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Histograms of MAD Tracking Results

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Abstract

Two Fortran programs are described that process MAD tracking output for 10^4 or more particles, and produce histograms. The `loshst` program produces histograms of the particle losses by turn and by position along the orbit. The `trkhst` program computes means and standard deviations of the particle positions in 6D phase space and the emittances in all three directions, and produces histograms of the particle distributions at the end of the MAD tracking run.

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1 INTRODUCTION

In circular machines such as ELFE at CERN [1] and muon storage rings, the particles make a rather small number of turns. It then becomes possible to study their behaviour by tracking many particles. A typical number is 30000, close to the limit imposed by the ZEBRA space available in MAD [2]. Inspecting lists with such a large number of particles is impossible. I have therefore written two short Fortran programs that read the MAD output, and prepare histograms. They are described in the next two chapters. Section 4 describes how to track a large number of particles in a MAD run.

2 Program `loshst`

The program `loshst` makes three histograms of the particle losses. The numbers below are the histogram ID in HBOOK [3].

1. Histogram of the particle losses as a function of the distance along the machine
2. Histogram of the particle losses as a function of the turn in the machine
3. 2D histogram of the particle losses as a function of distance and turn

The Fortran code `loshst.f` is in my WWW directory wwwslap.cern.ch/∼keil/Fortran. During execution, it asks the user three questions:

please enter name of MAD listing file You, the user, should give the name of the standard MAD output file. Then, `loshst` starts analyzing the MAD output file at the line containing " Particle(s) lost. . . ", and finishes at the line containing " Final particle positions after turn. . . ".

please enter name of loshst output file At the end of `loshst` execution, this file contains the histograms, printed in standard HBOOK style.

Enter name of histogram file You, the user, should give the name of the file into which the histograms are written. It is a standard HBOOK histogram file that can be processed further by paw++ [4], etc.

Figure 1 shows the lego plot of the particle losses for a triangular muon storage ring with three 500 m long straight sections and about 2 km circumference. Collimators are at the centre of practically all quadrupoles. Their aperture corresponds to three rms beam radii. The particles are launched with Gaussian distribution functions corresponding to the nominal emittance and nominal energy spread, truncated at 2.5 standard deviations. The losses occur mainly in the long straight sections, and during the first few turns.

3 Program `trkhst`

The program `trkhst` computes means and standard deviations of the particle coordinates and emittances at the end of a tracking run with MAD, and prepares histograms. If you, the user, asks for it, it also writes a file with initial conditions for another MAD tracking run. Specifically, `trkhst` writes the following ten histograms. The numbers below are the histogram ID in HBOOK.

1. Histogram of the horizontal particle coordinate x
2. Histogram of the horizontal particle slope p_x
3. Histogram of the vertical particle coordinate y
4. Histogram of the vertical particle slope p_y
5. Histogram of the longitudinal particle coordinate t
6. Histogram of the relative energy error δ
7. 2D histogram of the horizontal phase space (x, p_x)
8. 2D histogram of the vertical phase space (y, p_y)

