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Recent Advances on the Numerical and Experimental Study of the Powder Transfer Stage in Powder Metallurgy

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Abstract. *The aim of this work is to show the potential of the Particle Finite Element Method (PFEM) in the simulation of the powder transfer stage, in powder metallurgy industrial processes. The most innovative aspects of the work are: a) the intensive use of the particle finite element method technology to trace the motion of a representative set of particles in the solid and b) the solution of inherent problems associated with new meshing definition and data transfer during the calculation. Comparison of experimental results and numerical simulations are used to assess the performance of the method.*

1 INTRODUCTION

Although the finite element method [1] is still one of the most powerful tools used for mechanical modeling, it exhibits some disadvantages in problems where very large strains and displacements occur. These difficulties are related to the appearance of high mesh distortions, typical of forming processes like powder compaction/transfer processes in PM. In consequence, Jacobian determinants become negative at a number of sampling points during the process, this precluding the continuation of the calculations. In order to overcome this problem other techniques have been investigated. Recently, meshless methods combined with optimal connectivity generators, as Delaunay triangulations, have been successfully explored in Lagrangian fluid problems [2]. This technical combination is known as Particle Finite Element Method (PFEM).

Due to the fluid-like behavior of the powder during the transfer process, it seems reasonable to investigate the performance of such techniques in modeling powder transfer problems in PM. This is the goal of the work presented in this paper.

2 THE PARTICLE FINITE ELEMENT METHOD. FUNDAMENTALS

The PFEM grounds on the description of the continuum behavior of the solid in terms of a finite number of particles (of infinitesimal size) from which the behavior of the remaining particles is described by interpolation. The process of calculation, the actualization of the resulting fields and the setting of new initial conditions are repeated at each time step of the simulation.

2.1 Problem formulation

Let $B = \{X_i ; i : 1...N_p\}$ a finite set of particles X_i that are selected to model the continuum medium. Let $x_i = x(X_i, t)$ the particle position function, at time t, of the particle X_i, and $v(X_i, t)$ and $a(X_i, t)$ the velocity and acceleration vectors of the same particle.
The associated dynamic problem consists of finding the displacements field, $u(X_i, t)$, through resolution of the momentum equation (1):

$$Ma + F^{int}(u) - F^{ext}(u) = 0 \qquad (1)$$

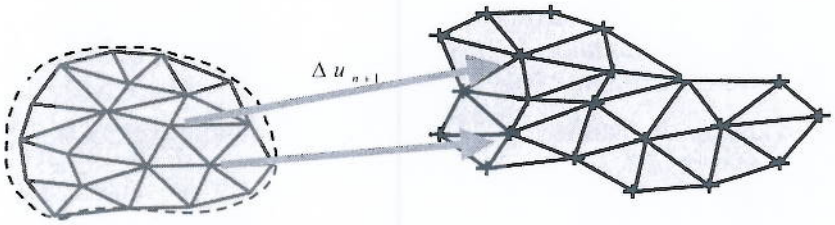

Fig. 2.1.1 Initial and current configurations and connectivity on the selected set of particles

Completing the dynamic problem we consider the initial conditions $u(X_i, 0) = u_0$, $v(X_i, 0) = v_0$ and $a(X_i, 0) = a_0$. Time integration is carried out by a standard Newmark integration method [1], which that can be expressed as follows:

$$\begin{aligned} M_{n+1}a_{n+1} + K_{n+1}u_{n+1} &= F^{ext}_{n+1} \\ u_{n+1} &= u_n + \Delta t v_n + \frac{1}{2}\Delta t^2\left[(1-2\beta)a_n + 2\beta a_{n+1}\right] \\ v_{n+1} &= v_n + \Delta t\left[(1-\gamma)a_n + \gamma a_{n+1}\right] \end{aligned} \qquad (2)$$

where M_{n+1} is the mass matrix, K_{n+1} the stiff matrix, F^{ext}_{n+1} are the external forces (volumetric and contact forces), Δt the time step and γ, β are the Newmark integration parameters.

2.2 Numerical strategy

Once the new variable fields, arisen from the calculation, are known, their update is performed. For intensive deformation processes, if the reference connectivities are kept constant, the convected positions translate into highly distorted meshes, which strongly deteriorate the robustness of the computations. In order to avoid this problem, a new optimal connectivity must be computed.

