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ESME: LONGITUDINAL PHASE SPACE PARTICLE TRACKING - PROGRAM DOCUMENTATION

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1. INTRODUCTION

The program ESME has been developed to model various manipulations of the beam in a circular accelerator that are effected by controlling the radiofrequency accelerating potentials like, for example, stacking, bunch shaping, bunch rotation, change of harmonic number, and so on. The advantages of this program over earlier versions and other programs of which the author is aware are precise treatment of the nonlinearity of the equations of motion, a convenient and extensive set of routines for generating initial distributions, flexibility in the specification of variation of parameters with respect to time or properties of the distribution, and rather complete graphical output. Because it was found rather early in the development that the program would continue to evolve, some thought has gone into organizing it so that such additions do not usually require pervasive modifications. This programming effort has not, of course, entirely escaped the typical difficulties associated with generality and elaboration, viz., proliferation of input parameters and errors hiding in infrequently used sections of the code or freshly introduced in a recent modification. To confront the first difficulty an effort has been made to require few parameters for a simple problem by establishing reasonable defaults and by separating various program features so that only the relevant ones need be considered. The second difficulty prompts the following disclaimer: the program is the result of the author's particular needs and interests so that certain features used infrequently or only in early stages of the development may not have been properly modified as the program evolved. However, the program structure is sufficiently modular that such bugs as remain are likely isolated to special functions where they can be easily found when their effects have been characterized. In the detailed description which follows a few features have been noted as being less fully tested. Such dubious elements could be excised from the program with little loss from what have been claimed as its principal virtues. This writeup has been produced to help new users at CERN to get started with the code and is being distributed at Fermilab partly as imformation for possible users and partly to document the basis for many design calculations for the TeV I Project.

2. THE COORDINATE SYSTEM

The phase space coordinates used in ESME are the azimuth of a particle at the time that the accelerating potential passes through the synchronous phase and its total energy in MeV. The values of the azimuth $-\pi < \theta < \pi$ are positive upstream

of what is taken as a single accelerating gap. For those very special cases for which it is signficant to distribute the RF sources, the program can be used if the segments between RF stations are the same and the stations themselves are identical. Otherwise tedious program modification would be necessary. A result of this choice of coordinate system is that a well behaved bunch will generally be centered about $\theta = 0$ [mod h]. If there are h equivalent bunches in a calculation, one will generally choose to look at a single one by setting the periodicity parameter (called FRAC in the program) equal to the harmonic number h so that the calculation is restricted to $\pm\pi/h$ with periodic boundaries, i.e., what leaves one boundary immediately reappears at the other.

The definition of the phases ψ_1 and ψ_2 of the RF sources can be subtle in some complicated prodcedures, but by reference to typical cases the desired phase programs for the complicated cases can be constructed. The simplest example is a stationary bucket produced by a single frequency source. In this case $\psi_1 = 0$ or π according as the lattice is below or above transition, i.e., $\psi_1 = \phi_s$. If another harmonic h_2 is added to change the bucket shape, ψ_1 is unchanged and ψ_2 = const. is whatever relative phase is required to produce the desired bucket shape. ψ_1 can be set to some value other than ϕ_s, for example, to stretch a bunch along the spearatrix at the unstable fixed point.

When $\dot{p} \neq 0$, ψ_1 usually is ϕ_s calculated from V_1, but if V_2 is present there may be corrections resulting from acceleration produced by V_2. Both ψ_1 and ψ_2 may be changed linearly, individually or in concert, during the initiation or conclusion of a stacking operation, for example. ψ_2 may also change continuously with respect to ψ_1 if RF source 2 is being run asynchronously as specified by a momentum error parameter.

Because of the variety of possibilities it has proven helpful to fix RF source 1 as the principal one and regard source 2 as in some way auxiliary so that the phase of source 2 is always defined relative to the phase of source 1. To maintain the primacy of source 1 in a case where one source starts out dominant but becomes less important during the manipulation (e.g. rebunching at a new harmonic), the parameters associated with the sources are interchanged when the bucket height produced by source 2 exceeds that produced by source 1. That is, when the bucket height from source 2 is greater, it <u>becomes source 1</u>.

