Title
MAFCO III - A CODE FOR CALCULATING PARTICLE TRAJECTORIES IN MAGNETIC AND ELECTRIC FIELDS

Permalink

Author
Perkins, W.A.

Publication Date
1972-09-01

MAFCO III — A CODE FOR CALCULATING PARTICLE TRAJECTORIES IN MAGNETIC AND ELECTRIC FIELDS

W. A. Perkins and S. J. Sackett

September 1972

LBL-765 c.

DISCLAIMER

MAFCO III — A Code for Calculating Particle

Trajectories in Magnetic and Electric Fields[*]

W. A. Perkins and S. J. Sackett

Lawrence Berkeley Laboratory
University of California
Berkeley, California

August 3, 1972

ABSTRACT

MAFCO III will calculate the three-dimensional trajectory of a
relativistic (or non-relativistic) particle of arbitrary mass and
charge in time-varying (or constant) three-dimensional magnetic and
electric fields. The magnetic fields must be specified by infini-
tesimal current elements whose configuration and time variation can be
very general. Electric fields can be specified by point charges and
infinitesimal charged elements which can also have a time variation,
and by regions of constant electric field. The electric field due
to the time variation of the magnetic field is calculated and added
to the specified electric field. The magnetic field arising from
a time-varying charged element, however, is neglected. The program
is written in FORTRAN and COMPASS and requires a memory allotment
of $110,000_8$ words.

---

1. Introduction

MAFCO III was written to solve some of the problems that arise in plasma physics and accelerator design regarding the motion of charged particles in complicated magnetic and electric fields. Whereas MAFCO[1] calculates the magnetic field from the current elements, and MAFCO II[2] calculates the guiding center motion in a magnetic field which is applicable for particle motion with small gyroradii, MAFCO III calculates the particle's trajectory. Some other computer codes[3,4] have been written to follow the motion of particles in a magnetic field. MAFCO III is more general than the other programs in that it can handle relativistic calculations and has provisions for time-varying magnetic fields and electric fields. The particular input for electric fields required by MAFCO III is not appropriate for problems in which potential distributions specify the electric field. Other programs[4] should be used for problems of that type. Also, it is assumed that no permeable material is present. Some two-dimensional codes[5,6] are available for calculating trajectories in the presence of permeable material.

In specifying the magnetic field the current-carrying conductors must be approximated by straight lines, circular loops, arcs of circles, or a series of points designating the geometry of a general current element (the code puts a straight-line element between each pair of points). The cross section of these current elements is assumed to be infinitesimal. This is usually a good approximation; for those cases in which the conductor's cross section is not negligible, it may be easily approximated with several infinitesimal elements.

· In specifying the electric field, one can use charged elements with the geometries described, point charges, and electric fields that

are constant over a given region of space. All of these except the last may be time varying.

The time variation of the current elements and charged elements can be specified by a table of points. (The variation is taken to be linear between the points.) Other options are: (1) a sine-wave rise and an exponential decay and, (2) an exponentially-decaying sine-wave variation.

The units used by the code are:

Time	microseconds
Distance	centimeters
Velocity	centimeters per second
B (magnetic field)	gauss
E (electric field)	volt per centimeter
Mass	grams
Charge	esu
θ (angle)	degrees
W (energy)	MeV
p (momentum)	MeV/c .

2. Theory

A. Equations of Motion

The equations of motion for a charged particle in an electric and a magnetic field are as follows

$$\frac{d\underset{\sim}{R}}{dt} = \underset{\sim}{v} = f(\underset{\sim}{R}, \underset{\sim}{v}, I) , \qquad (1)$$

$$\frac{d\underset{\sim}{p}}{dt} = \frac{e}{c} (\underset{\sim}{E} + \underset{\sim}{v} \times \underset{\sim}{B}) , \qquad (2)$$

where

$$\underset{\sim}{v} = \underset{\sim}{p}/(m_0 \gamma) \qquad (3)$$

and

$$\gamma = (p^2 + m_0^2 c^2)^{1/2}/(m_0 c) \qquad (4)$$

is the ratio of the particle's total energy to its rest energy. The quantity m_0 is the particle's rest mass, e is its electric charge, $\underset{\sim}{R}$ is its spacial coordinate, $\underset{\sim}{v}$ is its velocity, I represents the currents, and c is the velocity of light.

The trajectory of the particle is obtained by integrating Eqs. (1) and (2) with the use of Eqs. (3) and (4). The integration is done in rectangular coordinates, using fourth-order Adams-Moulton predictor-corrector with starting procedure based on Zonneveld's formulas.[7] A variable step size is used to ensure accuracy, but steps are forced to land on multiples of a specified print interval.

B. Magnetic Field Changing with Time

The magnetic field for the current-carrying elements is calculated by the same equations as are used in MAFCO.[1] The currents can be constant in time or have one of the following three types of variation:

I. Table of I_i and t_i values. For a given time t the current I is calculated by the linear interpolation,

$$I(t) = I_i + (I_{i+1} - I_i) \frac{(t - t_i)}{t_{i+1} - t_i} .$$ (5)

II. A sine-wave rise with an exponential decay as would occur with an inductive and resistive element powered by a capacitor bank which is crowbarred at peak field.

$I(t) = 0$ for $t \leq t_o$,

$I(t) = I_o \sin \left[\frac{\pi}{2} (t - t_o)/\tau_r \right]$ for $t_o < t \leq \tau_r + t_o$,

$I(t) = I_o \exp - \left[(t - t_o - \tau_r)/\tau_d \right]$ for $t > \tau_r + t_o$,   (6)

where t_o is the time at which the current starts flowing, τ_r is the rise time, and τ_d is the characteristic decay time.

