ON-LINE MODEL DRIVEN CONTROL OF THE SLC ELECTRON DAMPING RING[*]

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INTRODUCTION

Model driven procedures have been used for control of the linac, beam transport lines and storage rings at SLAC[1,2]. These procedures, based upon computer models of the machine lattice, are used for on-line calculation of the strengths of beam line components which yield desired lattice parameter values. They are also used for routine operation of the machine and for diagnosing and correcting errors of various types, as well as for aiding physicists in the acquisition and presentation of data. Successful operational experience in the use of such procedures at the PEP[3] and SPEAR[4] storage rings has led to the decision that this method of operation will be used for control of all of the SLC subsystems: two-mile Linac, Arcs, Final Focus Region, Positron Return Line and the Damping Rings and their associated injection/extraction beam transport lines.

Many procedures have been developed and used successfully for the commissioning and routine operation of the electron Damping Ring[5]. Some of these procedures have been used for controlling the injection transport system from Linac to Ring (LTR) and for the extraction transport system from Ring to Linac (RTL). The purpose of this paper is to describe the development of the on-line model driven control procedures and their implementation in the SLC computer control system[6].

ON-LINE ENVIRONMENT

The hardware in each SLC subsystem is monitored and controlled by CAMAC modules which are connected to a local microprocessor cluster. Each microprocessor cluster is in turn linked to a DEC VAX 11/780 which serves as central processor for the system. Each microprocessor cluster has pointers to a portion of the Control System Database which contains information about devices within that subsystem. In general, a microprocessor cluster receives an operational configuration for its subsystem's equipment from the VAX; it then attempts to set the equipment and reports its success or failure back to the VAX.

The SLC I&C group provides control system service routines for hardware monitoring, display and control, database access and data acquisition, as well as touch panel and graphics display drivers and an on-line HELP facility, as compiled and linked sharable images written in FORTRAN 77; the modelers (and others) then write Application Driver programs, also in FORTRAN 77, which are linked to these sharable images to form executable images called SCP's (SLC Control Programs). Several different SCP's, each containing a common core of control system service routines and one or more Application Drivers, may be run simultaneously on the VAX and used to control SLC subsystems; a scheduling algorithm for SCP subroutines which prevents SCP's from conflicting with one another is one of the services provided by the SLC I&C group.

LOGICAL STRUCTURE OF MODEL DRIVEN CONTROL

The two tasks facing the creators of model driven control software are off-line development and on-line implementation. We have consolidated the off-line modeling effort into three programs: Configuration Update, Orbit Study and Chromaticity Correction. These programs were designed as stand alone codes which could be conveniently integrated into the control system. In order to facilitate this integration, an Application Driver program is used to interface the Control System Database and the touch panel, display and data acquisition software of the SCP to the model driven control programs.

A crucial step towards a truly automated control system is a common database of information that can be used by control procedures for on-line correction of errors. In the case of model driven control procedures we will distinguish between the existing Control System Database containing information about the state of a subsystem's hardware and a Model Database containing information pertaining to the mathematical model of that subsystem.

The generation of the Model Database, which contains the Twiss parameter values at each beam line element and is used by all of the model driven control programs, is controlled by the Configuration Update program which performs the communication between the SCP and the modeling program (COMFORT) through the use of a special portion of system memory called a Global COMMON Block. The relationships between the Application Driver, the Model and the SLC Control System are illustrated in Fig. 1.
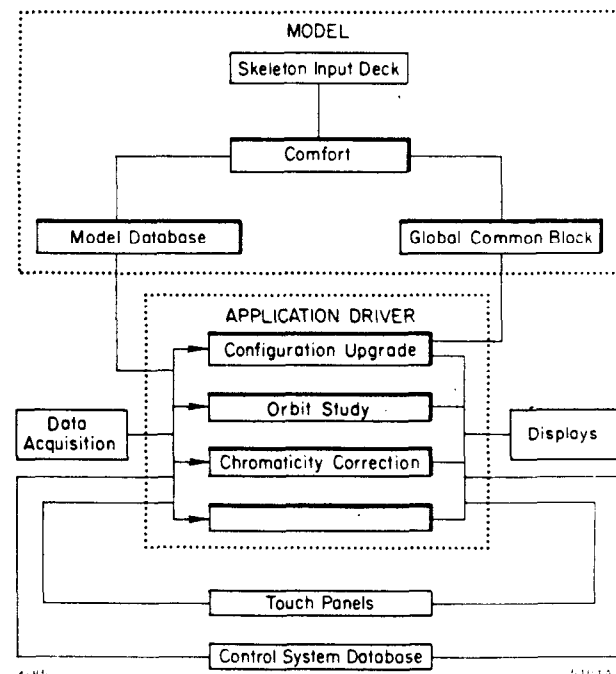

Fig. 1. Functional diagram of the model driven control system.

