LAWRENCE LIVERMORE LABORATORY
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**CURRENT CTR COMPUTER CODES IN USE
AT LAWRENCE LIVERMORE LABORATORY**

Compiled by

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CURRENT CTR COMPUTER CODES IN USE AT LAWRENCE LIVERMORE LABORATORY

Compiled by J. A. Byers and J. Killeen

Abstract

The attached compilation is a list of the major computer codes (programs) currently used in CTR research at the Lawrence Livermore Laboratory. A brief description of each code is included. The codes listed here either exist in fully developed form or are in a state of active development. Many of those which are complete are being actively modified to include new effects.

Introduction

This summary of computer codes in use by the Livermore CTR group has grown considerably since the first publication some years ago. Rather than adhere to the simple listing alphabetically by author as used previously, it was felt desirable to reorganize the structure generally along specific program lines. Thus, the following classifications are used: Astron, Mirror, Toroidal, General Simulation, Linear Theory, and Other.

The classification of particular codes is somewhat arbitrary; for example, simulation codes used for study of velocity space instabilities have been included in the Mirror section even though these codes might be considered of more general application. Other examples of this type also exist. A considerable amount of overlap also exists, i.e., similar codes will exist for several classifications, all dealing with the same general topic. For example, separate equilibria codes exist in each of the three groups, Astron, Mirror, and Toroidal, even though each code uses similar techniques and in fact may derive from one original code. Therefore, we feel it is desirable to list such codes as they actually exist in their separate versions rather than list just one all inclusive version.

Astron Program

SUPERLAYER

A time-dependent numerical model of the Astron, with which injection and trapping can be studied in detail, has been developed. The effects due to the resistors and neutralization have been included. The model is axially symmetric. The E-layer electrons

are simulated by many thousands of finite-size superparticles, which move in the r - z domain and have velocity components v_r , v_θ , and v_z . The model is relativistic and the electromagnetic fields are obtained by solving four wave equations - three for the vector potential and one for the scalar potential. The E-layer current and the current induced in the resistor wires are included in the above field equations. The computed self-fields are added to the external field to give the field configuration as a function of time.

Authors: J. A. Byers, J. P. Holdren, A. B. Langdon, M. E. Rensink, J. Killeen, and A. A. Mirin

Reference: M. Brettschneider, J. Killeen, and A. A. Mirin, Numerical Simulation of Relativistic Electrons Confined in an Axisymmetric Mirror Field, Lawrence Livermore Laboratory, Rept. UCRL-72616 Preprint (1972); to be submitted to J. Comput. Phys.

LAYER, MINILAYER

This is a program for computing the formation of the electron layer in Astron. The Vlasov equation for the electron distribution function $f(r, z, u_r, u_z, t)$ is solved by difference methods. The magnetic field due to the layer is computed by solving the field equations simultaneously. The program MINILAYER is a simplified version of LAYER which confined the electrons to a fixed radius, r_0 .

Authors: J. Killeen and A. A. Mirin

References: J. Killeen and S. L. Rompel, J. Comput. Phys. 1, 29 (1966).
J. A. Byers and J. Killeen, Methods Comput. Phys. 9, 259 (1970).

TLAYER

For simulation of axial motion of a thin E-layer. The layer is regarded as a collection of charge rings concentric to the walls, rotating with velocity $\approx c$ and moving axially with velocity $\ll c$; only the axial motion is followed explicitly. The fields are solved in the retardationless limit (Darwin model). The field equations and particle densities are Fourier transformed in the axial direction, after which the radial integration may be done analytically. Thus, the code's independent variables are only z and t , rather than r , z , and t , as in SUPERLAYER, and therefore TLAYER is very fast.

Resistor currents are proportional to $\partial A / \partial t$, so each field Fourier mode satisfies a first order differential equation that is integrated in time along with the particle equations. No approximation need be made about the L/R time vs other time scales.

TLAYER is used when the greater generality of SUPERLAYER is not required. Presently, it is used to study axial focussing of pulses, and pulse stacking.

Author: A. B. Langdon

RELATIVISTIC NEGATIVE MASS

A two-dimensional (r, θ) particle-following code applicable to a relativistic beam in Astron-like geometry. The fields are obtained by a marching-in-time solution of the full set of Maxwell's equations. Effects treated are the negative mass instability and interaction with resonant tank modes. Energy spread of the beam is allowed. External B_0 and cold plasma effects are included. The next steps are:

- (1) including a resistive layer and its wall supports in order to model the Astron resistor cans,
- (2) allowing complicated radial betatron orbits as starting conditions, and
- (3) constructing a linearized version, with $\exp(im\theta)$ assumed, so as to allow study of z dependent effects in a two dimensional (r, z) model.

