

ICMF'2001 — 4th Int. Conference on Multiphase Flow,
New Orleans, Louisiana, U.S.A.
May 27 – June 1, 2001

Aspects of Efficient Parallelization of Disperse Gas-Particle Flow Predictions Using Eulerian-Lagrangian Approach

Th. Frank, K. Bernert, K. Pachler

Chemnitz University of Technology
Faculty of Mechanical Engineering and Process Technology
Research Group on Multiphase Flow
Chemnitz, Germany

Name of the authors

Dr. Thomas Frank, Dr. K. Bernert, K. Pachler

Affiliation / Address of corresponding author

English translation of affiliation see header information.

Address : Technische Universität Chemnitz

Fakultät für Maschinenbau und Verfahrenstechnik

Forschungsgruppe Mehrphasenströmungen

Dr. Th. Frank

Reichenhainer Straße 70

09107 Chemnitz, Germany

email : frank@imech.tu-chemnitz.de

Tel.: +49 (371) 531 46 43

Fax : +49 (371) 531 46 44

Abstract

Disperse multiphase flows are very common for processes in mechanical and thermal process technology (e.g. gas-particle or gas-droplet flows, coal combustion, pneumatic conveying, erosion phenomena). Furthermore processes for the separation of solid particles from gases or fluids and for the classification and particle size analysis are an important field of interest in process technology. Already a single phase flow calculation and more than ever the phase-coupled iterative prediction of disperse two phase flows is very time-consuming and leads to high demands in computer resources. Effective numerical algorithms as well as the power of parallel computing systems are needed to solve real problems from engineering.

The paper deals with different methods for the efficient parallelization of Eulerian-Lagrangian approach which is widely used for the prediction of disperse gas-particle or gas-droplet flows. The presented results are based on the 3-dimensional Eulerian-Lagrangian approach developed by the research group of the authors over the last few years [1, 2, 3, 4, 5], where trajectories of a large number of particles/droplets are calculated from the equations of motion of the disperse phase along with the continuity, momentum and turbulence model equations of the fluid phase.

The parallelization methods are developed for parallel computers of MIMD architectures like e.g. Cray-T3D/E or clusters of workstations (COW's). Parallelization of the finite volume solution algorithm of SIMPLE kind for the set of continuity, Navier-Stokes and turbulence model equations is carried out by application of a domain decomposition method to the block structure of the numerical grid as proposed by Perić et al. in [8, 7, 6]. Distribution of grid and fluid flow data over processors of the parallel machine allows the arrangement of multiple grid blocks / domains on the same processor node. In order to accelerate the fluid flow prediction Multi-Grid method has been introduced to the solution procedure. Furthermore the results show a satisfying efficiency of the parallelization of the numerical algorithm, which is based on explicit message passing using MPI as parallelization paradigm.

For the Lagrangian solution algorithm two different parallelization methods are investigated and compared with each other. The first method is based on a static domain decomposition (SDD) approach and the same distributed storage of the grid and fluid flow data as used by the grid partitioning method of the Navier-Stokes solver. Once a grid block of the numerical grid is assigned to a processor node of the parallel computer this assignment is static and remains unchanged for the whole calculation process. Each node process calculates particle trajectory segments and source term contributions on the grid blocks assigned to this processor node. Particle state at the interface to a neighbouring grid block is submitted to a host/master process and is then redistributed to the appropriate processor node for continuation of the calculation process.

In the second parallelization method — the so-called Dynamic Domain Decomposition (DDD) — a dynamic load balancing has been introduced to the numerical algorithm. The first class of processes — the so-called servicing nodes — use again the distributed storage of the grid and fluid flow data as in the previous method. An additionally introduced second class of processes — the so-called calculating nodes — perform the calculation of particle trajectory segments and source term contributions on a certain number of grid blocks. But in contrast to the first method a calculating process is no longer limited to calculations on a fixed part of the numerical grid. These calculating processes are able to obtain grid and fluid flow data necessary for further particle phase calculation dynamically during calculation time.

