Initial Penetrations in Contact Interfaces

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1. Introduction

Contact definitions allow the modeling of interaction between one or more parts in a simulation model and have become a necessity in any small or large deformation problem. The main objective of the contact interfaces is to eliminate any “overlap” or “penetration” between the interacting surfaces and they accomplish this by first detecting the amount of penetration and then applying a force to remove them. Depending on the type of algorithm used to remove the penetration, both energy and momentum is conserved. This article discusses the presence of penetration in non-tied penalty-based contact interfaces during the initialization of the problem, usually termed as “initial penetration”, its effects on the accuracy, robustness of the model and how LS-DYNA® has features that can minimize its adverse effects.

2. Detecting Penetrations

In order to detect the penetration due to contact, LS-DYNA first performs a global search using the Bucket-Sort approach and then a local search using the incremental search technique, to find the closest master segment for any given slave node or a segment. Once a closest segment is found, it projects the slave nodal coordinates onto the closest master segment to compute its orthogonal distance. This is shown in **Figure 1**. The projected normal distance is computed using a local coordinate system that is embedded in the master segment and is updated every cycle. Based on the sign of the projected distance, LS-DYNA determines if the node is inside (penetration) or outside (no-penetration) the master segment. Projected distance that is less than 0 indicates that a penetration has occurred while a positive projected distance indicates a no penetration condition.

3. Initial Penetration

Initial penetration is a term used frequently to describe the amount of penetration that exists between a node and its closest master segment (in the case of classic node/segment treatment) or between two interacting segments (in the case of “segment-based” treatment) ***during the initialization of the problem***. This is shown in **Figure 2** by considering only the thickness on the master segment for simplicity.

4. Need for Penetration-Free Simulation Model at First Cycle

Existence of penetration at the first cycle in non-interference contact definitions, which is after the initialization of the problem, has several adverse effects on the quality of the simulation. LS-DYNA attempts to remove any penetration that may exist at the first cycle by applying forces to the nodes involved. This initial force can in some instances be very large which may have adverse effects on the stability of the model. These forces could also lead to localized initial stresses and strains that may be non-physical. Additionally, if the penetrations were unable to be removed completely at the first cycle, they tend to be carried over to the subsequent cycles leading to a "negative energy" condition altering the numerical accuracy of the simulations. Experience with large and complicated models show that any existence of penetration at the first cycle effects repeatability and robustness when the model is run using multiple combinations of software and hardware. These shortcomings of initial penetrations motivate both the developers and the users to find a method that not only eliminate the issues but they do that in a way that requires minimum user effort.

5. Default Treatment to the Handle Initial Penetrations in Node/Segment Contact

In the default treatment, when a slave node is found to penetrate its closest master segment, LS-DYNA updates the nodal coordinates to remove the penetration. Who gets updated depends on the contact definition itself. When the contact definition belongs to the family of "Single Surface" such as "AUTOMATIC_SINGLE_SURFACE" or "AUTMOATIC_GENERAL" or "AIRBAG_SINGLE_SURFACE" to list a few, then both the slave node AND the master segment is moved by the amount. When the contact definition belongs to the family of "ONE-WAY or TWO-WAY", then only the slave nodal coordinates are updated to remove the penetration.

In both cases, the removal of penetration is performed using three iterations. At the end of these three iterations, it is possible for penetrations to exist and is entirely based on the model content and the sequence of the contact definitions. For example, we can have two contact definitions C1 and C2 in that order. During the first iterative pass, if we detect penetration of slave node SN1 with master segment MS1, we update the nodal coordinate of SN1 such that it lies exactly on the surface of MS1. Within the same iterative pass, we now check for penetrations due to C2. If SN1 belongs to C2 and is found to penetrate another master segment MS2 in the opposite direction, then we again update the nodal coordinates of SN1 which could void the step performed earlier while handling C1. This type of situation could result in the existence of penetration of SN1 even after 3 iterative pass.

6. Advantages and Disadvantages of the Default Initial Penetration Removal

Process

Pros	Cons
1. Eliminates manual removal process thereby saving user's time and effort. 2. Eliminates contact stresses at time zero (cycle 1)	1. Distorts original geometry at locations where the penetrations are detected. 2. Nodal coordinates after the removal process could still penetrate other neighboring segments and may lead to instability issues.

7. Treatment of Initial Penetrations when IGNORE = 1 for Node/Segment Contact

IGNORE parameter available in both *CONTROL_CONTACT and *CONTACT_{OPTION} (Optional Card 'C') keywords allows a new method of handling the presence of initial penetrations. When IGNORE=0, LS-DYNA uses the old default method by updating the nodal coordinates of the offending nodes/segments. This is illustrated in **Figure 3**. When IGNORE = 2, LS-DYNA does exactly the same steps as described above with the exception that a list of offending nodes and their initial penetration values are written into D3HSP file.