Author: J. A. Byers

ASTRON EQUILIBRIA AND STABILITY

The equilibrium magnetic field for Astron configurations is computed; a given vacuum magnetic field and the fields due to the E-layer and plasma are included, assuming axial symmetry and $B_\theta \equiv 0$. The components $B_r(r, z)$ and $B_z(r, z)$ are derived from the stream function $\psi(r, z) - rA_0$. The E-layer is described by a distribution function that depends on the canonical angular momentum and the energy. Various models of the E-layer are included. The function $\psi(r, z)$ satisfies a nonlinear partial differential equation (Ampere's law) that is solved by finite-difference methods, using an iterative procedure. Stability of the equilibria computed are checked by the energy principle.

Authors: J. Killeen and M. E. Rensink

References: D. V. Anderson, J. Killeen, and M. E. Rensink, Phys. Fluids **15**, 351 (1972).
D. V. Anderson, Computation of Plasma Equilibria and Stability in Astron and Minimum-B Mirror System, Lawrence Livermore Laboratory, Rept. UCRL-51030 (1971).

COILS FOR ASTRON MAGNETIC FIELD ROUTINE

COILS determines the magnetic field quantities for a system of coaxial coils. The individual coils may be of arbitrary size, shape, and current density. Field quantities are determined anywhere within the coil system at the option of the user. Field quantities available are: $B_z, B_r, |B|, A_\theta, rA_\theta, dB_r/dz$ and dB_z/dz .

Author: J. W. Beal

Mirror Program

IONS

This code solves the complete time-dependent Fokker-Planck equation for ions, including the collisional effects of the electrons on the ions. The model is a mirror-confined plasma. The ion distribution is a function of velocity coordinates v and θ . The electrons are assumed to be isotropic with a given distribution. Sources and mirror machine end losses are included, and the plasma potential is computed.

Authors: J. Killeen and A. A. Mirin

References: J. Killeen and K. D. Marx, Methods Comput. Phys. 9, 422 (1970).

A. A. Mirin, Program Ions - Two Dimensional Fokker-Planck Equations for Ions and Electrons, Lawrence Livermore Laboratory, Rept. UCID-16014 (1972).

MULTI-SPECIES FOKKER-PLANCK

This program solves the time-dependent Fokker-Planck equations for electrons and several species of ions. The equations are separated in velocity space (v, θ) , and the coupled nonlinear partial differential equations for the functions $f_a(v, t)$ are solved by difference methods. The equations include source and loss terms appropriate for neutral injection mirror machines, and the plasma potential is computed. Thermonuclear reaction products are included.

Authors: J. Killeen, A. A. Mirin, J. P. Holdren, and A. H. Futch, Jr.

Reference: A. H. Futch, Jr., J. P. Holdren, J. Killeen, and A. A. Mirin, Plasma Phys. 14, 211 (1972).

MINIMUM-B EQUILIBRIA

We have developed a three-dimensional code that solves for plasma equilibria in open-field geometries, which allows analysis of most minimum-B mirror systems. Open confinement with $p = p(B)$ only requires the hydromagnetic equilibrium equation to reduce to one elliptic, scalar partial differential equation involving a tensor pressure. The finite difference form of the equation is solved by an implicit iterative algorithm similar to the ADI (alternating direction implicit) method.

Cylindrical grid coordinates are employed, and the mesh spacing is variable to allow representation of far boundary conditions. We have time-optimized the program, so the memory requirements are large. To allow a reduction in the domain to be studied, the present code used planes of inversion symmetry common to many minimum-B devices. Ioffe bar devices, Baseball II, 2X-II, 2X-11, and the proposed mirror fusion experiment are representable.

Author: J. Killeen

Reference: D. V. Anderson and J. Killeen, Computation of Stable Equilibria in Minimum-B Mirror Devices, Lawrence Livermore Laboratory, Rept. UCRL-73311 Preprint (1971); to be published in J. Comput. Phys.

