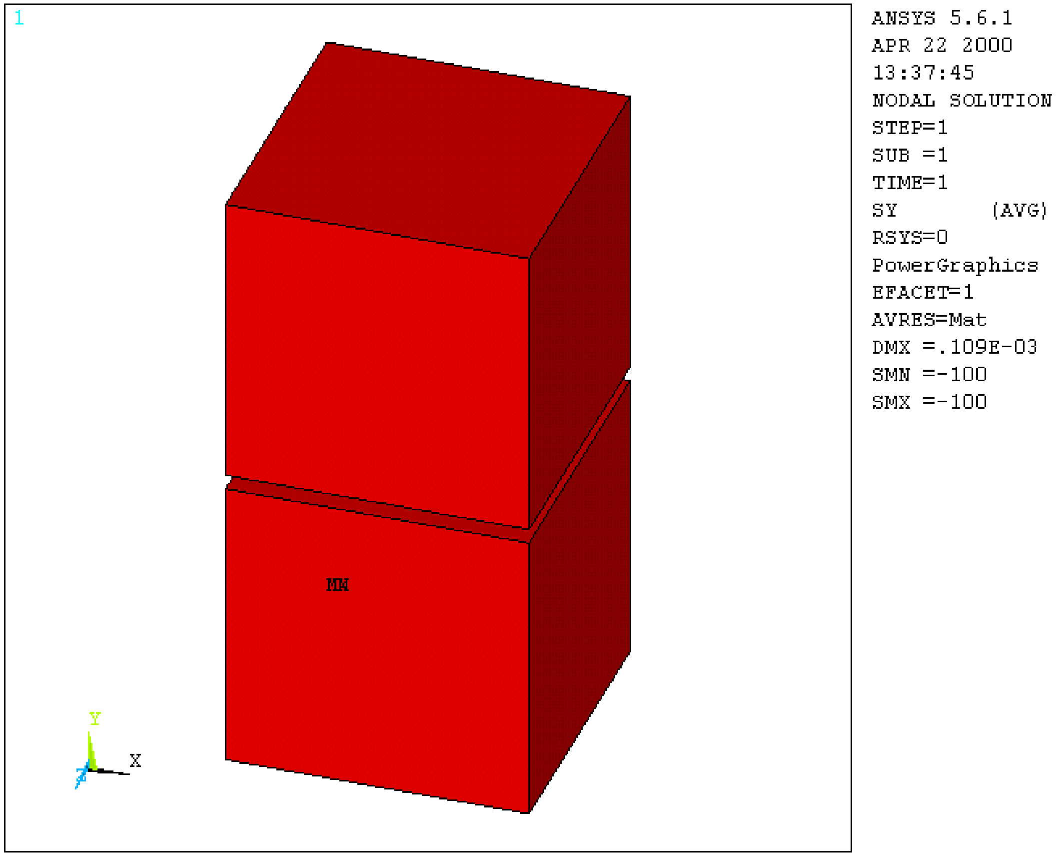


Example 1B: Blocks within PINB

OFFST=.5

Blocks are separated but *within* pinball region.

