APPLICATION OF ONLINE MODELING TO THE OPERATION OF SLC*

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Abstract

Online computer models of first order beam optics have been developed for the commissioning, control and operation of the entire SLC including Damping Rings, Linac, Positron Return Line and Collider Arcs. A generalized online environment utilizing these models provides the capability for interactive selection of a desired optics configuration and for the study of its properties. Automated procedures have been developed which calculate and load beamline component set-points and which can scale magnet strengths to achieve desired beam properties for any Linac energy profile. Graphic displays facilitate comparison of design, desired and actual optical characteristics of the beamlines. Measured beam properties, such as beam emittance and dispersion, can be incorporated interactively into the models and used for beamline matching and optimization of injection and extraction efficiencies and beam transmission. The online optics modeling facility also serves as the foundation for many model-driven applications such as autosteering, calculation of beam launch parameters, emittance measurement and dispersion correction.

Introduction

Much of SLAC's Linear Collider (SLC) has been commissioned and is now being routinely operated with the help of online model-driven control algorithms. The software which generates the online models here at SLAC has been evolving for quite some time, and has been discussed in previous papers.[1] This paper discusses the nature of these models as they exist today and the protocols which have been established for their generation and storage online for use by the control system.

The Models

The SLAC complex is made up of accelerator sub-systems of several different types: linac, damping rings, storage rings, standard transport lines and the combined-function Collider Arcs (see Figure 1). Daily operations entail delivery of beams of electrons and positrons to various parts of the machine, sometimes at very different energies. Integrated models which allow the operators to establish and control any beam, from production to delivery, quickly and easily are essential.

COMFORT[2] was chosen as the online optics modeling program because it can handle each major type of accelerator sub-system (transport line, linear accelerator and storage ring), it was already integrated into the control system environment[1] and because, as its authors, we knew its internals intimately and could modify and maintain it easily.

A "building block" approach was adopted in order to provide maximum flexibility in the selection and modeling of beamlines. This scheme was implemented via a three-tiered selection hierarchy. At the lowest level we divided the SLAC complex into the smallest set of unique "atomic" pieces from which any desired beamline could be constructed; these are the model SECTIONs. Figure 1 shows the SLAC complex and illustrates this division. The dots are the division points; they are referred to as *marker points.* Each SECTION has its own model which can be generated individually or in series with any other SECTION with which it shares a marker point. A model LINE is a beamline made up of a contiguous sequence of model SECTIONs; a model REGION is a group of one or more SECTIONs within a LINE which is defined so that operators can select geographical regions of the machine regardless of SECTION boundaries.

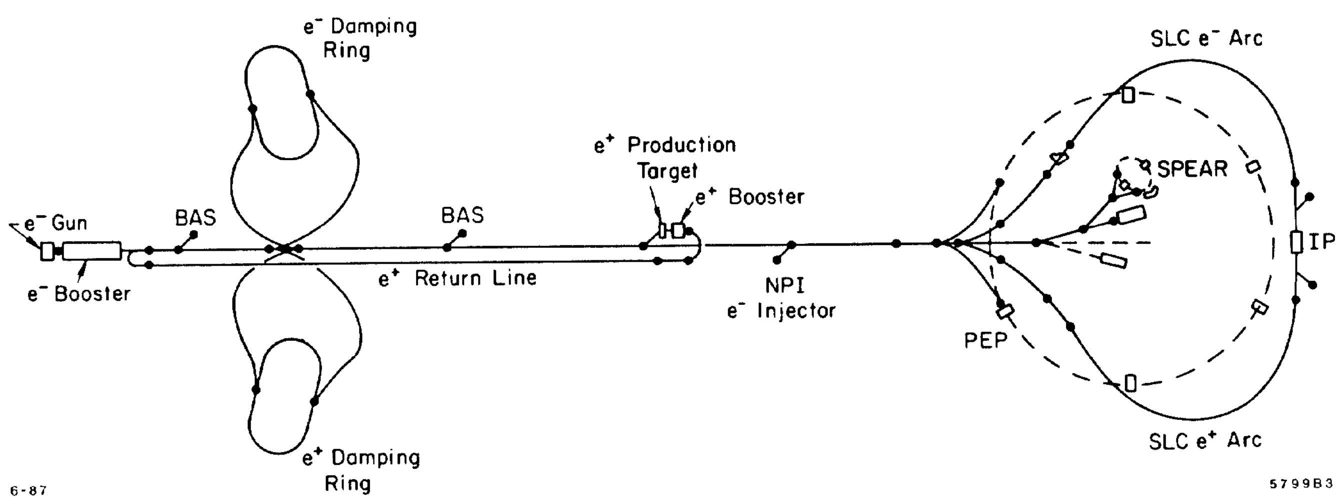

Fig. 1. Schematic layout of SLAC complex showing modeled areas (solid lines) and treaty points (dots).