PERPENDICULAR ION WAVES, 1D

A one-dimensional particle-following code applicable to $k_{\parallel} = 0$ electrostatic modes, i.e., the waves propagate exactly perpendicular to the external magnetic field. The wave vector is constrained to one direction only, but full account is taken of the two-dimensional gyration motion. The electrons are treated as a uniform background, consistent with E/B motion. Essentially any distribution $f(v_{\perp})$ can be considered.

Author: J. A. Byers

LINMIR

This linearized code investigates finite geometry effects on electrostatic mirror instabilities. Slab models are assumed. All linear quantities vary as $\exp(ik_{\perp}y)$. In the z-dependent version, ions at present have only perpendicular motion. Ion transit (in z) effects could be included if necessary. Electron response is along z only. Realistic mass ratios are used. Emphasis to date has been on the behavior of mirror flute modes in short systems ($L/a_1 < 100$). In the x-dependent version, the drift cone mode is examined for finite geometry effects in the plane perpendicular to B.

Author: J. A. Byers

MIRPLA

A 2-1/2 dimensional code (two spatial coordinates and three velocities) designed for investigation of electrostatic mirror instabilities. The model is a plasma slab in a straight magnetic field, $B = [0, 0, B_x(z)]$. The ion equations of motion have been arranged to conserve $\mu = v_1^2 / 2B$ and $W = v_1^2 + v_2^2$ exactly in zero electric field. The Poisson solver, a sine periodic version obtained from Langdon, uses rectangular grids. The boundary conditions are periodic in x , but in z particles are destroyed on the walls. This allows potentials to build up. The code so far has been used to study the modified negative mass mode.

Authors: D. Fuss and B. McNamara

BOUNCE 1D

This code calculates the motion of electrons on one magnetic field line in a magnetic well. Gyromotion is not calculated; conservation of magnetic moment is assumed. A number of ion species (or ion gyro-frequency harmonics) are represented by differential equations with response characteristic of linear ion response in a mirror plasma. Several boundary conditions are available for particles or fields, including periodic, reflecting, or grounded.

Authors: R. C. Harding and H. L. Berk

SUPERADIABATICITY

A code designed to study superadiabaticity and confinement properties of particles moving in magnetic mirror fields and responding to fluctuating electric fields. The fluctuating electric field is arbitrarily assumed as a function of space and time. The particles are followed using a 3D particle mover obtained from Birdsall and Fuss.

Author: J. A. Byers

DCS

This two-dimensional simulation follows charged particles in self-consistent electrostatic fields with an arbitrary potential on the boundary. An iterative procedure is used to solve for steady-state solutions, and this code has been used for direct conversion simulation (DCS) calculations.

Authors: R. P. Freis and J. A. Byers

MAFCO

This code takes a given set of current-carrying elements of arbitrary geometry and calculates the magnetic field B at any point in space and also calculates the line of force passing through any desired point in space. In practice, however, computer memory and available machine time usually require that most of the current-carrying conductors be approximated by straight lines and circular loops.

MAFCO was written to solve some of the magnetic field problems that arise in plasma physics (although it could perhaps be useful in other areas). In particular, the complex confining magnetic fields used in fusion research need to be calculated accurately and rapidly to facilitate design and use of these configurations.

In the MAFCO code it is assumed that the currents are dc and no permeable material is present.

Authors: W. A. Perkins and J. C. Brown

Reference: W. A. Perkins and J. C. Brown, MAFCO - A Magnetic Field Code for Handling General Current Elements in Three Dimensions, Lawrence Livermore Laboratory, Rept. UCRL-7744, Rev. II (1966).

ORBIT CODE TIBRO, 3D

A code that calculates the path of a charge particle in a static iron-free magnetic field. A version of MAFCO is used to calculate the magnetic field at each orbit point, either directly or by interpolating within a grid of previously calculated values. The differential equations of motion are solved by finite-difference methods. A predictor-corrector routine is used, in which a desired accuracy range is maintained by reducing or increasing the size of the time step as needed.

Author: J. Foote

PERPLA

This is a two-dimensional electrostatic code for following charged particle motion in a 32×32 mesh (expandable to any $2^M \times 2^N$ rectangular mesh), with double periodic boundary conditions (useful for uniform or periodic plasmas), and with applied $B_z(x,y)$ normal to the plane of motion. Applications have been made to the cyclotron-loss cone mode and drift-cyclotron-loss-cone modes. PERPLA has run on the CDC 6600 with up to 16,384 particles; now coding for CDC 7600 in order to be able to run up to 10^5 particles.

