COMPUTER CONTROL STRATEGIES AT SIN

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Abstract

The computers connected to the SIN control system have been programmed to be a "third operator", performing primarily calculation intensive or repetitive functions. Written primarily in FORTRAN, programs exist which display the effects of trimcoils in both SIN accelerators on phase and betatron frequencies. Beamlines may be modeled by displaying beam envelopes and parameters given bending magnet and quadrupole settings and beam ellipse parameters anywhere in the beamline. Programs are used to perform a number of jobs in the normal tuning procedure. Selected subsets of device values from previous setups may be restored, using ramping functions if necessary. Horizontal and vertical waists may be formed using the quadrupole triplet and slits following extraction from the injector cyclotron. The beam may be centered at injection into the ring and in the proton channel from ring extraction to the beam dump. Proper focussing on target may be obtained and emittance measurements are possible there and in the injection channel. Finally, total operator (and program) performance is periodically measured by a "Bonus" number describing the quality of tune of the entire system.

Introduction

SIN, one of three operating "meson factories", has been supplying 590 MeV protons to two target stations since early in 1974.1) To achieve this, a human operator must control an injector cyclotron producing 72 MeV protons, an injection path of some 30 meters, the ringcyclotron and a proton channel of some 60 meters. Although the operator can exercise this control through a number of manual "Setpoint" units2), two computers, effectively equivalent to one Setpoint unit, are also available. (See Fig. 1.) To date, the major software development aim on these computers has been to augment the normal complement of two human operators by performing those tasks for which completely defined algorithms could be written down. It is these programs, transforming the computers into a "third operator", which are discussed below.

Much of this application software is written by physicists to use devices for which they hold design and development responsibility. The language used in all such cases is FORTRAN and the computer is the IBM-1800, which is, by today's standards, not particularly powerful. However, the narrowing of scope required by these circumstances has proven to be of benefit by focussing efforts on single, simple problems. Assembler language subroutines are used in some cases for speed or better core usage and only a few programs are written entirely in assembler. The PDP-11/40 is programmed entirely in assembler and is used as a very intelligent peripheral processor invisible to the user.3)

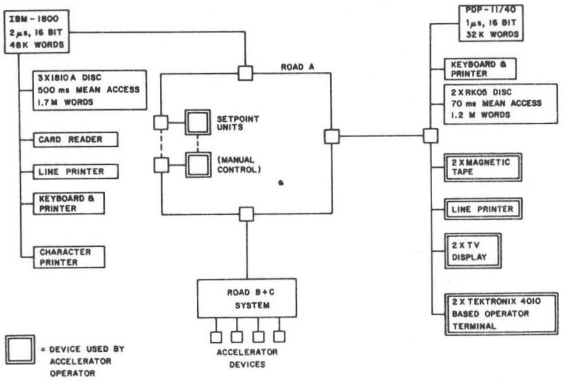

Fig. 1. A schematic representation of the SIN control system showing those aspects relevant to the computer control effort.

Below are discussed the major programs in the order in which they might be executed during a normal setup procedure. We shall emphasize the viewpoint that an operator might take to them, since in practice, an operator can choose to use or ignore most programs.

Parameter Initialization

One very useful tool for examining the behavior of beamlines theoretically is Graphic Transport, a code using a first order transfer matrix calculation to determine beam properties. We assume (for all programs described here) that the real beam may be treated as an ellipse in each transverse phase plane. (Horizontal and vertical planes are labeled x and y, respectively, with z the direction of beam travel. Program Transport4) serves as the model for our formalism.) All beam parameters and quadrupole, bending and steering magnet excitations may be input from the operator's console for up to nine predefined beamlines. Transport calculations may be performed forward or backward between any two points in the beamline which are not inside a magnet.

Results may be displayed in one of three forms. Numerical values for all relevant beam ellipse parameters, valid to ± 0.2 mm, or the beam ellipse in both x and y planes may be shown at any point in the beamline. However, the greatest utility of the program is realized by using a graphical display of x and y envelopes as functions of z as in Fig. 2. The beamline designer, beam dynamicist or accelerator operator may learn the effects of various focussing elements, may learn to tune the beamline, without the worries attendant to such experimenting with real beam. He receives easily interpreted feedback with a very small turn-around time.

