Analyzing Nonlinear Contact

Convenient tools help analyze problems in which the contacting area between touching parts changes during the load history.

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In a wide range of structural applications, bonded contact element methods are sufficient to calculate stresses between parts in assemblies in which multiple components are bolted, welded, glued or otherwise joined together. In cases such as gears, cams, levers and other assemblies with moving parts, however, the contact area between components changes during the load history. For these types of nonlinear analyses, mechanical solutions from ANSYS provide robust contact technology along with diagnostic tools that can help obtain converged, accurate solutions to problems that otherwise would be quite challenging to handle.

Initial Contact Information

Rigid-body motion in which parts are not initially in contact is often a common convergence problem. Defining and verifying contact between parts, therefore, is an important first step in the analysis. Initial contact status is easily checked in mechanical solutions from ANSYS, including whether or not parts that are thought to be in initial contact are truly touching.

Using mechanical simulation within the ANSYS Workbench environment, you may insert a `Contact Tool` underneath the `Connections` branch, as shown in Figure 1. Specific contact regions can be selected or

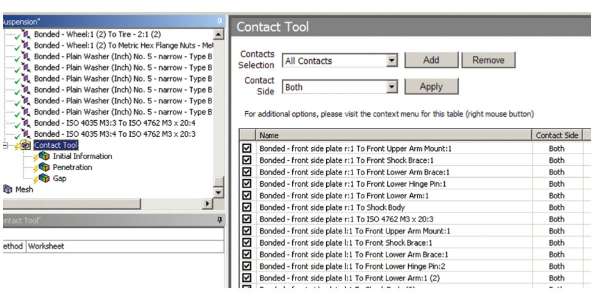

Figure 1. The contact tool can be used to check initial contact status.

deselected, and plotting/listing of only the contact or target side is possible from this worksheet. Multiple `Contact Tool` branches may also be inserted for reviewing contact regions in different groups.

The `Initial Information` branch is included by default, although users may insert contour results of initial `Status`, initial `Penetration` or initial `Gap` as well. If you right-click on Contact Tool and select `Generate Initial Contact Results`, the initial contact information will be calculated and presented in tabular form, as shown in Figure 2. The rows conveniently summarize the type of contact and highlight possible problems in different colors: orange (possibly large penetration or gap), yellow (frictionless or frictional contact pair having an initially open state) or red (bonded or no-separation contact initially having an open state). This allows models with large numbers of contact regions to be easily examined.

