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G I A N T — a computer code for General Interactive ANalysis of Trajectories*

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ABSTRACT

Many model-driven diagnostic and correction procedures have been developed at SLAC for the on-line computer controlled operation of *SPEAR*, *PEP*, the *LINAC*, and the *Electron Damping Ring*. In order to facilitate future applications and enhancements, these procedures are being collected into a single program, **GIANT**. The program allows interactive diagnosis as well as performance optimization of any beam transport line or circular machine. The test systems for **GIANT** are those of the SLC project.

The organization of this program and some of the recent applications of the procedures will be described in this paper.

INTRODUCTION

Computer control programs based on model-driven procedures for the operation of accelerators, storage rings and beam transport systems have been used for more than a decade since it was introduced at *SPEAR*. Today, this method is routinely used for operation of *PEP*, *SPEAR*, the first two *LINAC* sectors, and some of the *SLC* systems such as the *Damping Ring* and its associated beam transport lines – *LTR* (from Linac To Ring) and *RTL* (from Ring To Linac). Similar procedures are either planned for or are being implemented in the *SLC* control program for the start up and daily operations of all other *SLC* subsystems such as the *ARC's*, *FFS* (Final Focus System), *PRL* (Positron Return Line), and the *LTA* (Linac to Arc).

These control programs fall generally into the categories of storage ring, accelerator, or beam transport, and typically consist of several modules which include the Modeling routines, Application Driver, I/O, and the Database Interface. The more than a dozen control programs that are needed for successful operation of SLC would require the duplication of many of these common modules, thus increasing the burden on computing resources, and complicating the tasks of program maintenance, updating, enhancement, and documentation.

A design objective of the SLC control program is to provide a standard structure which when integrated with sophisticated data acquisition devices and user interfaces could be adapted to any beam transport system regardless of its classification. Some of the most important functions of this program are to assist in commissioning of the system through intelligent diagnosis, and in optimizing its performance once the system has become operational.

GIANT, a General Interactive ANalysis program for Trajectories, is being developed to contain some of these functions in an integrated form. One of the most important features of **GIANT** is its applicability to both storage rings and transport lines. In addition to some of the well-known procedures used in existing control programs, **GIANT** will contain the error correction schemes used in the design studies of the SLC system.

The extensive research in the past twenty years in the fields of mathematical system theory, control theory, and artificial intelligence has resulted in great many new techniques for modeling and control of complicated dynamic systems. **GIANT**, in addition to incorporating the more traditional procedures, is intended to serve as a tool for exploring the applicability of some of these ideas such as parameter identification, adaptive and optimal control, and knowledge based expert systems, to the control and operation of charged particle transport systems. In particular, we will investigate the possibility of enhancing **GIANT**'s diagnostic capabilities by providing it with a collection of inference rules and heuristic knowledge of machine operation (which will be provided by accelerator experts) in addition to the lattice and element information which is included in the control and model databases.

The purpose of this paper is to describe the organization of this code, its operating environment, the procedures, and its present status.

FUNCTIONAL ENVIRONMENT

GIANT, as a program for lattice diagnosis and beam optimization, will be developed in two stages. The first version will be used for off-line simulation studies. The aim is to enable the user to investigate beamlines (actual or planned) for isolating possible lattice errors and to experiment with various correction procedures. This is a stand alone interactive program with the input consisting of data files of beam position measurements (obtained from either real machines or simulation programs) and the model database. Text and graphic output are provided to facilitate interactive analysis. The code is written in FORTRAN 77 and in the interest of portability, every attempt is made to avoid the nonstandard features of the language. Graphic routines are modularly designed and implemented to allow easy conversion to other systems.

The online version of **GIANT** will be a module in the SLC model driven control system. In addition to **GIANT**, this group of software consists of modules for Configuration update, Orbit Study, and Chromaticity Correction (Fig. 1) The process of integrating the entire package and interfacing it with the control system I/O and database is achieved through the Application Driver program[1].

In this configuration, all of the data to be analyzed are measurements of beam centroid and will be obtained through data acquisition hardware and software system. In addition, the Configuration Update program will generate the model database which contains the mathematical description of the model to be used by **GIANT**.

The user interfaces consisting of touch panels, mouse, and text and graphic displays are standardized in function so that their logical layouts remain uniform and independent of the subsystem being analyzed.