While Graphic Transport can supply some parameter values and can read and set magnet power supplies in the existing SIN beamlines, it is much more common to begin a setup by reproducing past values known to have resulted in good beams. A SAVE program reads and provides a printout of all computer-accessible

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devices (ADC's, DAC's, counters, etc.) and can store the DAC values in a named disc file. All devices are organized into groups and subgroups. Program DSET is able to load the DAC's for devices in a selected subgroup with values from a selected Save file (turn on) or from a "null" file containing zeros (turn off). This last feature and the use of ramp functions to set sensitive parameters such as the ring magnet current have led to enhanced reproducibility in the setting of large magnets. DSET also reports on and ceases to try to change devices which do not respond as expected, alerting the operator to faulty equipment or to a conflict between what he is trying to do and what the program is attempting.

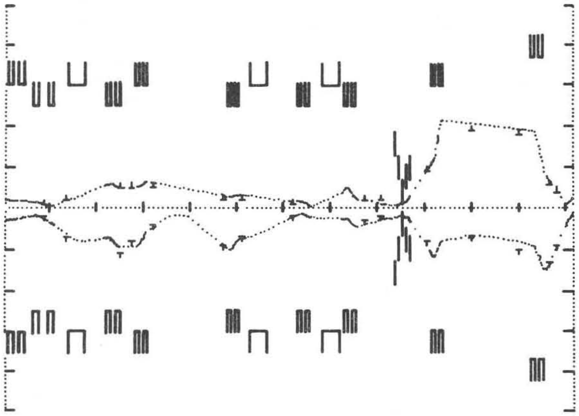


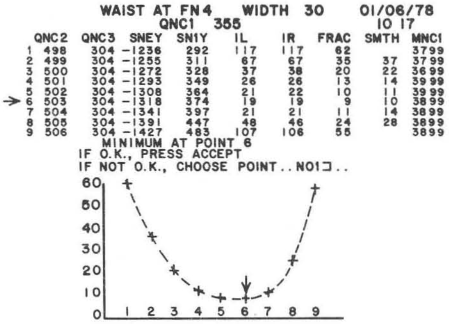
Fig. 2. A Graphic Transport display of x and y envelopes in the SIN proton channel. Tic marks occur along the vertical axis every cm and along the horizontal axis every 5 m. Small 'T' marks represent profile monitor measurements. The initial beam conditions represent a best fit to these measurements. Target M sits at 42 m, Target E at the right hand border.

Injector and Injection Path

The effects of arbitrary trimcoil excitations on phase and radial and vertical betatron frequency histories in either cyclotron may be graphically displayed by TCDIS. Since measured phase points may also be displayed, the operator may find isochronizing trimcoil corrections by "fitting" these points. The program uses tables of precalculated radial trimcoil field integrals, performing mostly addition and subtraction operations and executing quite quickly. When setting up the injector cyclotron, the operator can perform the two iterations normally sufficient to attain ± 5° maximum phase excursion in a reasonable time.

Immediately after extraction from the injector cyclotron, we first encounter a "tuning" process which has been automated. Within the first eight meters of the beamline are a quadrupole triplet followed by two steering magnets and two pairs of slit jaws in each focussing plane.5) The existance of a waist in one slit in each plane was assumed in the design of the beamline and, in practice, yields highly reproducible beam conditions up to injection into the ringcyclotron. Waist formation should therefore be done accurately during every setup or tuning period. However, because each quadrupole steers the beam and affects both waists, the human operator must carefully perform many iterations to achieve satisfactory waists.

The computer procedure developed to perform this tedious operation consists of scanning an appropriate pair of quadrupoles over preset ranges and recording the fraction of the beam current lost on a slit of fixed width. Simultaneously, by using the second slit to locate the beam, the appropriate pair of steering magnets may be adjusted to maintain the beam on the beamline optic axis throughout this procedure. The parameter values yielding minimum beam loss are reset to form the desired waist. (See Fig. 3.)



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               WAIST AT FN4    WIDTH  30      01/06/78
                         QNC1  355                10 17
    QNC2  QNC3  SNEY  SN1Y    IL    IR  FRAC  SMTH  MNC1
  1  498   304 -1236   292   117   117    62        3799
  2  499   304 -1255   311    67    67    35    37  3799
  3  500   304 -1272   328    37    38    20    22  3699
  4  501   304 -1293   349    26    26    13    14  3999
  5  502   304 -1308   364    21    22    10    11  3999
→ 6  503   304 -1318   374    19    19     9    10  3899
  7  504   304 -1341   397    21    21    11    14  3899
  8  505   304 -1391   447    48    46    24    28  3899
  9  506   304 -1427   483   107   106    55        3899
          MINIMUM AT POINT 6
        IF O.K., PRESS ACCEPT
        IF NOT O.K., CHOOSE POINT..NO1⊐..
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Fig. 3. A typical waist search display. Magnet values are DAC units, current values are in units of 10 mA. The plot shows percentage of current intercepted (in tenths of %) at each measurement point.

