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Guidelines for Obtaining Contact Convergence

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At A Glance … FTT

- FTT specializes in gas turbine, turbomachinery, and propulsion components, systems, and engineering for aircraft, space, industrial power, and clean energy
- Headquartered in Jupiter, Florida with approximately 200,000 sq ft of facilities for engineering, component & system assembly & test
- Incorporated in October 1998
- More than 170 people with an average experience base of >19 years
- More than 300 patent applications filed since incorporation
- Developed the world's first miniature turbofan for small aircraft requiring high fuel efficiency and performance

Turbine Rig Developed, Instrumented and Assembled for NASA in FTT's Jupiter, FL Facility

FTA37F – Two-Spool Turbofan Developed for the Army for Applications Requiring Performance *and* Fuel Efficiency

Our Vision:

- To be the preferred supplier of turbomachinery technology and hardware in the world

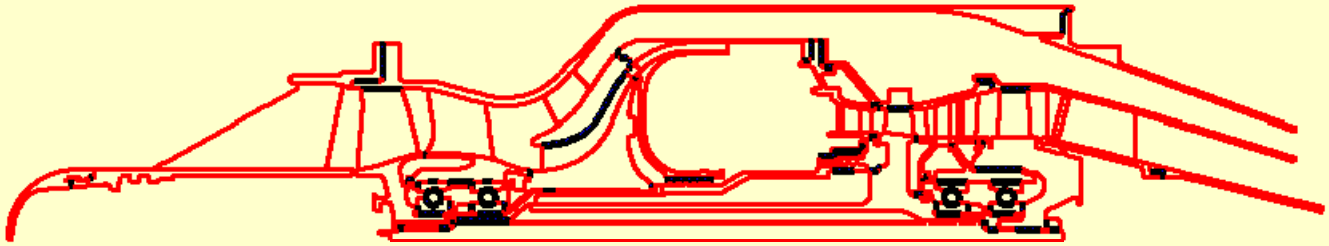
FTT … A leader in innovation and technical excellence

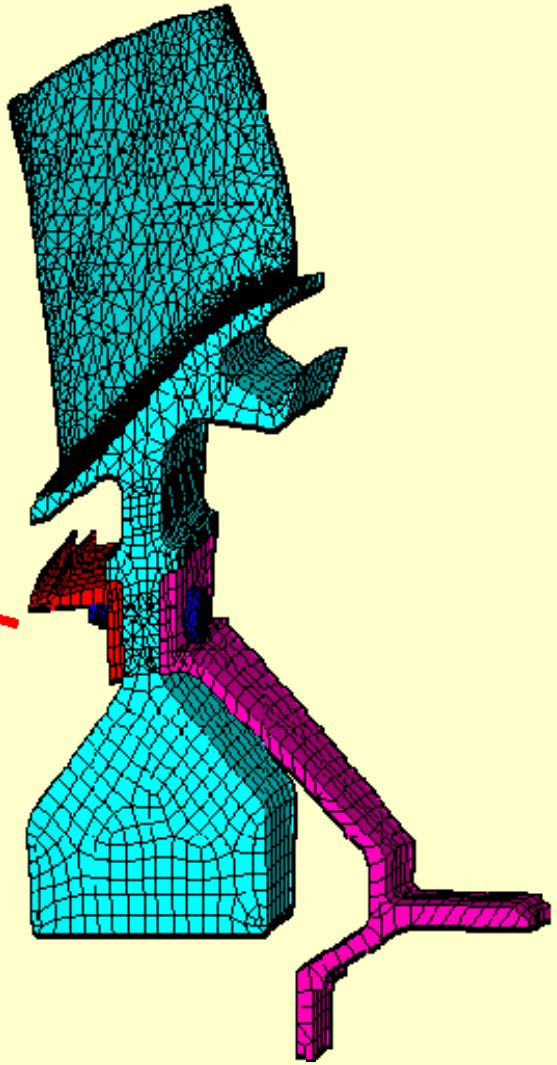
Debugging Contact Analyses

- Contact elements are a powerful feature in ANSYS, however the numerous behavior options and inputs can be daunting.
- An estimated 75% of the internal support calls at my company are related to difficulty with contact element convergence.
- Over many years, I have developed a methodical process for troubleshooting and debugging contact analyses.
- These techniques may or may not be unique to gas turbine applications.

Typical Turbomachinery Applications

- 2D axisymmetric engine assembly models.
  - Small Models, many (100+) contact pairs





- 3D component assembly models
  - Large Models, few (1-10) contact pairs

Newton Raphson Method

$[K]\,[U] = [F^a]$ For contact problems, [K] is a nonlinear function of [U]

Nonlinear equations written as: $[K_i^t]\,[\Delta U_i] = [F^a] - [F_i^{nr}]$

Displacement change between iterations: $\{U_{i+1}\} = \{U_i\} + \{\Delta U_i\}$

$[K_i^t]$ = Jacobian matrix (tangent matrix).

i = current equilibrium iteration number.

$[F^a]$ = Vector of applied loads.

$[F_i^{nr}]$ = Vector of restoring loads (opposes the internal nodal loads).

$[R] = [F^a] - [F_i^{nr}]$ Residual, or out-of-balance force vector.

$[R] < 0.001\,[F^a]$ Convergence criteria (Residual must be less than 0.1% of the applied load.

Newton Raphson Method

$[K]\,[U] = [F^a]$ $\qquad$ $[K_i^t]\,[\Delta U_i] = [F^a] - [F_i^{nr}]$ $\qquad$ $\{U_{i+1}\} = \{U_i\} + \{\Delta U_i\}$

1. During equilibrium iterations, ANSYS makes a guess at $[\Delta U_i]$
2. $[K_i^t]\,[\Delta U_i]$ is then calculated and ideally, should exactly equal $[F^a]$ for a converged solution. In reality, there will be some out-of-balance force $[F_i^{nr}]$. *Consider that if* $[K_i^t]$ *is very high, a huge force is calculated for a bad guess at* $[\Delta U_i]$
3. The Residual out-of-balance force vector $[R] = [F^a] - [F_i^{nr}]$ is calculated and compared to convergence criteria $[R] < 0.001\,[F^a]$
4. At the next iteration, $[\Delta U_i]$ is adjusted and $[R]$ is recalculated.
5. Iterations continue until convergence is achieved.