Name	Contact Side	Type	Penetration (mm)	Gap (mm)	Geometric Pene…	Geometric Gap…	Resulting Pinball (mm)
Bonded - Shock Shaft:1 To Piston:1	Contact	Bonded	6.4837e-015	0.	0.	7.1214e-004	0.2033
Bonded - Shock Shaft:1 To Piston:1	Target	Bonded	5.0468e-015	0.	5.5755e-004	7.1058e-004	0.17888
Bonded - Shock Shaft:1 To Ball End:1	Contact	Bonded	2.1615e-013	0.	9.0913e-002	6.2606e-009	0.25664
Bonded - Shock Shaft:1 To Ball End:1	Target	Bonded	3.1021e-014	0.	0.31222	5.3562e-009	0.3161
Bonded - Shock Shaft:1 To Spring Cup:1	Contact	Bonded	9.1238e-015	0.	0.	0.10217	0.26344
Bonded - Shock Shaft:1 To Spring Cup:1	Target	Bonded	8.9593e-015	0.	0.	7.2879e-002	7.3943e-002
Bonded - E-Clip:1 To Piston:1	Contact	Bonded	9.9028e-015	0.	8.6165e-009	6.7188e-009	9.525e-002
Bonded - E-Clip:1 To Piston:1	Target	Bonded	9.9028e-015	0.	8.1576e-009	8.4217e-009	0.19016
Bonded - E-Clip:2 To Piston:1	Contact	Bonded	1.4854e-014	0.	7.8736e-009	7.8119e-009	9.525e-002
Bonded - E-Clip:2 To Piston:1	Target	Bonded	4.9514e-015	0.	6.4577e-009	6.8869e-009	0.20406
Bonded - Ball End:1 To 0.25 Ball:1	Contact	Bonded	2.8281e-014	0.	1.6928e-002	0.11229	0.11776
Bonded - Ball End:1 To 0.25 Ball:1	Target	Bonded	9.3321e-015	0.	2.8342e-002	9.3884e-002	0.4397
Bonded - Ball End:1 To Spring Cup:1	Contact	Bonded	1.9806e-014	0.	1.9635e-003	0.20737	0.27889
Bonded - Ball End:1 To Spring Cup:1	Target	Bonded	1.9806e-014	0.	1.7406e-003	0.11672	0.12108
Bonded - Ball End:1 To Plain Washer (Inch) No. 5 …	Contact	Bonded	0.	0.	0.	0.	0.10171
Bonded - Ball End:1 To Plain Washer (Inch) No. 5 …	Target	Bonded	0.	0.	0.	0.	0.2032
Bonded - 0.25 Ball:1 To ISO 4762 M3 x 12:12	Contact	Bonded	1.4948e-014	0.	2.6615e-002	8.9457e-002	0.3079
Bonded - 0.25 Ball:1 To ISO 4762 M3 x 12:12	Target	Bonded	7.5064e-014	0.	0.10051	0.10545	0.11615
Frictionless - Shock Spring Adjust Nut.ipt:1 (2) To…	Contact	Frictionless	2.2712e-003	0.	2.2712e-003	N/A	0.56365
Frictionless - Shock Spring Adjust Nut.ipt:1 (2) To…	Target	Frictionless	0.	7.6289e-005	0.	N/A	2.6427
Frictionless - Shock Body (2) To Shock Cartridge:…	Contact	Frictionless	0.4643	0.	0.4643	N/A	4.219
Frictionless - Shock Body (2) To Shock Cartridge:…	Target	Frictionless	0.73535	0.	0.73535	N/A	0.73716
Frictionless - Shock Body (2) To Shock Cartridge …	Contact	Frictionless	0.	0.10171	0.	N/A	2.7907
Frictionless - Shock Body (2) To Shock Cartridge …	Target	Frictionless	0.2855	0.	0.2855	N/A	0.80642
Bonded - Shock Body (2) To Piston:1 (2)	Contact	Bonded	1.9828e-014	0.	0.26625	0.23864	0.30927
Bonded - Shock Body (2) To Piston:1 (2)	Target	Bonded	1.5784e-013	0.	0.23564	0.2403	0.24046
Bonded - Shock Body (2) To Plain Washer (Inch) …	Contact	Bonded	0.	0.	0.	0.	0.28976
Bonded - Shock Body (2) To Plain Washer (Inch) …	Target	Bonded	0.	0.	0.	0.	0.2032
Bonded - Shock Cartridge:1 (2) To O-Ring:1 (2)	Contact	Bonded	1.9806e-014	0.	0.	0.31462	0.43157

Figure 2. Types of contact are summarized, with potential problems highlighted in various colors.

Contact Result Tracker

Nonlinear solutions of large models may consume considerable CPU time, after which users may be disappointed to find that incorrect model setup or unanticipated contacting areas lead to an invalid solution.

The ability to track results can help alleviate such problems. Prior to solving, you can request certain results for specific contact regions and monitor these results during the course of the analysis. Then, if the contact solution starts to deviate from the expected behavior, the analysis can be stopped without having to wait until the end of the run to find out that the analysis setup may not be correct.

To track contact results, drag-and-drop a contact region branch from the `Connections` branch to the `Solution Information` branch. In the Details view of the `Result Tracker` that appears, the user may select a number of items for a given contact region, including but not limited to the number of contacting elements and the maximum contact pressure. Add as many `Result Tracker` items as necessary.

As an example, Figure 3 shows the number of contacting elements for seven contact regions while the nonlinear solution is progressing. Note that the contact region Frictional-seal3 is in near-field (open) contact throughout the solution. On the other hand, the contact region Frictional-opening was open until a time of 0.4, when a large number of elements came into contact. This helps a

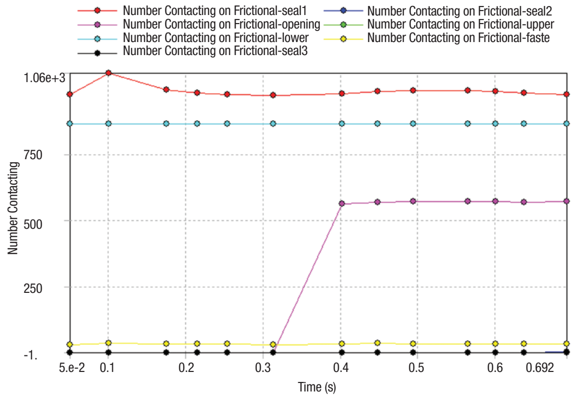

Figure 3. The number of contacting elements is shown as the nonlinear solution is progressing.

user understand if each contact region is increasing or decreasing in the contacting area. If the behavior is unexpected, the solution may be stopped to examine the intermediate results.