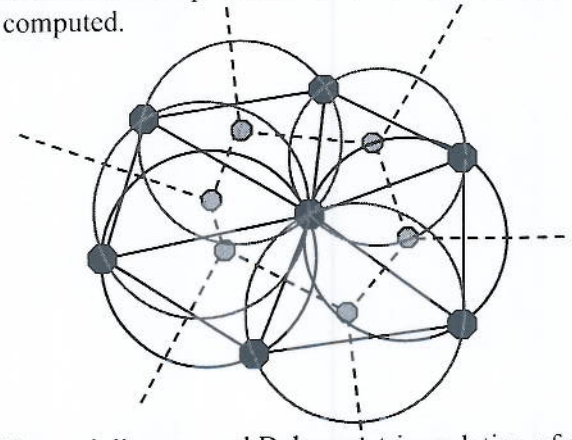

Fig. 2.2.1 Voronoi diagram and Delaunay triangulation of a cloud of points

Keeping unaltered the representative particles of the domain, but considering updated

spatial positions, the corresponding Voronoi diagrams and Delaunay triangulations are carried out.

As an illustrative example, in figure 2.2.1, and for an arbitrary cloud of points (large black points), their Voronoi diagrams (dotted lines, empty circles and small red points) and the resultant Delaunay triangulation (continuous lines) are presented. The main advantage of this type of triangulation is that it leads to rather undistorted spatial discretization for the next time step.

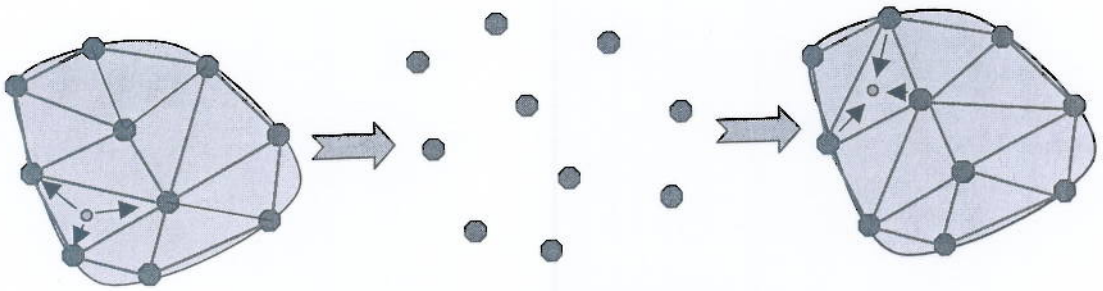

Fig. 2.2.2 Variable transfer process.

Next, the variable fields should be transferred between the reference and current configurations. This is performed in straightforward way by making a local smoothing and "transporting" the information by means of the particles to the updated position. This transfer methodology generates fewer errors than the conventional projection one, because a nodal "exact" transport of variables is performed during each time step

This information transfer method is schematically shown in figure 2.2.2, where, for an initial configuration, the smoothing of the properties to the nodes is carried out first, and, then, the nodes are moved to the updated spatial position. Finally an interpolation to the new configuration sampling points is done, to proceed to the new computation stage. The different stages of the computational process are sketched in Chart 2.2.1.

Step 1: Initialization: Set of v_n, a_n and $\bar{q}_{n+1}$ (set of internal variables) at time t

Step 2: Connectivities generation: Using Delaunay triangulations techniques, a new connectivity relationship between particles is obtained [2]

Step 3: Interpolation of new sampling points: for the updated particle positions and connectivities, new interpolations to sampling points is performed

Step 4: Solution of incremental non linear general problem: Under the connectivity stated in step 2, equation (1) is solved by a standard FEM method [1]

Step 5: Nodal upload and information transport: Once solved the currently time problem, the new nodal variable fields are updated.

Step 6: Setting of new initial conditions: The convected set of variables are considered as initial conditions at time $t+1$, then the process goes to step 2.

Step 7: End of process

Chart 2.2.1 Summary of the computational process in a given time step

3 REPRESENTATIVE SIMULATION. PODER TRANSFER MODELLING

The powder transfer stage is an important part of the powder forming process. Recently, its practical importance in the final obtained compaction density distribution has

been recognized. Non-homogeneous densities obtained in this stage of the process could cause serious defects in finished mechanical parts like local weaknesses and defects, and crack appearance. Numerical simulation can then became an useful tool to optimize the kinematics of punches during transfer stage, helping to obtain more homogeneous density distributions at the beginning of the subsequent pressing stage.

3.1 Numerical results

In order to show the performance of PFEM in modeling powder transfer processes, a transfer in a rectangular shaped chamber transfer, displayed in figure 3.1.1 is experimentally and numerically performed.

The chamber dimensions are 100 mm height and 50 mm width. Upper and lower punches are both of the same width, 10 mm, and the transfer distance between them is kept constant in 30 mm. Punches displacements are 50 mm during 1 second. The material is rock powder with an apparent density of 3,4 gr/cm^3. In the experimental set up the material is settled in 20 colored layers, of 5 mm height, to facilitate the particle tracking during the process displaying results amenable to be compared with the numerical simulations.