III. An exponential decaying sine wave. (One can also use this type for a sine-wave variation by using a large value for the decay time.)

$$I(t) = 0 \quad \text{for} \quad t \leq t_o ,$$

$$I(t) = I_o \exp[-(t-t_o)/\tau_d] \sin \left[\frac{\pi}{2} (t-t_o)/\tau_r \right]$$
$$\text{for} \quad t_o < t \leq t_m ,$$

$$I(t) = 0 \quad \text{for} \quad t > t_m .$$ (7)

The equations for the electric fields caused by the changing magnetic fields are calculated from the vector potential $\underset{\sim}{A}$ by

$$\underset{\sim}{E} = -\frac{\partial A}{\partial t} \cdot \qquad (8)$$

$\underset{\sim}{A}$ depends on time only through $I(t)$, and the equation for $\underset{\sim}{A}$ was obtained by integration of

$$\underset{\sim}{A} = \frac{\mu_o I}{4\pi} \oint \frac{d\underset{\sim}{\ell}}{r} \qquad (9)$$

for each type of current element. Here

$$\underset{\sim}{E} = -\frac{\dot{I}(t)}{I(t)} \underset{\sim}{A} \cdot \qquad (10)$$

The equations for the electric fields caused by changing currents in CIRCULAR LOOPS, ARCS, and STRAIGHT LINES are given in Appendix A of Ref. 2.

C. Electric Fields for Charged Elements

The equations for the electric fields created by charged elements are calculated from

$$\underset{\sim}{E} = -\underset{\sim}{\nabla}\phi \qquad (11)$$

and

$$\phi = \frac{Q/L}{4\pi\epsilon_o} \int \frac{d\ell}{r} \quad , \qquad (12)$$

where Q is the charge and L is the length of the charged element. The resulting electric fields are:

I. Ring Charge

$$E_\rho = \frac{1 \times 10^{-8} cQ}{\pi\rho \left[(A + \rho)^2 + \tilde{Z}^2\right]^{\frac{1}{2}}} \left[K(k) - \frac{A^2 - \rho^2 + \tilde{Z}^2}{(A - \rho)^2 + \tilde{Z}^2} E(k)\right],$$

$$E_{\tilde\theta} = 0$$

$$E_{\tilde Z} = \frac{10^{-8} cQ\tilde{Z}}{2\pi A\rho} \left(\frac{k^2}{1 - k^2}\right) \frac{E(k)}{\left[(A + \rho)^2 + \tilde{Z}^2\right]^{\frac{1}{2}}} . \tag{13}$$

II. Arc Charge

$$E_\rho = \frac{10^{-8} cQ}{4A\rho(\Phi_2 - \Phi_1)} \frac{k^2}{\left[(A + \rho)^2 + \tilde{Z}^2\right]^{\frac{1}{2}}} \left\{ 2(A + \rho)\left[F(\omega_2,k) - F(\omega_1,k)\right] \right.$$

$$+ \frac{(A^2 - \rho^2 + \tilde{Z}^2)}{\rho} \left[\frac{E(\omega_1,k) - E(\omega_2,k)}{1 - k^2} + F(\omega_2,k) - F(\omega_1,k)\right.$$

$$\left.\left. + \frac{k^2 \sin\omega_2 \cos\omega_2}{(1 - k^2)(1 - k^2 \sin^2\omega_2)^{\frac{1}{2}}} - \frac{k^2 \sin\omega_1 \cos\omega_1}{(1 - k^2)(1 - k^2 \sin^2\omega_1)}\right]\right\} ,$$

$$E_{\tilde\theta} = \frac{1 \times 10^{-8} cQ}{\rho(\Phi_2 - \Phi_1)} \frac{1}{\left[(A + \rho)^2 + \tilde{Z}^2\right]^{\frac{1}{2}}} \left[(1 - k^2 \sin^2\omega_2)^{-\frac{1}{2}} - (1 - k^2 \sin^2\omega_1)^{-\frac{1}{2}}\right],$$

$$E_{\tilde Z} = \frac{10^{-8} cQ}{2A\rho(\Phi_2 - \Phi_1)} \left(\frac{k^2}{1 - k^2}\right) \frac{\tilde{Z}}{\left[(A + \rho)^2 + \tilde{Z}^2\right]^{\frac{1}{2}}} \left\{ E(\omega_2,k) - E(\omega_1,k) \right.$$

$$\left. - k^2 \left[\frac{\sin\omega_2 \cos\omega_2}{(1 - k^2 \sin^2\omega_2)^{\frac{1}{2}}} - \frac{\sin\omega_1 \cos\omega_1}{(1 - k^2 \sin^2\omega_2)^{\frac{1}{2}}}\right]\right\} . \tag{14}$$

III. Straight Line Charge

$$E_x = \frac{2 \times 10^{-8} cQ}{|\rho_2 - \rho_1|} \left\{ \frac{X_2 - X_1 + |\rho_2 - \rho_1| (X_2 - X_0)/\rho_2}{\rho_2^2 - \rho_1 \cdot \rho_2 + \rho_2 |\rho_2 - \rho_1|} \right.$$

$$\left. + \frac{X_2 - X_1 + |\rho_2 - \rho_1| (X_1 - X_0)/\rho_1}{\rho_1^2 - \rho_1 \cdot \rho_2 - \rho_1 |\rho_2 - \rho_1|} \right\} , \tag{15}$$

$$\rho_1 \cdot \rho_2 = (X_1 - X_0)(X_2 - X_0) + (Y_1 - Y_0)(Y_2 - Y_0) + (Z_1 - Z_0)(Z_2 - Z_0)$$

$$|\rho_2 - \rho_1| = \left[(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2 \right]^{\frac{1}{2}} , \tag{16}$$

where E_Y and E_Z are obtained by cyclic permutations of X, Y, Z .