3. THE DIFFERENCE EQUATIONS

In the conventional derivation of the differential equation for synchrotron oscillations one starts from equations like:

$$E_{i,n+1} = E_{i,n} + eV_n \sin\phi_{i,n}$$

$$\phi_{i,n+1} = \phi_{i,n} + \omega_n \tau_{i,n+1}$$

where $E_{i,n}$ is the energy of the i^{th} particle on its n^{th} passage around the ring, $\phi_{i,n}$ is phase of the radiofrequency of angular frequency ω_n and amplitude V_n when i^{th} particle makes its n^{th} traversal of the accelerating gap, and $\tau_{i,n+1}$ is the circulation period for the i^{th} particle on its $n+1^{st}$ circuit of the ring. By setting a synchronoism relation between the circulation frequency and the radiofrequency and taking $\beta_i = v_i/c \equiv \beta_s$ for all particles, one arrives at a familiar second order non-linear differential equation. This equation is sometimes solved numerically in calculations of behaviour of particle distributions. When recourse is made to a computer, however, one can achieve a far more accurate treatment of the above difference equations by solving them directly, because they are appropriate to the computer nearly as they stand. Then one can precisely calculate each β_i and thereby treat the kinematics precisely at nearly the same rate of computation as one can iterate the difference equation approximation to the already approximate differential equation. The nonlinearity in the dependence of $\tau_{n,i}$ on $E_{n,i}$ can be included through any order to which the dependence of the lattice parameter γ_t (transition energy gamma) on momentum is known.

The treatment starts from the assumption of a reference orbit of known average radius R_0 on which the average field $\langle B_y \rangle$ is known. A particle which follows the reference orbit has a momentum:

$$p_0 = 2.997925 \times 10^2 \langle B_y \rangle R_0$$

where p_0 is in MeV/c, R_0 is in meters and $\langle B_y \rangle$ is in Tesla. A particle of momentum p_0 has

$$\beta_0 = v_0/c = (1+(m_p c^2/cp_0)^2)^{-1/2}$$

so that the angular frequency of its circulation is

$$\Omega_0 = \beta_0 c/R_0 .$$

If one synchronizes the RF frequency on each turn so that

$$\omega_n = h\Omega_{o,n} \equiv h\Omega_{s,n} ,$$

then

$$\phi_{i,n+1} = \phi_{i,n} + 2\pi h \frac{\Omega s,n}{\Omega_{i,n+1}}$$

To simplify calculations in which there is more than one RF frequency present it is convenient to replace the RF phase variable by an azimuthal angle θ measured from the RF source location in a direction opposite to the direction of particle circulation. (This convention disposes of the usual - sign relating θ to ϕ);

$$\theta_{i,n} = \phi_{i,n}/h.$$

If $\Omega_{i,n+1} \equiv \Omega_{s,n+1}$ then the ϕ-equation shows that θ as defined will increase by 2π each turn. Thus it is natural to write the ϕ-equation in a "rotating frame" by subtracting 2π each turn. With these changes the difference equations become:

$$E_{in,+1} = E_{i,n} + eVn^{(1)}\sin(h_1\theta_{i,n} + \psi_n^{(1)}) + eV_n^{(2)}\sin(h_2\theta_{i,n} + \psi_n^{(2)}) + \ldots$$

$$\theta_{i,n+1} = \theta_{i,n} + 2\pi \frac{\Omega_{s,n}}{\Omega_{i,n+1}} - 1$$

where the possibility of multiple radiofrequencies each with its own amplitude and independent phase has been indicated. In fact, because the rhs of the energy equation is simply a Fourier expansion of an arbitrary periodic function it is obvious that any type of repetitive waveform can be used; the sinusoidal form is merely a familiar case resulting from the natural properties of resonant RF sources. As disucssed in the preceding section on coordinates, the definition of phase used in the program has been specialized slightly so that in a typical case $\psi_1 = \phi_s$, the synchronous particle is at $(\theta, E) = (0, E_s)$, and ψ_2 is defined relative to the zero of $\sin(h_1\theta+\psi_1)$.

