Thermal Coupling Method Between SPH Particles and Solid Elements in LS-DYNA

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INTRODUCTION:

Heat transfer is very important in many industrial and geophysical problems. Many of the problems of geophysical and industrial fluid dynamics involve complex flows of multiple liquids and gases coupled with heat transfer. The motion of the surfaces of the liquids can involve sloshing, splashing and fragmentation. Thermal and chemical processes present further complications. The simulation of such systems can sometimes present difficulties for finite difference and finite element methods, particularly when coupled with complex free surface motion, while smoothed particle hydrodynamics can easily follow wave breaking, and it provides a reasonable simulation of splash on a length scale exceeding that where surface tension must be included.

SPH is a Lagrangian method for solving partial differential equations. Essentially, the domain is discretized by approximating it by a series of roughly equi-spaced particles. They move and change their properties (such as temperature) in accordance with a set of ordinary differential equations derived from the original governing PDEs. Cleary and Monaghan (1995) extended the method to heat conduction and then to coupled heat and mass flows due to that SPH has a range of strong advantages in modeling industrial heat and mass flows:

1. The Lagrangian framework allows momentum dominated flows to be easily handled.
2. Complex free surface and material interface behavior, including break-up into fragments, can be modeled naturally.
3. Complicated physics such as multi-phase, realistic equations of state, compressibility, radiation, solidification and fracturing can be added with comparative ease.

For the thermal coupling between any two parts in LS-DYNA, the standard way is through thermal contacts which require the contact areas between those two parts. Due to particle property, SPH particles can handle extremely large deformations, particles can be moved without limitation. In real engineering applications, SPH particles may have very complex free surface and material interface behaviors, including break-up into fragments, and new surfaces will be generated automatically every cycle when interacting with Solid elements. It is quite difficult to update new contact surfaces and calculate the true contact areas between SPH particles and Solid elements. Here we introduce a new thermal coupling method between SPH particles and Solid elements through keyword *DEFINE_ADAPTIVE_SOLID_TO_SPH with icpl=3 and iopt=0 options without using thermal contacts.

KEYWORD IN LS-DYNA AND APPLICATIONS:

Keyword *DEFINE_ADAPTIVE_SOLID_TO_SPH is used to adaptively transform a Lagrangian solid Part or Part Set to SPH particles, when the Lagrangian solid elements comprising those parts fail (Shown in Fig 1), or used as hybrid elements to couple between original SPH parts and Solid parts. One or more SPH particles (elements) will be generated for each failed element. The SPH particles replacing the failed element inherit all of the properties of the failed solid element, e.g. mass, kinematic variables, and constitutive properties.

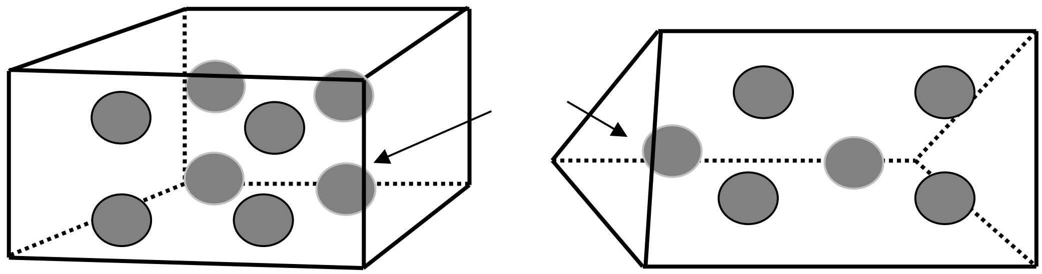

Fig 1. Transform Solid elements into SPH particles

With ICPL=0, this keyword is used for debris simulation, no coupling happens between newly generated SPH particles and solid elements, user need to define node to surface contact for the interaction between those two parts. When ICPL=1 and IOPT=1, the newly generated SPH particles are bonded with solid elements as one part through the coupling (Hybrid elements).