The equations for the electric field from a point charge are given in Ref. 2.

D. Transformation of Coordinate Systems for Circular Loops and Arcs

The equations specifying the electric and magnetic field created by loop charges (and/or) currents are given for the coordinate system whose center coincides with the center of the loop and for which the loop lies in the X-Y plane. Equations to transform the field point to this coordinate system are given in Section 2B of Ref. 1. Equations to transform the field components back to the laboratory system are given there also.

These same transformation equations are used for the circular arcs.

E. Total Field

The total electric and magnetic fields are obtained by summing each component over all elements. For example,

$$\sum B_X = \sum_{j=1}^{N} (B_X)_j (\text{CIRCULAR LOOP}) + \sum_{j=1}^{M} (B_X)_j (\text{CIRCULAR ARC})$$

$$+ \sum_{j=1}^{L} (B_X)_j (\text{STRAIGHT LINE}) + \sum_{j=1}^{K} (B_X)_j (\text{GENERAL ELEMENT}). \qquad (17)$$

3. Input-Output

A. Program Cards

The program is available on library tape number 13898 and on PSS for use on the Lawrence Berkeley Laboratory 7600. The required sequence of control cards is as follows:

JOBNAME,05,TIME LIMIT IN CU'S,110000.ACCOUNT NUMBER,YOUR NAME

*7600

REQUEST,MAFCO3,HY,Z,13898.

or

LIBCOPY,MAFLIB,MAFCO3,MAFCO3.

REWIND,MAFCO3.

MAFCO3.

7-8-9 multiple punch in column 1.

MAFCO3 data deck

6-7-8-9 standard white end-of-job card.

B. Input Cards

In concise form the input is as given in Table I. If a
current or charged element is constant in time, then one does not need
any GENERAL TIME-VARYING CURRENT CARDS for that element.

Table I - MAFCO III Input

The first card contains the number of problems (integer, right-
adjusted, in columns 1-5).

The following section of cards is repeated for each problem.

- -

The 1st card contains comments concerning problem in columns 1-80.

The 2nd card of this section contains, in right-adjusted columns,

Format (9I5,1X,A10)

1-5	Number of LOOPS.
6-10	Number of ARCS.
11-15	Number of STRAIGHT LINES.

16-20	Number cf GENERAL CURRENT ELEMENT groups.
21-25	Number of POINT CHARGES.
26-30	Number of CONSTANT POLAR ELECTRIC FIELDS.
31-35	Number of CONSTANT RECTANGULAR ELECTRIC FIELDS.
36-40	Number of GENERAL TIME-VARYING CURRENTS AND CHARGES.
41-45	Number of particle trajectories.
46-55	Name of file containing generator overlay. (See Appendix A).

CIRCULAR LOOP cards (one for each loop in this problem) containing X, Y, Z, A, Alpha, Beta, I, Gen. time varying current (GTVC)(0 if current is D.C.), G (0 for current only, 1 for charge only, -1 for current and charge); Format (7F10.3,2I5). If G = -1, this is followed by another card with VOC (velocity of beam/velocity of light); Format (1E20.6). (When G = -1 for the other current elements this extra card is also needed. The charge is calculated from $Q = 0.1IL/VOC$.)

CIRCULAR ARC cards (two for each arc in this problem). Card 1 contains X, Y, Z, A, Alpha, Beta, I, GTVC, G; Format (7F10.3,2I5). Card 2 contains Φ_1, Φ_2; Format (2F10.3).

STRAIGHT-LINE cards (one for each straight line in this problem) containing X_1, Y_1, Z_1, X_2, Y_2, Z_2, current from 1 to 2, GTVC, G; Format (7F10.3,2I5).

GENERAL CURRENT ELEMENT cards (one group for each element in this problem). First card contains X, Y, Z of the first point, current along points, number of points, GTVC, G; Format (4F10.3,3I5). Following cards contain X, Y, Z of succeeding points; Format (3F10.3).

POINT CHARGE cards (one for each point charge) containing X, Y, Z, Q; Gen. time varying charge; Format (3F10.3, 1E20.6, I5).

CONSTANT POLAR ELECTRIC FIELDS cards (two for each field) containing R_{min}, R_{max}, θ_{min}, θ_{max}, Z_{min}, Z_{max}; Format (6F10.3);

ϵ_R, ϵ_θ, ϵ_Z; Format (3F10.1).

CONSTANT RECTANGULAR ELECTRIC FIELDS cards (two for each field) containing X_{min}, X_{max}, Y_{min}, Y_{max}, Z_{min}, Z_{max}; Format (6F10.1) ϵ_X, ϵ_Y, ϵ_Z; Format (3F10.1).

GENERAL TIME-VARYING CURRENT CARDS (Note: One group for each time varying current in this problem.)

> 1st card number of points, time at first point, current at first point (I5, 2F10.3) succeeding cards containing T and I of remaining points, four pairs per card; Format (8F10.3).

There must be at least 5 points per table.

For standard time-varying currents use the following format instead of the above.

