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Status of Compact Synchrotron Light Source Work at TAC

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Abstract

A compact electron synchrotron for x-ray lithography is a design project at the Texas Accelerator Center. The design is a four super-period symmetric cell lattice that is 18.8 meters in circumference. Numerical tracking results including edge fields affect the theoretical and mechanical design of the machine. An integrated magnet and lattice design algorithm is discussed. Structural design and measurement system parameters for a prototype superferric 3 Tesla 90° dipole are discussed. The prototype dipole magnet is currently under construction.

I. Introduction

Profitable x-ray lithography production of semiconductors requires an inexpensive and reliable radiation source. Compact synchrotrons must be cost effective for their use in this application. Technical specifications concerning the electronics manufacturer are the optical source properties of the electron beam, and the synchrotron radiation bandwidth. The optical source properties should be $\sigma_x \leq 1$mm, and $\sigma'_{x,y} \leq 1$mr. The majority of the synchrotron radiation bandwidth should fall between 6 and 10 Å.[1,2]

The adopted design philosophy is: 1.) Simplify the dipole magnet by excluding radial gradients in the magnetic field. "Nonzero gradients produce second (and higher) order aberrations in the field."[3] This is known as the feedup effect.[3,4] 2.) Select the largest magnetic field strengths where ferric magnets can be constructed efficiently. The machine uses a 3 Tesla superferric dipole. 3.) Determine the minimal configuration satisfying the requirements for a production machine. Emittance considerations, with zero gradient dipoles, dictate a four fold symmetry.[9] 4.) Follow an integrated magnet and lattice design algorithm.

II. Review of TAC Machine Concept

The storage ring consists of 4 super-periods. Lattice functions are symmetric about the center of the dipoles and the centers of the straight sections. Figure 1 shows the optical functions for the lattice. Both horizontal and vertical betatron functions are focusing at the dipole centers. There are three quadrupole magnets in each straight section; and two families of quadrupole magnets for flexibility and tune adjustment. Both the horizontal and vertical betatron functions are focused at the dipole centers. The dispersion function is nonzero in the straight sections. The machine footprint is within a 4 by 4 meter box. Table 1 lists the linear lattice parameters for this machine.

Table 1- Linear Lattice Parameters

Beam Energy (MeV)		787
Number of Super-periods		4
Circumference (meters)		18.88
Number of Bending Magnets		4
Magnetic radius (cm)		87.44
Peak Magnetic Field (T)		3.0
Field Index of Dipole Magnets		0
Critical Wavelength (Å)		10.0
Energy Loss per Turn (KeV)		38.8
Horizontal Betatron Tune		3.23
Vertical Betatron Tune		1.16
Momentum Compaction Factor		$-.724 \times 10^{-2}$
Horizontal Natural Chromaticity		-3.1
Vertical Natural Chromaticity		-8.3
Beam Emittance (meter·rad)		2.03×10^{-7}
Energy Spread ($\frac{\sigma_E}{E}$)		0.725×10^{-3}
Damping Times (ms):	τ_x	2.49
	τ_y	2.56
	τ_ϵ	1.29
RF Frequency (MHz)		476
Harmonic Number		30

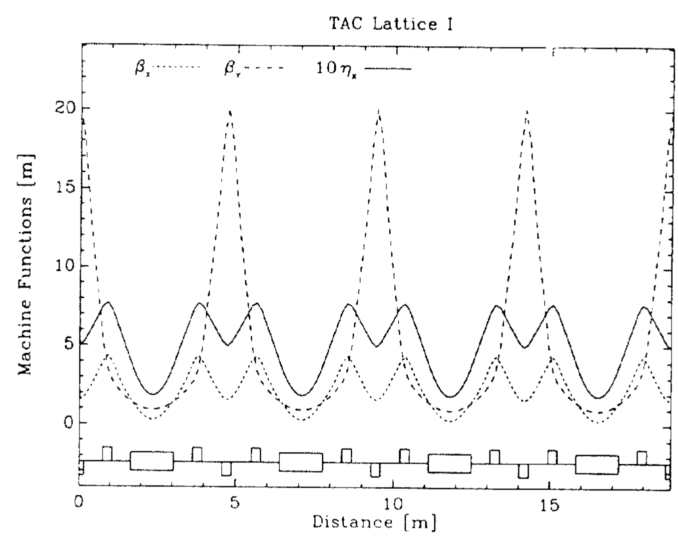

Fig. 1. Machine functions for TAC1 lattice.