4. DATA

4.1 Overview

Generally input data are read according to NAMELIST statements so that only parameters which need to be changed from current values need to be provided. Furthermore, because defaults have beei ovided for many parameters which are appropriate in typical applications, a simple problem can be specified with very little data. Although the defaults do not provide a complete input set, there are defaults even for parameters which are usually specific to a given problem. These defaults have been provided so that neglect to specify a parameter will not necessarily cause the program to fail; if the program continues with a default value in place of the appropriate value the results will, of course, be wrong, but the fact that execution continues may permit more than a single error to be found in a test run.

The input parameters are nearly all distributed by function amongst seven NAMELISTs in subroutines serving those functions. The subroutines are called in response to single character commands in the data set which invoke the desired program facilities. These data commands are discussed in the first section following, and the contents of the various NAMELISTs are detialed in succeeding sections. The only datum routinely used which is not NAMELIST input is a title for the graphical output.

The program has a number of dummy enteries for the installation of special purpose routines. Such routines may request additional parameters and these may well not be in the NAMELIST format as the user prefers. It should be noted that for many paraemters the order of entry is immaterial, but it is important that the lattice parameters be entered (R command) before the RF parameters (A command) and that both be entered before establishing the initial particle distribution (P command). Thus a normal data sequence will be R, A, P with other commands in any convient order. The order of disucssion of the commands reflects this important point.

4.2 Summary of the Data Commands

The principal functions of the program are activiated by single character commands in the data. These commands may lead to the reading in of data relevant to a particular aspect of the problem and/or action upon the data. The data requested by particular commands will be detailed in later sections. In this section the commands and their purposes are tabulated. There is some mnemonic value in the letter associated with a given function, and the intended association is indicated by underlining a letter in the command purpose. Underling of the command itself is meant to indicate that this is a basic command likely to be needed in any application. Remember the R, A, and P

are most important and should be invoked in that order.

COMMAND	FUNCTION
R	read in lattice (ring) parameters and initialize quantities dependent solely on lattice.
A	read RF (acceleration) paraemters.
P	populate phase space with an initial distribution.
C	read in parameters governing the tracking cycle.
O	read in parameters governing graphical output.
E	execute particle tracking according to current paraemters.
Q	quit the program.
D	display the distribution (periodic displays will occur without D command by conditions specified with O).
G	retreive (get) a set of parameters from TAPE7 (if all are good, no need for R, C, A, P, and O).
S	save distribution and current parameters on TAPE8.
T	enter dummy routine SHAZAM at main entry to tinker with any quantity in COMMON storage - almost anything except loop counters and arithmetical intermediates.
1	additional entries to SHAZAM to provide arbitrary user defined functions.
.	
.	
.	
9	
W	write a comment into the printed output.
I	initialize the random number generator with an octal integer read according to 02Ø format.
H	set up and execute history plots of selected parameters.
F	calculate the FFT of the θ distribution and set up for analysis every turn if desired

4.3 Lattice Parameters

The parameters are read in NAMELIST |RING| and the values stored in COMMON |RINGP|. This read is in SUBROUTINE RINGPAR which also derives quantities like η, γ_t, etc. which depend only on lattice parameters. RINGPAR is called by the data command R. The input parameters are:

NAME	MEANING OR FUNCTION	UNIT	DEFAULT
REQ	The average radius of the central orbit	m	None
GAMMAT	Transition gamma = $(\text{ALPHAØ})^{-2}$	-	None
ALPHA1	Coefficient of $\Delta p/p$ in $\alpha_p = \sum_{i=0}^{3} \alpha_i (\Delta p/p)^i$ where $\Delta p/p$ is taken w/central orbit unless EKALPH ≠ 0 is given as kinetic energy of the orbit to which α_i are referred	-	None
ALPHA2	Coefficient of $(\Delta p/p)^2$ in series for α_p		
ALPHA3	Coefficient of $(\Delta p/p)^3$ in series for α_p		
EKALPH	Kinetic energy corresponding to the momentum of the orbit about which α_p is expanded	MeV	EKØ

