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COMPUTATIONAL NEEDS FOR MODELLING ACCELERATOR COMPONENTS*

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The particle–in–cell code MASK is being used to model several different electron accelerator components. These studies are being used both to design new devices and to understand particle behavior within existing structures. Studies include the injector for the Stanford Linear Collider and the 50 megawatt klystron currently being built at SLAC. MASK is a 2D electromagnetic code which is being used by SLAC both on our own IBM 3081 and on the CRAY X-MP at the NMFECC. Our experience with running MASK illustrates the need for supercomputers to continue work of the kind described.

INTRODUCTION

Simulations of scientific hardware by computer programs is common place in HEP. These programs serve both as design aids and as aids in understanding the physics. Prior to 1982, the beam dynamics programs available at SLAC did not include self consistent models for both RF fields and the self fields of intense beams. The search for a program which could be used as a design aid for the high powered klystron needed for the Stanford Linear Collider (SLC), and the SLC injector buncher, led us to MASK, a particle-in-cell code, written principally by Adam Drobot of Science Applications Inc. (SAI). The program, written in FORTRAN was running on CRAY computers and being used mainly by the plasma physics community. We were able to implement a version of MASK on the IBM 3081 at SLAC. Run time comparisons were made using the CRAY-1S at the National Magnetic Fusion Energy Computation Center (NMFECC) and SLAC's IBM 3081. A ratio of about 1 to 14 was found, CRAY to IBM, for the two cavity klystron problem which we used in the comparison. MASK is only partially vectorized and further efforts along these lines would be an improvement for running on CRAY computers.

Both the injector and the klystron have been successfully modeled and work continues on these as well as on a number of other problems. Although we would have liked to run all our MASK jobs at SLAC, run time considerations made us turn to the CRAY for some of our work. As the klystron simulation is iterative, with each iteration itself a MASK run of several thousand time steps duration, first complete runs on our IBM required a week to get the job through the system. Today, with the iteration automated, and running on a CRAY X-MP, a comparable job takes about a half hour of computer time and is usually through the system in less than a half day. Although the injector problem has been comfortably running at SLAC, plans to increase the region being simulated make it desirable to also move this problem to the CRAY.

MASK is a particle-in-cell (PIC) code used to study particle motion in a plasma. It includes; relativistic beam dynamics, particle self fields, and RF fields. Axial symmetry is assumed, and in the devices we modelled an r - z coordinate system was used. In MASK the region to be studied is covered with a mesh, electric and magnetic fields are propagated forward in time from equations derived from differencing Maxwell's equations on the mesh. Macroparticles within the cells of the mesh represent large numbers of real particles. As time evolves, the

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fields act on the macroparticles, affecting their motion and in turn the macroparticles contribute to the space charge and 3-D current density at the mesh. Poisson's equation serves as the initial condition and is imposed periodically during the evolution. Particle position and velocity coordinates are propagated in three dimensions while electric and magnetic fields are propagated in two dimensions.

A large number of diagnostic aids are provided in MASK. These include; particle density plots, phase space plots of position and velocity components, field contour and field intensity plots, time histories at specified points of current or field intensities, Fourier decomposition in time or space, energy flow and emittance calculations.

Computation time depends on the number of macroparticles, mesh size, and the magnitude and number of time steps. The program requires that the time step satisfy the Courant condition, that is, be less than the mesh size divided by the product of the velocity of light and the square root of two. Memory requirements also strongly depend on the number of macroparticles and the size of the mesh.

EXAMPLES

A critical 25 cm section of the collider injector[1] has been modelled with MASK on the IBM 3081. This section includes the buncher and the first three cavities of the accelerator structure. The electron gun, subharmonic buncher, and remaining accelerator structure are currently excluded from the study. The mesh size and time step were 1 mm and 1.37 ps. respectively.

The traveling wave in the injector which bunches and accelerates the pulse is generated in MASK by means of ports on the upper boundary of each cavity. By varying the amplitude and phase of an applied RF voltage across each port, an electric field is generated at the port and propagated throughout the mesh. The port voltage is ramped up slowly to avoid introducing transient fields. This first stage of building up the fields before electrons are introduced takes 6144 time steps, about 40 minutes on our IBM. The fields produced in this way are saved and used with subsequent runs studying the pulse dynamics.

The next stage of the study, particle bunching and acceleration, takes 1024 time steps, about 17 minutes on the IBM using 2400 macroparticles. Figure 1 is an R - Z profile of the modelled section, showing in composite the particle density of one pulse traversing the region studied. The pulse entering on the left is shown at nine different time steps. Radial growth of the bunch is contained by an external magnetic field. The buncher section comprises the left half of the figure while the first three accelerator rings are the remaining 12.5 cm. Simulated particle behavior is in good agreement with expectations as regards bunch length, energy and emittance growth. The effects of space charge are noticeable here and in the next figure. Figure 2 shows phase space plots of the longitudinal component of the particles momentum as a function of z. Particle energy has risen from 200 keV on entry to the buncher to about 1.37 MeV on exiting the third accelerating cavity.