1st card negative integer giving function type, up to four constants for function Format (I5,4F10.3); e.g., sine-wave rise, exp. decay: -1, t_o = starting time, τ_r = rise time of quarter sine wave, τ_d = exp. decay time. For exponential-decaying sine wave: -2, t_o, t_m = time after which current equals zero, τ_r, τ_d.

> Boundary card (one) which contains:
>
> R_{min}, R_{max}, θ_{min}, θ_{max}, Z_{min}, Z_{max}; Format (6F10.3).
>
> Particle Trajectory cards (two for each trajectory in the above

fields) containing

R, θ, Z, t_{min}, Delta-t, t_{max}, No. of revolutions to print out betatron oscillation frequencies; Format (6F10.1, I5).

W, U_x, U_y, U_z, Mass, Charge, specified angle print out flag; Format (6F10.1, I5).

(a) W (kinetic energy) $\neq$ 0, U_X, U_Y, U_Z are the relative velocities.
(b) for W = 0, U_X, U_Y, U_Z are particle's velocity components.
(c) If charge is omitted, code uses -e. If mass is omitted, code uses m_e.

(d)   If the specified angle print-out flag is nonzero, a card giving two angles at which print out is desired must follow this card; Format (2F10.1).

The symbols in Table I are defined as follows:

  (1) CIRCULAR LOOP

         (X, Y, Z) = coordinates of the center of the loop.

         A = radius of loop.

         Alpha, Beta = Euler angle specifying orientation of loop.

         I = current passing through loop.

See Fig. 1 of Ref. 1 for more details.

  (2) CIRCULAR ARC

         (X, Y, Z) = coordinates of the center of imaginary loop

                formed by extending the arc.

         A = radius of arc.

         Alpha, Beta = Euler angles specifying orientation of arc.

         Phi 1 = angle between starting point of arc and

                $X_1 Z_1$ plane (see Fig. 1 of Ref. 1).

         Phi 2 = angle at which arc ends; $\Phi_2 > \Phi_1$.

         I = current passing through arc.

  (3) STRAIGHT LINE

         (X_1, Y_1, Z_1) = coordinates of one end of the line.

         (X_2, Y_2, Z_2) = coordinates of the other end of the line.

  (4) POINT CHARGE

         (X, Y, Z) = coordinates of point charge.

         Q = charge in statcoulombs (esu).

  (5) PARTICLE TRAJECTORY CARDS

         (R, θ, Z) = coordinates of particle at start of trajectory.

         t_{min} = starting time.

Delta t = print-out time step.

t_{max} = ending time for calculation.

W = particle's starting energy (MeV)

(U_X, U_Y, U_Z) = particle's starting velocity in X, Y, and Z directions.

The maximum number of each type of element that can be used for one problem is:

CIRCULAR LOOPS	200
CIRCULAR ARCS	200
STRAIGHT LINES	300 (max)
GENERAL CURRENT ELEMENTS	100 (max), or
	2400 points (max)
POINT CHARGES	100
CONSTANT POLAR ELECTRIC FIELDS	25
CONSTANT RECTANGULAR ELECTRIC FIELDS	25
GENERAL TIME-VARYING CURRENTS	100 with max of 1500
	points total for GTVC.

Since the STRAIGHT LINES and GENERAL CURRENT ELEMENTS use the same memory storage space, the total number of these elements that **can** be used is limited (see Ref. 1).

C.   Output

All output information is labeled. First, all of the input information is printed out to identify the problem. The gyroradius, $\underset{\sim}{B}$, particle momentum, and γ are printed out at the starting and ending point of the trajectory. As the particle moves along the trajectory, columns of t (time) R, θ, Z, W, v_x, v_y, v_z, B, and E are printed out at intervals of delta-t until t_{max} is reached or until the particle leaves the designated boundary.

4. Sample Problems

A. Trapping Electrons with Inflector Coil

This is a calculation showing how the inflector field traps a 3.72 MeV electron in the compressor of an electron ring accelerator.[8] The guide field is created by two sets of coils which vary slowly in time. The electron is trapped by a rapidly varying inflector coil. Coil Sets 1 and 2 are simulated by twenty-four circular loops each. The inflector coil is simulated by ten $180°$ arcs. Their input currents are in the form of tables of I versus time which are obtained from the experimental data. The input data for this problem are shown in Table II.

Figure 1 shows the R-θ projection of the trajectory of the electron for different strengths of the inflector field: (a) zero current in the inflector coil, (b) I_O amperes in the inflector coil, (c) $2I_O$ amperes in the inflector coil and (d) $3I_O$ amperes in the inflector coil. The dashed rectangle indicates the location of the injection pipe (septum). The sinewave-shaped curve shows that with no inflector field the electron strikes the injection pipe on the third turn. With I_O amperes in the inflector coil the electron just barely missed the injection pipe, but with $2I_O$, the electron misses with a good margin (which is necessary for a beam of finite width). With $3I_O$ in the inflector coil the electron strikes the injector pipe on the first turn.

B.   Trajectory of Particle Inside Electron Ring

For some calculations it is useful to assume that the relativistic electron ring can be represented by infinitesimal rings possessing both charge and current.   (Low-energy protons could be represented by charged rings.) One then can calculate the trajectory of an electron or proton in these fields as well as the vacuum fields. The input for a sample problem of this form is shown in Table III. We have injected an electron into an electron ring which has a Gaussian cross section and for which each electron has kinetic energy of 15 MeV.

In this example we have taken the vacuum field to be formed by two circular loops. The time variation of the vacuum field is a sinesoidal rise with an exponential decay (see Sect. 2.B.). The rise time is taken to be 350 μsec and decay time, 8000 μsec. The radial and axial position of the particle for the first three turns is shown in Fig. 2.

