ORTHOGONAL AUTOMATIC STEERING INTO THE ZERO GRADIENT SYNCHROTRON (ZGS) USING ACHROMATIC MAGNETS*

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Summary

In the past, steering of the 50-MeV proton beam into the main ring of the ZGS was performed empirically. The method was unsatisfactory because of the heterogeneity of the magnet adjustments. An algorithm was developed that described the orthogonal position of the beam in terms of exit position, exit angle, and position in the center achromat. Any combination of steering parameters can be made by adjustment of the achromatic magnets. The necessary modes of operation, functions, and readouts are combined in a consolette. The consolette is interfaced with the central control computer as an on-line, time-shared input/output (I/O) device. When a steering change is desired, the computer, via stepping motors, adjusts the four magnets for the required solution.

Introduction

The 50-MeV injector system of the ZGS is comprised of a current power supply (2 kA), three achromatic bending magnets (ABM), the inflector magnet, the electronic shunts for the ABM's and inflector, and the Main Control Room (MCR) controls and displays.

The purpose of the control system is to provide a repeatable and accurate adjustment of the injector system. Repeatability of adjustments is guaranteed by the use of an algorithm which will calculate changes in the magnet current; computations and commands are effected by the Control Data Corp. (CDC-924A) central control computer.

Algorithm

The algorithm was developed by E. A. Crosbie[1] and is given as:

Inflector exit position (ΔX)

$$\Delta X = -0.99860\, x_0 - 176.280\, x'_0 - 214.067\, \Delta I_1/I - 28.938\, \Delta I_2/I + 243.005\, \Delta I_3/I + 1.1292\, \Delta I_4/I - 1.1292\, \Delta p/p\,. \quad (1)$$

Inflector exit angle ($\Delta X'$)

$$\Delta X' = 0.0000637\, x_0 - 0.99016\, x'_0 - 1.35464\, \Delta I_1/I + 0.00184\, \Delta I_2/I + 1.35280\, \Delta I_3/I + 0.052336\, \Delta I_4/I - 0.05236\, \Delta p/p\,. \quad (2)$$

ABM-2 center position (ΔC)

$$\Delta C = 0.00000\, x_0 + 33.895\, x'_0 + 46.314\, \Delta I_1/I - 3.196\, \Delta I_2/I + 43.118\, \Delta p/p \quad (3)$$

where
x_0 = beam offset entering the achromats
x'_0 = beam angle entering the achromats
ΔI_1-ΔI_3 = a change in the ABM currents
ΔI_4 = a change in the inflector current
I = beam equilibrium orbit current
p = central momentum of the particle

General Description

The implementation of the control system was divided into three construction phases, each phase a part of a closed loop control system. Figure 1 shows the complete closed loop system and denotes the three construction phases. The construction philosophy permitted the most flexibility in the system implementation. Feasibility was verified (Phase I), the system became operational quickly (Phase II), and maximum operational capabilities were achieved (Phase III).

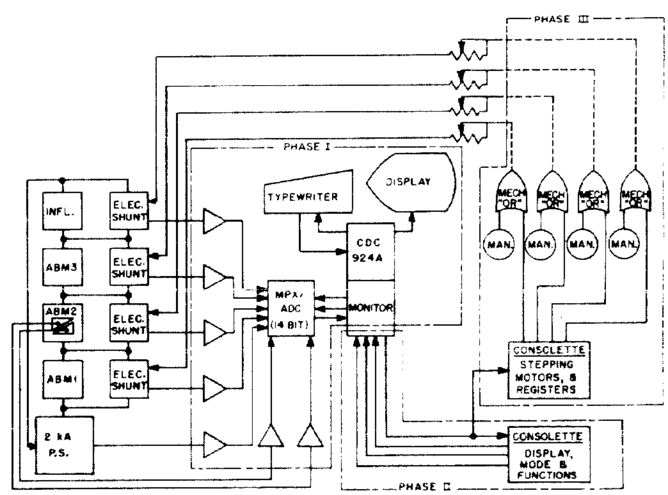

Fig. 1 Automatic Steering System Block Diagram (Including Phase I, Phase II, and Phase III Construction)

Phase I

The instrumenting of the steering system was the first concern. The power supply and each magnet have a 50-mV shunt for 2000 A; each electronic shunt has a 50-mV shunt for its capacity of 100 A. To achieve the greatest accuracy, the power supply shunt and each electronic shunt are instrumented. Thus, the value for each magnet current is the power supply value

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minus the shunt value. The shunt voltages are amplified for a full scale of 10 V.

In ABM-2, there is a set of pi electrodes for measuring the beam's center position.[2] The pies are used as a check against Eq. (3) and as a troubleshooting aid for linac-source central momentum changes.

The data are input into the monitor/924A central computer control system.[3] A software package was developed that displayed the measured values, the requested orthogonal parameters, and calculated current changes. This software allowed the operator to use the existing controls to institute regimented orthogonal changes in the steering. The time demands on the principle I/O devices of the computer, the display scope and typewriter, necessitated the next phase.

Phase II

The I/O equipment disadvantage was eliminated through the use of a monitor station as an I/O device. The I/O device has taken the form of a control panel or consolette. The consolette and its software package have all of the options available to the operator as before. Manual adjustments of the magnets can be made by the operator, but the time consumed and the accuracy desired make this difficult.