Authors: C. K. Birdsall and D. Fuss

Toroidal Program

RADIAL TRANSPORT FOR TOROIDAL PLASMAS

This code solves the initial-value problem given by the differential equations of plasma transport in toroidal confinement systems. The equations are one-dimensional and cylindrical coordinates are used. The dependent variables are $n(r,t)$, the number density of electrons and ions; $T_e(r,t)$ and $T_i(r,t)$, the electron and ion temperatures; and $B_\theta(r,t)$ and $B_z(r,t)$, the poloidal and toroidal components of the magnetic field. The equations are solved by an implicit difference method. The mathematical model is formulated in a general way so that the form of the transport coefficients can be changed without modifying the basic structure of the code. Coefficients included in the code are appropriate for banana, plateau, and classical regimes of Tokamak transport theory.

Authors: J. Killeen and A. A. Mirin

Reference: J. Killeen, The Numerical Solution of Radial Transport Equations for Toroidal Plasmas, Culham Laboratory, Culham, England, Rept. PPN 20/71 (1971).

ELECTRONS

We have developed a new electron Fokker-Planck code, called ELECTRONS, to study the problem of runaway electrons in toroidal experiments. Electron-electron and electron-ion collisions are included, and the ions are described by a Maxwellian distribution with ion density and temperature as given parameters. We solve the two-dimensional Fokker-Planck equation for $f_e(v, \theta, t)$, where v is the magnitude of velocity, and θ is the angle between the velocity vector and the electric field.

Authors: J. Killeen, A. A. Mirin, and K. Berger

RUNAWAY

This is a version of the separated Fokker-Planck equation code to solve the runaway problem. The electrons are represented by

$$f_e(v, \theta, t) = \sum_l f_l(v, t) P_l(\cos \theta).$$

The equations for $f_c(v,t)$ are solved by difference methods. One or more ion species is also included. Several λ -modes can be solved for each species. The electric field is taken to be uniform in the $\theta = 0$ direction.

Authors: J. Killeen, A. A. Mirin, and R. P. Berger

BETA

This program computes finite beta plasma equilibria in axially symmetric configurations. The magnetic field is derived from a stream function (r,z) which satisfies a nonlinear, second-order, partial differential equation. The resulting boundary-value problem is solved by difference methods. Applications have included the stuffed cusp and levitron.

Author: J. Killeen

References: J. Killeen and K. J. Whiteman, Phys. Fluids **9**, 1846 (1966).

S. Fisher and J. Killeen, Phys. Fluids **14**, 1240 (1971).

TUBE I, IT

These programs compute magnetic surfaces in stellarator type configurations. The equations of a field-line trajectory are solved for many circuits around a torus. The intersections of the field line with $\phi = \text{constant}$ planes are plotted. In TUBE I, the field due to helical windings are computed by numerically integrating the Biot-Savart equation for each circuit. In TUBE IT, the helical fields are approximated using an expansion in toroidal harmonics.

Authors: J. Killeen, R. P. Freis, and A. A. Mirin

References: J. Killeen, H. P. Furth, and R. P. Freis, The Calculation of Toroidal Magnetic Field Configurations, Lawrence Livermore Laboratory, Rept. UCRL-50161 (1967).

C. W. Hartman, J. Killeen, A. A. Mirin, and M. Uman, report in preparation (1972).

TUBE IV

This program computes magnetic surfaces and constant-B contours for levitrons and other axially symmetric toroidal configurations.

Authors: J. Killeen and R. P. Freis

RIPPLE III, IV

These programs solve the linearized hydromagnetic equations as an initial-value problem in order to study resistive instabilities of a current sheet. RIPPLE III solves the problem in slab geometry, and RIPPLE IV solves the problem in cylindrical geometry. In IV, the equations are Fourier analyzed in θ and z ; hence, the perturbed variables $\vec{V}_1$ and $\vec{B}_1$ are functions of r and t . The tearing, rippling, and gravitational modes can be studied as well as mixed modes.

Author: J. Killeen

Reference: J. Killeen, Computational Problems in Plasma Physics and Controlled Thermonuclear Research, Lawrence Livermore Laboratory, Rept. UCRL-71205 Preprint (1968); to be presented at 9th Scottish Univ. Summer School in Phys. of Hot Plasmas.