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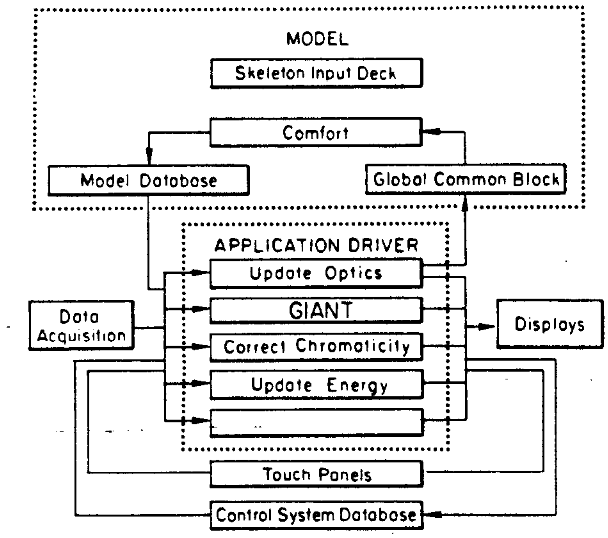

Fig. 1. Structure of SLC model driven control system.

ORGANIZATION

From our experience of on-line computer control machine operation, we have found that the model-driven commissioning and operation procedures can be grouped into two types: *System Diagnostic Procedures; Beam Optimization Procedures.* The diagnostic procedures are needed for start up and commissioning of beam lines. After the beam has been transported through the beamline, these routines are used to analyze beam centroid positions. The purpose of the analysis is to investigate possible errors in the beam line such as alignment errors, field errors, calibration errors and position monitor malfunctions. In addition, these procedures may be used to save files of *reference orbits.* These files may subsequently be used to detect component malfunction, or to restore the machine after shut downs. After start-up operation is completed, beam optimization procedures are needed then to compensate for errors in the system and to calculate the system parameters and corrector strengths required for routine operation. Some of the typical applications of these procedures are trajectory and dispersion correction.

Input

The input to **GIANT** consists of three files:

1) *Beam Position Measurements* — This file contains the horizontal and vertical measurements of beam centroid position at monitor locations. In addition to their magnitudes, the file also contains standard deviation of measurements and a flag indicating the state of each monitor (on/off.)

2) *Corrector Strengths* — This file contains the horizontal and vertical strengths of orbit or trajectory correctors that were in effect when the beam position was recorded.

3) *Model Database* — A beamline not containing any transverse coupling element can be represented by a COMFORT[2] dataset. The model of the beamline is defined by values of the strengths, lengths, type, and location of the elements contained in this dataset. From this, COMFORT will calculate the Twiss parameters β, and α, the dispersion function η, and η', and the betatron phase advance at each element.

Structure

Although many machine diagnostic and corrective methods may be formulated in algorithmic forms, and hence can be implemented in **GIANT**, there are occasions when there is no substitute for the heuristic knowledge of an expert physicist or an experienced operator. Additionally, in the early stages of machine operation, it may be desirable to manually examine the effect of various parameters. Accordingly, **GIANT** is structured to allow using established methods of diagnosis and correction, as well as experimenting with intuitive and non-algorithmic ideas. Functionally **GIANT** is divided into three modules: *Manual Adjust, Element Check, Trajectory Correction.* Each module may be used to simulate the effect of changes in element parameters on orbit/trajectory, or to modify the model database to reflect modeling errors or hardware changes.

PROCEDURES

The trajectory calculations by *Manual Adjust, Element Check,* and *Trajectory Correction* modules are based upon the values of the transport matrices from a given position monitor, lattice element, or corrector to the beam position monitors, and are calculated from the model Twiss parameters. Although the functions of **GIANT** are described in terms of trajectories, they can also be used to analyze orbits in storage rings. In that case the choice of the starting point is arbitrary, and the closed orbit can be considered as a trajectory with appropriate initial values at the starting point z_0, z_0' and ΔE_0, where z means either x or y, E stands for energy.

Manual Adjust

The purpose of this procedure is to allow manual examination of the trajectory sensitivity to variations in initial conditions or element parameters. This could be an aid in *walking* the beam through the beamline at commissioning time, or examining various lattice regions for misalignments. *Manual Adjust* accomplishes this by allowing introduction of artificial *kicks* or energy changes at any desired position. The selected parameter is assigned to a knob which can be set to arbitrary values by the user. The program then simulates the effect of the parameter change on trajectory, and displays the result graphically. The parameter change options are:

1) $(z_0, z_0', \Delta E_0)$ at any beam position monitor — this would permit the user to analyze the beamline one section at a time by *taking out* the effect of the entrance condition to that section. The energy error is determined by including its contribution using the dispersion function from the model.

