COMPUTER-BASED VISUALIZATION AND MANIPULATION OF ORBIT WARPS IN THE ZERO GRADIENT SYNCHROTRON (ZGS)*

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Summary

The low energy orbit warps in the ZGS are corrected by eight current-regulated single-turn kicker windings. The currents regulated in these coils can be set individually by the operators through a central digital control system. Since large first harmonic warps are produced by small current changes in single coils, blind, individual adjustment of the eight currents is seldom productive. This paper describes a computer program and interactive graphic display system which allow accelerator operators to visualize the effects of single or multiple kicker coil current changes. The display provides numeric as well as graphic representation of the orbit warp produced. Localized orbit bumps can be inserted by specifying location and size. The program can be used for off-line visualization purposes only, or optionally the desired currents can be introduced immediately by the computer.

Introduction

The main guide field magnet of the ZGS consists of eight large zero gradient bending magnets, each of which is equipped with a single-turn bucking winding called a kicker coil. The currents induced in these coils by the guide field are independently controlled by eight digitally programed regulators. Since the current in these coils will reduce the main guide field, they are used to manipulate the low energy orbit warps. These parts of the system are shown at the right side of Fig. 1. The power supply shown is required if insufficient voltage is induced from the main field.

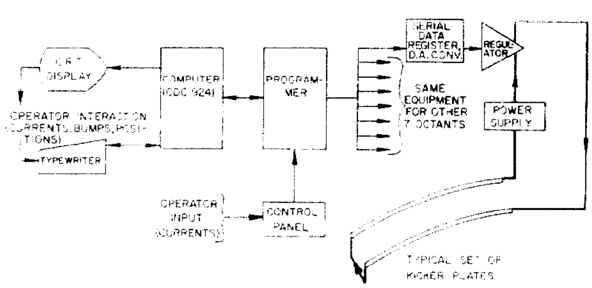

Fig. 1 System Block Diagram Showing the Two Methods of Orbit Warp Control

Normal operator control of the kicker coil currents is accomplished by requesting individual current changes through the ZGS programmer,[1] a stored program digital control system which provides most of the timing and control synchronization for the ZGS. The programmer in turn transmits the new control information to the appropriate regulator.

Since a modest individual current change will produce a large first harmonic orbit warp around the entire machine, the procedure of optimizing each of the eight currents individually to maximize captured or accelerated beam intensity is seldom productive. The set of eight independent variables becomes "locked" into a nonoptimum state, as happens so often in the tuning of accelerators. Additionally, as the orbit is changed in the injection region, compensations are necessary in injection steering and timing so that intensity will not be lost due to poor matching.

To help solve some of these problems, various existing software and hardware systems were combined as shown in Fig. 1. The aforementioned programmer and the computer are parts of the ZGS central control computer facility and are described elsewhere.[2] The display system utilizes a 20-in flat-faced CRT and can produce alphanumerics as well as high quality graphics.

Computer Program KICKER

The accelerator operator utilizes the system by typing a command to execute the background program KICKER. (The program is brought in and operated without interfering with the other monitoring and control activities of the computer.) Once loaded, the program obtains the present current settings from the programmer memory and types them out as in the following sequence:

```
xbj     kicker ←———————— (operator command to execute program)

* 09    JAN. 1973      12;20;59 * ←——(computer output during loading)

MODE    /1/    /2/    /3/    /4/    /5/    /6/    /7/    /8/ ←—(octants)
CRT     24.7   39.0   14.5   18.2   28.0   31.2   21.2   12.3 ←—(currents)
```

The column headings represent octant numbers, and the currents are in amps. The operator can now proceed to make single or multiple current changes by tabbing to the desired octant column(s) and typing the new current(s). In order to visualize the effects of changes, the program's display capabilities are invoked by typing the option word "show" in the first typewriter field.

CRT Display Format

A display similar to Fig. 2 will now appear on the CRT face. (This figure and all subsequent ones were made from the CRT system's hard copier output, which can be obtained at any time by typing the option word "copy.") The display components from top to

*Work performed under the auspices of the U.S. Atomic Energy Commission.

bottom are as follows: (a) date and time, (b) straight section nomenclature with the accelerator shown unwrapped and the injection straight section at both ends, (c) the theoretical beam position at each straight section and octant center in inches, (d) the radial orbit warp graph, (e) the octant nomenclature and corresponding kicker coil current in amps, (f) the calculation assumptions as to injection tune and field, both of which can be changed by typing the option words "tune" or "field" respectively followed by the new values, (g) the program's recommendations as to changes necessary in injection timing and steering due to orbit changes in the injection region, and (h) the program options to remind the operator of various features available and to provide proper spelling.