Understanding Solution Output

Understanding the solution output is key to troubleshooting convergence problems: Key terms are:

Force Convergence Value – This is the residual out-of-balance force vector $[R] = [F^a] - [F_i^{nr}]$ shown previously.

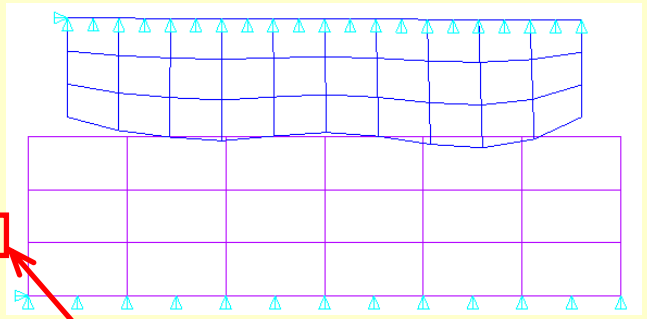
Criterion – Force convergence criteria $[R] < 0.001\ [F^a]$ The force convergence value must be below this value for convergence.

Max DOF Inc – The maximum displacement that occurred on any node in the model during the previous iteration.

Scaled Max DOF Increment – Line search parameter x Max DOF Inc. (This is the displacement vector actually used).

Typical Solution Output

```
ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= crap.rdb
 FOR POSSIBLE RESUME FROM THIS POINT
    2D CONTACT ELEMENTS:    7 CONTACT POINTS HAVE TOO MUCH PENETRATION
    FORCE CONVERGENCE VALUE  = 0.8836E+08  CRITERION= 0.5102E-04
   EQUIL ITER   1 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.1495E-01
    LINE SEARCH PARAMETER =  0.9965     SCALED MAX DOF INC = -0.1490E-01
    FORCE CONVERGENCE VALUE  = 0.2978E+06  CRITERION=  1015.
   EQUIL ITER   2 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.5928E-02
    LINE SEARCH PARAMETER =  0.8926E-01 SCALED MAX DOF INC = -0.5291E-03
    FORCE CONVERGENCE VALUE  = 0.2149E+06  CRITERION=  1021.
   EQUIL ITER   3 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.2503E-02
    LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC =  0.2503E-02
    FORCE CONVERGENCE VALUE  = 0.7388E+05  CRITERION=  1099.
   EQUIL ITER   4 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.1707E-02
    LINE SEARCH PARAMETER =  0.2963     SCALED MAX DOF INC =  0.5059E-03
    FORCE CONVERGENCE VALUE  = 0.8894E+05  CRITERION=  1123.
   EQUIL ITER   5 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.1181E-02
    LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC =  0.1181E-02
    FORCE CONVERGENCE VALUE  = 0.4430E+05  CRITERION=  1166.
   EQUIL ITER   6 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.1707E-03
    LINE SEARCH PARAMETER =  0.5845     SCALED MAX DOF INC = -0.9977E-04
    FORCE CONVERGENCE VALUE  = 0.2803E+05  CRITERION=  1188.
   EQUIL ITER   7 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.7212E-04
    LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.7212E-04
    FORCE CONVERGENCE VALUE  =  7756.      CRITERION=  1214.
   EQUIL ITER   8 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.1465E-04
    LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.1465E-04
    FORCE CONVERGENCE VALUE  =  1869.      CRITERION=  1239.
   EQUIL ITER   9 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.3498E-05
    LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.3498E-05
    FORCE CONVERGENCE VALUE  =  442.6      CRITERION=  1264.     <<< CONVERGED
   >>> SOLUTION CONVERGED AFTER EQUILIBRIUM ITERATION   9
```



Maximum displacement that occurred this iteration using the Newton-Raphson method.

Line search parameter and adjusted maximum displacement used.

Calculated residual out-of-balance force and criteria for convergence.

Typical Solution Output (continued)

```
 ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= crap.rdb
  FOR POSSIBLE RESUME FROM THIS POINT
     2D CONTACT ELEMENTS:     7 CONTACT POINTS HAVE TOO MUCH PENETRATION
     FORCE CONVERGENCE VALUE  = 0.8836E+08  CRITERION= 0.5102E-04
    EQUIL ITER   1 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.1495E-01
     LINE SEARCH PARAMETER =  0.9965     SCALED MAX DOF INC = -0.1490E-01
     FORCE CONVERGENCE VALUE  = 0.2978E+06  CRITERION=  1015.
    EQUIL ITER   2 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.5928E-02
     LINE SEARCH PARAMETER =  0.8926E-01 SCALED MAX DOF INC = -0.5291E-03
     FORCE CONVERGENCE VALUE  = 0.2149E+06  CRITERION=  1021.
    EQUIL ITER   3 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.2503E-02
     LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC =  0.2503E-02
     FORCE CONVERGENCE VALUE  = 0.7388E+05  CRITERION=  1099.
    EQUIL ITER   4 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.1707E-02
     LINE SEARCH PARAMETER =  0.2963     SCALED MAX DOF INC =  0.5059E-03
     FORCE CONVERGENCE VALUE  = 0.8894E+05  CRITERION=  1123.
    EQUIL ITER   5 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.1181E-02
     LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC =  0.1181E-02
     FORCE CONVERGENCE VALUE  = 0.4430E+05  CRITERION=  1166.
    EQUIL ITER   6 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.1707E-03
     LINE SEARCH PARAMETER =  0.5845     SCALED MAX DOF INC = -0.9977E-04
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    EQUIL ITER   9 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.3498E-05
     LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.3498E-05
     FORCE CONVERGENCE VALUE  =  442.6      CRITERION=  1264.     <<< CONVERGED
    >>> SOLUTION CONVERGED AFTER EQUILIBRIUM ITERATION   9
```

Characteristics of a good solution:

Force convergence values are steadily decreasing with little or no oscillation.

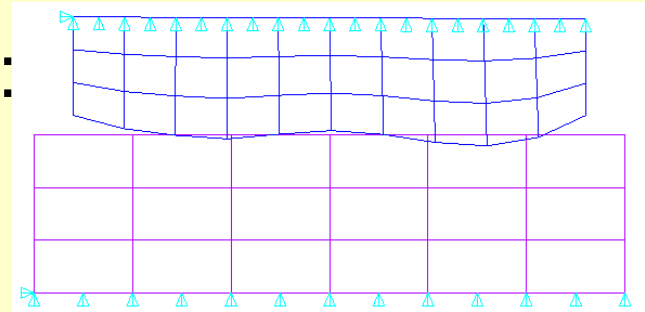
Max DOF values are small and steadily decreasing. Any large values mean that a part has broken free and flown off into space.