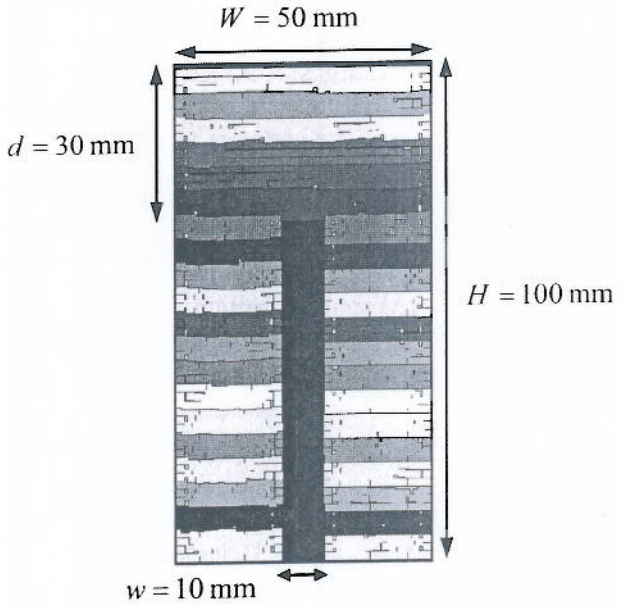

Fig. 3.1.1 Geometry and initial configuration of the transfer chamber

In figure 3.1.2 the experimental and numerical results are presented. There it can be observed that a complete transferred column exists between the upper and lower punches At the outer parts of the chamber a zone with no transference is clearly defined. In between, a transition zone of partial transfer is observed, which can be measured for the purposes of comparison with numerically obtained results.

In the figure it can be checked that the previous pattern is quite precisely reproduced by the numerical results. Both the pattern of layers and the dimensions of each of the previous zones are reproduced by the numerical simulations. In addition, the final density distribution, as relevant measure very difficult to obtain experimentally, is naturally provided by the numerical modeling.

It is remarkable that the large strains undertaken by the material at the transition zone, did not pose special problems to the robustness of the numerical modeling using the PFEM. This seems to be the substantial advantage of the proposed methodology in comparison with more standard finite element procedures.

4 CONCLUSIONS

In this work the usefulness of the novel PFEM technique has been examined in the context of powder forming processes. The main conclusion is that it provides a large additional robustness, in comparison with alternative FEM techniques, without affecting the capability to reproduce the physical phenomena taking-place during the powder transfer process.

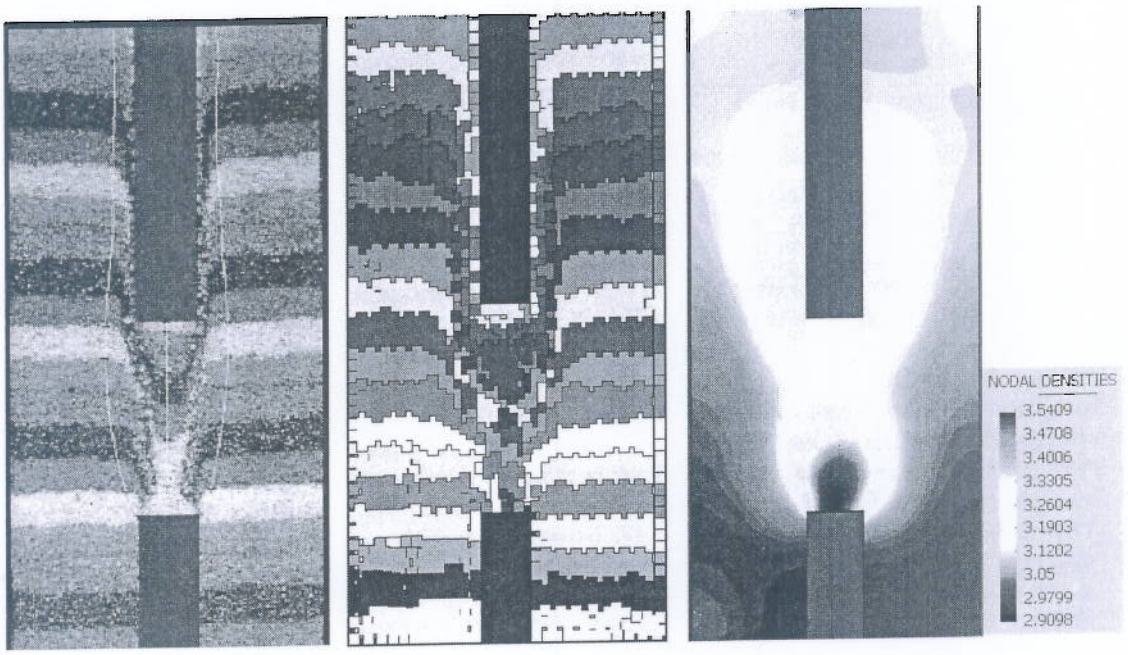

Fig. 3.1.2 Displacements and density fields after the powder transfer stage. Left): experimental final pattern of the layers, center): numerical final pattern of layers and right): numerically obtained density distribution.

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