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NUMERICAL SIMULATION OF SURVEY MISALIGNMENT EFFECTS IN THE ATA STRUCTURE*

E. R. Close†

1. Abstract

A computer program MSALIGN incorporating solenoidal magnet positioning errors, survey alignment errors, and structure support sag has been written and used to simulate the Advanced Test Accelerator (ATA)[1] in order to investigate the effects of errors on the transported beam. Runs using up to 10K particles to represent the beam were made over ensembles of up to 100 misaligned machines. They show that for the ATA design tolerances the resultant beam steering is acceptable and easily corrected using steering magnets. Also, that for changes within a factor of 2 to 3 over design values the variation is linear. The program MSALIGN is general in design. Given the appropriate misalignment procedure it can simulate other machines or study other types of errors.

2. Introduction

The Advanced Test Accelerator (ATA) consists of linear induction acceleration modules and concentric solenoidal magnets mounted in support structures placed linearly one after another to form a 256-foot accelerator. Electrons are injected from a 2.5 Mev foilless anode gun and exit at 50 MeV after passing through 190 acceleration cells that each add 0.25 MeV. The placement of the magnets in the support structure is subject to a positioning error which in turn leads to a survey alignment error. Also, the two point support of the magnet structures cause a systematic error due to the resultant structure sag. The superposition of these effects results in the magnet axis being positioned off the ideal optical axis. The manner in which these errors are introduced into the ATA is directly simulated. The beam, represented by a collection of particles drawn as a sample from a distribution, is taken through an ensemble of misaligned machines. Distributions are constructed to show the effect of these errors on the beam as it exits from the structure at 50 MeV. It is also possible to investigate the effect of injector misalignments by appropriate definition of the beam entering the ATA.

3. Model

Although derived for the ATA, the model used has a more general applicability. It consists of modules called Canonical Assemblies (CA) and Canonical Elements (CE). Given a global (laboratory) origin GO and an optical axis OA defining the ideal accelerator axis, a sequence of CA can be placed along this axis with individual translational offsets. Also, each CA can be pointed in space along a direction defined by individually rotation each CA about its local origin. In the ATA this is used to simulate the survey alignment of support structures, (CA), containing either 5 or 10 magnets. Within each CA there are defined one or more CE. Each CE can also have a translational offset with respect to the optical axis of the CA in which it is contained and a rotation about its own local origin. For the ATA this is used to simulate the positioning errors of the individual magnets, (CE), and the structure sag.

Each CA, Fig. 1, consists of a local origin $\tilde{O}$ and coordinate axis, $(\tilde{x}, \tilde{y}, \tilde{z})$ which define the position and direction of the CA with respect to the GO, a drift space of length $L_D \geq D$ and one or more CE.

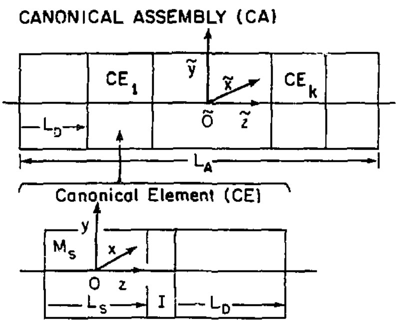

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Fig. 1 Typical Canonical Assembly and Canonical Element.

Each CE consists of a local origin O and coordinate axes (x, y, z) which define the position and direction of the CE with respect to the CA, a region M_S of length $L_s \geq 0$, an impulse $I \geq 0$, and a drift region of length $L_D \geq 0$. For the ATA M_S is a solenoidal transformation and I the energy gain $\Delta E \geq 0$ of the acceleration modules. Beam space charge effects are not included.

A misaligned accelerator is simulated by using a specified algorithm to place the CA along the accelerator optical axis and also the CE within each CA.

For the ATA the algorithm is as follows. In a given support structure (CA) each solenoid (CE) is mispositioned by placing its magnetic center transversely at a point $(\delta r, \emptyset)$ where δr and $\emptyset$ are drawn from distributions uniform respectively in $(0 \leq \delta \leq r_{max})$ and $(0 \leq \emptyset \leq 2\pi)$.

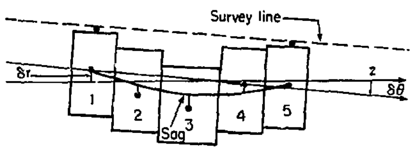

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Fig. 2 Typical Misaligned ATA Assembly.

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The mispositioned first and last solenoid of the support structure are used to perfectly align the CA thus causing the structure to be tilted out of the ideal horizontal plane (survey alignment error $\delta\theta$) and then each element is positioned vertically along a curve representing the structure sag, Fig. 2. This is repeated for all structures.

The beam is modeled by drawing samples from a Gaussian distribution to define the momenta and positions of a collection of particles. This initial state vector (P, X) is transformed through the system using appropriate translation and rotation matrices to define it locally in each CE. At the end of the structure the final state vector $(P, X)_f$ is saved. This process is then repeated for many machines, or beam samples, to generate a statistical sample of final state vectors. Studies can be done on the effect of parameter changes. In particular, alignment tolerances, beam positioning errors, and field or energy errors can be easily studied.

4. Diagnostics

There are basically two types of diagnostics that are of interest, those showing deviations of the accelerator from the ideal machine and those that show the beam behavior. For investigation of ATA misalignments, the latter are of primary interest.

For the beam the basic data available is the beam sample in the form of the state vector $(P, X)_f$ which is saved for each misaligned machine. Beam behavior can be determined by analyzing this statistical sample of final state vectors. The information extracted from the samples will depend on the use of the program. For the ATA the desired results are the beam size and displacement as a function of alignment tolerances and support structure sag, or of mispositioned beam.