EKØ	Kinetic Energy of the central orbit	MeV	None
EK2	Kinetic energy at the end of a magnetic field change (EK2 = 0. → B const.)	MeV	0.
T1	Starting time for magnetic field change (T1 ≠ 0 → start tracking part way through ramp)	s	0.
T2	End time for magnetic field change operative for EK2 ≠ 0	s	None
KURVEB	Specifies form of magnetic field ramp 1. linear ramp from PØ (EKØ) to P2′ (EK2) 2. increasing parabolic ramp 3. biased sinusoidal ramp 4. decreasing parabolic ramp	-	1
FRAC	Azimuthal periodicity; limits calculation to $-\pi/FRAC \leq THETA \leq \pi/FRAC$ with periodic b.c.	-	1

4.4 Radiofrequency Parameters

The parameters specifying the accelerating potential are read according to NAMELIST |RF| which resides in SUBROUTINE RFPROG which is invoked by the data command A. The input parameters are:

NAME	FUNCTION OR MEANING	UNIT	DEFAULT
H1	Harmonic number for the principal RF source	-	1.
H2	Harmonic number for an auxiliary RF source, if any. Program will force the source producing the greater bucket height to be source 1	-	1.
HW1	Harmonic number of the "supression" of source 1 (for suppressed bucket systems; HW1 = 1 is normal)	-	1.
HW2	Harmonic of bucket suppression for source 2	-	1.
PSI1I	Initial phase of RF source 1	rad	0.
PSI2I	Initial phase of RF source 2	rad	0.
PSI1F	Final value of phase of source 1 when phase change has been requested (linear variation provided)	rad	0.
PSI2F	Final value of phase of source 2	rad	0.
MPH1	Number of beam turns for change from PSI1I to PSI1F	-	1
MPH2	Number of beam turns for change from PSI2I to PSI2F	-	1
V1Ø	Initial peak voltage of RF source 1	MV	$1.x10^{-6}$
V2Ø	Initial peak voltage of RF source 2	MV	$1.x10^{-6}$
V1	Final peak voltage of RF source 1	MV	$1.x10^{-6}$
V2	Final peak voltage of RF source 2	MV	$1.x10^{-6}$

M1 Number of beam turns for change from V1Ø to V1 - 1

M2 Number of beam turns for change from V2Ø to V2 - 1

DELTA2 Momentum offset $\Delta p/p$ corresponding to the frequency difference between source 2 and $h_2\Omega_s$. Source 1 is always synchronous. (This is a little used feature and may have problems.)

KURVE(1) Selection of voltage program for source 1 - 1

1. linear variation
2. isoadiabatic change
3. sigmoid variation
   $V_m^{(1)} = V_o^{(1)} + (V_M^{(1)} - V_o^{(1)})*(\frac{m}{M} - \frac{1}{2\pi} \sin \frac{2\pi m}{M})^{1/2}$
4. cubic spline representation of arbitrary function from a table read from TAPE1Ø - 1

KURVE(2) Selection of voltage program for source 2 (as above for KURVE(1)) - 1

NT1 Number of table entries for $V^{(1)}$ program (if present) - None

NT2 Number of table entries for $V^{(2)}$ program

V1TABL(NT1,5) The $V^{(1)}$ program consists of NT1 entires. The five elements of each entry are the turn number m_T, the relative amplitude at that turn ($0 < V1TABL(m_T,2) < 1$), and the three cubic spline coefficients for function $V_m^{(1)}$ in the neighborhood of m_T: - None

$$V_m^{(1)} = V_o^{(1)} + (V_M^{(1)} - V_o^{(1)}) \times [V1TABL(m_T,2)] + V1TABL(m_T,3) \times (m-m_T) + V1TABL(m_T,4) \times (m-m_T)^2 + V1TABL(m_T,5) \times (m-m_T)^3$$