8. Recommendations

The most obvious recommendation would be to have no initial penetrations at all. However, this is rather difficult due to the nature of the model building process and the number of design changes that usually occur during the course of the product lifecycle. Accepting this, there are several methods to treat initial penetrations and they are briefly discussed here:

8.1 Use of external pre-processors.

Instead of a fixed number of iterations to remove penetration by LS-DYNA, external pre-processors allow a user-defined number of iterations until a certain level of acceptable penetrations are reached. This approach may assure zero or minimal penetration levels but comes at the cost of geometry update which may be undesirable from the design perspective. Additionally, they still may not resolve issues such as dependent nodal penetrations where one contact interferes with another as discussed above. Lastly, depending on the penetration condition, it is extremely difficult to match the penetration-check algorithms between the pre-processors and LS-DYNA as the checks are refined in newer releases in LS-DYNA. Using external pre-processor is recommended for simple models as long as the updated coordinates do not deviate significantly from the original geometry which in complicated models could be extremely difficult to verify. LS-PrePost® (version 2) provides a feature to detect and remove initial penetrations. More information on this new feature can be viewed at http://www.lstc.com/lspp.

8.2 Contact thickness scaling

LS-DYNA allows scaling of contact thickness in several ways which has no effect on the structural thickness specified in the section definitions. The first method involves scaling of contact thickness that affects ALL segments for a particular contact definition.

The first method involves using any of the parameters such as SST, MST, SFST, SFMT in individual contact keyword *CONTACT_{OPTION}. SST and MST values override values specified in the section definitions while SFST and SFMT SCALE them. Using this method, one can quickly replace or scale-down the contact thickness for the entire contact but comes with certain drawbacks. If the penetration levels are located in a localized region, using this approach we are scaling down all the segments that has no penetration levels associated which could create additional clearances between components that originally did not have any initial penetrations.

The second method involves replacing or scaling the contact thickness at a PART level using the _CONTACT option in the *PART keyword. Parameter OPTT can be used to override the thickness or parameters SFST can be used to scale the contact thickness. This method is highly recommended if the penetration level exists in a localized region since it only affects the scaling or overriding of values for the part that uses the _CONTACT option.

8.3 IGNORE parameter in *CONTACT and *CONTROL_CONTACT keyword

Considering the difficulties in using any external pre-processor to remove initial penetrations, the option of using the IGNORE parameter to remember the penetration history without modifying the nodal coordinates is very attractive considering it involves the minimum of users time and effort. During the course of a product lifecycle, several design changes related size and shape will be incorporated. Size changes, involving shell component thicknesses, will alter the initial penetration conditions if IGNORE parameter is not considered which may lead to geometry updates that may alter the solution. Using IGNORE=1 causes LS-DYNA to skip the geometry update step thereby preserving the geometry while considering size changes.

9. Acknowledgements

It is with extreme pleasure that I acknowledge Dr. Lee Bindeman, for sharing information related to segment-based contacts, Dr. Jason Wang for sharing information related to the MPP version of LS-DYNA, and Dr. Morten Jenson for reviewing this article.

10. References

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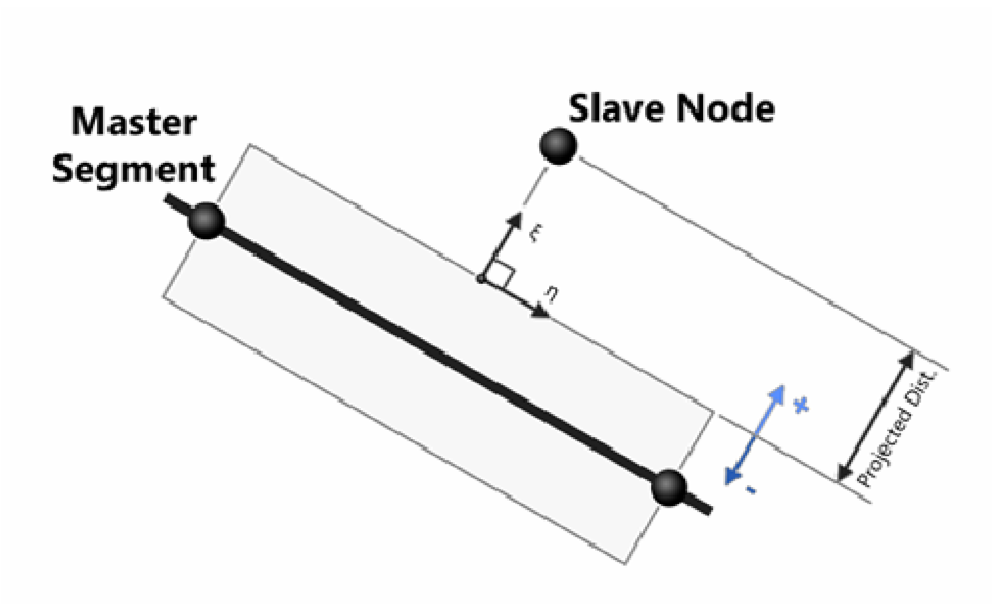