REFERENCES

1. W. A. Perkins and J. C. Brown, "MAFCO-A Magnetic Field Code for Handling General Current Elements in Three Dimensions," Lawrence Radiation Laboratory, Livermore, Rept. UCRL-7744 Rev. II (1966). [An earlier version appears under the same title in J. Appl. Phys. 35, 3337 (1964).]

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

3. R. Knox, "TIBRO-GENERAL," Lawrence Radiation Laboratory, Livermore, Rept. UCRL-50910 (1970).

4. S. Sackett and R. Healey, "JASON-A Digital Computer Program for the Numerical Solution of the Linear Poisson Equation," Lawrence Berkeley Laboratory, Rept. UCRL-18721 (1969).

5. B. Olsen, C. Besev, J. S. Colonias, "Computer Design and Optimization of Iron Cored Particle Focussing Device," UUIP-586, Uppsala University, Institute of Physics (April, 1968).

6. Ph. Leconte and J. Mougey, "Orbite - A Computer Code for Particle Trajectories in Magnetic Fields," Dept. de Physique Nucleaire a Haute Energie, CEN-Saclay.

7. J. A. Zonneveld, Automatic Numerical Integration (Mathematisch Centrum, Amsterdam, 1964), p. 23.

8. D. Keefe, G. R. Lambertson, L. J. Laslett, W. A. Perkins, J. M. Peterson, A . M. Sessler, R. W. Allison, Jr., W. W. Chupp, A. U. Luccio and J. B. Rechen, Phys. Rev. Letters 22, 558 (1969).

APPENDIX A

At the option of the user, some or all of the data describing the coil geometry and time-varying current tables may be generated by a user-provided program. The deck structure required to use this option is as follows:

```
JOB NAME,05,TIME LIMIT IN CU's,110000.ACCOUNT NUMBER,YOUR NAME
*7600
REQUEST,MAFCO3,HY,Z,13898.
 or
LIBCOPY,MAFLIB,MAFCO3,MAFCO3.
RUN,SC,B=GEN.
COPY,MAFCO3/RB,1FM,GEN/RB,1F,LGO/RBR.
RETURN,MAFCO3,GEN.
LINK,X.
7-8-9 Multiple punch in column 1.
     OVERLAY(NAME,1,0)
     PROGRAM PNAME
C
     COMMON/COUNTR/NCG,NLOOP,NARC,NLINE,NGCL,NPC,NPE,NRE,NGTVC,
    * NTRJ,NTAPE
     COMMON/COILS/XL(200),YL(200),ZL(200),AOFL(200),ALPHA(200),
    * BETA(200),XIOFL(200),KURL(200),VCL(200),
    * XARC(200),YARC(200),ZARC(200,AARC(200),ALPARC(200),
    * BETARC(200), XIARC(200),KURA(200),APHI1(200),APHI2(200),
    * VCA(200),
```

```
      * X(2400),Y(2400),Z(2400),XIL(300),NPOINT(100),KURLN(300),

      * VCLN(300),

      * XE(100),YE(100),ZE(100)Q(100),KQ(100),

      * RMIN(25),RMAX(25),THMIN(25),THMAX(25),ZMIN(25),ZMAX(25),

      * EPSR(25),EPSTH(25),EPSZ(25),

      * XMIN(25),XMAX(25),YMIN(25),YMAX(25),ZEMIN(25),ZEMAX(25),

      * EPSX(25),EPSY(25),EPSZE(25)

        COMMON/ITABLE/TK(1500),EYC(1500),NPTC(100),NADD(100)
C

        main code for generator
C   RETURN TO MAFCO III.

        CALL GENOR

        CALL ABORT

        END

        generator subroutines, if any.
7-8-9 multiple punch in column 1.

MAFCO3 data deck

6-7-8-9 standard white end-of-job card.
```

The name on the overlay card must be the same as the name given
in columns 46-55 of the second data card for the problem. If the
generator requires card input, they should be placed just before
the "boundary card" for the problem. MAFCO III will print out
generated as well as input coil data so this need not be done
in the generator. Generated data must be stored in the common
blocks COILS and ITABLE in accordance with the following table.

Storage allocation for generation of N elements:

Elements	Counter	Array	Index limits
loops	NLOOP = NLOOP+N	XL,YL,ZL AOFL,ALPHA BETA,XIOFL KURL,VCL	NLOOP+1 to NLOOP+N
arcs	NARC = NARC+N	XARC,YARC ZARC,AARC ALPARC,BETARC XIARC,KURA APHI1,APHI2 VCA	NARC+1 to NARC+N
straight[1] lines	NLINE = NLINE+N	X,Y,Z XIL,KURLN VCLN	$2 \cdot$NLINE+1 to $2 \cdot$(NLINE+N) NLINE+1 to NLINE+N
general[2] current elements	NGCL = NGCL+N	X,Y,Z XIL NPOINT KURLN,VCLN	$2 \cdot \text{NLINE} + \sum_{J=1}^{NGCL} \text{NPOINT}(J) + 1$ to $2 \cdot \text{NLINE} + \sum_{J=1}^{NGCL+N} \text{NPOINT}(J)$ NLINE+NGCL+1 to NLINE+NGCL+N NGCL+1 to NGCL+N NLINE+NGCL+1 to NLINE+NGCL+N
general[3] t.v. currents	NGTVC = NGTVC+N	NPTC TK,EYC	NGTVC+1 to NGTVC+N $\sum_{J=1}^{NGTVC} \text{NPTC}(J) + 1$ to $\sum_{J=1}^{NGTVC+N} \text{NPTC}(J)$