Basic Contact Modeling Guidelines

- Try to ensure that parts that are initially in contact are built line-on-line.
- If possible, avoid gaps or large interference fits (common for radial pilots). For these cases, set keyopt(9)=4 [ignore geometric fit, use CNOF only, ramp]. This also requires keyopt(12)=4 [no separation, always] and small FKOP (opening stiffness).
- Run **CNCHECK** and to verify initial contact status.
- Always run contact solution in batch mode, not interactive. This provides a cleaner record of the solution process for debugging purposes.

Interpreting CNCHECK Summary

Summary given for each contact pair:



```
*** NOTE ***                            CP =      13.190   TIME= 07:00:01
Deformable-deformable contact pair identified by real constant set 4
and contact element type 6 has been set up.
Contact algorithm: Augmented Lagrange method
Contact detection at: Gauss integration point
Default contact stiffness factor FKN          1.0000
The resulting contact stiffness              0.15119E+11
Default penetration tolerance factor FTOLN   0.10000
The resulting penetration tolerance          0.39685E-02
Frictionless contact pair is defined
Update contact stiffness at each iteration
Average contact surface length               0.13228
Average contact pair depth                   0.39685E-01
Default pinball region factor PINB            1.0000
The resulting pinball region                 0.39685E-01
*WARNING*: Initial penetration is included.

*** NOTE ***                            CP =      13.190   TIME= 07:00:01
Max.  Initial penetration 2.954468206E-02 was detected between contact
element 138 and target element 129.
You may move entire target surface by : x= 1.168198279E-03, y=
-2.952157771E-02, z= 0,to reduce initial penetration.

*** WARNING ***                         CP =      13.190   TIME= 07:00:01
The closed gap/penetration may be too large.  Increase pinball if it is
a true closed gap/penetration.  Decrease pinball if it is a false one.
**************************************
```

Element options (keyopts)

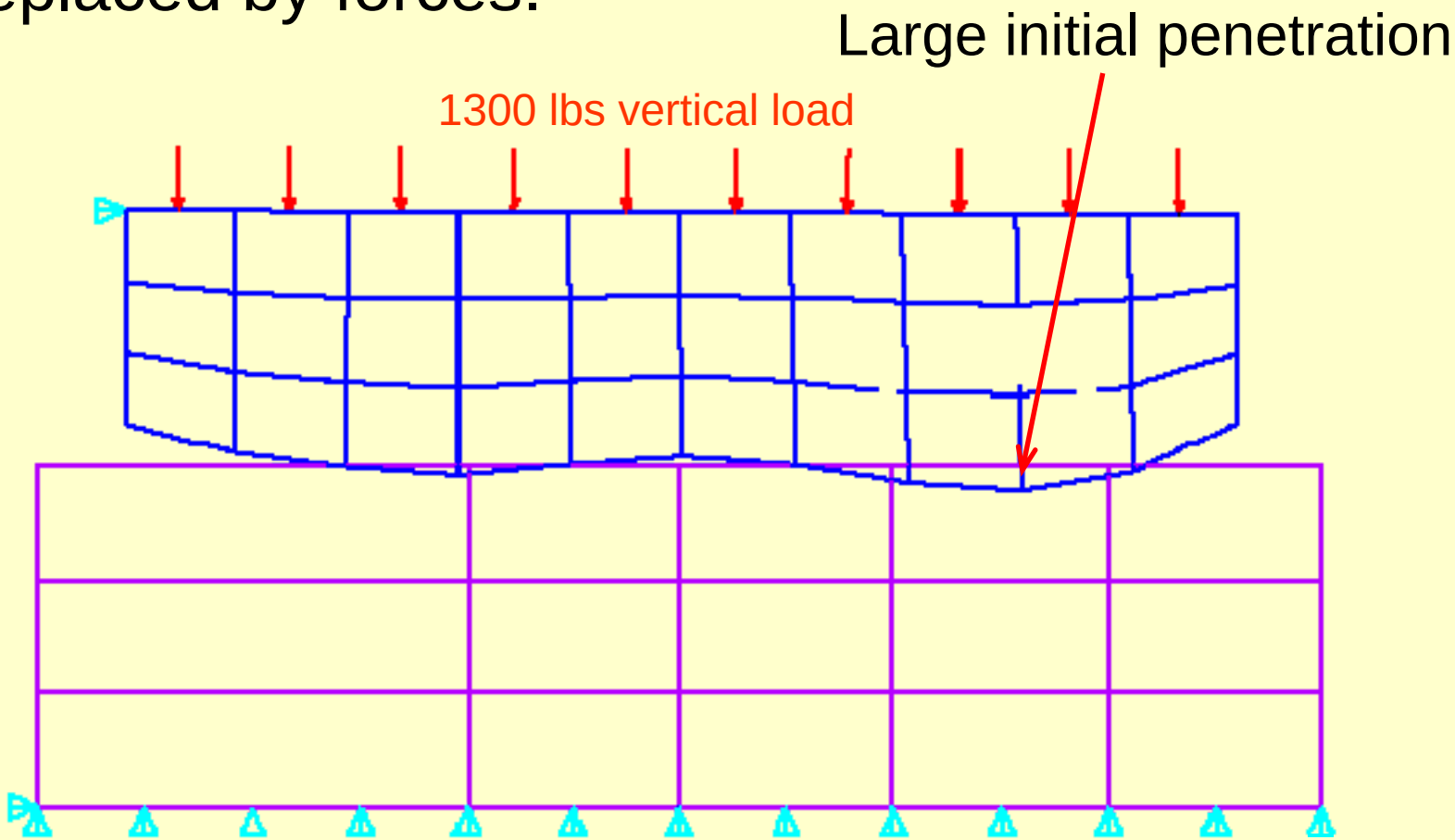
Real constant values

Lists initial contact gap/interference. Compare this to the pinball distance.

Pay attention to any warnings given.

What can go wrong? Example 1

Consider this model: Displacements on contact part are replaced by forces.