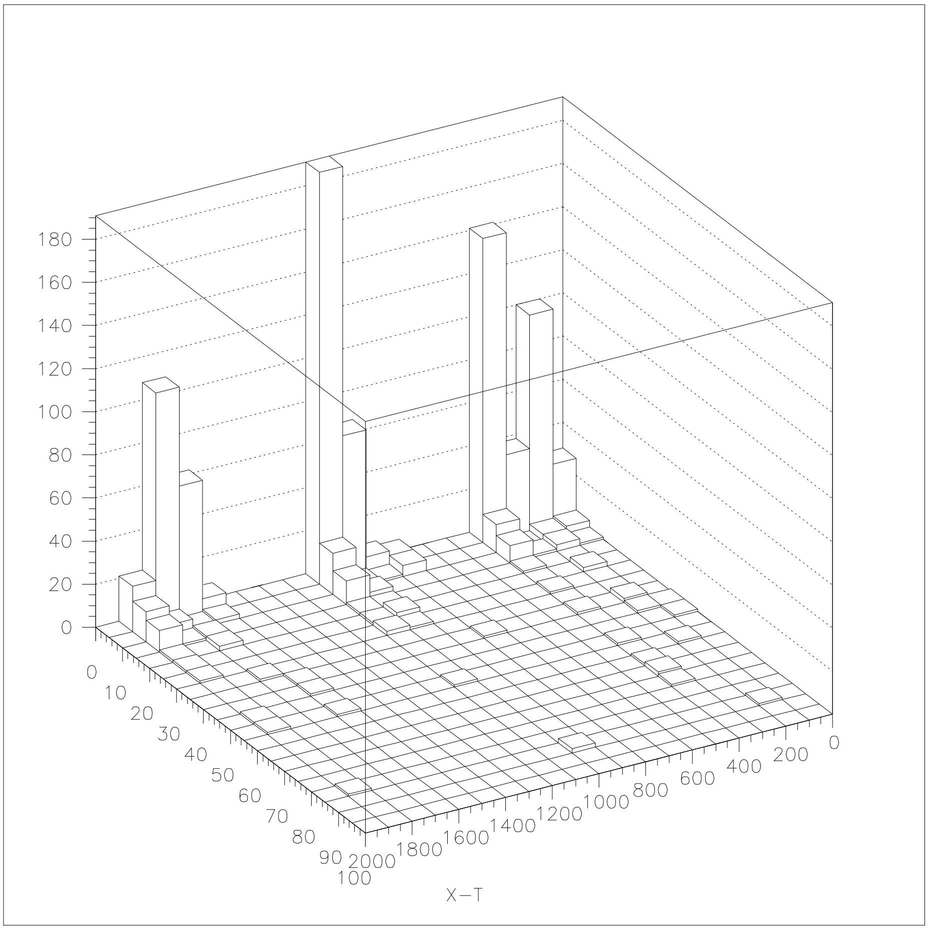

Figure 1: Particle losses around the muon storage ring of 2000 m circumference for 100 turns

9. 2D histogram of the longitudinal phase space (t, δ)
10. 2D histogram of the transverse projection (x, y)

In all histograms, the channels are chosen such that all particles are included and the channel boundaries are at round numbers.

The Fortran code `trkhst.f` is in my WWW directory wwwslap.cern.ch/∼keil/Fortran. During execution, it asks the user four or five questions:

please enter name of TSAVE file You, the user, should give the name of the file that MAD wrote with the TSAVE command.

please enter name of trkhst output file At the end of `trkhst` execution, this file contains a short listing of the means and standard deviations of the six particle coordinates, and the three emittances, computed from the means, standard deviations and correlations [5], followed by the histograms, printed in standard HBOOK style. I used `trkhst` to measure the synchrotron radiation loss and emittance blow up in ELFE.

Do you want to write a START file - (F/T)? If you, the user, reply with T, `trkhst` will write a file containing all the particles in the TSAVE file with the means subtracted from all six coordinates. I found this file useful for launching tracking runs with MAD through successive turns in ELFE. Synchrotron radiation losses in the arcs of ELFE cause a mean energy offset and mean position offsets at the end of a turn. In practice, one would set up ELFE such that the mean energy error and the mean position errors at the entrance of the next turn vanish. This is precisely what is done in the START file.

please enter name of START file If your answer to the previous question was T, then you should now enter the name of the START file to be written.

Enter name of histogram file You, the user, should give the name of the file into which the histograms are written. It is a standard HBOOK histogram file that can be processed further by paw++, etc.

Figure 2 shows a contour plot of the particle distribution in (t, δ) phase space after the sixth turn through ELFE. The plot is centred at a negative value of δ because of the synchrotron radiation loss during this turn. The banana shaped distortion is caused by the RF waveform. Particles with $t = 0$ travel at the crest of the RF wave, and get the maximum acceleration, while particles with $t \neq 0$ are accelerated less.