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The Control System Environment

The overall structure of the SLC control system has been discussed elsewhere[3] and will not be detailed here.

The COMFORT optics program has been converted into a batch process with access to the SLC database.

Generation of a model begins in the SCP with the selection of a model LINE. Next the operator selects the REGIONs of the selected LINE which he wishes to consider. The REGIONs available for selection are displayed on a touch-panel dynamically, based on what has been defined for the selected LINE.

To generate a model the operator requests a COMFORT run to compute the optics for the selected area. A request-for-computation message is deposited in a VMS mailbox which is attached to the COMFORT. The COMFORT process responds by reading the request message from its mailbox and acting upon it. The initial conditions for the run are contained in the request message itself; COMFORT reads input files for each of the selected model SECTIONs, performs the requested computations sequentially on the selected SECTIONs, and generates a group of output files containing the computed optics. The SCP may then read these files and present the results graphically to the operator. Figure 2 illustrates this process.

The Database

Magnet set-points in the database are specified in two ways. Each magnet has an integrated strength control value (*BDES*) which is given in engineering units:

$$BDES_{dipole} = \int B\, dl \qquad (\mathrm{KG-m})$$

$$BDES_{quadrupole} = \int \left(\frac{\partial B}{\partial x}\right) dl \qquad (\mathrm{KG})$$

$$BDES_{sextupole} = \int \left(\frac{\partial^2 B}{\partial x^2}\right) dl \qquad (\mathrm{KG-m^{-1}}).$$

These BDES values correspond directly with magnetic measurements data taken for each magnet. The BDES control values are translated into current values (amps) at the microprocessor level via a polynomial characterization of the measurement data for each magnet and the result used to set that magnet's power supply.

For a variable energy profile machine, however, BDES values alone are not enough to retain desired lattice properties (such as betatron phase advance in FODO cells) for different beam energies. Therefore an additional control value for each magnet that is independent of beam energy is also saved in the database.

These values are known as *KMOD* values; they are computed from values of BDES and beam energy for each magnet taken from the design for a particular optical lattice:

$$KMOD_{dipole} = \frac{BDES_{dipole}}{(B\rho)l} \qquad (\mathrm{m^{-1}})$$

$$KMOD_{quadrupole} = \frac{BDES_{quadrupole}}{(B\rho)l} \qquad (\mathrm{m^{-2}})$$

$$KMOD_{sextupole} = \frac{BDES_{sextupole}}{(B\rho)l} \qquad (\mathrm{m^{-3}})$$

where $B\rho$ is the magnetic rigidity of the beam at the magnet and l is the effective length of the magnet. From these defining equations we can see that, for any magnet, the BDES control value needed for any beam energy is related to its KMOD value by:

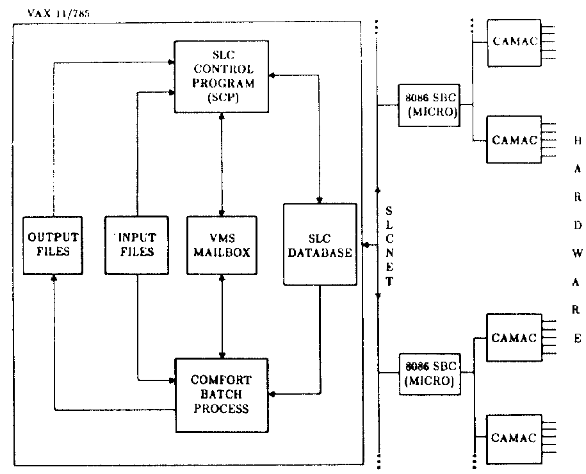

Fig. 2. Functional diagram showing how modeling fits into the SLC control system environment.