With ICPL=1 and IOPT=0, this keyword is used as Hybrid Elements coupling SPH with Solid. Hybrid elements are used as transit layers between SPH particles and Solid elements, for a portion of grid model comprises SPH particles because the likelihood of enduring large deformation, while the rest of the model comprises FEM solid elements, hybrid elements are placed between the solids and the particles, each hybrid element comprises two layers: solid layer and particle layer.

A new function was introduced into this keyword for the pure thermal coupling between SPH particles and Solid elements with ICPL=3 and IOPT=0. In this function hybrid elements were used, we have the SPH formulation and at the same time we have the Solid meshes which clearly describe the material interfaces. Solid elements constrain SPH nodal locations. SPH particles here provide real thermal coupling between original SPH parts and Solid element parts, also a coupling conductivity parameter between SPH part and Solid part was introduced here in the 8^{th} parameter of the keyword input *DEFINE_ADAPTIVE_SOLID_TO_SPH (as shown in Fig 4).

EXAMPLES

Case 1:

A simple 3D pure thermal conduction example was tested here. For both SPH and Solid parts, initial temperature conditions were set to 0.0. On the surface nodes of the right side of the SPH part, a constant thermal BC was set (as shown in Fig 2). The thermal coupling between SPH and Solid part was applied through keyword *DEFINE_ADAPTIVE_SOLID_TO_SPH with icpl=3 and iopt=0. The default coupling conductivity between SPH and Solid parts was set (average value of the conductivities of two parts). Fig 3 shows the temperature results from the thermal conduction and the thermal coupling between SPH part and Solid part.

