A New Paradigm for Solving Plasma Fluid Modeling Equations

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A new paradigm for solving plasma fluid modeling equations is proposed and verified in this paper. Model equations include continuity equations for charged species with drift-diffusion approximation, electron energy equation, and Poisson's equation. Resulting discretized equations are solved coupledly by the Newton-Krylov-Schwarz (NKS) [1] scheme by means of a parallelized toolkit called PETSc. All model equations are nondimensionalized and are discretized using fully implicit finite-difference method with the Scharfetter-Gummel scheme for the fluxes. At electrodes, thermal flux is considered for electrons, while both thermal and drift fluxes are considered for ions. A quasi-1D argon gas discharge with a radio frequency power source (13.56MHz, V_{p-p} = 200 Volts), gap distance=20 mm and 20 $mm \times 20$ mm (100x100 mesh points) in size is used as the test case.

Results of evolution of potential and plasma number density are shown Fig. 1, which are comparable to previous studies. Table 1 lists all the resulting timings of the present parallelized code using different combination of preconditioners (Addtive Schwarz Method and Block-Jacobi) and linear equation solvers (GMRES and BiCGStab) for 10 RF cycles (100 time steps each cycle) for the number of processors up to 28 of a PC cluster system (dual cores and dual processors each node, 2.2GHz and InfiniBand networking). Note the Block-Jacobi, which does not require any overlapping in preconditioning, can be considered as a special case of general ASM preconditioning, which requires the communication for overlapping the updated data at interfacial nodes. In addition, both LU and ILU linear equation solvers are tested in solving the preconditioned matrix equation in each subdomain. At each time step only three outer (Newton) iterations with ∼40 inner iterations are needed for convergence. Results show that with the present test case the combination of block-Jacobi precon-

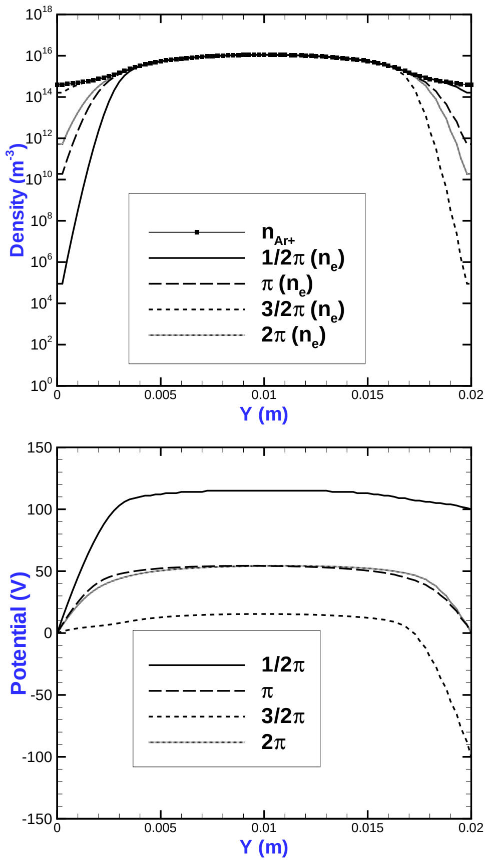

Figure 1. Distribution of densities and potential.

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Simulation Time of Solvers and Preconditioners

No. Proc.	GMRES				BCGS			
	ASM		BJacobi		ASM		BJacobi	
	ILU	LU	ILU	LU	ILU	LU	ILU	LU
2	7211	4524	6002	4224	6032	4257	5881	4646
4	3676	2073	3043	2083	3353	2448	2988	2590
8	2205	944	1572	1035	2928	1133	1493	1271
16	1245	919	935	1044	1112	1101	775	1196
28	816	657	462	608	673	671	455	635

Table 1. Simulation time for various preconditioners and solvers (1000 time steps, unit in seconds).

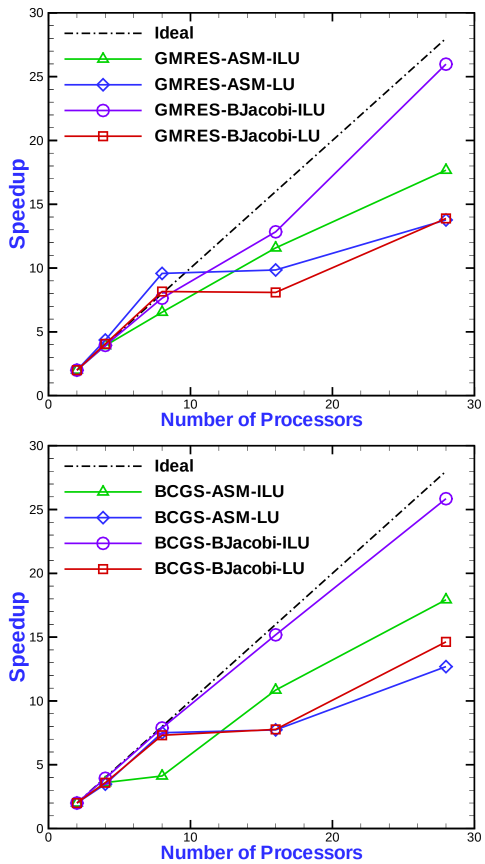

Figure 2. Parallel performance of different preconditioners and solvers.

ditioner with ILU and BiCG-Stab performs the best with 92.8% of parallel efficiency at 28 processors (Fig. 2). However, it seems the parallel performance of ASM precoditioner improves with increasing number of processors (not shown), which requires more tests in the very near future.

We conclude preliminarily that the plasma fluid modeling equations can be efficiently solved using the NKS scheme if proper preconditioner and linear equation solver are selected. Future works in this direction include adding more model equations, including excitation, chemical reactions, possibly radiation transport, and the Navier-Stokes equation solver into the present parallelized code.

REFERENCES

1. X.C. Cai et al, Proceedings of the Eighth International Conference on Domain Decomposition Methods (1997) 387.