V2TABL(NT2,5) Like V1TABL above but for $V_m^{(2)}$ - None

4.5 Tracking Cycle Parameters

Parameters principally related to details of the particle tracking process are read according to the NAMELIST |CYCLE| in SUBROUTINE CYCPROG which is invoked by the data command C. The possible input parameters follow:

NAME	FUNCTION OR DEFINITION	UNIT	DEFAULT
MTURNS	Number of turns to be tracked with fixed parameters	-	100
MSTEP	Number of tracking steps (minimum) per synchrotron period. (Active only for SWITCH(8)=.TRUE., accelerated calculation feature - use cautiously)	-	100
ACCELØ	Number of beam turns per tracking step (maximum). (Active for SWITCH(8)=.TRUE., accelerated calculation).	-	1.

ITRAP	Indicate a condition for which tracking should be interrupted before MTURNS 0: no trap 1: trap on minimum bunch width 2: trap on minimum bunch height 3: trap for η = ETRAP (tolerance $\Delta\eta/\eta = \pm.01$) 4: trap for ϕ_s = PHISTRP (tolerance $\Delta\phi_s = \pm.005$) 5: trap for $\eta > 0$ - transition crossing	-	0
LGRTHM	Select difference equation used in tracking 1: complete kinematics, α(local) to $(\Delta p/p)^2$ 2: $\beta_i = \beta_s$, $\alpha_p \neq \alpha_p(\Delta p/p)$ 3: complete kinematics, $\alpha_p \neq \alpha_p(\Delta p/p)$ 4: complete kinematics, α_p to order $\Delta p/p$	-	3
SWITCH(i)	Activates optional program feature for SWITCH(i)=.TRUE.		
	(1) Voltage program called each step	-	.TRUE.
	(2) Phase change program called each step	-	.FALSE.
	(3) Adjust RF voltage for constant bucket height	-	.FALSE.
	(4) Adjust RF voltage for constant bucket area		
	(5) Time cycle in second (T1 and T2); number of turns MTURNS must be >M(T2)	-	.FALSE.
	(6) Include a second RF source	-	.FALSE.
	(7) Collect a history of variable parameters and properties	-	.FALSE.
	(8) Accelerate calculation by taking several beam turns	-	.FALSE.
	(9) Calculate mean and rms width of theta and E projections of distribution	-	.FALSE.
	(10) Phase feedback from bunch centroid (infinite bandwidth)	-	.FALSE.
	(11) Turn-by-turn FFT of azimuthal distribution	-	.FALSE.
	(12) Run RF source 2 at frequency determined by momentum difference $\Delta p/p$ = DELTA2 from ρ_s		
	(13) Use completely linear RF waveform	-	.FALSE.
SDECR	If SWITCH(4)=.TRUE. multiply bucket area by SDECR each turn	-	1.
HDECR	If SWITCH(3)=.TRUE. multiply bucket height by HDECR each turn	-	1.
ETATRP	If ITRAP=3, stop tracking when ETA=ETATRP	-	.001
PHISTRP	If ITRAP=4, stop tracking when $\lvert\sin\phi_s\rvert$=PHISTRP	-	.95
PHISLIM	If SWITCH(3) or SWITCH(4)=.TRUE. do not allow voltage reduction such that $\lvert\sin\phi_s\rvert$>PHISLIM	-	.95

4.6 Parameters Defining the Initial Distribution

The distribution of the particles to be tracked is established according to parameters read in according to NAMELIST |POPL8| from the USBROUTINE POPUL8 which is invoked by the data command P. The available parameters follow:

NAME	FUNCTION OR DEFINITION	UNIT	DEFAULT
KIND	Chooses a type or mode distribution	-	1
	1: Rectangular outline NTH by NE points, limited by THMIN, THMAX: TMIN, TMAX		
	2: Uniform rectnagular grid NTH by NE, same limits		
	3: Random uniform in THETA, Gaussian in E where rectangular limits like KIND=1; E limits are ±20		
	4: Random uniform distribution of NTHxNE points within rectangular limits like KIND=1		
	5: Gaussian in THETA, uniform random in E where rectangular limits are extremes in E and $\pm 2\sigma$ in THETA		
	6: Rectangular raster, regular in THETA, E spacing of raster lines averages to Gaussian		
	7: Matched bunch outline of NPOINT particles, SBNCH eVs		
	8: Uniform, equispaced, matched bunch of appx. NTHxNE particles		
	9: Uniform, random, matched of NPOINT particles		
	10: Bi-Gaussian, NPOINT particles 95% within contour of SBNCH eVs		
	11: NPOINT uniformly spaced particles on flow lines just above and below bucket boundary (not heavily used)		
	12: Random uniform in E, parabolic in THETA		
	13: Parabolic matched distribution of NPOINT particles, SBNCH eVs		
THMIN	Lower THETA limit on rectangular distribution	rad	None
THMAX	Upper THETA limit on rectangular distribution	rad	None
TMIN	Lower kinetic energy limit on rectangular distribution	MeV	None
TMAX	Upper kinetic energy limit on rectangular distribution	MeV	None
NTH	Number of grid points in THETA direction	-	2
NE	Number of grid points in E direction	-	2
SBNCH	Area of a matched or bunch	eVs	1.
IPOP	Specifies which RF source to use in matching	-	1
	1: RF source 1 (eV_1, ψ_1, h_1)		
	2: RF source 2 (eV_2, ψ_2, h_2)		
	3: Sum of sources 1 and 2		
THOFF	Amount to displace distribution in THETA direction	rad	0.

NPOINT	Number of particles in matched distribution (except kind = 8 where NTH and NE are used)	-	1
PARTION	If PARTION=.TRUE., the distribution is partitioned ir classes which may be plotted with distinct symbols	-	.FALSE.

4.7 Parameters Controlling Graphical Output

The quantity and form of graphical output is determined by parameters read by NAMELIST |GRAPH| residing in SUBROUTINE GRAFSET. This subroutine is called by the O data command.

NAME	FUNCTION OR DEFINITION	UNIT	DEFAULT
NPLOT	Number of turns between plots of distribution	-	None
IOPT	Selects contour to appear on distribution plot	-	None
	0: no contour 1: bucket created by RF source 1 2: bucket created by RF source 2 3: bucket created by sum of source 1 and 2 4: a matched contour having the area of the initial bunch, SBNCH 5: a matched contour containing 95% of the distribution		
IREF	Selects the RF source used in the matching for IOPT = 4 or 5	-	1
	1: RF source 1 2: RF source 2 3: sum of RF sources 1 and 2		
THPMIN	Lower THETA limit for plots	rad	None
THPMAX	Upper THETA limt for plots	rad	None
DEPMIN	Lower energy limit for plots in MeV from E_s	MeV	None
DEPMAX	Upper energy limit for plots in MeV from E_s	MeV	None
TITLE	If TITLE=.TRUE., read a title for graphical output following the NAMILIST |GRAPH| data	-	.FALSE.
PLTSW(i)	Plot options, PLTSW(i)=.TRUE. activates feature	-	.FALSE.
	(1) Plot each class in the distribution (see PARTION in distribution parameters) with its own symbol and interconned points of the same class (2) Like (1) above except omit interconnecting lines (3) Interconnect all points (regardless of PARTION) (4) Suppress captions, axis labels, etc. (5) Suppress symbols at individual points for PSTSW(i)=.TRUE. (6) Replace scatter plot of distribution by six lines indicating mean and ± sigma for THETA and E projections (7) Suppress THETA histogram (8) Suppress E histogram		
DTHCURV	Move contour on plot in THETA direction	-	0.
DECURV	Move contour on plot in E direction	-	0.