The Model

The program COMFORT[7] is used to generate the model of the Damping Ring and its transport lines. In order to keep SCP's at a manageable size and to speed system response time, COMFORT and the SCP's are separate VAX processes, one created by the other whenever necessary. A block of system memory called a Global COMMON Block is permanently allocated to handle the inter-process communication. Parameters of any device which are not static and which effect the first order optical properties of these subsystems (such as the field strengths of magnets) are communicated to the COMFORT process in this fashion.

In addition to receiving data on the transient properties of devices in a subsystem through the Global COMMON Block, the COMFORT process reads information about the static properties of subsystem devices from a disk file known as a Skeleton Input Deck which is generated off-line by the modelers. Included in this skeleton deck is the specification of points defined by the modelers in each subsystem's lattice where beam parameters may be fit.

Upon request, the Configuration Update program will load the Global COMMON Block with the present values of a subsystem's devices, call the COMFORT process, check for runtime errors when COMFORT exits and receive the computed results of the run; if fitting was involved, it will check the computed values of those device parameters which were designated as variables for validity and then present the results of the fitting to the user on the display. When a COMFORT run is successfully completed, a special COMFORT subroutine generates a series of disk files containing the first order optical properties of the subsystem. This group of disk files is called the "Model Database" and is used by the other Application Driver programs as described below.

The Model Database for an SLC subsystem consists of two (in the case of the linac and transport lines) or three (in the case of storage rings) files generated by COMFORT at the completion of a successful run as outlined above. These files are described briefly below.

1) TWSS file: contains type codes, names, positions along the beam line and characteristics of the subsystem's devices; also includes the so-called Twiss parameters of the subsystem (phase advances, beta, alpha and eta values along the beam line).

2) MATR file: contains orbit/trajectory "sensitivity" matrix elements relating displacements of the beam at Beam Position Monitors (BPM's) to angular deflections of the beam at dipole correcting elements.

3) PARM file (for storage rings only): contains beam, machine and RF-related parameters for the subsystem (damping times, equilibrium emittances, bunch length and energy spread, synchrotron frequency, *etc*).

The Application Driver

The Application Driver contains programs which provide the interface between the user, the SLC control system, the Control System Database and the Model Database through the use of the system tools provided by the SLC I&C group and described earlier. After the Model Database for an accelerator subsystem is generated or updated, the programs contained in the Application Driver can use it for control of that subsystem.

In each specific model driven task (such as Orbit Study or Chromaticity Correction), the Application Driver will allow the user to make measurements, determine the scope of desired corrections, find an optimal correction, display the outcome and finally to implement the correction by changing the appropriate parameters in the Control System Database. In the next section we will illustrate some of the interactions between these Application programs and the Control System Database, Model Database, the COMFORT process, and the control system I/O.

THE MODEL DRIVEN PROCEDURES

Configuration Update

The Configuration Update procedure provides three touch panels for users: the first, the "driver" panel itself, is common to all subsystems; the remaining two panels are specific to each subsystem to be modeled and are called "set up" panels. The procedure used for updating a Damping Ring configuration is described below to illustrate the functions provided by each of these touch panels.

The initial step in updating the first order optical configuration of the Damping Ring is to check on the status and present values of the devices which will be varied in a modeling run to achieve desired beam parameters; this is done from one of the set up panels.

The next step is the specification of desired beam fitting parameters. Another set up panel is provided for this purpose. Provision has been made in the Damping Ring skeleton input deck for fitting beam parameters at the beginning and end of a superperiod and at the beginning and mid-point of a standard cell.

Finally, COMFORT is called from the driver panel to perform the calculation of variable values and the generation of the Model Database as described above in section 3.2. Upon completion, the results of the run are presented to the user on the display. If the calculated solution values are acceptable, the user allows the variable elements to be ramped from their present values to the newly computed values in a specified number of steps. The user may also view the contents of the Model Database via two displays: one will display the contents of the TWSS file as a plot of the lattice functions around the Ring, including a schematic of the magnetic elements as shown in Fig. 2; the other will show the contents of the PARM file on the display in tabular form.