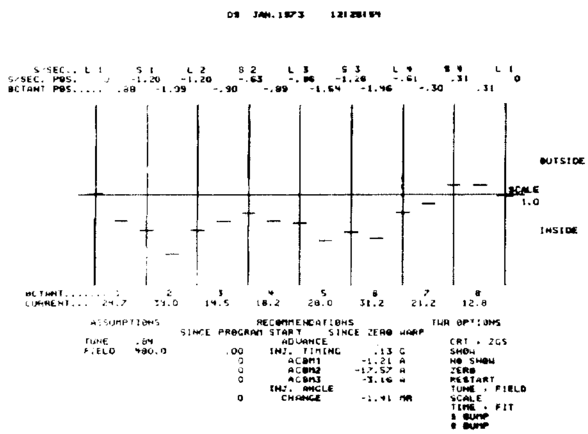

Fig. 2 CRT Display at Program Start Time Showing the Kicker Coil Effects on a No-Warp Accelerator

The orbit positions are shown only for the straight sections and octant centers since they produce a usable graph while requiring only 16 sets of computations. The orbit warp graph does not pretend to show the actual beam position but rather the effect of the kicker coil currents on whatever warp exists naturally due to various irregularities. Therefore, this type of plot is only useful for comparison with other similar plots to point up differences which occur from time to time due to operator tuning. To use the display in an orthogonal manner, that is to see the orbit displacement effect due to current changes, the operator calls for a zero warp condition to be assumed by typing the option word "zero." A display similar to Fig. 3 will now appear. It is obtained by subtracting the present warp shape from itself and all subsequent warps to show only the effects of subsequent changes. The currents are unchanged, but the program recommendations "since zero warp" are now zero. This column of figures will show what changes to make in injection timing and steering (both in milliradians and the three injection achromatic bending magnet currents) while the lefthand column shows the net changes necessary since the program was started.

Use of the Program

There are two principle methods of warp manipulation available to the operator. He can employ single or multiple current changes and after noting their

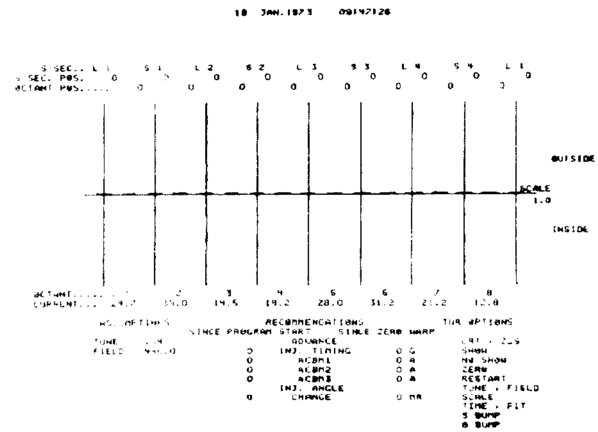

Fig. 3 CRT Display After a "Zero" Command Is Given Showing a No-Warp Condition -- Incremental Changes to the Existing Warp Can Now be Shown

effect, learns how to compensate for the undesirable effects. Since a means of visualization is provided, most operators can become quite adept in this procedure.