Nonlinear Diagnostics

The contact stiffness k_n is the most important contact parameter for the penalty-based approach, influencing both convergence behavior and accuracy. During equilibrium iterations, if the force residuals plateau (as shown in the example in Figure 4), chances are high that contact stiffness is preventing force convergence. While contact stiffness may be a cause for the high residuals, you may not be certain simply by looking at the force convergence behavior.

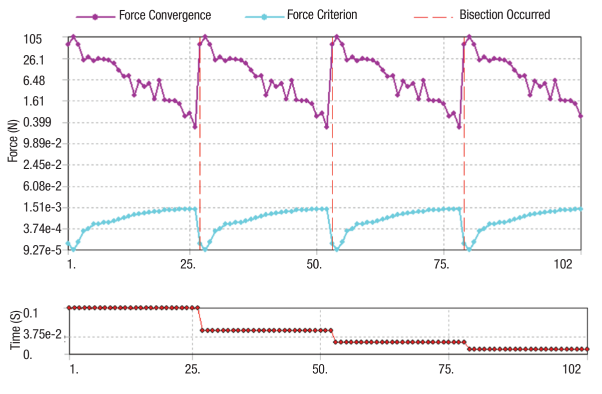

Figure 4. Contact stiffness might be preventing force convergence if force residuals plateau.

During the Newton–Raphson iteration, convergence is achieved when force equilibrium is satisfied. When using mechanical simulation in ANSYS Workbench, the user can request Newton–Raphson residual output, so regions of high out-of-balance forces can be reviewed. This helps in determining where force imbalance is high and, if the area is associated with a contact region, which contact regions may have too high of a contact stiffness defined.

In mechanical simulation within ANSYS Workbench, prior to initiating a solution, select the `Solution Information` branch. In the Details view, a value of "4" can be entered for the Newton–Raphson Residuals. In cases of an incomplete solution, contours of Newton–Raphson residuals for the last four iterations will be available under the `Solution Information` branch, and contour plots can be generated as shown in Figure 5. In this example, a solid cylinder pushes down on two hollow cylinders; half of the model is displayed. The highest residuals are between the two concentric hollow cylinders, indicating that the contact stiffness defined for that region may be too high and, consequently, should be lowered.

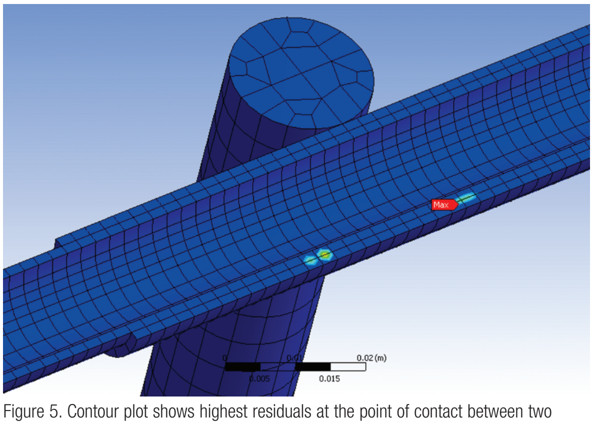

Figure 5. Contour plot shows highest residuals at the point of contact between two concentric hollow cylinders.

Contact Post-Processing

Post-processing is the most important step of any analysis, and contact problems are no exception. Always review contour plots of contact status, pressure and penetration to verify that the mesh adequately captures the contact behavior and that results are correct. Contact penetration is in units of length, so deformation can be compared in the same direction as contact. If the penetration is a small fraction of the deformation, you can safely assume that any variation in penetration would not affect results significantly.

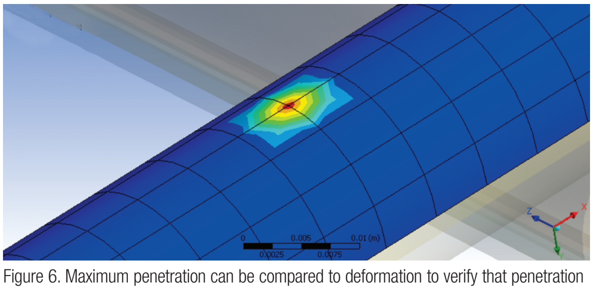

Figure 6. Maximum penetration can be compared to deformation to verify that penetration is negligible.

In Figure 6, maximum penetration is 4.256×10^{-3} mm. This value can be compared to the deformation on the same contact surface to verify that the penetration is negligible. Checking the contact status may indicate that contact detection is occurring at a very localized region and may warrant a finer mesh. ■