4.8 Selection of Parameters to be Recorded on History Plots

When SWITCH(7) in the cycle data is set, CYCPROG records a selection of interesting parameters for each tracking step on TAPE9. Any parameter can be plotted against any other by giving a pair of indices for each plot. The indices are elements of the array NPLT(2,28) read in by NAMELIST |HISTRY| from subroutine HISTORY. This subroutine is invoked by the H data command. Up to 28 index pairs may be given. The parameters are labelled by the index values as follows:

NAME	FUNCTION OR DEFINITION	UNIT	DEFAULT
NPLT(i,j)	i = 1, 2; j = 1, 28		None
	1: turn number	-	
	2: eV_1, peak acceleration from source 1 per turn	MeV	
	3: eV_2, peak acceleration from source 2 per turn	MeV	
	4: ψ_1, phase of RF source 1	rad	
	5: ψ_2, phase of RF source 2 relative to source 1	rad	
	6: p', change of synchronous momentum	MeV/c/s	
	7: θ_{AV}, mean THETA of distribution	rad	
	8: E_{AV}, mean total energy of distribution	MeV	
	9: σ_θ, rms width of distribution	rad	
	10: σ_E, rms height of distribution	MeV	
	11: E_s, synchronous total energy	MeV	
	12: ϕ_s, synchronous phase for source 1	rad	
	13: ε_L, longitudinal emittance of distribution (only correct for uncorrelated distributions as it now stands; should be changed to be more useful)	eVs	
	14: θ_s, number of synchrotron periods per totation period	-	
	15: S_B, bucket area	eVs	
	16: H_B, bucket height	MeV	
	17: η, $1/\gamma_T^2 - 1/\gamma_s^2$	-	
	18: ACCEL, the number of beam turns per tracking step in an accelerated calculation	-	
	19: $\Delta\theta$, the THETA of a particle which started from 0, E_s; a measure of numerical error	rad	
	20: ΔE, the E coordinate of the particle which started at the synchronous point 0, E_s	MeV	
	21: τ, the beam circulation period	s	
	22: t, the integrated time	s	
	23: $Famp_1$, Fourier amplitude selected by NC1	-	
	24: $Famp_2$, Fourier amplitude selected by NC2	-	
	25: $Faze_1$, the phase of Famp	rad	
	26: $Faze_2$, the phase of Famp	rad	
	27: $Spare_1$, open to plot anything of interest	-	
	28: $Spare_2$, open	-	

4.9 Parameters Controlling FFT

The routine FOURFIT is invoked by the data command F. This routine will read data according to NAMELIST |FFT| and analyze the current distribution using these data. If SWITCH(11) is set in the cycle data, the same analysis will be carried out every tracking step and two selected amplitudes will be stored on the history tape. The parameters are:

NAME	FUNCTION OF DEFINITION	UNIT	DEFAULT
NBINFFT	Number of bins in representation of THETA distribution	-	256
NC1	Number of amplitude and phase selected for history	-	h_1
NC2	Number of amplitude and phase selected for history plot	-	None

5. PROGRAM AVAILABILITY

The program is available from the author as a CDC UPDATE source file in Fortran V. Because continual additions are made to the code there will be no guarantee that the material provided will be entirely consistent with this writeup, but basic features have been fairly stable for over a year. There are several hundred lines of comment in the code which would help some one wishing to change it for special purposes. No other documentation is available except for various examples of application. See for instance IEEE Trans. on Nucl. Sci. v NS-30 #4 p. 2627-2629 ("RF Exercises Associated with Acceleration of Intense Antiproton Bunches at Fermilab", J.E. Griffin, J.A. MacLachlan, Z.B. Qian), the same p. 2630-2633 ("Time and Momentum Exchange for Production and Collection of Intense Antiproton Beams at Fermilab", J.E. Griffin, J.A. MacLachlan, A.G. Ruggiero, K. Takayama), or Design Report Tevatron I Project, Sections 4.9-4.10 and Ch 6.