Received: 15 July 2020 | Accepted: 9 November 2020

DOI: 10.1002/pamm.202000305

Adaptive Particle Finite Element Method (A-PFEM) in Metal Cutting Processes

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Machining is very common in industry, e.g. automotive industry and aerospace industry, which is a nonlinear dynamic problem including large deformations, large strain, large strain rates and high temperatures, that implies some difficulties for numerical methods such as Finite element method. One way to simulate such kind of problems is the Particle Finite Element Method (PFEM) which combines the advantages of continuum mechanics and discrete modeling techniques. In this work we introduce an improved PFEM called the Adaptive Particle Finite Element Method (A-PFEM). The A-PFEM introduces particles and removes wrong elements along the numerical simulation to improve accuracy, precision, decrease computing time and resolve the phenomena that take place in machining in multiple scales. At the end of this paper, some examples are present to show the performance of the A-PFEM.

1 Motivation

The Finite element method (FEM) is one of the most widely used methods in the industry [1]. However, the main limitation of the FEM is that the quality of the results depends on the quality of mesh [2] . In machining processes where the material undergoes large deformations and large configurational changes, if a Lagrangian formulation is used, the mesh moves with material and the elements become so distorted that maybe some elements have negative Jacobian, up to a point where it is impossible to continue with the numerical simulation. To overcome this difficulty the Particle Finite Element Method (PFEM) which was first introduced in [3] for problems with liquid solid interaction is a promising technique. The main advantage of the PFEM is that boundary can be repeatedly detected thanks to α-shape method [4] and domain be remeshed continuously during the simulation, which enables simulations with large configurational changes [5]. Even though PFEM still have a small flaw to machining processes, because keeping the same number of particles along the numerical simulation is problematic, in some regions of the domain the particles are concentrated meanwhile in other regions the particles moves away. The previous situation generates low quality of the finite elements and in some cases wrong holes as shown in Fig. 1.

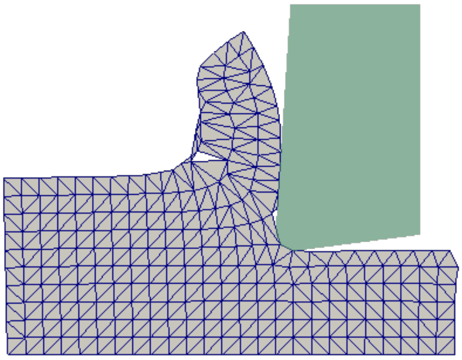

Fig. 1: Low qualitiy elements and a wrong hole

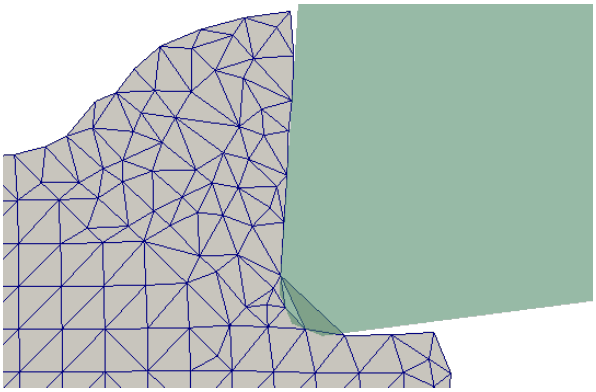

Fig. 2: A bad element over the tool

2 Adaptive Particle Finite Element Method

To make the distribution of particles more smooth during machining simulation, one can insert the Gauß point as a new particle into the elements which become too large. The information of the inserted particles can be approximated by interpolation of the particles around. The internal variables for the new particles are the internal variables available at the closer old Gauß points from solving FEM problem in the last time step for simplicity. To solve the contact problem a node to surface strategy is used. So besides adaptive insertion of particles one shall also remove the bad elements whose nodes are outside the tool but the most part is inside the tool as shown in Fig. 2. In summary the difference between A-PFEM and PFEM is that in

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every time step bad elements will be removed after the α-shape method and new points are inserted adaptively after FEM calculation.