III. Integrated Design Algorithm

A synchrotron is usually modeled isomagneticly with linear fringe fields and nonlinear multipole kicks to simulate field errors and chromatic corrections. In a compact machine the magnetic fringe fields comprise 20% to 50% of the design orbit. Multipole components of the fringe field significantly alter the beam dynamics. A computer program COMSYN numerically integrates the

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exact equations of motion for particles in a synchrotron.[5] The program determines linear and nonlinear lattice parameters using either field simulation data or data from a magnetic field mapping. The program operates within the structure of an integrated design algorithm.

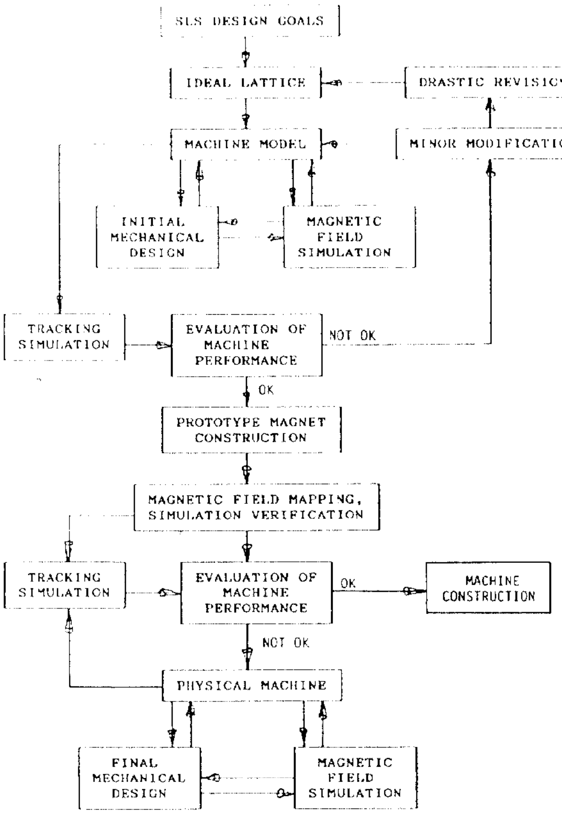

Fig. 2. Flowchart of Integrated Design Algorithm.

The integrated design algorithm's goal is a predictable compact synchrotron design. The user establishes the goals and constraints for the machine design. Traditional isomagnetic codes, for example DIMAD[6], generate an ideal lattice configuration. Interaction between the mechanical design and field simulation develops a working machine model. Tracking simulation, using COMSYN, provides an evaluation of machine performance using 3-D field simulations. Tracking data also provides feedback to the machine model before the construction of prototype magnets. Tracking analysis is then done with measured field data to predict and improve machine performance. The algorithm requires a single prototype dipole before machine construction. Figure 2 contains a flowchart of the integrated design algorithm.

IV. Aspects of Interactive Lattice Design

Dynamic aperture calculations were made for a competing lattice where the beam size in the edge field regions was smaller than the TAC lattice 1.(See Figure 3.) The dynamic aperture was unsatisfactory for this lattice because the dispersion function was too large in the straight sections. The simulation revealed a design rule for symmetric lattice design. Figure 4 shows contours of the natural emittance for values of the machine functions β_x and η_x at the centers of the dipoles.[7,8] The beam energy is 787 MeV, and the B field is 3 Tesla. The magnet bend angle is 90°.