FIGURE 1 SLAVE NODE PROJECTION

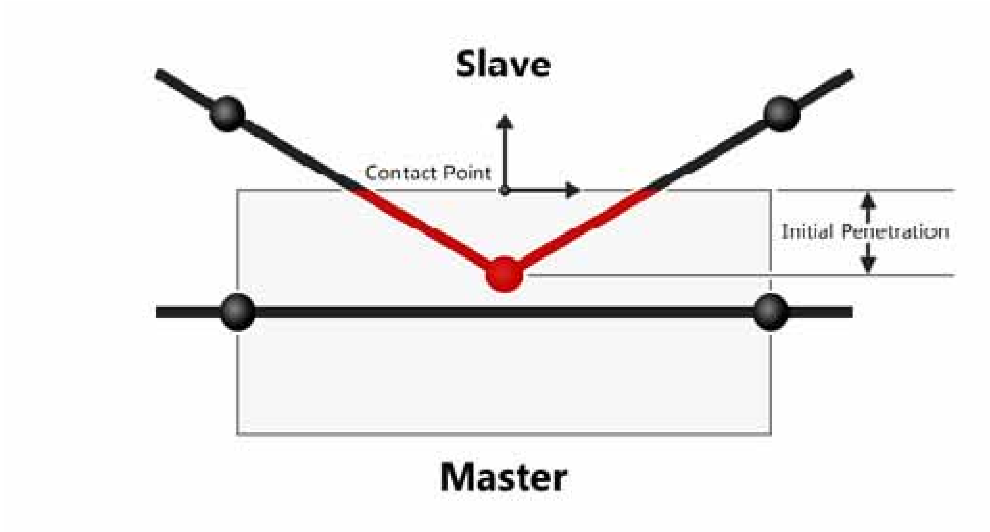

FIGURE 2 INITIAL PENETRATION

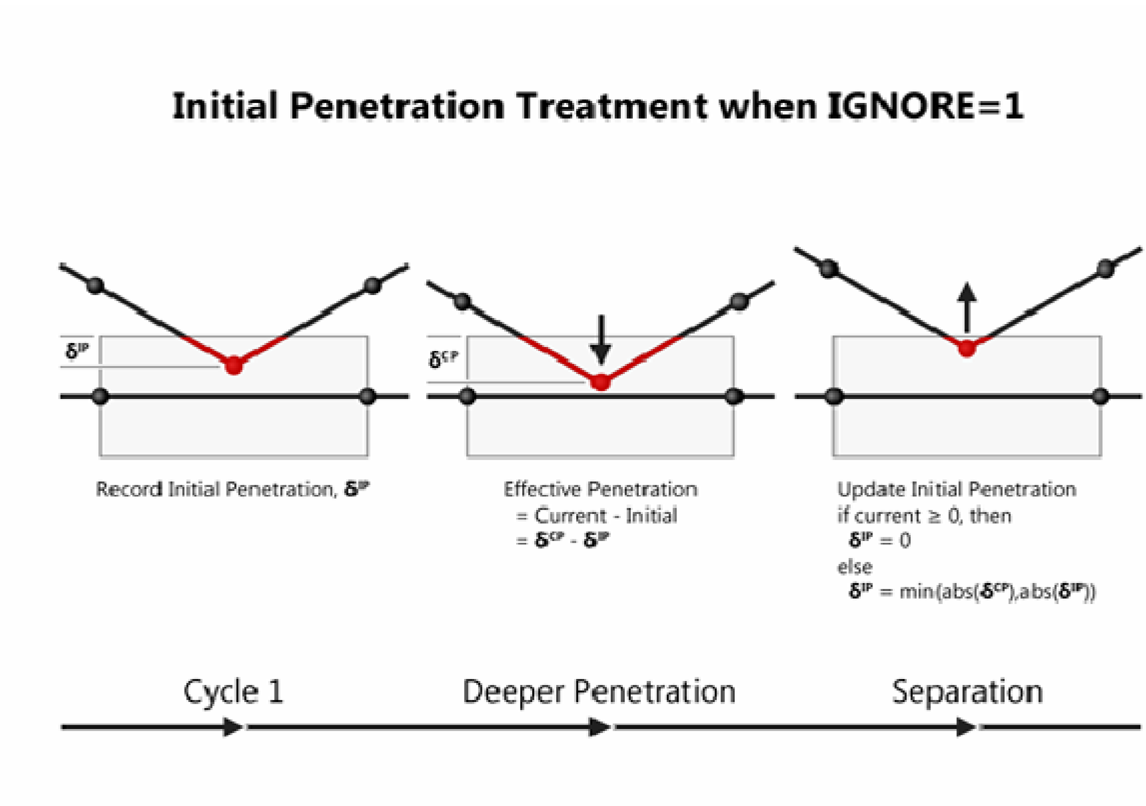

FIGURE 3 PENETRATION TREATMENT FOR *IGNORE > 0*