It is easily demonstrated that the beam ellipse and emittance are fully determined by the slit openings after establishing a waist as above. Density contours in phase space may be determined by instructing the program to set the slit widths so that different fractions of the total beam are intercepted. Standard values for this fraction are 99%, 95% and 80%. Table I contains typical data obtained for the 72 MeV proton beam.

Table I. Typical Beam Emittance Data

Plane	Fraction	Slit 1	Slit 2	Emittance
	%	(mm)	(mm)	(π mm-mrad)
X	95	2.9	10.9	4.8
	80	1.9	8.3	2.3
Y	95	9.1	2.8	5.0
	80	7.3	1.8	2.5

Ringcyclotron

Since the operation of the ringcyclotron itself is described in some detail in two other papers at this conference6,7) and since that discussion necessarily involves delving into a number of programs, we will present here only a very cursory view of those programs. At injection into the ringcyclotron, two separate centering operations are automated. The beam may be directed through a hole in the body of one of the movable probes (ΔΣ1) set at a particular radius using the first external injection magnet (AND1). This is normally sufficient to obtain many turns of accelerated beam which may then be centered by program CENT by measuring turn spacings with each of three differential probes (ΔΣ1,2,3) and calculating corrections to the second external magnet (AND2) and

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the internal electrostatic element (EIC).

At high beam currents, extraction efficiency is all important. Coherent radial oscillations may be purposely introduced by program STERN which changes the active injection elements by amounts predetermined to move the orbit center by a certain distance in a certain direction, thereby enforcing a methodical search technique on the operators for optimum extraction. Beam phase is monitored by a graphical display of the signals of 13 fixed phase probes vs. radius. Cavity voltage and vertical beam steering magnet excitations are used as independent variables by programs CAVSC and SNDSC which plot current on a probe immediately before extraction. The former parameter may then be adjusted so that a "valley" between turns coincides with the electrostatic extraction element septum (EEC).

Proton Channel

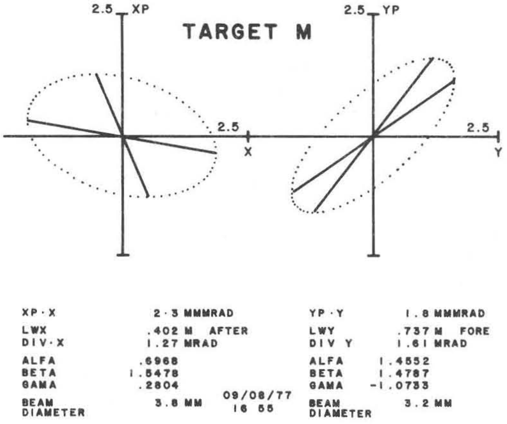
The 590 MeV protons extracted from the ring-cyclotron may be automatically steered down the proton channel to the two in-beam targets (M and E). The measurements for this and similar processes are made by oscillating finger "profile monitors", signals from which are digitized to give a beam current vs. position profile in a single transverse plane.8) The analysis of a single profile is done by calculating the first and second moments of the peak shape using integer arithmetic. A great deal of work has been done in Fourier analyzing profile shapes to attempt to detect double peaks, for instance. This analysis is not much used in normal operation since no correction algorithms exist and the operator must correct pathological situations.9)

The proton channel steering process controls 5 large bending and 12 small steering magnets to obtain the desired beam position at each of 17 profile monitor locations. The first set of programs to do this (both historically and during a normal setup) divides the beamline into four horizontal and three vertical sections and treats each section as an independent unit. The beam profile is measured over a 6 cm range with a 0.2 mm resolution during the time the finger makes one pass through the beam. (This time is about 1 sec. but may be adjusted over a wide range.) The correction calculation is based on influence matrices for the dipole magnets determined previously at standard quadrupole settings. Two iterations are normally enough during an initial setup to achieve desired positions ± 0.3 mm. These programs execute for about three minutes and require about 120 finger sweeps through the beam.

A streamlined version of this process may be run periodically to test and maintain beam position. The streamlining consists partly in eliminating displays and treating only deviations less than 2 mm: larger deviations cause warnings to the operator. The fastest version of this program uses non-intercepting position monitors which are clearly superior to the finger monitors, in principle. However, these probes are not as reliably accurate as the finger probes and are still under development.