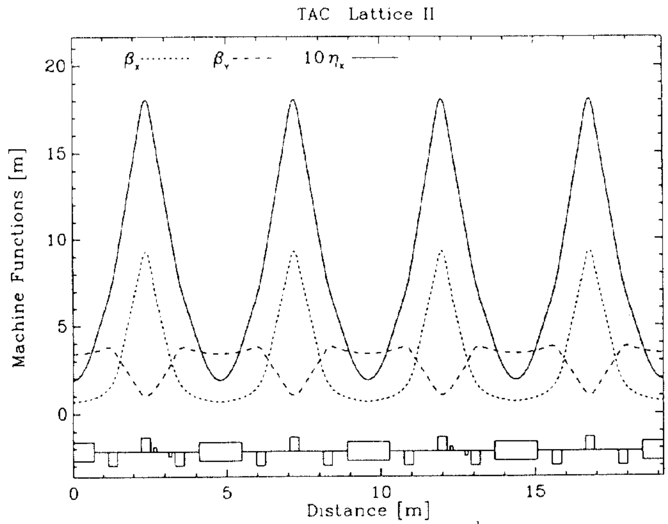

Fig. 3. Machine functions for TAC lattice II.

The line intersecting the tangents of the emittance contours represents a curve of minimum emittance for a given dispersion at the magnet center. Machines should be designed to operate close to this line to minimize dispersion in the straight sections. The TAC 1 and 2 lattices are plotted for comparison.

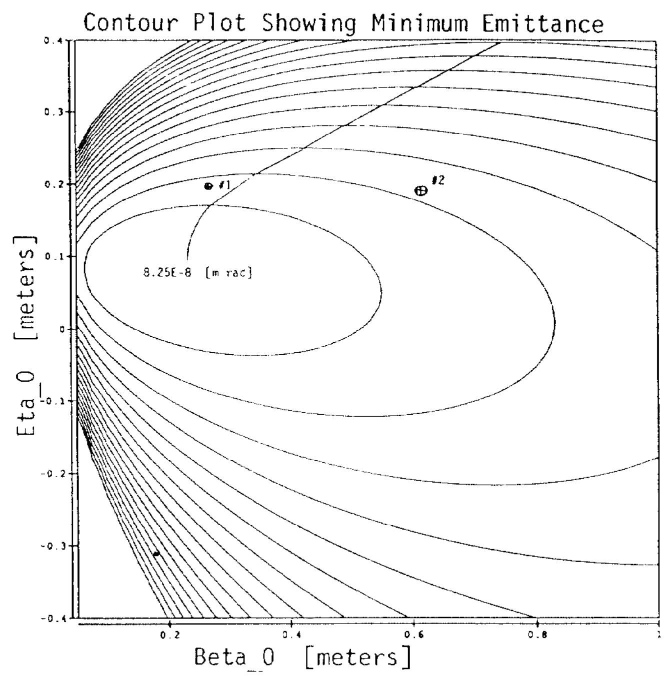

Fig. 4. Contour Plot Showing Minimum Emittance. E= 787 Mev. B=3 Tesla. θ_m = 90°. This is for the symmetric cell case.

V. Interactive Magnet Design

The objective was a zero gradient dipole operating between 1 and 3 Tesla. The radial conductor placements were first optimized by simulation using POIS-

SON. Mechanical design data for flat coil and saddle coil fringe fields were simulated using the 3-D code MAGNUS. The different were compared by evaluating their dynamic aperture within the TAC 1 machine model. Tracking simulations using COMSYN indicate that saddle coil winding geometry is superior. Figure 5 shows the radial magnetic field profile as generated by Poisson. Figure 6 shows a MAGNUS generated saddle coil geometry for the prototype dipole. Figure 7 plots the edge field profile for the saddle coil geometry.