What can go wrong? Example 1

```
ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= crap.rdb
  FOR POSSIBLE RESUME FROM THIS POINT
     2D CONTACT ELEMENTS:    5 CONTACT POINTS HAVE TOO MUCH PENETRATION
     FORCE CONVERGENCE VALUE  = 0.3607E+08  CRITERION=  1.556
    EQUIL ITER   1 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.2334E-01
     LINE SEARCH PARAMETER =  0.9970     SCALED MAX DOF INC =  0.2327E-01
     FORCE CONVERGENCE VALUE  = 0.2732E+06  CRITERION=  153.0
    EQUIL ITER   2 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.1881E-01
     LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC =  0.1881E-01
     FORCE CONVERGENCE VALUE  = 0.1279E+06  CRITERION=  130.3
    EQUIL ITER   3 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.1322E-01
     LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC =  0.1322E-01
     FORCE CONVERGENCE VALUE  = 0.2540E+05  CRITERION=  41.88

 *** WARNING ***                         CP =      16.780   TIME= 10:10:36
 There are 1 small equation solver pivot terms.

 *** ERROR ***                           CP =      16.780   TIME= 10:10:36
 The value of UY at node 74 is 2.159160168E+10.  It is greater than the
 current limit of 1000000.  This generally indicates rigid body motion
 as a result of an unconstrained model.  Verify that your model is
 properly constrained.

 *** ERROR ***                           CP =      16.800   TIME= 10:10:38
 *** MESSAGE CONTINUATION ---- DIAGNOSTIC INFORMATION ***
 If one or more parts of the model are held together only by contact
 verify that the contact surfaces are closed.  You can check contact
 status in the SOLUTION module for the converged solutions using
 CNCHECK.
    >>> DOF LIMIT EXCEEDED.  MAX VALUE= 0.2159160E+11  LIMIT= 0.0000000
        IT MAY BE DUE TO PREDICTOR IS ON.
    PREDICTOR IS TURNED OFF FROM THIS POINT ONWARDS.
 *** LOAD STEP     1   SUBSTEP     1  NOT COMPLETED.  CUM ITER =      4
 *** BEGIN BISECTION NUMBER   1    NEW TIME INCREMENT=  0.50000
```

ANSYS detects too much penetration.

ANSYS applies huge penalty force [F_i^{nr}]. Note: Applied load = 1300 lbs.

Excessive penalty force pushes contact part out of orbit.

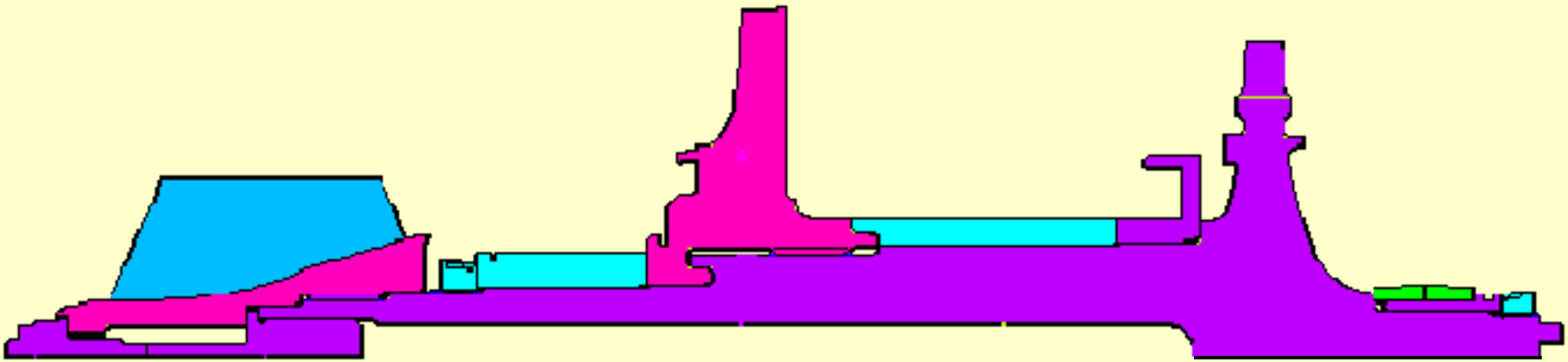
ANSYS tries to correct by bisection (applied load is cut in half, and ANSYS tries again) -- Problem continues with multiple bisections, never converges.

Example 1, Lesson Learned

- Ensure parts are initially in contact, but not excessively.
- In this case, the use of enforced displacements instead of forces will converged nicely.
- What if I don’t want enforced displacements?
- Try using contact damping (Real constant 11 – FKOP) with standard contact. Ramp over several (5+) load steps.
- Try using keyopt(9)=4 to ramp interference fit over several load steps. Note: This also requires the use of keyopt(12)=4 – No separation (always) with a small opening stiffness (FKOP)
- Run first load step with enforced displacements to obtain convergence, then run second load step with enforced displacements removed, and desired forced applied.

What can go wrong? Example 2

2D axisymmetric rotor assembly. Many contact pairs.



What can go wrong? Example 2

```
EQUIL ITER  19 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.1604E-05
F Convergence Norm=  68.758      Previous Norm=  195.31
 LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.1604E-05
 FORCE CONVERGENCE VALUE  =  51.50      CRITERION= 0.7489E-04
EQUIL ITER  20 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.1927E-05
F Convergence Norm=  51.504      Previous Norm=  68.758
 LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC =  0.1927E-05
 FORCE CONVERGENCE VALUE  =  42.31      CRITERION= 0.7642E-04
EQUIL ITER  21 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.2000E-01
F Convergence Norm=  42.309      Previous Norm=  51.504
 LINE SEARCH PARAMETER =  0.5000E-01 SCALED MAX DOF INC = -0.9999E-03
 FORCE CONVERGENCE VALUE  =  155.0      CRITERION= 0.7798E-04
EQUIL ITER  22 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.2961E-01
F Convergence Norm=  155.00      Previous Norm=  42.309
 LINE SEARCH PARAMETER =  0.5000E-01 SCALED MAX DOF INC =  0.1481E-02
 FORCE CONVERGENCE VALUE  = 0.3575E+06  CRITERION= 0.7957E-04
EQUIL ITER  23 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.4825E-03
F Convergence Norm= 0.35754E+06  Previous Norm=  155.00
 LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.4825E-03
 FORCE CONVERGENCE VALUE  =  430.1      CRITERION= 0.8120E-04
EQUIL ITER  24 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.5157E-04
F Convergence Norm=  430.13      Previous Norm= 0.35754E+06
 LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.5157E-04
 FORCE CONVERGENCE VALUE  =  195.3      CRITERION= 0.8285E-04
EQUIL ITER  25 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.2183E-04
F Convergence Norm=  195.31      Previous Norm=  430.13
 LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.2183E-04
 FORCE CONVERGENCE VALUE  =  68.76      CRITERION= 0.8285E-04
EQUIL ITER  26 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.1613E-05
F Convergence Norm=  68.758      Previous Norm=  195.31
 LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.1613E-05
 FORCE CONVERGENCE VALUE  =  51.50      CRITERION= 0.8285E-04
 >>> SOLUTION NOT CONVERGED AFTER  26 EQUILIBRIUM ITERATIONS
*** LOAD STEP     1   SUBSTEP     1  NOT COMPLETED.  CUM ITER =     26
*** BEGIN BISECTION NUMBER   1    NEW TIME INCREMENT=  0.10000
```

Note poor convergence:

- Force convergence values oscillating wildly.