Orbit Study

This on-line study uses the Model to calculate the optimal change in corrector strengths and to predict a corrected orbit.

Two possible methods for orbit correction are the Least Squares Method and the Harmonic Method. The Least Squares Method uses a correction matrix calculated by COMFORT (see MATR in 3.3). This matrix, representing the relationship between the orbit deviation at a monitor and a corrector's kick, is used for least squares optimization of the orbit deviations. The Harmonic Method expresses the orbit and its correction as Fourier expansions in terms of the Twiss functions.[9] The user can interactively select a subset of harmonics to be compensated.

Different displays can be activated from the touch panel, which allow the user to examine the data before implementing the solution or to study the predicted results (Fig. 3). The result of the calculations can be applied via a touch panel
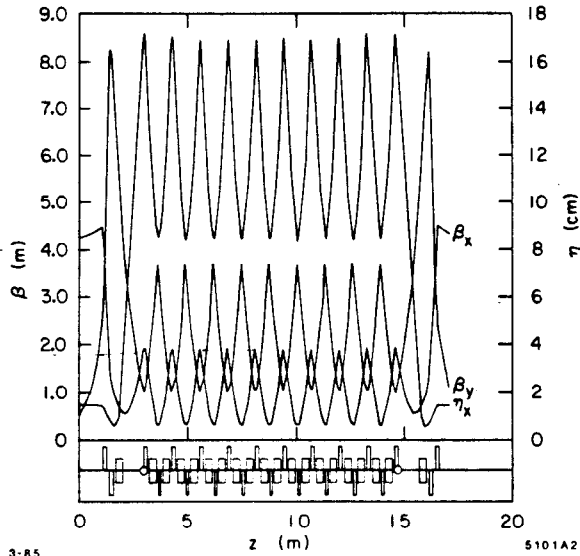
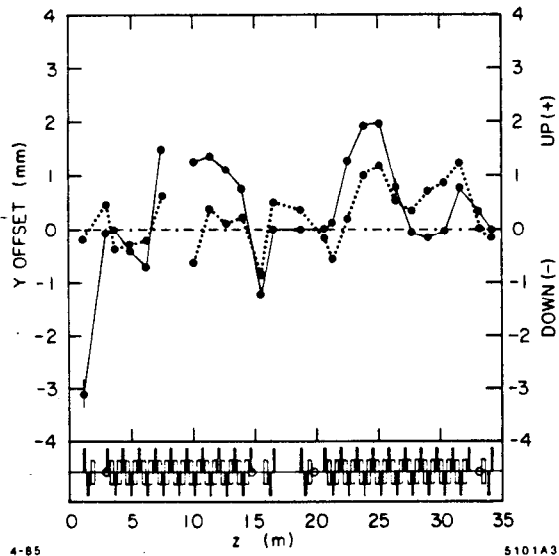Fig. 2. Damping ring Twiss parameter display.

Fig. 3. Measured and predicted orbits display for the damping ring.

command which changes the corrector strengths in the Control System Database. The user also can check the accuracy of the prediction by displaying both old and new monitor readings after the computed corrections have been implemented.

Chromaticity Correction

This correction procedure uses the Model to calculate changes in sextupole strengths and to predict corrected chromaticities.

After entering the data for variations of tune with RF-frequency, the user can obtain a display of the tune vs. the energy deviation and the chromaticity values using a least squares parabolic fit. The user can then enter desired chromaticity values and calculate the new sextupole strengths required. The results of the calculation can be applied by a touch panel command which change the values for sextupoles' field strengths in the Control System Database. After remeasuring the variation of tune with the RF-frequency, a display showing both new and old data can be used to check the predicted changes.

Another useful feature for machine physics study is a display of the tune diagram showing the resonance lines. The user can enter the order of the sum/difference resonance lines to be shown as well as the range of tune values to be included in the display.

SUMMARY

From our experience we have found the structure of the modeling programs for the Damping Ring can easily be extended to other SLC systems. We have demonstrated this possibility in extending it to the LTR model control programs by substituting the orbit correction procedure with a trajectory correction procedure.

At present, a general trajectory/orbit analysis and correction program, GIANT,[8] is being developed for this purpose while this structure of model driven control is being generalized for any SLC system.

ACKNOWLEDGMENTS

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