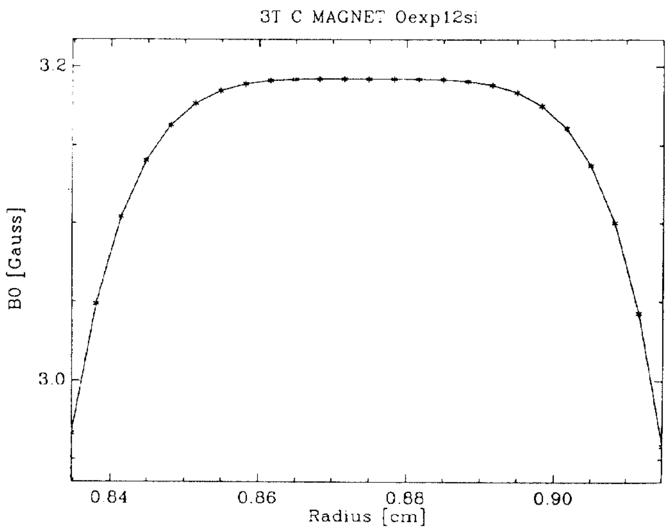

Fig. 5 Radial profile of magnetic field as modeled by POISSON.

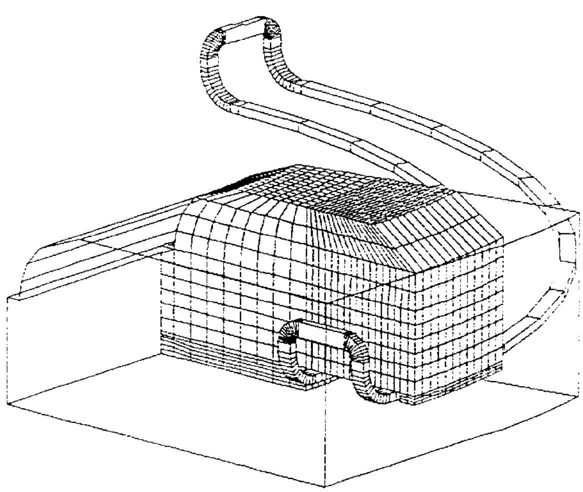

Fig. 6 MAGNUS generated saddle coil geometry.

VI. Magnetic measurement system

The measurement system will consist of a Bell BHT-921 cryogenic hall probe which has been modified to operate with a Group 3 DTM-130-DG teslameter. The teslameter is also modified to measure field intensities of 0.6, 1.2, 3.0, and 6.0 Tesla. The teslameter is now on order and has a delivery date of MAY, 1991. The probe is mounted in a cart which travels along a removable track through the magnet. The hall probe can also be actuated radially. The cart enters the magnet from a vacuum interlock. The interlock allows adjustment of the hall probe height so that the magnet can be mapped in and out of the midplane.

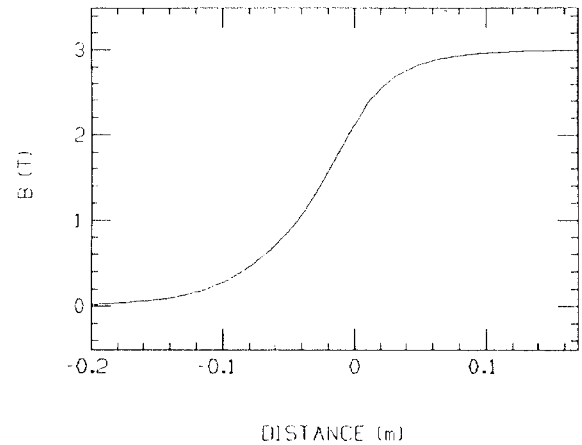

Fig. 7 Edge field profile as generated by MAGNUS.

VII. Conclusions

The TAC1 lattice is optimized using an integrated design algorithm . Design rules for symmetric cell machines have been developed. Magnet design has been accomplished using field simulation codes and numerical tracking in an interactive manner. The prototype dipole is under construction and should be completed by summer 1991. The magnet will be mapped in and out of the midplane.

VIII. References

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