- Finally, bisection occurs.

- Iterations would continue with several more bisections until ANSYS gives up.

What can go wrong? Example 2

Contact stiffness too high: Default contact stiffness (FKN) is suitable for heavy contact where two parts “mash” into each other.

Axial contact between parts results in relatively “light” contact forces. Try reducing axial contact stiffness by an order of magnitude (FKN=0.1).

```
 FORCE CONVERGENCE VALUE  = 0.9715E+07  CRITERION= 0.5102E-04
EQUIL ITER   1 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.1115E-04
F Convergence Norm=  4048.0      Previous Norm=  4048.0
 LINE SEARCH PARAMETER =  0.9294     SCALED MAX DOF INC =  0.1037E-04
 FORCE CONVERGENCE VALUE  =  328.3      CRITERION= 0.5206E-04
EQUIL ITER   2 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.9013E-05
F Convergence Norm=  328.28      Previous Norm=  4048.0
 LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.9013E-05
 FORCE CONVERGENCE VALUE  =  14.78      CRITERION= 0.5312E-04
EQUIL ITER   3 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.6943E-06
F Convergence Norm=  14.778      Previous Norm=  328.28
 LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.6943E-06
 FORCE CONVERGENCE VALUE  = 0.3573      CRITERION= 0.5421E-04
EQUIL ITER   4 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC= -0.1025E-07
F Convergence Norm= 0.35729      Previous Norm=  14.778
 LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC = -0.1025E-07
 FORCE CONVERGENCE VALUE  = 0.1098E-01  CRITERION= 0.5531E-04
EQUIL ITER   5 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.1155E-08
F Convergence Norm= 0.10979E-01  Previous Norm= 0.35729
 LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC =  0.1155E-08
 FORCE CONVERGENCE VALUE  = 0.1866E-03  CRITERION= 0.5644E-04
EQUIL ITER   6 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.1767E-08
F Convergence Norm= 0.18658E-03  Previous Norm= 0.10979E-01
 LINE SEARCH PARAMETER =   1.000     SCALED MAX DOF INC =  0.1767E-08
 FORCE CONVERGENCE VALUE  = 0.6699E-05  CRITERION= 0.5760E-04 <<< CONVERGED
```

Note solution is now well behaved.

Convergence achieved in 6 iterations.

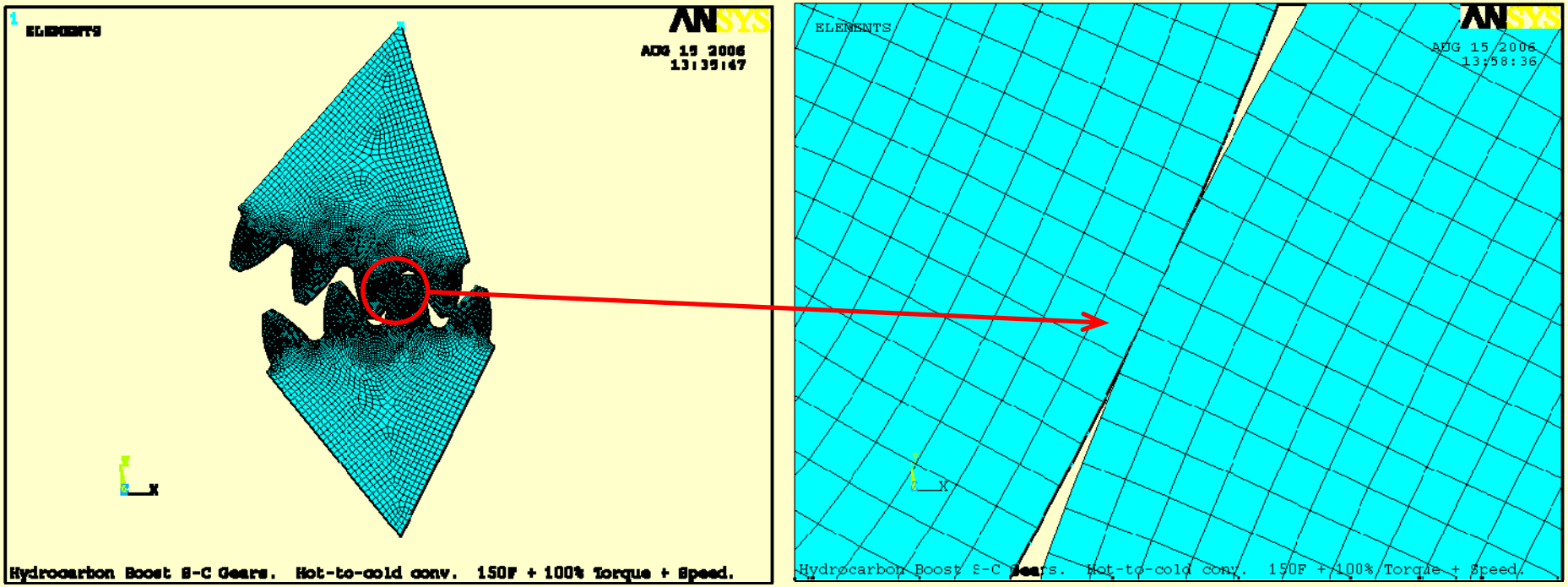
Lessons Learned: Example 2

- When contact is maintained, but residual out-of-balance force cannot be reduced to convergence value, try reducing FKN by 10x or more.
- Reducing FKN usually aids convergence and reduces number of equilibrium iterations.
- Use caution and monitor resulting contact surface penetration.
- Use caution when simulating press-fits such as radial snaps because any penetration will relieve a certain amount of preload.