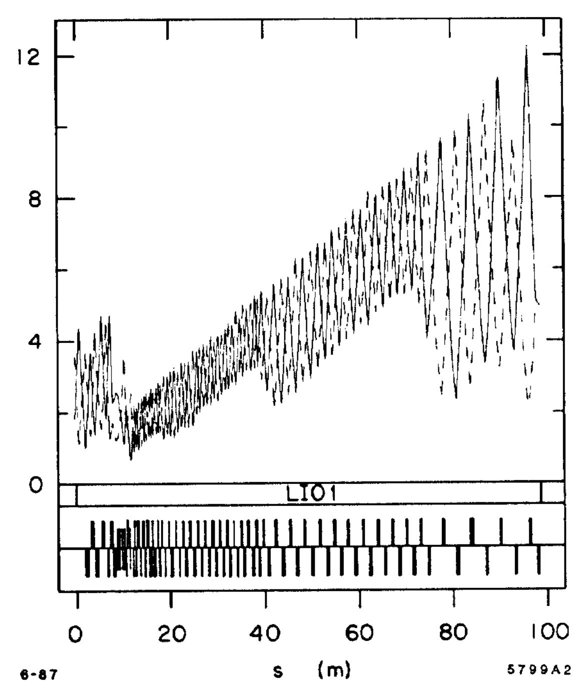

Fig. 3. Typical Twiss parameter display showing beamline elements in iconic form at the bottom.

$$BDES_{magnet} = B\rho \cdot KMOD_{magnet} \cdot l_{magnet}$$

The KMOD value for a dipole magnet is its bend angle per unit length and is a constant determined by local beamline geometry; these values are computed once and stored permanently in the database. The KMOD values for quadrupoles and sextupoles come from optical lattices of which there may be many for any particular part of the machine. Sets of BDES and KMOD values may be saved in named *configuration* files which may be loaded by the operators at any time.

BDES control values for magnets may be changed by the operators; the "real" machine may have BDES values which are not in agreement with their corresponding KMOD values. A facility has been provided which allows KMOD values to be computed from the present BDES values and the extant beam energy profile. Conversely, new BDES values may need to be computed from the extant KMOD values as, for instance, in the case of automated klystron replacement. When a klystron becomes inoperative, a different klystron can be brought online automatically in order to recover the same beam energy at the beam delivery point; however, the beam energy profile between the faulted klystron and its replacement will now be different. In this case the same conversion facility is used to compute new BDES control values from the extant KMOD values and the new energy profile.

This magnet strength conversion facility, coupled with the configuration save and restore facility, gives us a flexible system for establishing and maintaining desired accelerator lattice properties over varying beam energies and for keeping an up-to-date model of the machine available at all times.

While complete sets of Twiss parameters at every point in a beamline are computed by COMFORT and written to output files, only a small subset of Twiss values that are needed by model-driven applications programs are actually loaded into the database. Twiss parameters are saved in the database at the locations of beam diagnostic elements (beam position monitors, beam width monitors, profile monitors and wire scanners), beam steering elements, and at marker points.

Model Input Files

The input files needed for online modeling can be divided into two categories: *model definition* files which are used to define model SECTIONs, REGIONs and LINEs and are read by SCP only, and *skeleton deck* files which are special standard format[4] input decks for each model SECTION which are read by COMFORT.

Model definition files contain definitions of all SECTIONs, LINEs and REGIONs. The model definition files are read once by each SCP at startup time or upon operator request (if, for instance, the files have been changed since SCP startup).

The second type of model input files, model skeleton decks, are standard format input decks for COMFORT. These decks contain a description of the static properties of the elements in each SECTION and give their relative positions. In addition, the skeleton decks contain pointers to the energy contributions of klystrons and to the strengths of quadrupoles and sextupoles in the database.

Model Output Files

The online model optics computation facility was designed to permit computation of the optics of any part of the machine, to be able to easily compare these optics with design optics, and to have this model available to all control stations. In addition, an operator should be able to perform lattice simulation and testing without interfering with other modeling work. which may be going on at other control stations. In order to implement these goals, we have defined three varieties of COMFORT output files which essentially contain three different models of each SECTION of the machine.

Whenever an optics computation is performed by COMFORT on behalf of a given control station, the output files generated have a special code appended to their filenames which identify the files as belonging to that control station.

The second type of COMFORT output file available to the control system is known as the *design* file. There is one unique design file for each model SECTION which contains the SLC design optics for that SECTION.

The third type of COMFORT output file is called the *database* file. This file contains the extant optics of the currently selected beam and beamline. There is one database file per model SECTION. The contents of the database optics files can be updated from any control station at any time.

A complete graphics presentation facility is provided which can display the contents of any of these files on request. Included in this facility are zooming and scaling options and the ability to depict beamline elements or their database identification numbers directly on the display beneath the plotted Twiss parameters. Figure 3 shows a typical β function display with the beamline elements depicted iconically at the bottom.

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