Note 1: Coordinates for line I are stored in $X(J), Y(J), Z(J)$

and $X(J+1)$, $Y(J+1)$, $Z(J+1)$, where $J = 2 \cdot I - 1$. If

lines are to be generated and general current elements

input by cards, the data for the general current elements

must be moved up in core before generation. Coding such

as the following will accomplish this:

```
    NF=NLINE+NLINE
    NS=NF+1
    I=NLINE+NGCL
    DO 10 J=1,NGCL
    NS=NS+NPOINT(J)
    K=I+N
    XIL(K)=XIL(I)
    KURLN(K)=KURLN(I)
    VCLN(K)=VCLN(I)
    I=I-1
 10 CONTINUE
    N2=N+N
 20 CONTINUE
    NS=NS-1
    I=NS+N2
    X(I)=X(NS)
    Y(I)=Y(NS)
    Z(I)=Z(NS)
    IF(NS.GT.NF) GO TO 20
```

where it is assumed that N lines are to be generated.

Note 2: Coordinates of the general current element I are stored

in $X(J)$, $Y(J)$, $Z(J)$, $J = 1$, $K + NPOINT(I)$, where

$$K = 2 \cdot NLINE + \sum_{L=1}^{I-1} NPOINT(L).$$

Note 3: Values for current table I are stored in $TK(J)$, $EYC(J)$,

$$J = K+1, \; K + NPTC(I), \text{ where } K = \sum_{L=1}^{I-1} NPTC(L).$$

Note 4: If element I is charged, the corresponding array element

giving the current table, $KURL(I)$, $KURA(I)$, or

KURLN(I) = KURLN(I) + 10000B). If element I has both

current and charge, the corresponding array element

must be made engative after modification, (e.g.,

KURLN(I) = - (KURLN(I) + 10000B)).

Note 5: Care must be taken during generation that array sizes

are not exceeded. No check is made for this in the

main code.
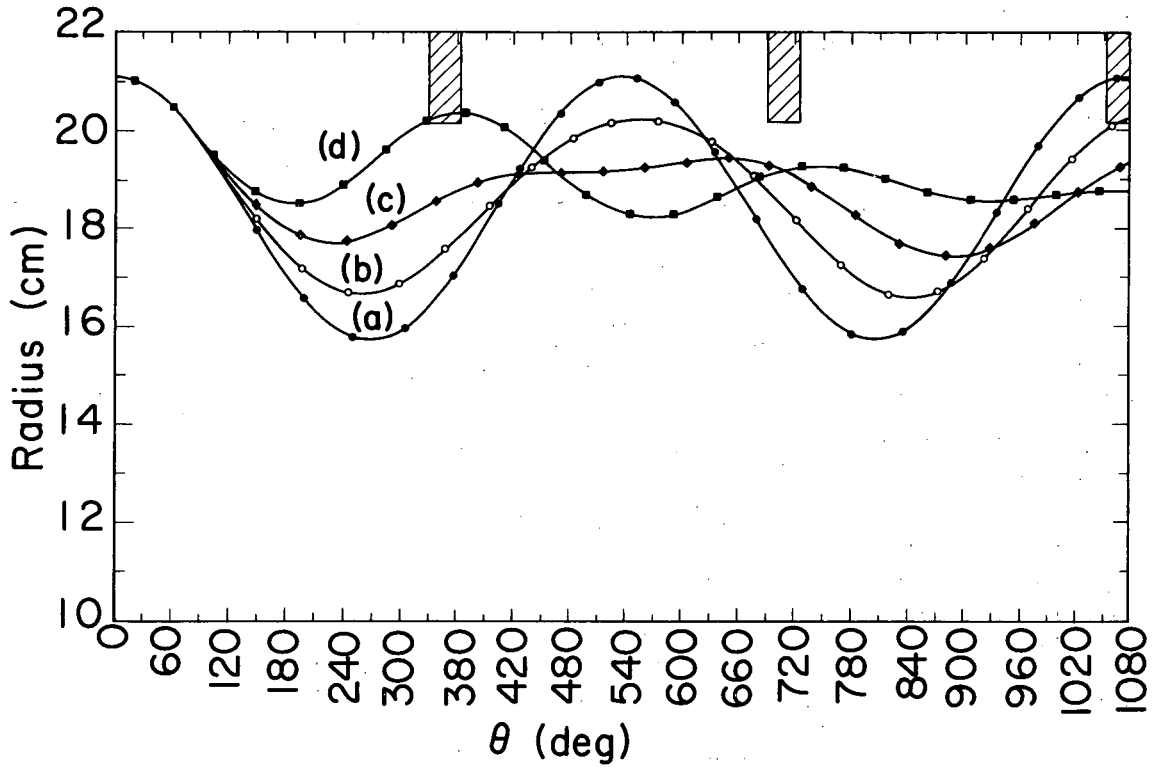
Fig. 1. Radius of electron as a function of angle for four inflector currents: (a) $I = 0$, (b) $I = I_o$, (c) $I = 2I_o$, (d) $I = 3I_o$.
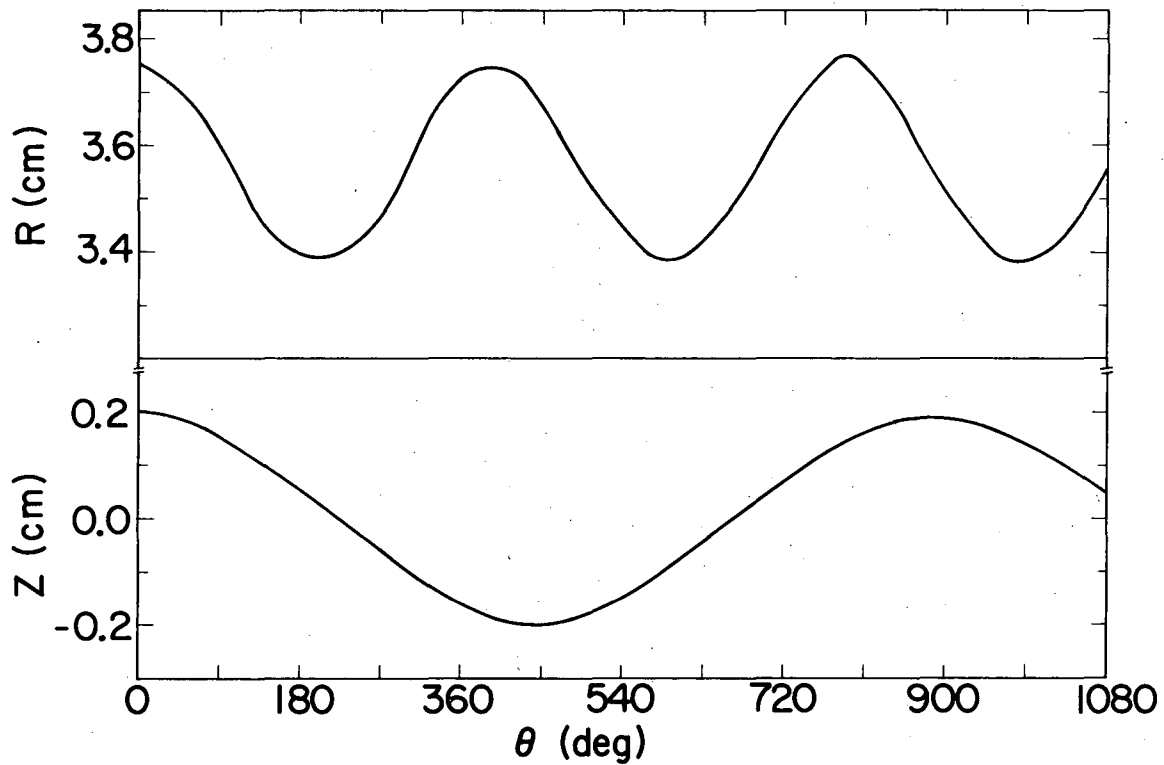
XBL 728 - 3753