What can go wrong? Example 3

Gear tooth analysis:

Note: Parts appear to be touching, but……



What can go wrong? Example 3

Gear tooth analysis:

Contact element info printed at beginning of solution (one set of info for each pair):

```
*** NOTE ***                            CP =      15.200   TIME= 13:59:38
Deformable-deformable contact pair identified by real constant set 12
and contact element type 4 has been set up.
Contact algorithm: Augmented Lagrange method
Contact detection at: Gauss integration point
Contact stiffness factor FKN                    1.0000
The resulting contact stiffness                0.11462E+12
Default penetration tolerance factor FTOLN     0.10000
The resulting penetration tolerance            0.49138E-03
Frictionless contact pair is defined
Average contact surface length                 0.48595E-02
Average contact pair depth                     0.49138E-02
Default pinball region factor PINB              1.0000
The resulting pinball region                   0.49138E-02
*WARNING*: Initial penetration is included.

*** NOTE ***                            CP =      15.200   TIME= 13:59:38
Min.  Initial gap 9.94310515E-07 was detected between contact element
11806 and target element 11771.
You may move entire target surface by: x= -9.017547135E-07, y=
4.189174583E-07, z= 0, to bring it in contact.
***************************************
```

Contact pair is initially open by very small amount.

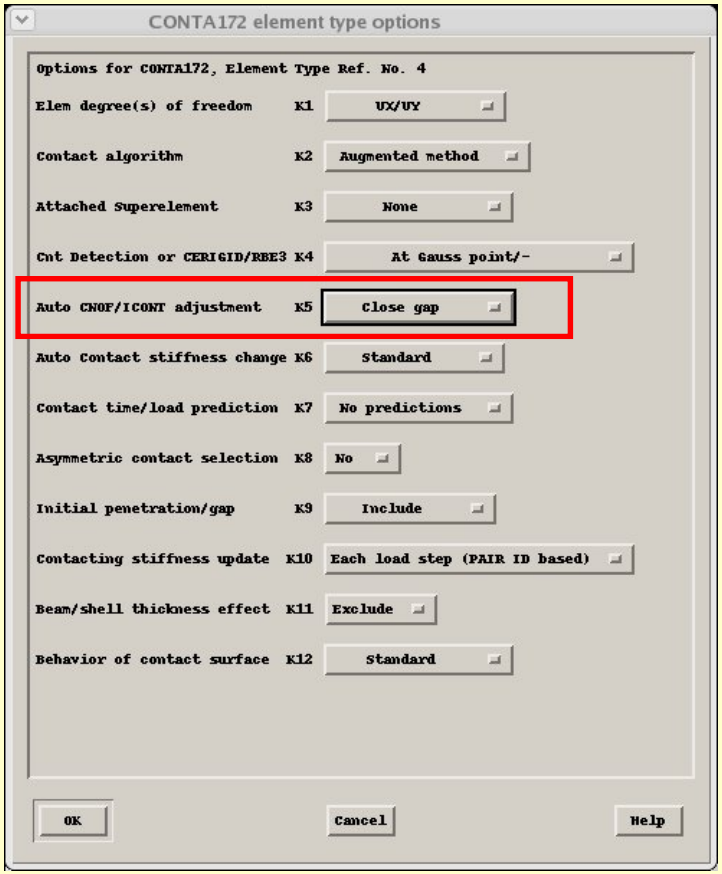
Surfaces are within the default pinball region though.

Solution fails with rigid body motion.

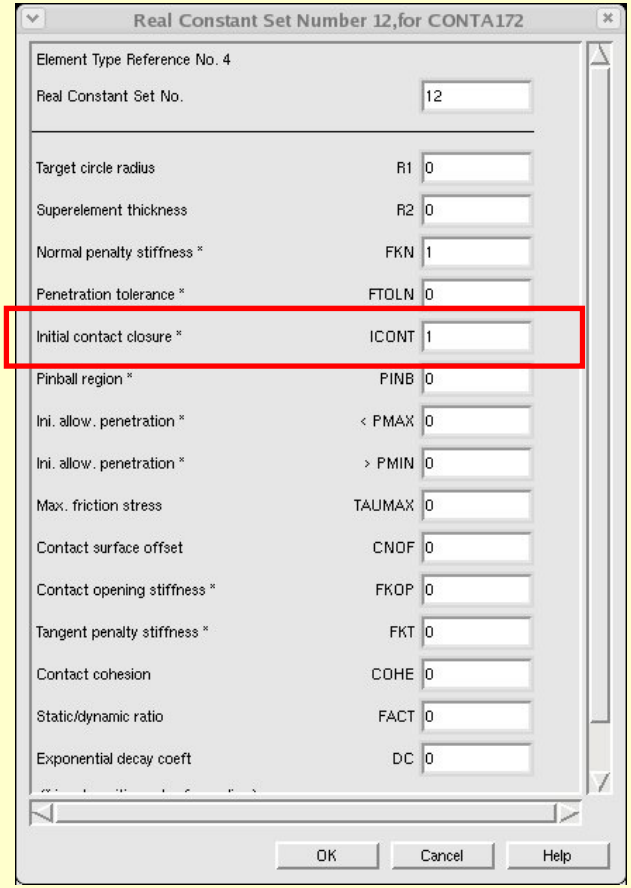
What can go wrong? Example 3

Initial Contact Closure: Allows minor, automatic adjustment.