SY=-100 as expected



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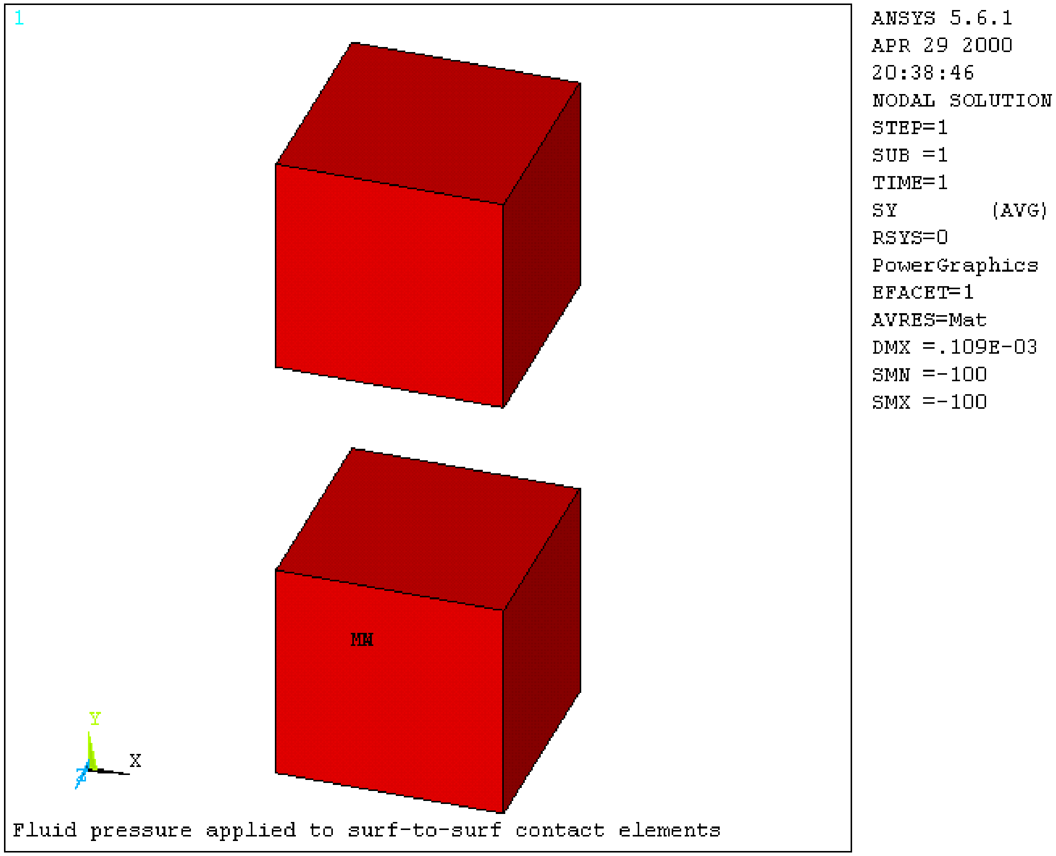
Example 1C: Blocks outside of PINB

OFFST=10

Blocks are separated and *outside* of pinball region.

SY=-100 as expected



Summary

Summary of Features

- Using verifiable examples, this document presented the beta features of thermal and pressure loading of the surface-to-surface contact elements.
- As shown, these will be powerful and useful enhancements. It is a big step in making ANSYS truly "Multiphysics", allowing the user to simulate more complex systems.
- Although most examples involved simple blocks, these illustrate all of the features, oftentimes verifiable with expected (hand-calc) solutions. (Maybe add more complex/interesting examples later)

Summary of Features (cont.)

- Note that, generally speaking, one should always use symmetric contact pairs for these thermal and fluid pressure features. For thermal contact *only*, asymmetric contact pairs are fine.
- Loads are always applied on contact elements only (CONTA171-174 elements) via SFE. Use of solid model loads (SFA, SFL) is not recommended.
- Results tend to improve if mesh density is similar between parts at interface. However, this is not a requirement as noted in the good results in the example problems.

Current Limitations

- Note that only PLANE13 supports large deformation/large strain effects. SOLID5 and 98 do not (only stress-stiffening). Hence, arbitrary structural-thermal contact may be best achieved with PHYSICS and LDREAD commands.
- Currently, it is quite difficult to use sequential coupled-field analysis for transient structural/thermal problems, especially in 3D (issues related to implicit time integration methods as used in thermal/structural problems). Please contact CSI on details of how best to approach these types of problems. Use of PLANE13 for 2D problems should not be as difficult.
- Electrical contact is currently not available.

Future Changes

- Planned changes/revisions:
  - SHELL57 support at 5.6.2 (beta)
  - KEYOPT(1)=2 TEMP DOF only (this feature will probably be beta at 5.7)
  - Thermal contact resistance TCR wording changed to “thermal contact conductance”
  - Changes in behavior of near- and far-field convection & radiation (maybe via KEYOPT)
  - View factor as a function of gap distance (wording changed for table index variable)
  - No need for “dummy” EX material
  - Sign direction for pressure on 171-174 fixed

Per conversations with developer Yongyi Zhu