Fig 2.   R and Z position of electron for three revolutions in fields
created by a coil and a simulated electron ring.

Table II. Input data for problem A

Column	5	10	20	30	40	50	60	75
	COMPRESSOR 4		COILS 1 + 2 + INFLECTOR					
	48	10			6	2		
	0.	0.	-25.11	32.7	0.	0.	1000.	1
	0.	0.	-25.11	33.6	0.	0.	1000.	1
	0.	0.	-25.11	31.8	0.	0.	1000.	1
	0.	0.	-25.11	30.9	0.	0.	1000.	1
	0.	0.	-24.19	32.7	0.	0.	1000.	1
	0.	0.	-24.19	33.6	0.	0.	1000.	1
	0.	0.	-24.19	31.8	0.	0.	1000.	1
	0.	0.	-24.19	30.9	0.	0.	1000.	1
	0.	0.	-23.27	32.7	0.	0.	1000.	1
	0.	0.	-23.27	33.6	0.	0.	1000.	1
	0.	0.	-23.27	31.8	0.	0.	1000.	1
	0.	0.	-23.27	30.9	0.	0.	1000.	1
	0.	0.	25.11	32.7	0.	0.	1000.	1
	0.	0.	25.11	33.6	0.	0.	1000.	1
	0.	0.	25.11	31.8	0.	0.	1000.	1
48 Circular Loops	0.	0.	25.11	30.9	0.	0.	1000.	1
	0.	0.	24.19	32.7	0.	0.	1000.	1
	0.	0.	24.19	33.6	0.	0.	1000.	1
	0.	0.	24.19	31.8	0.	0.	1000.	1
	0.	0.	24.19	30.9	0.	0.	1000.	1
	0.	0.	23.27	32.7	0.	0.	1000.	1
	0.	0.	23.27	33.6	0.	0.	1000.	1
	0.	0.	23.27	31.8	0.	0.	1000.	1
	0.	0.	23.27	30.9	0.	0.	1000.	1
	0.	0.	9.28	15.95	0.	0.	1000.	6
	0.	0.	10.25	15.95	0.	0.	1000.	6
	0.	0.	11.22	15.95	0.	0.	1000.	6
	0.	0.	12.18	15.95	0.	0.	1000.	6
	0.	0.	13.15	15.95	0.	0.	1000.	6
	0.	0.	14.12	15.95	0.	0.	1000.	6
	0.	0.	-9.29	15.95	0.	0.	1000.	2
	0.	0.	-10.25	15.95	0.	0.	1000.	2
	0.	0.	-11.22	15.95	0.	0.	1000.	2
	0.	0.	-12.18	15.95	0.	0.	1000.	2
	0.	0.	-13.15	15.95	0.	0.	1000.	2
	0.	0.	-14.12	15.95	0.	0.	1000.	2
	0.	0.	9.28	17.42	0.	0.	1000.	6
	0.	0.	10.25	17.42	0.	0.	1000.	6
	0.	0.	11.22	17.42	0.	0.	1000.	6
	0.	0.	12.18	17.42	0.	0.	1000.	6
	0.	0.	13.15	17.42	0.	0.	1000.	6
	0.	0.	14.12	17.42	0.	0.	1000.	6
	0.	0.	-9.28	17.42	0.	0.	1000.	2
	0.	0.	-10.25	17.42	0.	0.	1000.	2
	0.	0.	-11.22	17.42	0.	0.	1000.	2
	0.	0.	-12.18	17.42	0.	0.	1000.	2
	0.	0.	-13.15	17.42	0.	0.	1000.	2
	0.	0.	-14.12	17.42	0.	0.	1000.	2
	0.	0.	-1.022	22.7	0.	0.	-250.	4
	90.	270.						
	0.	0.	1.022	22.7	0.	0.	-250.	4
	90.	270.						
	0.	0.	-3.066	22.6	0.	0.	-250.	4
	90.	270.						
	0.	0.	3.066	22.6	0.	0.	-250.	4
	90.	270.						
10 Arcs	0.	0.	4.7	11.5	0.	0.	166.7	4
	90.	270.						
	0.	0.	-4.7	11.5	0.	0.	166.7	4
	90.	270.						
	0.	0.	-4.9	13.0	0.	0.	166.7	4
	90.	270.						
	0.	0.	4.9	13.0	0.	0.	166.7	4
	90.	270.						
	0.	0.	-5.1	14.5	0.	0.	166.7	4
	90.	270.						
	0.	0.	5.1	14.5	0.	0.	166.7	4
	90.	270.						
	5	0.	0.					
	73.	2.8	113.	4.	200.	8.	10000.	0.
	5	0.	0.					
	60.	0.	134.	.16	220.	4.	10000.	0.
	5	0.	0.					
	73.	2.8	113.	4.	200.	8.	10000.	0.
6 Time Variations	13	0.	0.					
	104.970	0.	105.	.50	105.005	.46	105.010	.40
	105.015	.29	105.020	.17	105.025	.08	105.030	-.02
	105.035	-.10	105.040	-.14	105.045	-.18	1000.	-.20
	5	0.	0.					
	73.	2.8	113.	4.	200.	8.	10000.	0.
	5	0.	0.					
	60.	0.	134.	.16	220.	4.	10000.	0.
Boundary Card	0.	22.7	0.	360.	-5.	5.		
	21.1	0.	0.	105.215	.00005	105.030	2	
2 Trajectories	3.72	0.	1.	0.				
	21.1	0.	0.	104.95	.00005	104.965	2	
	3.72	0.	1.	0.				