In addition, local orbit bumps can be created by specifying the location, size, and direction. The option words "o bump" (for a bump centered on an octant) or "s bump" (for a bump centered on a straight section) are typed in the first column followed by the bump size and polarity positioned in the proper column. The following sequence of inputs will result in the bumps shown in Fig. 4.

```
MODE    /1/    /2/    /3/    /4/    /5/    /6/    /7/    /8/
CRT     24.7   39.0   14.5   18.2   28.0   31.2   21.2   12.8
o bump         0.5 <--(operator request for a 0.5-in outside bump at octant 2)

s bump <-------------(no bump size given, so computer provides new headings)
        L1     S1     L2     S2     L3     S3     L4     S4 <--'
s bump                                     -0.6 <--(operator request for
                                                    a 0.6-in inside bump
                                                    at S3 location)
fit                          1.0 <--(operator request for a fiducial mark
                                     at 1.0-in outside at S2 location)
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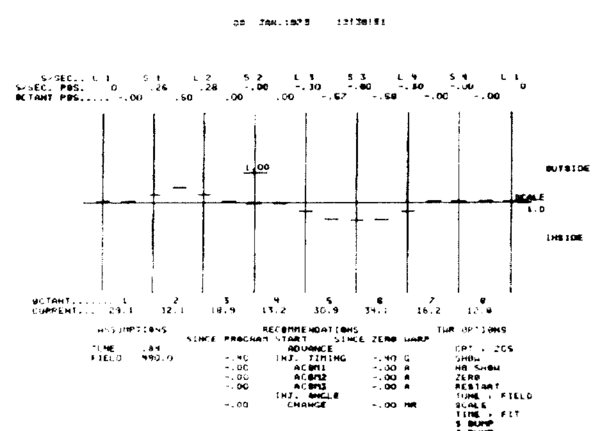

Fig. 4 CRT Display After a 0.5-in Outside Octant Centered Bump and a 0.6-in Inside Straight Section Centered Bump Have Been Requested

The orbit changes which result from octant centered and straight section centered bumps are limited to three and four octants respectively by employing simple geometric cancellation of the kicker currents based on the injection tune. Since injection timing and steering information are also provided, the operator can cancel the effects of poor matching and see the real effects of local orbit changes on circulating intensity.

Other information may be displayed with the orbit warp curve to aid the operator in steering decisions. The option word "fit" is typed in the first column followed by signed coordinates at any or all straight section columns. A fiducial line and dimension are displayed as in Fig. 4 at the S-2 location. These marks may represent measured beam positions obtained from the various ZGS electrode systems or even an intensity profile of beam loss information. A variation of this mode uses the option word "time" with the input numbers being the coasting time in microseconds from injection to the center of a split induction electrode. Utilizing the coasting time factor and the electrodes' survey information, the computer displays the same fit marks as above to represent the measured orbit warp.[3]

Visualization-Only Mode

Since not all changes to orbit warp conditions will be beneficial to circulating intensity, the operator may want to visualize and experiment without actually implementing the current changes. The option words "crt" and "zgs" will provide visualization-only or immediate implementation respectively.

Other Uses of the Program

As stated previously, both the injection tune and field are program variables and these can be changed to show their effect on beam position. In particular, the field can be raised gradually to show how the warp correction washes out with time. The program has also been used to study the effectiveness of orbit manipulation for ejection purposes at full energy. Of course, a derating factor must be used to account for the saturation effect of the magnet operating at about 20,000 G.

The next logical step for a program of this type would be to add an automatic curve fitting routine so that orbit locations could be specified directly. Such routines have been written and tested and could be incorporated if there is sufficient need.

Conclusions

The interactive computer program KICKER and its associated hardware systems have proven to be helpful both to daily machine tuning for optimum intensity and to detailed accelerator physics experiments. During the recent tuneup period following the titanium vacuum chamber installation (and during the preceding low-field dress rehearsal), the system helped to produce in a few shifts warp correction data which had taken months to acquire by the previous hit-or-miss methods.

References

[1] L. G. Lewis, Argonne National Laboratory, Computer Control of High Energy Accelerators, 1965 Particle Accelerator Conference, Washington, D. C., March 10-12, 1965, Published in IEEE Transactions on Nuclear Science (June 1965), Vol. NS-12, No. 3, pp. 1-8.

[2] M. Knott et al., Argonne National Laboratory, OMNIBUS-A Multiprogramming Executive System for the Zero Gradient Synchrotron Control Computer, 1969 Particle Accelerator Conference, Washington, D. C., March 5-7, 1969, Published in IEEE Transactions on Nuclear Science (June 1969), Vol. NS-16, No. 3, pp. 875-879.

[3] J. M. Bogaty, Argonne National Laboratory, A Fast Technique of Measuring Equilibrium Orbit Warps in the Zero Gradient Synchrotron at Injection, 1973 Particle Accelerator Conference, San Francisco, California, March 5-7, 1973, Session H.