RESTAB

This program solves for the resistive instabilities in a diffuse pinch. The equilibrium is specified by $B_{\theta 0}(r)$, $B_{z 0}(r)$, and $\rho_0(r)$. The first order equations for the perturbed variables B_1 and V_1 are Fourier analyzed in θ and z and the resulting equations for $B_{r1}(r,t)$, $B_{\theta 1}(r,t)$, $B_{z1}(r,t)$, $v_{r1}(r,t)$, $v_{\theta 1}(r,t)$, and $v_{z1}(r,t)$ are solved numerically using an implicit difference scheme. The effect of compressibility is included.

Authors: J. Killeen and J. Dibiase

MAFCO II

MAFCO II is written in FORTRAN language and can be used on any computer which can compile a machine language code from a FORTRAN deck and has a memory greater than 50,000 words. The code allows one to follow the guiding center trajectory of a particle in a magnetic field generated by rather general current elements. The magnetic field is calculated in the same manner as in MAFCO, with the addition that it can change with time. One can introduce electric fields that are constant over designed regions of space and others which are created by point charges. The current carrying conductors

must be approximated by straight lines, circular loops, arcs of circles, or series of points designating the geometry of a general current element. For the guiding center approximation to be valid, the particle motion must be adiabatic.

Authors: W. A. Perkins and D. Fuss

Reference: W. A. Perkins and D. Fuss, MAFCO II -- A Code for Calculating a Guiding Center Trajectory of a Particle in Magnetic and Electric Field, Lawrence Livermore Laboratory, Rept. UCRL-50438 (1968).

MAFCO-TIBRO

This code calculates single-particle guiding-center trajectories in cylindrical coordinates r , θ , z . The sources of magnetic field can be arbitrarily located circular current filaments or line currents. Arbitrary electric fields can be included.

Authors: R. P. Freis and E. J. Lauer

SHAPE

The SHAPE program generates specified magnetic field configurations in axisymmetric toruses. One starts by choosing an arrangement of poloidal-field shaping coils and an internal ring (or rings) producing closed magnetic surfaces. (The present version of SHAPE assumes $\nabla \times \underline{B} = 0$ but could be used with electron-beam machines for shaping surfaces outside the beam.) A toroidal field may be included. One then selects a reasonable number of points on one or more closed flux surfaces (corresponding to a set of trial currents in the trim coils), and specifies the desired variations δ_n from average at each point (these points shift, of course, during the optimization). SHAPE then minimizes the sum

$$S = \sum_{\text{surfaces}} \sum_{\substack{\text{points} \\ \text{on} \\ \text{surfaces}}} \left[\frac{B_n^2}{\langle B^2 \rangle_{\text{surface}}} - 1 - \delta_n \right]^2 \cdot w_n$$

where W_n are appropriately chosen weights. The reference shows examples: optimized configurations in which B is made to vary monotonically over a 2.5:1 range (increasing or decreasing with major radius) and a configuration in which $\Delta B/B = 0.005$ over a flux surface.

Authors: O. A. Anderson, D. Fuss, and K. Halbach

Reference: O. A. Anderson, D. Fuss, and K. Halbach, Plasma Phys. **12**, 207 (1970).

TORMAG

The TORMAG program has been derived for symmetry optimization of toroidal fields, e.g., in Tokamaks or the proposed relativistic pinch. (A practical magnet needs access gaps which may introduce intolerable asymmetries in strong field machines where oversized coils are not practical.) Field ripple may be greatly reduced by segmenting the coils and choosing optimum segment currents. These currents are computed by TORMAG using the MLR subroutine (see reference). TORMAG first finds the array b_{js} of toroidal field values at appropriately chosen points j generated by unit segment currents, and then calls MLR to minimize the modulus of the residual ϵ_j representing the deviation from average at each point. In a sample problem, using the T3A Tokamak geometry (but with three-segment coils) the field ripple is reduced from 4% to 0.1% without increasing the maximum current density or reducing access.

Authors: O. A. Anderson and D. Fuss

References: R. E. von Holdt, Minimize Linear Residuals, Lawrence Livermore Laboratory, CIC Rept. F3-001 (1969).

O. A. Anderson and H. P. Furth, Nuclear Fusion **12**, 207 (1972).

GUIDE

GUIDE is a new program for calculating guiding center motion in electric and magnetic fields. GUIDE also prints out J for particles that bounce, and displays drift rate information in all cases. GUIDE computes $v_{||}$ directly from the particle energy, and avoids errors that can arise from the Northrop-Teller equation. (The latter, as used in MAFCO II, introduces an order-of-magnitude error in a typical toroidal pinch calculation.) Furthermore, GUIDE includes all relativistic effects (not assuming $\gamma = \text{constant}$ as does MAFCO II).