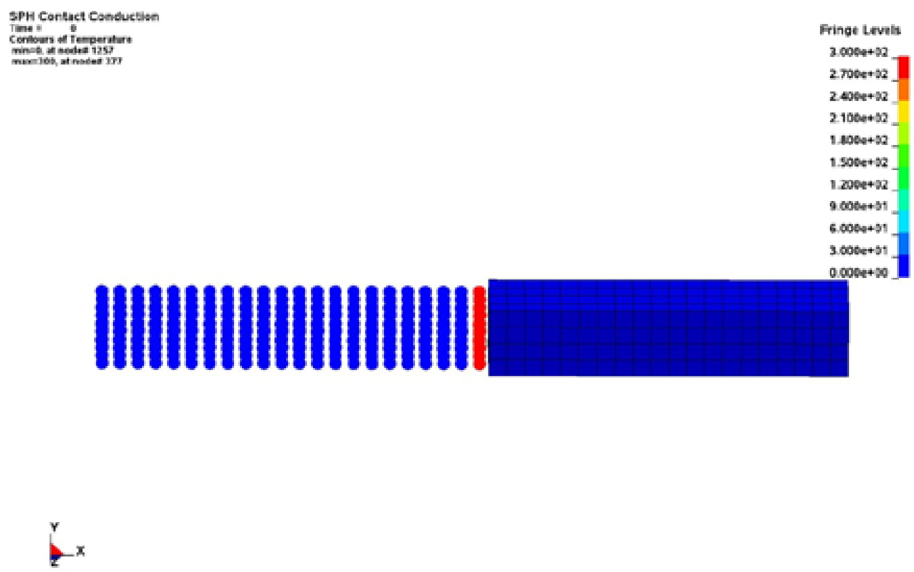

Fig 2. Initial set up for thermal coupling between SPH part and Solid part

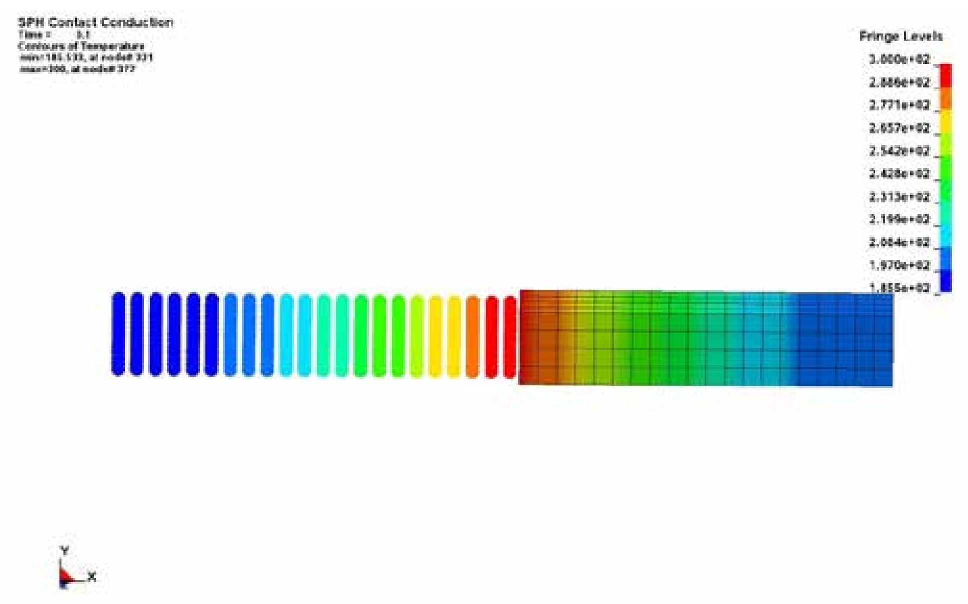

Fig 3. Temperature contour plot for thermal coupling between SPH part and Solid part

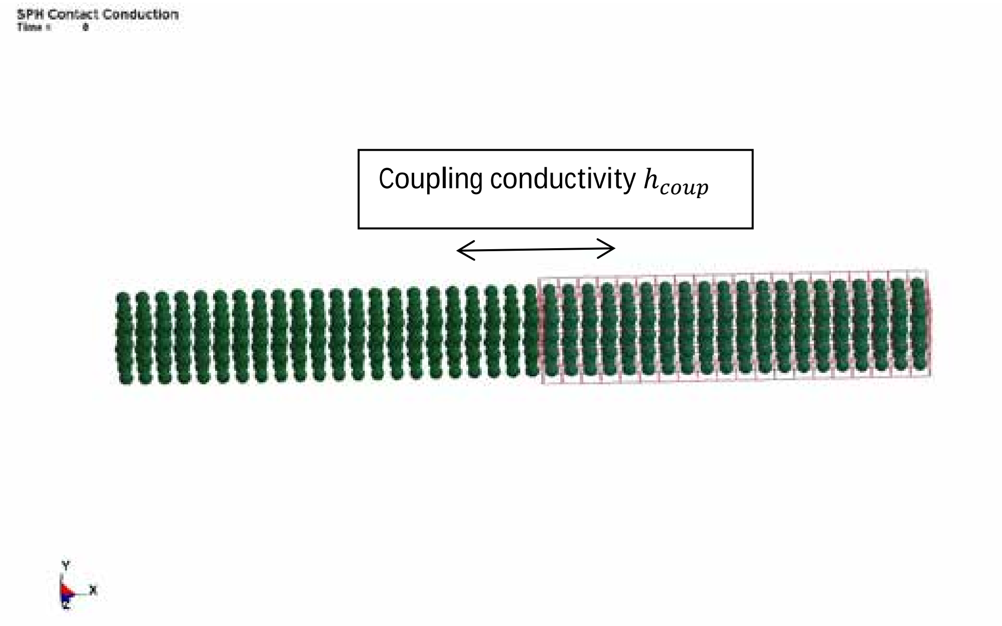

Fig 4. Hybrid element set up for thermal coupling between SPH part and Solid part

Case 2:

A more complicated high velocity impact problem was tested in this case. A SPH part hit a thin Solid plate with very high initial speed. During the impacting process, SPH part endured very complex free surface and material interface behaviors, including break-up into fragments and new surfaces generation every cycle when interacting with Solid plate. For the structure behavior, a node to surface contact was used for the interaction between SPH part and Solid plate. The temperature of the SPH body changed due to the conversion of mechanical work into heat through plastic deformation. The process was fast enough such that there is no heat transfer with the environment. Thermal coupling between SPH part and Solid plate was applied through *DEFINE_ADAPTIVE_SOLID_TO_SPH (Fig 6 shows the hybrid elements setup for this coupling) with ICPL=3 and IOPT=0, the default coupling thermal conductivity was set for the thermal interaction between SPH part and Solid plate. Fig 5 shows the temperature contour plot during thermal coupling processing for HVI problem between SPH part and Solid plate.