Phase III

The final construction phase consisted of closing the loop for the computer control of the injector system. The mechanical linkage for the manual vernier control of the four potentiometers was altered so that either the operator or stepping motors, on command from the computer, could vary them. The controls are designed for changes of 0.01 in in displacement (offset) and/or 0.1 mrad in angle (slope). Computer control can be disabled by means of a switch. Figure 2 shows the consolette.

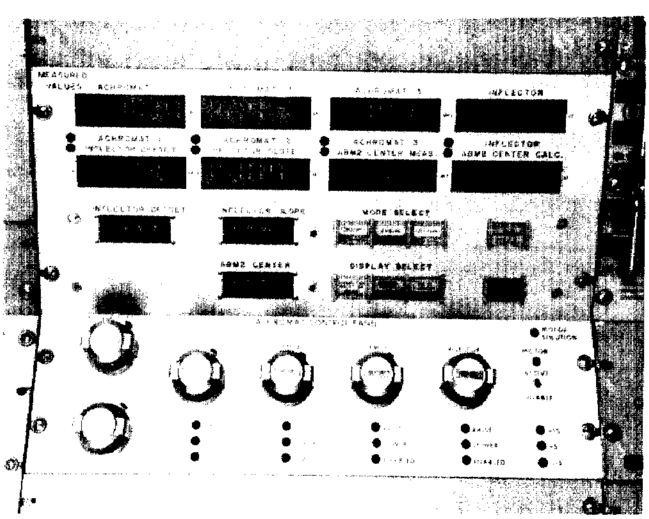

Fig. 2 Achromat Steering Controls

When a computer motor controlled response is requested, the three achromatic magnets and the inflector are adjusted simultaneously; control is initiated and completed within three ZGS cycles.

Panel Description

Figure 3 shows the layout in detail. The consolette for the steering controls is in two subassemblies: (1) the status panel (upper) is for display and mode selection, and (2) the control panel (lower) for manual/automatic adjustment of the power supply and magnets.[5] The status panel was completed for Phase II, and the control panel completed Phase III and the project. The status panel provides the nine flags for computer action through the use of the mode and display pushbutton switches.

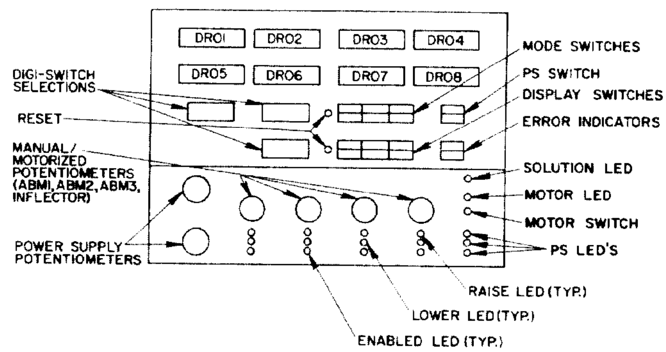

Fig. 3 Detailed Consolette Identification

The digital readouts (DRO) are

DRO-1 to DRO-4: Displays the measured values of the achromats and the inflector,

DRO-5 to DRO-7: Are duostate displays for either the steering positions or the magnet current solutions,

DRO-8: Is a tristate display that displays ABM-2 steering position, or inflector current solution, or the main power supply value.

There are three possible modes of operation: (1) manual, (2) solution, and (3) motor.

Manual Mode

This mode is intended for use when the operator wishes to randomly and manually tune the steering system. The data are updated once each ZGS cycle.

Solution Mode

This mode is used when the operator wishes to request a solution for steering parameters placed in the digiswitches. The operator has to effect the change manually.

Motor Mode

This mode is intended for use when the operator wishes to implement steering changes in an orderly manner. The operator selects, by means of digiswitches, the desired orthogonal solution. By depressing, momentarily, the "motor" switch, the computer is flagged for action. After computations (< 1 ZGS cycle), the computer will make two adjustments of the motorized potentiometers, a coarse adjust and a fine adjust. If a solution for the steering change is not possible (values exceed the power supply capability or values exceed the electronic shunt capabilities), alarm indicators inform the operator of this and await his further action; the motors are not energized.

Fabrication

The consolette's logic is TTL 7400 series mounted on commercial modular boards that were wire wrapped.[4] This allowed fast fabrication since only wiring lists and wire wrapping were necessary. All displays are light emitting diodes: DRO's and indicators. The displays are excellent in normal light as well as in the dimmed condition of the MCR. The potentiometers are double ended with one end connected to a digital vernier and the other connected, through a slip clutch, to stepping motors. The monitor station that was fabricated as a computer I/O device for the steering system can be expanded to service five more systems of similar complexity.

Total hardware cost for the system was $3,000.

Conclusion

The most significant improvement brought by this system has been the change in thinking of the operators. Steering corrections are done in a regimented manner in terms of finite orthogonal changes. The system is repeatable; and, thus, unsuccessful steering changes can be corrected back to original parameters in terms of orthogonal position.

This system, as described, served as an invaluable tool during retuning of the ZGS after titanium vacuum chamber installation. During the tuning period, this system made it possible for the ZGS operators not only to make sweep in injection angle and position without introducing additional unknown factors, but also allowed them to compensate for varying injection requirements while attempting to remove orbit warps.

Acknowledgments

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References

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