There are two versions: GUIDE I is restricted to axisymmetric cases but includes arbitrarily specified toroidal plasma currents. GUIDE II does not assume any field symmetry but does assume $\nabla \times \underline{B} = 0$.

Authors: O. A. Anderson and D. Fuss

ACTION

Contours for the longitudinal invariant J in axisymmetric magnetic fields are computed by ACTION. Using the contours that are displayed for J , B , and ψ , one finds for a particle mirroring at any point, the bounce time $T = \mu^{-1} \partial J / \partial B$ and toroidal drift frequency $\omega_d = -(c/eT) \partial J / \partial \psi$. Another chart displays contours from which one gets the Ware drift and velocity $cE/B_{\perp}$. Thus, in a typical configuration such as a toroidal relativistic pinch with separatrixes, one obtains almost at a glance all the relevant details on all possible J -conserving particle trajectories (up to the point of untrapping). The computer time used is considerably less than that for a single corresponding guiding-center trajectory.

Authors: O. A. Anderson and D. Fuss

LEVITRON STABILITY

This code calculates Nyquist stability diagrams for a levitron stabilized by feedback-controlled magnetic fields for small frequencies and by magnetic coupling to parallel metal plates for large frequencies.

Authors: R. K. Cooper and C. H. Woods

General Purpose Simulation Codes

X-V MOTION

A code that solves the Vlasov-Poisson equations for step functions distributions (any number of steps possible). It has been employed successfully in beam problems.

Author: H. L. Berk

SHOCK 1D

A one-dimensional code that is being used to construct an ion-acoustic shock wave. Electrons are considered as an adiabatic background, and fields are generated self-consistently from Poisson's equation.

Author: H. L. Berk

GENERAL ELECTROSTATIC. 1D

A one-dimensional, particle-following code applicable to general electrostatic problems. Periodic boundary conditions are assumed. Two (or more) charge species may be used with arbitrary weights allowed for all the particles. The code runs on the CDC 6600 and is set up to use the disks, so storage for the particles is not a limiting factor. Problems using upwards of 300,000 particles have been run. To date the code has been used for

- gentle beam instabilities approaching quasilinear conditions,
- laser heating of plasma. Here an externally imposed rf electric field is assumed. This version has been used extensively by the laser program at LLL.
- heat flow from a hot spot (Berk and Baldwin).

Author: J. A. Byers

GENERAL ELECTROSTATIC, LINEARIZED

A linearized version of the above nonlinear code. All linear quantities vary as $\exp(ikx)$. This code is useful primarily in conjunction with the above nonlinear code, e.g., for establishing maximum growth rate parameters in sensitive regimes of linear theory.

Author: J. A. Byers

PLASIM

Unmagnetized (one-dimensional) or magnetized (1-1/2-dimensional) two-species particle-simulation code with fast Fourier transform field solver. PLASIM has been used for algorithm experimentation and educational purposes.

Authors: D. Fuss, A. B. Langdon, and C. K. Birdsall

POISSON'S EQUATION SOLVERS

These use two- and three-dimensional fast Fourier transforms to solve Poisson's equation with various boundary conditions. They are as efficient as was felt possible without becoming too abstruse. Execution speed is three to six times faster than that of previous solvers used here, and working storage requirements are about half. Other inhomogeneous elliptic equations can be solved after simple changes.

Author: A. B. Langdon

NOVA

This is a highly modularized simulation-code superstructure general enough to encompass most simulation codes. It includes a routine for efficient buffering of particle coordinates onto disk, a general phase-space plotting package that avoids system overhead, a general initialization package, a control package, and examples of field solvers, particle pushers, and diagnostics. The intent is that a new application will require a minimum of new coding unique to that application.

Authors: B. McNamara and A. B. Langdon

BEAMSIM

The Beamsim code is intended primarily to aid in the interpretation of beam propagation experiments. Its most important feature is a detailed treatment of the beam particle dynamics. The plasma is highly collisional and is characterized by the scalar conductivity, the background electron density, and the electron energy. The beam and the plasma interact through the induced electric and magnetic field. The beam current and the plasma current are the sources for these fields.