3 Numerical Results

In the following cutting simulations using PFEM and A-PFEM respectively will be demonstrated for a material with Young's modulus $E = 210,000$ MPa, Poissons ratio $\mu = 0.3$, initial yield stress $\sigma_Y = 450$ MPa and hardening modulus $K = 129$ MPa. The above parameters are used to mimic steel. In the simulation a rigid body is used as the cutting tool, and normal contact between tool and workpiece is considered. For the finite element method a linear 3-node triangle element is used.

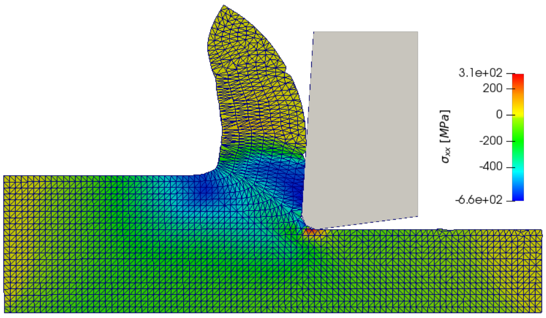

Fig. 3: Performance using PFEM

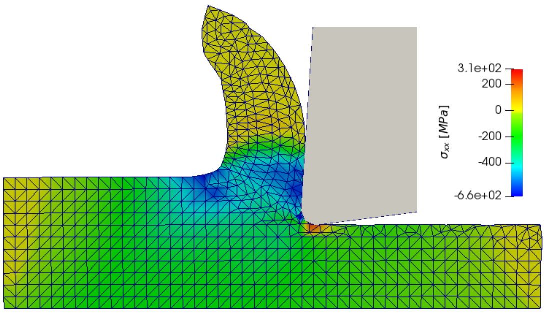

Fig. 4: Performance using A-PFEM

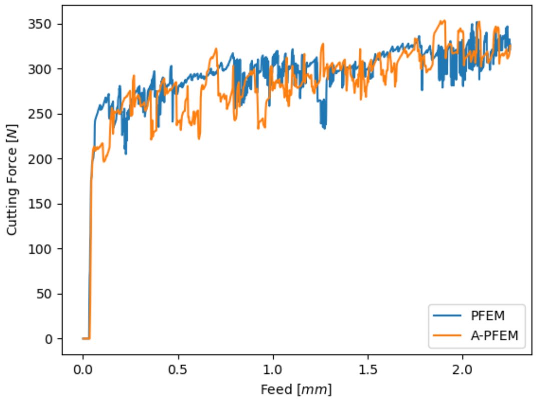

Fig. 5: Comparison of cutting forces

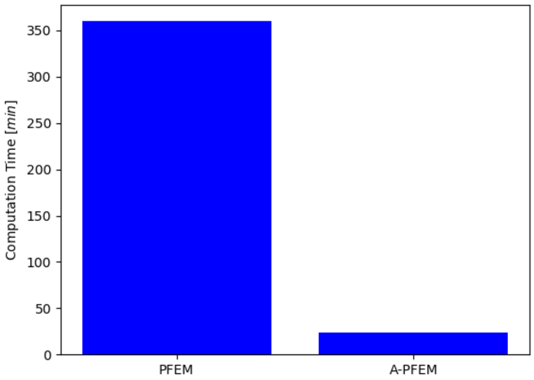

Fig. 6: Comparison of computation time

In Fig. 3 and Fig. 4 the normal stress σ_{xx} and in Fig. 5 the cutting forces are plotted. It was shown that the performances for both methods are almost the same. As expected the mesh quality of A-PFEM looks better and only more particles are used in deformed area, that means much fewer storage spaces are demanded for computation if using A-PFEM instead of PFEM and calculation time will be correspondingly much shorter as shown in Fig. 6. As conclusion A-PFEM has an evidently higher efficiency as traditional PFEM.

Acknowledgements Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - 252408385 - IRTG 2057. Open access funding enabled and organized by Projekt DEAL.

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