2) $(\Delta z')$ at any corrector — in addition to allowing *simulation* of various correction methods, this option can be used to manually correct the trajectory.

3) $(\Delta z')$ at any element — with this option one may study the effects due to element misalignment and/or modeling error.

For any of the above options, the changes in the parameters may be only for simulation purposes, or the program can be instructed to implement them.

Element Check

The function of this module is to systematically search for and identify dipole field errors due to misalignment or modeling errors. The following outline describes one such procedure implemented in *element check* after the trajectory is measured at the position monitors (Fig. 2):

1) Select the section of beamline to be investigated and compute the transfer matrices.

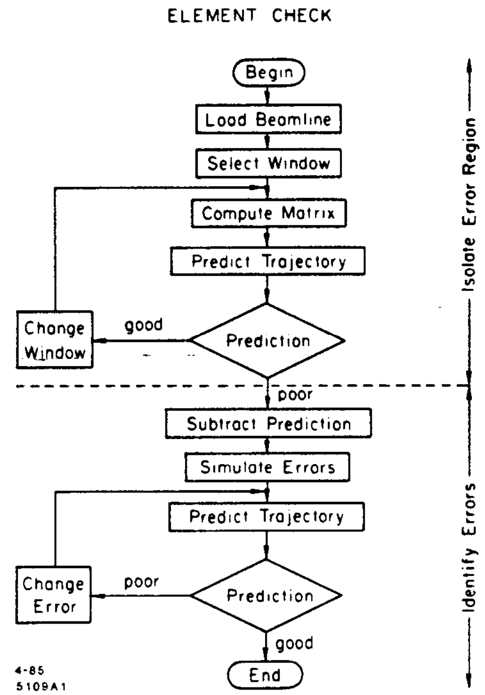

Fig. 2. Flow chart of element check procedure.

2) Calculate the values of $(z_0, z'_0, \Delta E_0)$ by fitting the simulated trajectory values to the measurements and compare the results. For a good fit, indicating no errors, proceed to the next beamline section and continue the process. A poor fit indicates that a region with dipole field error has been detected.

3) Calculate the contribution of the trajectory errors due to $(z_0, z'_0, \Delta E_0)$. Subtract it from the measured trajectory values to calculate the difference trajectory. Introduce dipole error in the region; determine its values such that the difference trajectory is minimized. An error is identified for a successful minimization of the difference trajectory. Otherwise, the error is introduced in the next magnetic element and calculation is repeated.

4) Continue this simulation study until the end of the beamline.

Trajectory Correction

After the lattice and modeling errors have been identified or corrected using trajectory information for a single beam, this procedure may be used to optimize the trajectories for either a single beam or both beams in the *LINAC*. All of the correction methods for transport lines and storage rings use the model database as produced by COMFORT to compute the appropriate transfer matrices between correctors and beam position monitors. The mathematical methods are the Newton's and the Least Squares procedures. The information gathered for the trajectory and the dispersion correction is obtained by the local bump perturbation methods, and for the orbit correction it is obtained by the Harmonic analysis as well as by the local bump distortion method. The program can either calculate the effects using a particular correction scheme, or if requested, implement it by modifying the strengths of hardware correctors. The predicted and measured trajectories are plotted in geometric or phase space. The corrector strengths are also displayed graphically.

PRESENT STATUS

Since the development of GIANT was begun about six months ago, we have been testing the procedures in GIANT either experimentally or by simulation. The Manual Adjust procedure was implemented into the on-line control program for the *SLC Damping Ring*. This procedure has been found to be very useful to assist the optimization of beam transmission from the *LINAC* to the *Damping Ring* experimentally. In addition, the Element Check procedure has been studied using a computer code which was developed for off-line error analysis of the *Damping Ring*. We have found that this procedure can work satisfactorily in some cases. More work will be needed to update this procedure to include features which will work under more realistic conditions. One of the applications of the off-line version of GIANT will be to facilitate studying this problem. Although the Trajectory Correction procedures are the same as those used in the existing control systems, they need to be tested for experimentally correcting both beams in the *LINAC* and for correcting the single beam trajectory by simulation in the *SLC arcs*. Additionally, the effect of nonlinearities on the first order correction scheme will be studied using the off-line version of GIANT.

We expect that the off-line program will be completed within the next few months. The on-line program will be ready for the commissioning of some of the SLC subsystems early next year.

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