The beam is simulated in a realistic fashion by a collection of particles moving at constant velocity parallel to the axis of the experimental tank. The perpendicular betatron motion of the particles results from interaction with the magnetic fields of the beam and the induced plasma currents. There is also degradation of the beam energy from interaction with the induction electric field and background gas. The effects of small angle scattering from nuclei are included.

Phenomena being studied are:

- hose instability into the nonlinear regime,
- beam equilibria and expansion,
- sausage mode,
- filamentation modes,

- nonadiabatic effects such as those resulting from a mismatch, and
- effects of the altered boundary conditions due to charge leaking.

Authors: J. M. Leary, E. P. Lee, and J. Bolstad

RATEEQNS

When the original version of BEAMSIM was first written, the physics of the plasma variables was taken from experiment rather than derived — a scalar conductivity characterized the medium, and was included in an ad-hoc manner. In the code RATEEQNS, the plasma variables are included in a more reasonable manner. We consider conductivity, plasma frequency, collision frequency, number density and energy of the background plasma electrons, and molecular number density. The conductivity is now calculated from the number density and the energy of the background plasma electrons. This neutral-dominated conductivity rather than the Spitzer conductivity is the appropriate one in our regime. The rate of creation of electrons is calculated by considering both direct deposition of electrons and also their disassociative recombination. The electron energy is calculated from the Ohmic heating and the direct deposition of energy.

Authors: J. M. Leary and E. P. Lee.

TWOSTRM

The TWOSTRM code was developed to study phenomenon of the relativistic two-stream instability and its saturation. We consider a highly relativistic, high-quality beam in a dense, partially ionized background with no external fields imposed.

The logic of this problem is the same as in the particle simulation code, BEAMSIM, except for the field calculation. These field calculations are again done at various z-stations, and these are essentially independent of one another. In the particle code, we merely had to solve for the z-component of the vector potential that involved solving the diffusion equation. In the field calculation for the two-stream problem, there are two important differences. First, we can no longer neglect the displacement in Maxwell's equation. Second, we can no longer use a simple Ohm's law, but instead we must add a reactive term to it.

Authors: J. M. Leary and E. P. Lee

2D MAGNETOHYDRODYNAMICS

We have developed a general method for solving numerically two-dimensional, two-fluid magnetohydrodynamic equations. The method uses second-order accurate, alternating

direction implicit finite-difference equations. The accuracy and implicitness of the codes which have been developed using this method are features not available in previously reported codes. The equations are solved in cylindrical coordinates with axial symmetry. The variables are then functions of r , z , and t . We denote U as a nine-component vector whose components are dependent variables and κ as a four-component vector whose components are the transport coefficients, each a function of U , i.e.,

$$U = (\rho, v_r, v_\theta, v_z, \theta_i, \theta_e, B_r, B_\theta, B_z)$$

and

$$\kappa = \kappa(U) = (\kappa_i, \kappa_e, 1/\tau_{eq}, n),$$

where θ_i and θ_e are the ion and electron temperatures.

Tokamak and Levitron geometries involve all three components of the fluid velocity and magnetic field. The computer codes written to calculate all nine dependent variables are also set up to calculate

$$U = (\rho, v_r, v_z, \theta_i, \theta_e, B_r, B_z)$$

appropriate for two-dimensional theta-pinch geometries and laser-produced plasma expansion studies.

Authors: J. Killeen and I. R. Lindemuth

Reference: I. R. Lindemuth, The Alternating-Direction Implicit Numerical Solution of Time-Dependent, Two-Dimensional, Two-Fluid Magnetohydrodynamic Equations, Lawrence Livermore Laboratory, Rept. UCRL-51103 (1971).

SQRPLA

This is a two-dimensional electrostatic code for following charged particle motion in a 32×32 mesh which has zero potential boundary walls, with applied $B_z(x,y)$ normal to the plane of motion. This was the first code to use the cloud-in-cell method. First applications were on diocotron instability and Alice injection. Typical numbers used were a few thousand particles and were run on the Larc computer. This code has recently been reformulated so as to be expandable to any $2^M \times 2^N$ rectangular mesh. SQRPLA runs on the CDC 6600 with up to 16,384 particles.