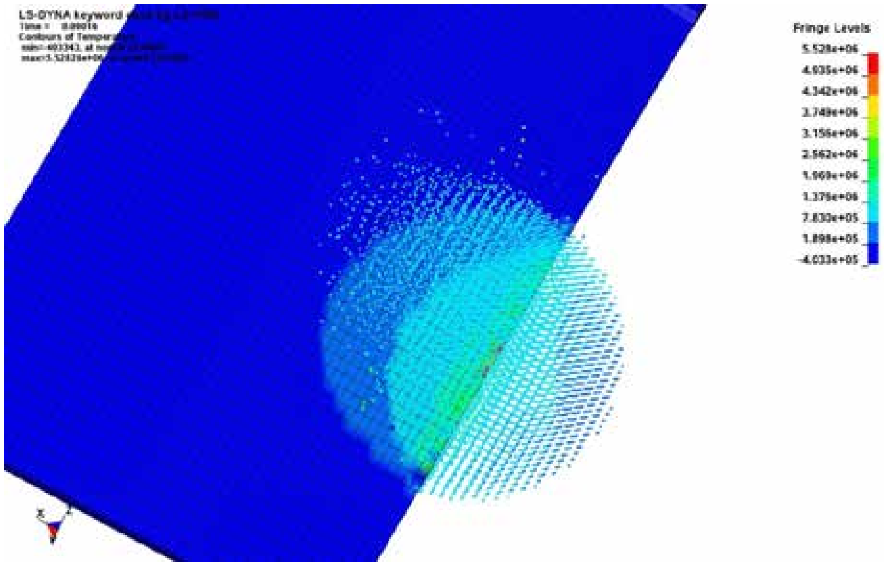

Fig 5. Temperature contour plot for HVI between Solid plate and SPH part with thermal coupling.

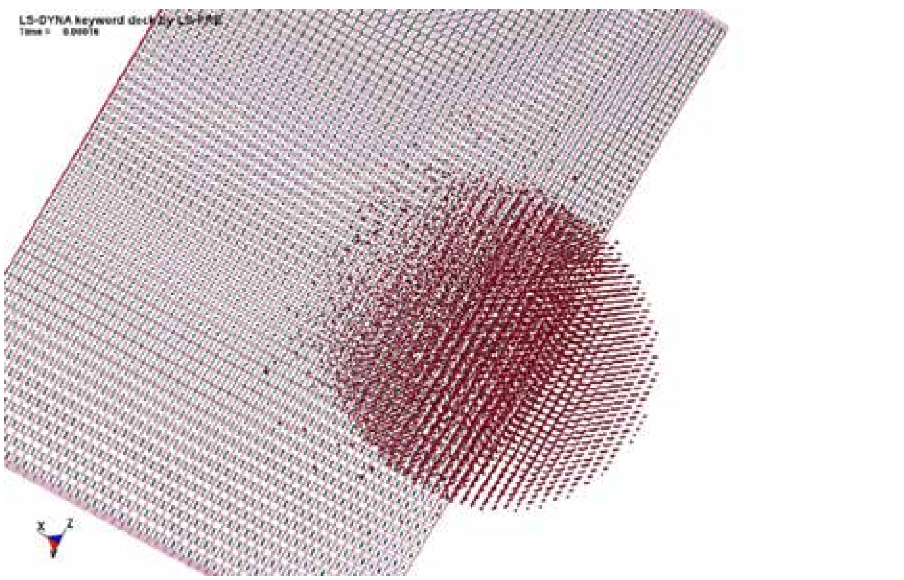

Fig 6. Hybrid element set up for HVI between SPH part and Solid plate with thermal coupling.

FUTURE WORKS

A more sophisticated coupling thermal conductivity model between SPH part and Solid part is needed for the further application of this keyword to the more complicated engeneering behaviors.