The final task in any setup is to form a double (x and y) waist on each target. This is particularly important at the first target to minimize the effects of scattering on the beam spot at the second target. The software procedure to form each waist starts by measuring the beam width at 9 profile monitors. A gradient search method determines a set of ellipse parameters at the start of the beamline which minimizes the total square deviation of the calculated envelope from the measurements and fixes the beam emittance to an accuracy of about 10%. The Graphic Transport display in Fig. 2 shows the quality of the final values.

Since the beam emittance is known and assumed constant, two profile measurements immediately before the first target define the ellipse and the nearest waist position. (See Fig. 4.) A gradient search is now performed using the last quadrupole to place the waist at the target location. The quadrupole steps are kept quite small and many measurements are made since small discrepancies between theory and reality can have regretable consequences with 4 kW of beam power. However, this program has proven quite successful and can be used while experiments are running. This latter property is extremely important because the normal manual procedure for target focussing requires the use of a special target wheel.8)



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XP·X              2·3 MMMRAD            YP·Y          1.8 MMMRAD
LWX              .402 M  AFTER          LWY          .737 M  FORE
DIV·X            1.27 MRAD              DIV Y        1.61 MRAD
ALFA            .6968                   ALFA      1.4552
BETA           1.5478                   BETA      1.4787
GAMA            .2804                   GAMA     -1.0733
BEAM              3.8 MM   09/08/77     BEAM           3.2 MM
DIAMETER                    16 55       DIAMETER
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Fig. 4. Display showing a beam ellipse measurement at the first target station in both x and y planes. LWX is the distance between the target and the nearest waist while ALFA, BETA and GAMA are ellipse parameters. Optimization has not been completed since waists occur when the major axes of the ellipses are vertical.

Beam Performance Summaries

Two measures of accelerator (and operator) performance are logged. Some 7 beam current values and direct losses at 12 locations are recorded every 15 minutes along with 25 indirect loss measurements from ionization chambers. The beam currents are also read every minute for a more accurate value of the beam current-time product. Shift by shift totals for all these quantities are available on paper for archives or at the console for the operator. These numbers are also combined into a measure of relative losses called the "Bonus" numbers, which are normally on constant display in the control room. The Bonus formula is constructed to reward low relative losses with high numbers, acceptable losses with numbers near zero and high losses with negative numbers (Fig. 5). The formula is parameterized to allow easy adjustment of the maximum Bonus, the range of acceptable losses and its sensitivity in the low loss region.10) Besides being useful as tuning guides, the Bonus numbers tend to generate a bit of healthy competition among operators.

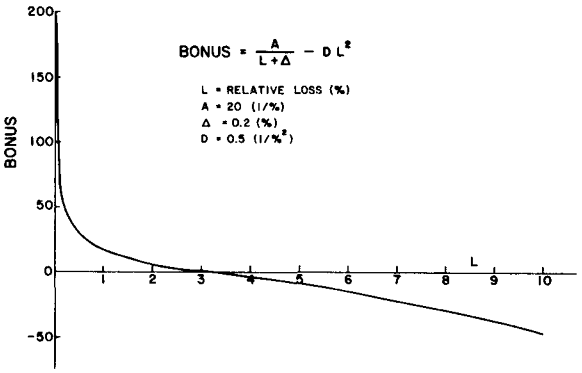

Fig. 5. A typical Bonus curve vs. relative beam loss. The parameters A, Δ and D may be set to yield desired maximum Bonus and "normal" tuning range.

Fault Location

Two programs aid the operator in diagnosing fault conditions from the control room. A manually activated program SCANNER can read a large number of contact closures (e.g., indicating power supply on/off, cooling water failure, vacuum failure) and give a display either of all conditions or only abnormal, fault conditions for an operator-selected set of devices. In either case, the display consists of text describing the contact status as fully as is practical to avoid confusion. In this way the program multiplexes, filters and interprets the contact statuses.

There is also program INTLK, interrupt-triggered by each interlock event, which prints a record of the offending interlock and seeks to tell the operator its cause by making measurements unique to each interlock, including reading and interpreting a small number of contacts using the same data base as SCANNER. While this does greatly reduce the information through which an operator must sift, in many cases the software is not yet advanced enough to pinpoint fault causes.

Conclusions

A few generalizations arise from software work at SIN. As has been mentioned often elsewhere, graphic displays are very powerful and should be used wherever practical. Simple mathematical models in simple programs work remarkably well: known complications and more accurate models are often not cost effective and don't perform to the standards of their more straightforward brothers. Both these ideas may be summarized from a different and more important point of view: the more the human operator understands what the program is doing, the more the program will be used.

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