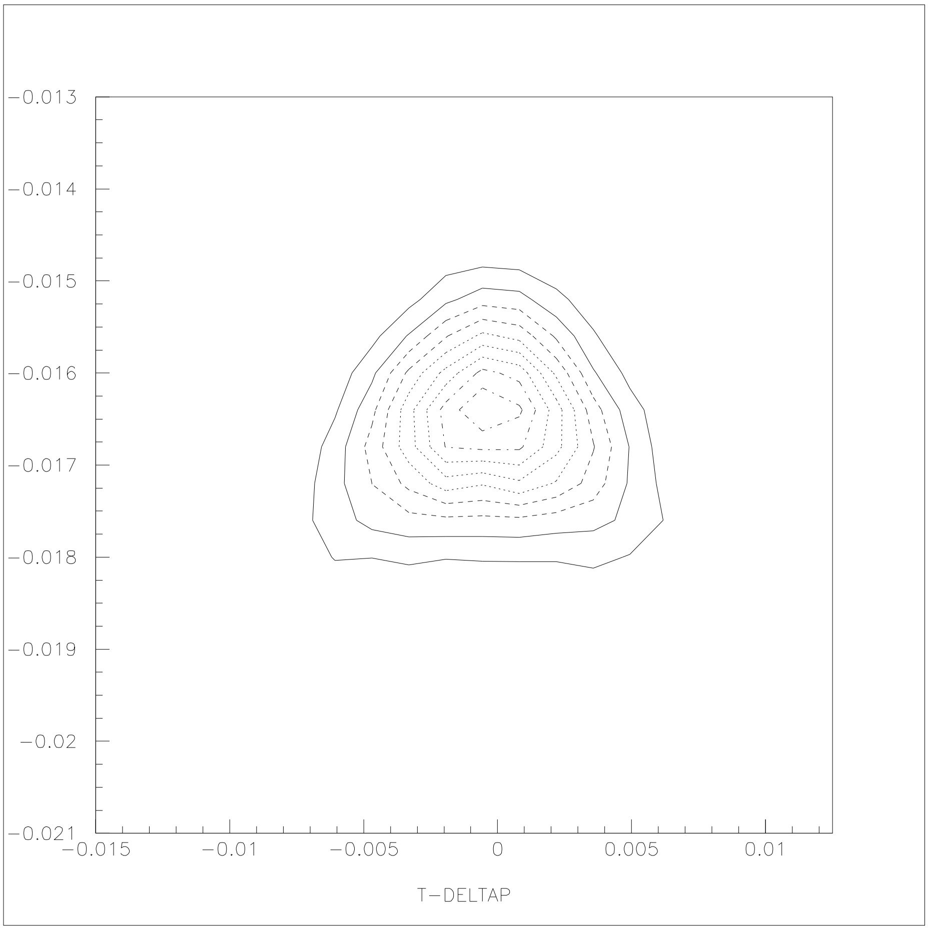

Figure 2: Particle distribution in (t, δ) phase space after the sixth turn through ELFE with abscissa t and ordinate δ

4 Tracking Data for MAD

Figure 3 shows the data for tracking with MAD. In normalized phase space the particle distributions are Gaussians with unity variance. They are transformed to unnormalized phase space in x, p_x, y, p_y and δ, using the emittances from the BEAM command, and the α and β functions at the beginning of the beam line. Using the variable `trunc` for truncating the Gaussian prevents MAD from evaluating TGAUSS before executing the DO loop, and giving all particles the same initial conditions. The normalized positions x_i and y_i are needed twice in the transformation. Therefore their repeated evaluation is forced by SET commands before the START command is executed.

```
!-- Track many particles
track
trunc:=2.5
do times=30000
set xi tgauss(trunc)
set yi tgauss(trunc)
! Starting conditions obtained by transforming from normalized
! phase space into (x,px) and (y,py) phase space,
! including alfx and alfy
start x=sqrt(beam[ex]*atsp[betx])*xi &
      px=(-atsp[alfx]*xi+tgauss(trunc))*sqrt(beam[ex]/atsp[betx]) &
      y=sqrt(beam[ey]*atsp[bety])*yi &
      py=(-atsp[alfy]*yi+tgauss(trunc))*sqrt(beam[ey]/atsp[bety]) &
      t=0 deltap=sigE*tgauss(trunc)
enddo
run turns=10 fprint=10 table="track"
tsave
endtrack
```

Figure 3: MAD data for tracking 30000 particles

Acknowledgement

I thank F.C. Iselin for advice how to exploit MAD Version 8 close to the limit.

References

[1] H. Burkhardt (ed.), *ELFE at CERN – Conceptual Design Report*, CERN 99-10 (Dec 1999).

[2] H. Grote and F.C. Iselin, *The MAD Program, Version 8.16, User’s Reference Manual*, CERN SL/90-13 (AP) Rev.4 (1995).

[3] CERN Program Library Y250.

[4] CERN Program Library Q121.

[5] D.A. Edwards and M. Syphers, *Handbook of Accelerator Physics and Engineering*, A.W. Chao and M. Tigner (eds.) (World Scientific, Singapore 1998) 50.