Table III. Input data for Problem B

Column	5	10	20	30	40	50	60	75	80
	1								
ELECTRON TRAJECTORY INSIDE AN ELECTRON RING									
	27				2	1			
2 Coils	0.	0.	10.	10.	0.	0.	353000.	2	
	0.	0.	-10.	10.	0.	0.	353000.	2	
	0.	0.	-.4	2.9	0.	0.	.3	1	-1
	.99946								
	0.	0.	-.4	3.1	0.	0.	.8	1	-1
	.99946								
	0.	0.	-.4	3.3	0.	0.	1.2	1	-1
	.99946								
	0.	0.	-.4	3.5	0.	0.	.8	1	-1
	.99946								
	0.	0.	-.4	3.7	0.	0.	.3	1	-1
	.99946								
	0.	0.	-.2	2.9	0.	0.	2.7	1	-1
	.99946								
	0.	0.	-.2	3.1	0.	0.	8.4	1	-1
	.99946								
	0.	0.	-.2	3.3	0.	0.	12.3	1	-1
	.99946								
Gaussian Ring	0.	0.	-.2	3.5	0.	0.	8.4	1	-1
	.99946								
	0.	0.	-.2	3.7	0.	0.	2.7	1	-1
	.99946								
	0.	0.	0.0	2.9	0.	0.	5.9	1	-1
	.99946								
	0.	0.	0.0	3.1	0.	0.	18.4	1	-1
	.99946								
	0.	0.	0.0	3.3	0.	0.	26.8	1	-1
	.99946								
	0.	0.	0.0	3.5	0.	0.	18.4	1	-1
	.99946								
	0.	0.	0.0	3.7	0.	0.	5.9	1	-1
	.99946								
	0.	0.	0.2	2.9	0.	0.	2.7	1	-1
	.99946								
	0.	0.	0.2	3.1	0.	0.	8.4	1	-1
	.99946								
	0.	0.	0.2	3.3	0.	0.	12.3	1	-1
	.99946								
	0.	0.	0.2	3.5	0.	0.	8.4	1	-1
	.99946								
	0.	0.	0.2	3.7	0.	0.	2.7	1	-1
	.99946								
	0.	0.	0.4	2.9	0.	0.	.3	1	-1
	.99946								
	0.	0.	0.4	3.1	0.	0.	.8	1	-1
	.99946								
	0.	0.	0.4	3.3	0.	0.	1.2	1	-1
	.99946								
	0.	0.	0.4	3.5	0.	0.	.8	1	-1
	.99946								
	0.	0.	0.4	3.7	0.	0.	.3	1	-1
	.99946								
2 Time Variations	5	0.	-1.						
	100.	-1.	200.	-1.	300.	-1.	5000.	-1.	
	-1	0.	350.	8000.					
Boundary	0.	10.	0.	360.	-2.	2.			
Trajectory	3.75	0.	.20	360.	.00001	360.004			
	15.	0.	1.	0.					