The main advantages of this dynamic domain decomposition approach are :

- dynamic work load distribution among the processors of the parallel machine; work load balancing is effective even on heterogenous computer systems like eg. workstation clusters with different computational power of processor nodes;
- independence of the algorithm performance from the subdivision of the numerical grid into grid blocks,
- independence of the algorithm performance from the flow regime (e.g. phase separation, differences in concentration distribution of the dispersed phase, local occurrence of strong particle-wall interaction).

The parallelization methods are implemented using standard message passing libraries (PVM, MPI) for portability. For two given test cases results of performance evaluations are given for calculations on a massively parallel cluster of workstations (COW) with up to 512 processor nodes. The presented results show, that computation time for the Eulerian-Lagrangian approach can be substantially decreased by using the dynamic domain decomposition (DDD) method in comparison with the commonly used static domain decomposition approach. For one of the investigated test cases less than 40% of the computation time of the SDD method has been required with the DDD method on a moderate parallel system with 12 processing nodes. The computation time has been reduced to less than 9% of the execution time on a single processor (serial execution) which corresponds to a speed-up of 11.2 and a parallel efficiency of the DDD method of about 0.93. This very high parallel efficiency will lead to a very good scale-up of the developed parallelization method on even larger parallel MIMD systems.

References

- [1] **Frank, Th., Wassen, E., Yu, Q.:** A 3-dimensional Lagrangian Solver for Disperse Multiphase Flows on Arbitrary, Geometrically Complex Flow Domains using Block-structured Numerical Grids, 7th Int. Symposium on Gas-Particle Flows, ASME Fluids Engineering Division Summer Meeting, Vancouver, BC, Canada, June 22–26, 1997, CD-ROM Proceedings, FEDSM97–3590
- [2] **Frank, Th., Wassen, E.:** Parallel Efficiency of PVM- and MPI-Implementations of two Algorithms for the Lagrangian Prediction of Disperse Multiphase Flows, JSME Centennial Grand Congress 1997, ISAC '97 Conference on Advanced Computing on Multiphase Flow, Tokyo, Japan, July 18–19, 1997
- [3] **Frank, Th., Wassen, E., Yu, Q.:** Lagrangian Prediction of Disperse Gas-Particle Flow in Cyclon Separators, ICMF '98 – 3rd International Conference on Multiphase Flow 1998, Lyon, France, June 8.–12., 1998, CD-ROM Proceedings, Paper No. 217, pp. 1–8
- [4] **Frank, Th., Schneider, J., Yu, Q., Wassen, E.:** Experimental and Numerical Investigation of Particle Separation in a Symmetrical Double Cyclone Separator, 8th Int. Symposium on Gas-Particle Flows, ASME Fluids Engineering Division Summer Meeting, San Francisco, CA, U.S.A., July 18–22, 1999, CD-ROM Proceedings, Paper No. FEDSM99–7865, pp. 1–10
- [5] **Frank, Th., Bernert, K., Schneider, J.:** Numerische Untersuchungen der Gas-Partikel-Strömung in symmetrischen Doppelzyklon-Abscheidern, VDI Berichte, Nr. 1511, 1999
- [6] **Perić M.:** "A Finite Volume Method for the Prediction of 3-dimensional Flows in Complex Ducts", Ph. D. Thesis, Imperial College, University of London, 1985.
- [7] **Perić M.:** "Ein zum Parallelrechnen geeignetes Finite-Volumen-Mehrgitterverfahren zur Berechnung komplexer Strömungen auf blockstrukturierten Gittern mit lokaler Verfeinerung", Abschlußbericht zum DFG-Vorhaben Pe 350/3–1 im DFG-Habilitandenstipendiumprogramm, Stanford University, USA, 1992.
- [8] **Schreck E., Perić M.:** "Parallelization of implicit solution methods", ASME Fluids Engineering Conference, June 22–23, 1992, Los Angeles (CA), USA.