Keyopt(5)=1 Close gap



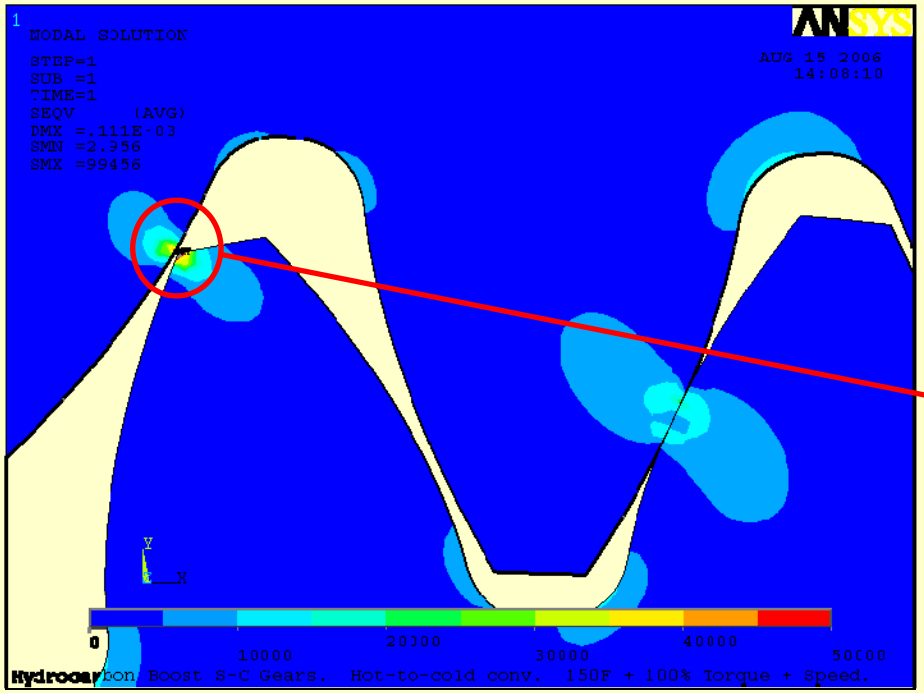
ICONT=1 Initial contact closure



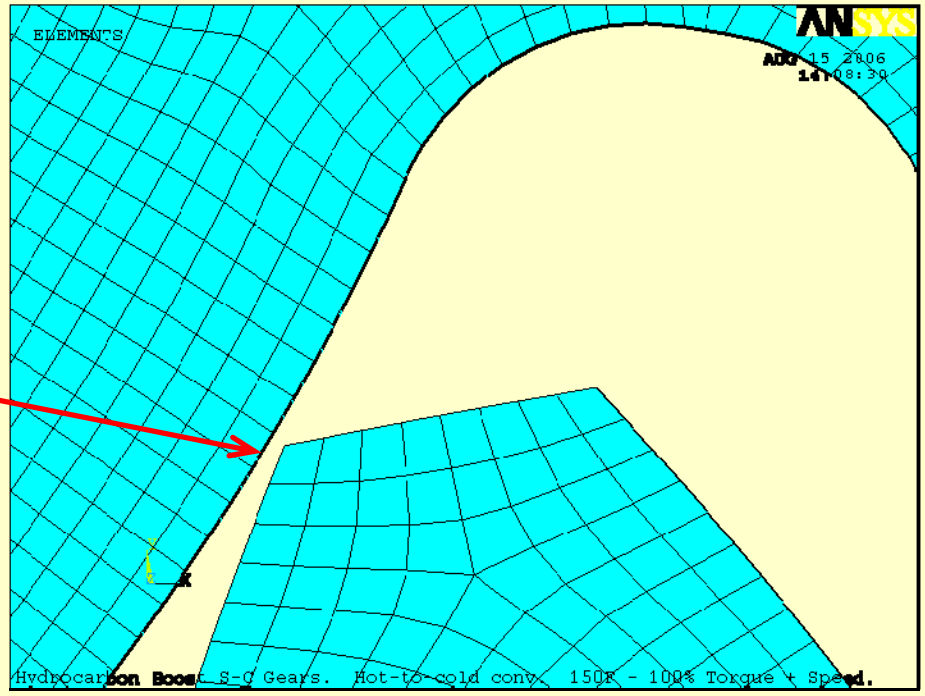
What can go wrong? Example 3

Nodes adjusted too much! Contact occurs where it shouldn't:

Solution Results:

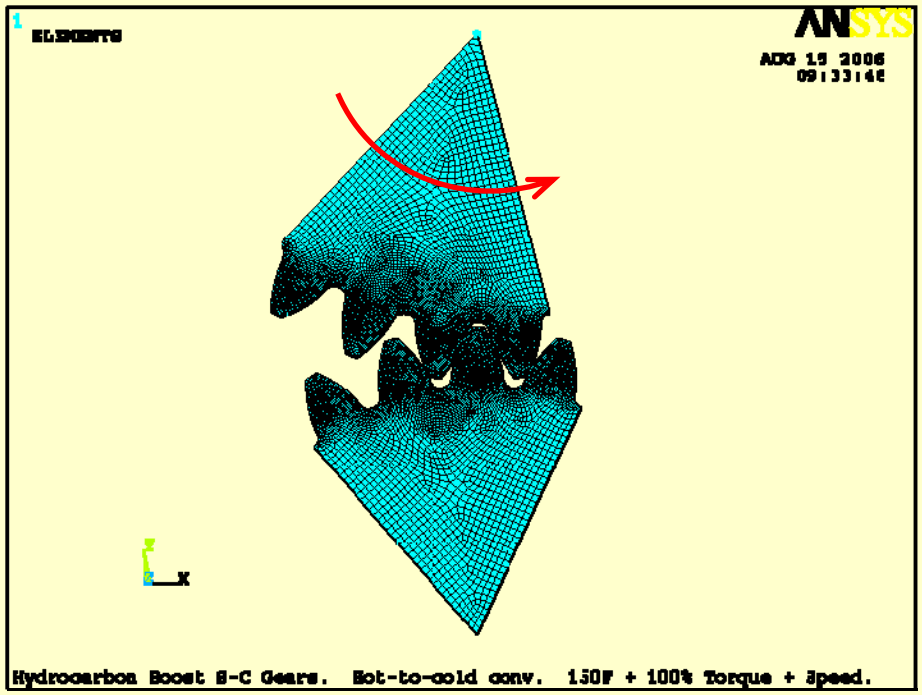


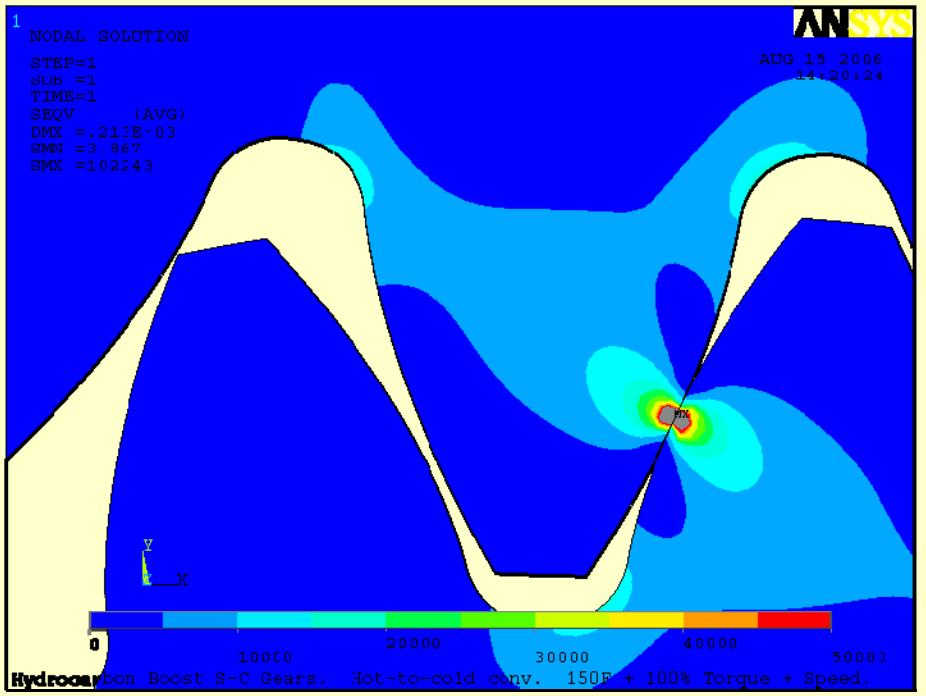
Initial Geometry (no contact):



What can go wrong? Example 3

Better solution: Move gear slightly to create initial contact.





Lessons Learned: Example 3

- Ensure parts are initially in contact.

- If rigid body motion occurs, initial contact was probably not established.

- If possible, physically move parts to create just touching or very slight overlap of contact surfaces.

- Try keyopt(9)=1, 3, or 4 (excludes geometric gap).

- Above methods are preferred, but keyopt(5)=1-3, and real constants: ICONT, PMIN, PMAX can be used ***with caution.*** Be especially careful when simulating multi-body assemblies. ***These options can move parts and change your desired initial gap or interference.***

Contact Tools

CNCHECK command:

Lists status of each contact pair without running a solution.

CNCHECK,ADJUST will physically move contact nodes to be touching target surface (within a tolerance).

NLDIAG,NRRE,ON
PLNS,NRRE,,SETID
Stores and plots Newton Raphson residuals to identify trouble area.

```
*** NOTE ***                            CP =       2.470   TIME= 14:44:51
 Min.  Initial gap 2.100158742E-03 was detected between contact element
 11884 and target element 11857.
 You may move entire target surface by: x= -1.800540841E-03, y=
 1.081073272E-03, z= 0, to bring it in contact.

 ****************************************
*** NOTE ***                            CP =       2.480   TIME= 14:44:51
 Deformable-deformable contact pair identified by real constant set 14
 and contact element type 4 has been set up.
 Contact algorithm: Augmented Lagrange method
 Contact detection at: Gauss integration point
 Contact stiffness factor FKN                    1.0000
 The resulting contact stiffness                0.11749E+12
 Default penetration tolerance factor FTOLN     0.10000
 The resulting penetration tolerance            0.47937E-03
 Frictionless contact pair is defined
 Average contact surface length                 0.48595E-02
 Average contact pair depth                     0.47937E-02
 Default pinball region factor PINB              1.0000
 The resulting pinball region                   0.47937E-02
 *WARNING*: Initial penetration is included.

 *** NOTE ***                            CP =       2.500   TIME= 14:44:51
 No contact was detected for this contact pair.
 ****************************************


      4 CONTACT PAIRS ARE SELECTED
    CONTACT PAIR HAVING REAL ID =    11 IS INITIALLY OPEN
    CONTACT PAIR HAVING REAL ID =    12 IS INITIALLY CLOSED
    CONTACT PAIR HAVING REAL ID =    13 IS INITIALLY OPEN
    CONTACT PAIR HAVING REAL ID =    14 IS INITIALLY OPEN
```

Contact Trouble Shooting Guide

- All contact convergence problems fall in one of two categories (or both):
  1. Failure to detect contact resulting in rigid body motion.
  2. Contact achieved, but failure to reduce out-of-balance residual forces below convergence criteria.
- ***Use the output to determine which problem you have!*** The recommended corrective actions are different for each problem.

Failure to Detect Contact Resulting in Rigid Body Motion

Review contact pair summary. If there are initial gaps, move parts to establish initial contact, or use **CNCHECK,ADJUST** to align nodes.

Still have RBM? Yes

Use contact damping – With standard contact, set FKOP to negative value (Try starting value of -10). Ramp loads over several substeps.

Still have RBM? Yes

For initially open contacts that you expect to close, increase pinball (PINB).

Still have RBM? Yes

Add a weak spring for stability – Set contact behavior to no separation (always) keyopt(12)=4, Set FKOP=small value.

Still have RBM? Yes

Run initial load step with small displacement constraint to seat contacts (very slight overlap). Then remove constraints and apply desired loads in second load step.

Failure to Reduce out-of-balance Residuals Below Convergence Criteria

Identify contact pair(s) causing trouble. If not obvious, set NLDIAG,NRRE,ON. Run solution, Plot out-of-balance residuals using PNLS,NRRE.

↓

Reduce FKN to 0.1 or 0.01. Ramp load in 5+ substeps. (Verify that penetration is acceptable)

Still not converged? ↓

If large interference fit, use keyopt(9)=4 (CNOF only, ramped). Set behavior to no separation (always) keyopt(12)=4 with small value for FKOP. Ramp loads in several substeps (5+).

Still not converged? ↓

Contact stiffness update: Try keyopt(10)=2 [pair based, each iteration], then keyopt(10)=3 [element based, each substep] May try options 4, or 5 for stubborn problems.

Still not converged? ↓

Auto-stiffness change: Set keyopt(6)=2 [Very Aggressive]. -- Good success with this option! Can even reduce iterations on well behaved problems. I often use this as my default.

So frustrated you could strangle a puppy? ↓

Other options: Add small amount of friction [mu=0.05], Reduce FKN another 10x, consider ramping FKN up over successive load steps if penetration too great. Sacrifice a virgin.

Contact Trouble Shooting Guide

- Options I ***Do Not*** recommend:
  - Symmetric contact – no benefit for convergence issues.
  - CNOF/ICONT Automated adjustment keyopt(5)>1 This can cause contact where you don't want it, or change desired gap or interference. Better to address alignment issues with other methods.