This information is obtained by calculating the coordinates (<x>, <x'>, <y>, <y'>) of the beam centroid (c.m.) along each of the transverse phase space axis for each state vector sample $(P, X)_f$. The results are then binned and displayed in the form of histograms. In effect, the distribution of the beam c.m. in the 4-dimensional space (x, x', y, y') is displayed in the form of marginal distributions. For our model of the ATA with solenoidal focusing this is a sufficient presentation, since the rms beam widths are not a function of the system alignment errors.

5. Results

The results presented were obtained from runs set up to simulate the ATA structure. The basic parameters for these runs are given in Table I. In Figure 3 are shown the marginal distributions of the c.m. of a beam sample of 10K particles when taken through 100 machines aligned to design tolerances. The beam displacement does not exceed 10 mm in either x or y, which in the ATA can be corrected by the dipole steering magnets. The shape and width of these distributions does not change significantly as the structure sag goes from 0 to about 2X the design value of 50 mils. In each plot the values of the centroid of the plotted distribution are indicated. This is referred to below as the c.m. centroid <c.m.>.

In Figure 4 is plotted the <c.m.> for the design element placement error δr = 35 mils as the sag is varied from 0 to 2.29X the design value of 50 mils. The sag causes the distributions of Figure 3 to simply move to the left or right. An increase in the sag by about 2X results in an increased displacement of the beam of about 1 mm for x and about 2 mm for y.

In Figure 5 are plotted the maximum widths of the <x> and <y> distributions of Figure 3 as the element placement tolerance δr goes from 0 to 3X the design value of 35 mils. This is done for a sag of 0 and 50 mils. An almost linear variation is obtained, doubling the allowed tolerance will give rise to beams that are about twice as far displaced.

The use of a sample size of 100 machines appears to cause an error in |<x>| or |<y>| of .5mm and |<x'>| or |<y'>| of .5mrad when determining the beam centroid displacement due to alignment errors that are within the design tolerances. With a beam sample of 10K particles the final beam for a perfectly aligned machine was centered to within .2mm.

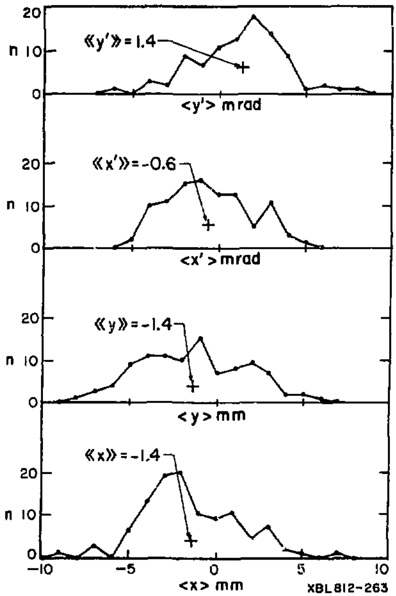

Fig. 3 Final Beam Centroid Distribution at Design Values.

To summarize, if σ_x and σ_y are the widths of the final 50 MeV beam, then alignment errors within the design tolerances cause uncorrected displacements that lie within a box determined by $(.82\sigma_x, .73\sigma_y)$. The displacement varies linearly as a function of either δr or the structure sag. This is easily corrected using steering magnets.

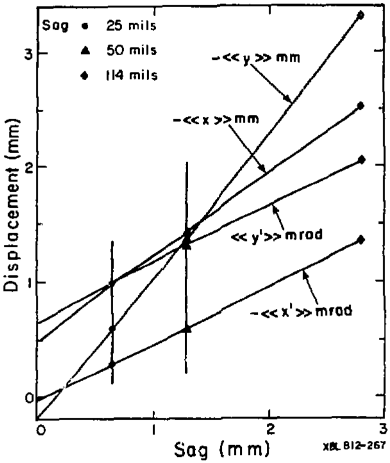

Fig. 4 Beam Centroid Distribution Displacement Versus Assembly Sag.

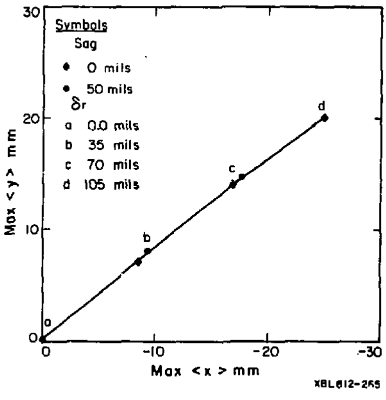

Fig. 5 Centroid Maximum Versus Alignment Error δr.

6. Acknowledgement

I would like to thank A. Paul of LBL for suggesting this simulation of ATA misalignements; R. Hester, K. Neil, E. Moor of LLL for their helpful discussions, suggestions and support; L. Smith of LBL for help in defining an appropriate solenoidal transfer matrix.

References

1. R. J. Briggs, et al., The Proposed Advanced Test Accelerator (u), UCRL-52652, March 1979, Lawrence Livermore Laboratory.

Table 1. Typical Run Parameters

Beam sample size	N_s = 10000	
Number of Machines	N_m = 100	
Beam Widths	Initial	Final
σ_x (mm)	57.0	11.2
$\sigma_{x'}$ (mrad)	20.4	15.3
σ_y (mm)	57.0	11.2
$\sigma_{y'}$ (mrad)	20.4	15.3
Execution Time		
LBL CDC7600	172 cpu sec	