Authors: C. K. Birdsall and D. Fuss

Linear Stability Theory Codes

CONVICT

This program determines the zeros of an input function (the dispersion) $D(k, \omega)$, obtaining the various branches $\omega_\alpha(k)$ for real k . The program then detects all maxima of $\text{Im} [\omega_\alpha(k)]$, and obtains the associated pulse shape $\text{Im} [\omega - kV]$ vs V for which the pair of equations $D = 0$ and $D_k + VD_\omega = 0$ hold. The program provides an optional test for the existence of a pinch by relaxing the second equation and tracing the branches $k_n(\omega)$ of $D = 0$ as $\text{Im} [\omega - kV]$ becomes large and positive.

Author: L. S. Hall

COP

This code follows $\text{Max} \{ \text{Im} [\omega(k)] \}$ as a function of the auxiliary parameters $\underline{a}$ of a dispersion relation $D(k, \omega, \underline{a}) = 0$. The program optionally provides the pulse shape $\text{Im} [\omega - kV]$ vs V from the associated saddle point $D = 0$, $D_k + VD_\omega = 0$. The code is designed primarily for on-line interaction with the user through the Octopus system, although off-line operation is optional.

Author: L. S. Hall

GRAD

This code permits determination of the variation of ω and k satisfying the saddle point equations $D = 0$, $D_k + VD_\omega = 0$ along a contour of constant proper frequency as some auxiliary parameter $\underline{a}$ is changed. The dispersion function $D(k, \omega, \underline{a})$ is an input subroutine, and the program is designed to permit on-line operation through Octopus. Pulse shapes can also be generated by GRAD.

Author: L. S. Hall

BLROOT

This solves for ω for drift-cyclotron-loss-cone modes and displays the solutions on a CRT screen. The dispersion relation was derived by Langdon especially for application to the computer experiments of Birdsall and Fuss in which plasma radius, ion gyro radius and wavelength are comparable. The system is periodic in x and y , and the unperturbed density is nonuniform in x . The electric field is sinusoidal in y and is expressed as a

Fourier series in x . The requirement that not all the Fourier coefficients are zero means as usual that a determinant is zero; this is the dispersion relation to be solved numerically. After the roots are found, the spatial structure of the modes can be plotted.

Authors: C. K. Birdsall, D. Fuss, and A. B. Langdon

GRIDISP

This solves the dispersion relation for longitudinal oscillations in a simulation code, including the effects of finite Δx and Δt . There is a choice of various velocity distributions, weighting functions (NGP, linear CIC, splines) and field difference equations. GRIDISP has been used to study grid-induced instabilities and the improvement in accuracy obtained with Boris-Langdon corrections to the acceleration calculation.

Author: A. B. Langdon

INTEGRAL EQUATION, NEGATIVE ENERGY WAVES

This code finds eigenvalues of reflection coefficients for negative energy waves on impinging resonance regions ($\omega = \omega_c$ s). Critical lengths of mirror machines have been found using this code.

Authors: H. L. Berk and L. D. Pearlstein

Other Codes

VIBE

This program calculates the eigenvalues and eigenfunctions of the radial Schroedinger equation for a given potential well. The equation is numerically integrated with a combination Runge-Kutta and Milne predictor-corrector scheme, and the final solution obtained using an iterative procedure.

Author: R. P. Freis

LENS

This code determines the behavior of relativistic beams passing through nonlinear magnetic lenses.

Authors: R. P. Freis and C. H. Woods

EXPORTS, TRANSPORT, RELGUN FOR ASTRON BEAM TRANSPORT

EXPORTS numerically integrates the differential equation describing the paraxial ray beam envelope. Beam trajectories under the influence of self-fields, emittance, and external vacuum fields are computed. Results demonstrated the effectiveness of the focussing elements as a function of particle energy, beam current, emittance and initial beam edge slope, and radius.

TRANSPORT was originally developed at Stanford Linear Accelerator and has been expanded and modified for use on the Livermore Octopus system. Basically, the code is a program for applying the matrix transformations of beam optics to the desired transport system. In its current state, TRANSPORT can trace a beam through the given system to first or second order, adjust parameters of the system to fit specific conditions, evaluate the effects of misalignments, and execute various other instructions that may be given.

RELGUN determines the self-consistent solution of Poisson's equation, the relativistic equations of electron motion, and the equation of charge continuity all subject to specified boundary conditions. In particular, the code applies to the case of an axially symmetric, solid-beam electron gun where the electrons are emitted with zero velocity from a space-charge limited cathode.

Author: J. W. Beal

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