SINGLE PASS COLLIDER MEMO

CN- 304

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DATE: Jul 17 10,85

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TITLE: ON THE IMPORTANCE OF HIGH ORDER MOMENTUM TERMS IN SLC OPTICS *

SLAC-CN--304

DE85 016249

1. Introduction.

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The evaluation of background levels at the SLC relies, in several cases, on the proper representation of how low momentum electrons propagate through the Arcs and the Final Focus System (FFS). For example, beam - gas bremsstrahlung in the arcs causes electrons of up to 6 % energy loss to be transported through to the IP ; secondary showers on edges of masks and collimators yield debris with a very wide momentum spectrum.

This note is a naive attempt at checking the validity of TRANSPORT and TURTLE calculations, by evaluating the contributions of the momentum terms to increasingly higher order, and checking the mutual consistency of the results produced by the two methods on a beam of wide momentum spread.

2. Procedure.

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Given a beam of zero emittance ($\text{sig}(x)=\text{sig}(y)=\text{sig}(x')=\text{sig}(y')=0$) at the input of the Linac to Arc matching section, we map the trajectories of the beam in phase space, just upstream of the Final Focus quadrupole Q3 [1], as a function of the momentum offset dp/p . This is done, in turn, up to 2nd, 3rd, or 'all' orders in dp/p [2].

Specifically, we plot, for a pencil beam originating at the input to ARCN FINAL, x vs. dp/p , x' vs. dp/p , y vs. dp/p , y' vs. dp/p , at Q3, in the following four cases :

- i) using the TRANSPORT matrix elements computed up to 2nd order, i.e. R_{j6} , T_{j66} , $j=1,4$;
- ii) using the TRANSPORT matrix elements up to 3rd order, i.e. R_{j6} , T_{j66} , T_{j666} , $j=1,4$: these are listed in table 1 ;
- iii) using the standard (old) Turtle [3,4], where the momentum expansion (for bending magnets) is carried out in terms of $\delta = dp/p$ [5] :

* Work supported by Department of Energy Contract
DE-ACO3-76SF00515

- iv) using Decay Turtle, where the momentum expansion is carried out in terms of $\xi = \delta / (1 + \delta)$, effectively including higher orders in δ [6].

3. Results.

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The phase space trajectories in x -, y -, x' -, y' -, vs. dp/p , are shown in figs. 1, 2, 3, and 4 respectively. 2nd and 3rd order Transport (cases i,ii) are represented by circles and crosses, respectively, in figs. 1a..4a; the Decay Turtle calculation (case iv) is the printed histogram in the same figures [7]. Figs. 1b...4b show the same plots as evaluated by Turtle (case iii). The following comments apply :

- At small values of dp/p ($< 1\%$), close to nominal beam conditions, there is, as expected, very little dispersion, and 3rd and higher order momentum terms are negligible on the scale used here. There is good agreement between TRANSPORT, TURTLE, and Decay Turtle.
- In x - p , there is good qualitative agreement between the 3rd order Transport calculation, and the more complete treatment by Decay Turtle (fig. 1a); the description given by old Turtle (expansion in δ rather than ξ) is clearly not appropriate for $\delta > 1.2\%$ (fig. 1b).

The main conclusion is indeed that higher order momentum terms, play an important - actually, a dominant - role for $|dp/p| > 1.5\%$; in fact, they flip the x - p trajectory from an even to an odd function of p ! The same effect, qualitatively, is observed when higher orders are included in Turtle. However, while 3rd order TRANSPORT qualitatively describes the trend of the x - p trajectory, Decay Turtle clearly suggests that orders beyond the 3rd play a significant role for $dp/p < - 2.5\%$.

- The importance of 3rd order terms is also apparent in the y - p trajectory (fig. 2a). Here, 3rd order TRANSPORT agrees fairly well with old Turtle. This is consistent with the fact that Decay and old Turtle differ mainly in the treatment of bending magnets, which act in the x -plane. Again, however, higher order terms in Decay Turtle clearly move the trajectory outwards, compared to TRANSPORT or old Turtle, for $dp/p < - 1\%$.
- The same comments that applied to x - p and y - p , apply to x' - p (fig.3) and y' - p (fig. 4), respectively.

These results raise the issue of the validity of the (Decay) Turtle calculations far from the reference orbit. According to the authors of the program, the reliability of the method depends [8] on the system under study and on the emittance of the beam. The real range of validity is determined by the maximum amplitudes and maximum angles that the trajectories make as they traverse the system. For example, when the amplitudes or angles become

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large enough that third order geometric aberrations in quads or sextupoles are important in individual elements, then TURTLE tracing clearly becomes invalid. This may be caused by a number of different factors and it is not possible to give a hard and rigorous rule. For the particular system studied here, the following assessment is probably valid :

- for the segments of the beam line containing only zero gradient bending magnets, Decay Turtle should be reliable out to $dp/p = 15$ to 20% ;
- when combined functions magnets are present (as is the case in the Arcs), the calculation is probably valid out to $dp/p = 3$ to 5% .

The ultimate test, however, is to check a few extreme trajectories against an 'exact' differential ray tracing program such as the one of J. Spencer's. This lies beyond the scope of this report.

Acknowledgements.

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I thank T. Fieguth and J. Murray for suggesting this study to me, and D. Carey for help with the Decay Turtle source code.

Footnotes.

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- [1] This location was chosen because off-axis or off-energy electrons hitting mask M1 at this point constitute the primary source of charged particle backgrounds for the MarkII or SLD detectors.
- [2] 'All' orders only to the extent that they are taken into account by Decay Turtle. For a discussion on this point, see ref. 3, pp. 9-13.
- [3] D.C. Carey, K.L. Brown, and Ch. Iselin, SLAC-246.
- [4] It was found important to include second order geometric effects (code 17. 0 ;))
- [5] This work was done using the 840924 version of Turtle ; the program has since been upgraded by D.Carey to include the same treatment of higher order momentum terms, as was already present in Decay Turtle. The present versions of Turtle (850408) and of Decay Turtle (TUR103 PAM) yield identical results.
- [6] See ref. 3, pp.24-27.

- [7] The sharp cutoff of the trajectory is due to magnet apertures limiting the amount of phase space transmitted through the Arcs and FFS.
- [8] K.L. Brown, private communication.

Table 1. Matrix elements from arc input to Q3

j	Rj6	Tj66	Tj666
1 (x)	-0.94736	21.99	0.9585
2 (x')	-0.01624	0.3772	0.01274
3 (y)	-0.06574	0.9001	0.05933
4 (y')	-0.00137	0.01803	6.548 E-4

Fig. 4

THE DIMENSIONAL PLOT OF DP/P VS Y'

TOTAL NUMBER OF ENTRIES = 422 INCLUDING UNDERFLOW AND OVERFLOW

ACROSS	UNDERFLOW	OVERFLOW
DOWN	0	0

SUM OF SQUARES = 4226.

(a)

DECAY TURTLE

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TRANSPORT

THE DIMENSIONAL PLOT OF DP/P VS Y'

TOTAL NUMBER OF ENTRIES = 415 INCLUDING UNDERFLOW AND OVERFLOW

ACROSS	UNDERFLOW	OVERFLOW
DOWN	0	0

(b)

OLD TURTLE