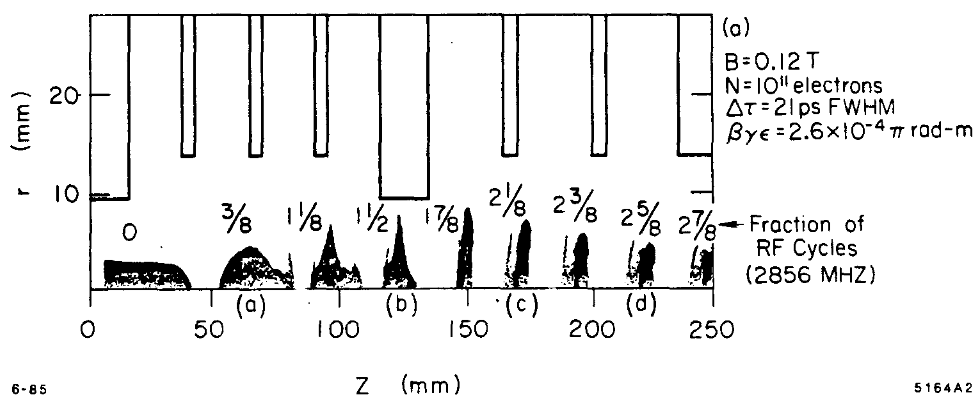

Figure 1. Superimposed electron density plots of a single bunch at different time steps.

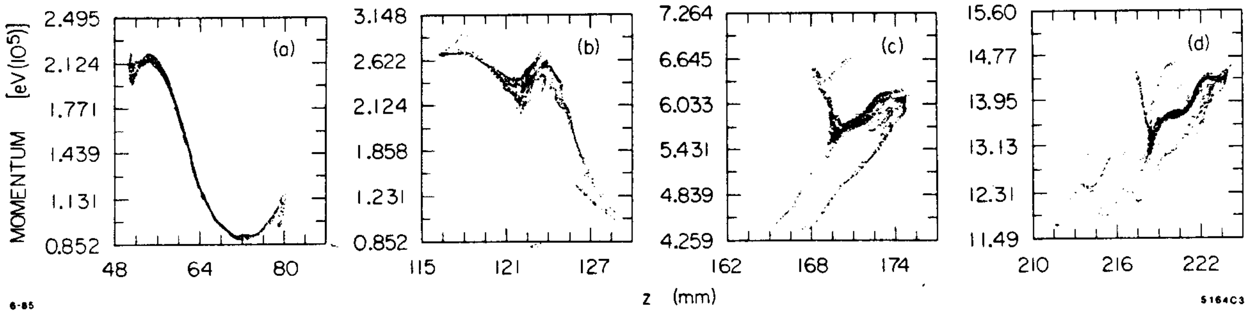

Figure 2. Longitudinal phase space as a function of Z for the bunch shown in Figure 1.

The drift tube sections of both the 35 MW XK-5 klystron currently in use at SLAC and the 50 MW tube in production for SLC have been modelled by Simon Yu[2] and Ken Eppley,[3] using MASK. As in the preceding description of the injector, the klystron cavities are replaced by input ports. The amplitude and phase of the applied RF voltages across the ports are determined by linear theory for the input and idler cavities and by iteration of the MASK run for the ultimate and penultimate cavities. Figure 3 is a particle density plot which shows the beam in the 50 MW tube at peak power. The position of the six ports are located at the gaps in the top of the figure. Klystron efficiency as determined by this simulation is in approximate agreement with the actual tubes. The simulation reflects the sensitivity of the actual tubes to slight variations in the magnetic fields, resonant frequencies of the cavities, and to variations in the tube radius. To compute the power output for one value of power input takes about a half hour of CRAY X-MP time.

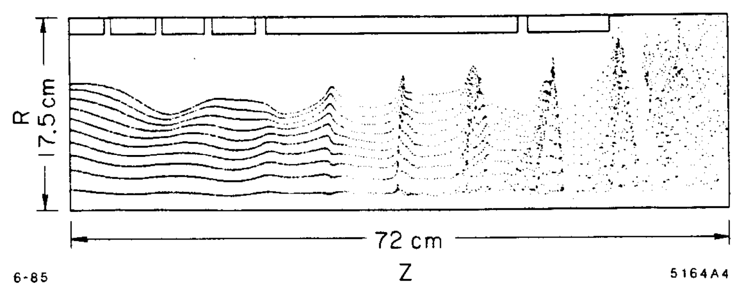

Figure 3. Electron density plot for the 50 MW klystron.

CONCLUSION

The type of simulations described require supercomputers if meaningful progress is to be made. Our expectations and our needs will grow as more powerful programs, fully three dimensional, are being written to further improve our ability to model hardware.

ACKNOWLEDGEMENTS

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