DEM simulation of particles of complex shapes using the multisphere method: application for additive manufacturing

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Introduction – We develop a numerical tool for modeling the transport mechanism of powder particles during additive manufacturing. In this type of manufacturing process, objects are created by selectively melting particles of a powder bed through a laser or electron beam (Fig. 1). Understanding the mechanical behavior of the powder as a function of material properties, size distribution and particle shape is essential for the optimization of the production process. We adapt a software (LIGGGHTS) for particle-based simulations using the Discrete Element Method (DEM) in order to account for the complex geometries of the powder particles, as well as for the dynamic boundary conditions for the granular material which are inherent to the manufacturing process.

Particle model – Powder particles of complex shapes are modeled as sphere clumps (rigid bodies) using the multisphere method. Constituent spheres of a rigid body interact with spheres belonging to neighbouring particles through viscoelastic forces according to the Hertz-Mindlin model. Indeed, one problem with the multisphere method is that the mass and moment of inertia of the resulting sphere clumps are incorrectly computed as a result of the (artificial) contribution of the sphere-sphere overlaps (Fig. 2). Here we present an analytical (exact) method to compute the mass and moment of inertia of rigid bodies in DEM using the multisphere method.

The inertia tensor is diagonalized through a principal axis transformation, the orthogonal transformation matrix of which \( \hat{J} \) is used to transform a vector \( \mathbf{u} \) in the body's fixed frame to the inertial frame through the equation, \( \mathbf{u}_i = \hat{J} \mathbf{u} \). Finally, the motion of the rigid body is computed by numerically solving the following equations:

\[
\dot{\mathbf{r}}_b = \mathbf{v}_b + \mathbf{w} \times \mathbf{r}_b, \quad \dot{\mathbf{v}}_b = \mathbf{a}_b - \mathbf{w} \times (\mathbf{v}_b - \mathbf{w} \times \mathbf{r}_b) - \mathbf{g}
\]

Modeling the transport mechanism of the particles during the manufacturing process – The boundary conditions associated with the device’s complex geometry are modeled by importing triangular meshes, which are interpreted as frictional walls.