

CONTROLS FOR THE CERN INTERSECTING STORAGE RINGS

O. Gröbner, D. Neet, P. Rieben, B. Sagnell, G. Schaffer
R. Scholl*, K. Unser, P. Wolstenholme

CERN - Geneva - Switzerland

Introduction

The CERN Intersecting Storage Rings Project (ISR) was described by Kjell Johnsen at the Second National Accelerator Conference.^{1,2} The present paper describes some aspects of the control system for this project.

Outline of Operations

The two concentric storage rings with a diameter of 300 m, will be filled by protons which have been accelerated in the existing 28 GeV Proton Synchrotron (PS). The protons are extracted from the PS by a fast ejection system and then transferred alternatively to Ring I and Ring II of the ISR. After injection into the rings, the protons are stacked on the proper orbit by RF acceleration. The filling process may take about 20 minutes.

The beam transfer tunnel TT2 (Fig. 1) for filling the anti-clockwise ring has a branch off into another tunnel TT2a which passes under the ISR. This beam channel can be used, when the ISR is not being filled, to deliver fast- or slow-extracted PS beams to a new experimental area called the West Hall.

Beam channel TT3 has been added to provide for fast or slow ejection from the anti-clockwise ring. The fast ejection system of this ring can be used to stretch the 20 bunches of the PS pulse and the slow ejection system to provide virtually d.c. beams to the West Hall.

Each ring is equipped with a fast-acting magnetically-triggered beam dump, for emergency use and for routine dumping of beams which are no longer useful.

A significant factor in ISR operation will be that four cascaded machines, the 50 MeV linac, the 800 MeV booster (under construction), the 28 GeV synchrotron and the ISR must be working together properly for optimum results.

Main Design Criteria

In the large accelerators and other high-energy physics apparatus being built today, the required quantity of control equipment forces the basic design of the control system to be reconsidered. In such situations the techniques suitable for small systems cannot be indiscriminately applied.

The ISR has 300 magnet power supplies, 2 km of vacuum pipe with hundreds of pumps and gauges, and over 100 beam observation stations in the rings alone. In such a system, it is virtually impossible to display all the incoming data to the operator, or to effect control of the large number of elements in the usual straightforward ways. Information must be pre-processed and presented to the operator in a condensed form, if only to keep the operating area small enough to be overseen by one or two men. Controls must be highly multiplexed for the same reasons.

In conflict with the above requirements is the fact that the ISR is in itself an experiment and must have a very flexible control system: much of its equipment will pass through a long development period as will the control routines themselves. Any form of pre-processing or multiplexing tends to reduce flexibility, by reducing bandwidth and destroying information. By using a digital computer as the pre-processor or the multiplexer some of the flexibility can be retrieved, but to an extent which is limited on economic grounds.

Also when a large number of instruments has to be installed, they must be inexpensive, reliable and simple.

In the ISR control system, extensive use will be made of time division multiplexing and digital computer control techniques. The input and output sub-systems for the computer are being designed to use a minimum of components, and all systems are as modular as possible for ease of maintenance. To help gain flexibility, for widely distributed control and monitoring stations a well-tested frequency division multiplex scheme will be employed.^{3,4} The man-machine interface will use multiple CRT displays, which can present a wide variety of information on vacuum pressures, beam position and current, magnet settings, and so on. Many of the controls will pass through the computer system so that each operation can become more sophisticated, simplifying the panels themselves. Even making extensive use of these "general" displays and controls, however, the number of panels is still quite large.

The bulk of the control electronics is installed in 9 auxiliary buildings which will normally be unattended. These buildings are re-

*On leave from SLAC - Stanford University

quired so that auxiliary equipment can be kept out of the main ring tunnel, because access for servicing in the tunnel is severely limited: a stacked beam which represents perhaps 10 hours of potential running time should not be dumped.

The operations are controlled from the storage ring control room (SRC) in which beam transfer, ISR and switchyard controls are located. The rack layout (Fig. 2) is based on the following concept. Two straight rows of consoles house all control and monitoring panels used by the operators for established operational routines. Special devices and additional displays for machine development purposes, as well as back-up electronics are arranged in rows of racks at the sides. The controls for the various areas are arranged in separate consoles, and two or three operators may be active simultaneously. The computer is linked to various control and monitor units in the consoles, but the bulk of the computer equipment and the program development area is clear of the operational consoles.

Adequate rack space is provided to develop the RF control system. These controls are not described in this paper.

Vacuum Controls

To obtain the design aim of the ISR, i.e. maintaining two circulating beams of 20A over periods of hours requires an average pressure of about 10^{-9} Torr in the nearly 2 km long vacuum chamber. The necessary pumping capacity is provided by more than 300 pumps of different types, ranging from turbomolecular stations to sputter ion pumps, titanium sublimation pumps and additional cryopumps located at the intersecting regions used for experiments. Furthermore, all parts of the vacuum chamber must be baked up to 300° C to remove surface contamination. Such a bake out involves several weeks of work and once it has given good results one will avoid repeating it at all cost. The controls of the vacuum system, therefore, are designed such that possible accidents involving the whole ring can be avoided.

The ISR vacuum chamber is subdivided into 24 sectors separated by fast acting valves. The operation of the valves is interlocked such that they can only be opened if the pressure in both neighbouring sectors is below a given value. If this pressure is exceeded, the valves close. However, when there is a stored beam, the closing must be delayed until the beam dumping mechanism has been triggered.

The design pressure will be obtained by using 260 sputter ion pumps with a nominal speed of 400 ℓ /sec. The use of 4 turbomolecular pumping stations per sector makes it possible to start the ion pumps at pressures below 10^{-5} Torr. In this way, the required high voltage power is reduced and small and economic power

units can be used. Large power supplies capable of operating a number of pumps in parallel were not chosen, because of system reliability and servicing; also individual pump currents must be available for pressure monitoring during the bake out period, as well as for sector valve interlock functions.

During normal operation the pressure in the vacuum system will be outside the range where the sputter ion pump current can be used for pressure monitoring. Therefore, approximately 500 ultra-high vacuum gauges of the Bayard-Alpert type with modulator will be used in the 10^{-7} to 10^{-11} Torr range. The gauge control units will be installed in the equipment buildings, some 100 m from the gauge heads. The gauge readings and a set of status signals from 250 control units can be transmitted to the SRC where suitable displays and recording facilities are provided in which the control computer plays an essential role. Graphical representations of the pressure distribution along a selected sector of the ISR can be shown to the operator and slow pressure increases which might indicate a developing fault in some piece of equipment can be detected by the computer and brought to the operator's attention.

Besides the total pressure, also the composition of the rest gas in the vacuum chamber must be known. This information is obtained by a set of 24 rest gas analysers to be recorded and displayed in the SRC.

Beam Observation

Luminescent screens and secondary-emission grid monitors,⁵ will be used for setting up the beams in the transfer channels, while routine checking is done with pick-up electrodes and beam current transformers. Oscilloscopes and television displays will be provided on the control console to observe these monitors. The pick-up electrodes and current transformers will also be connected to the computer for checking permanently on drift in beam position and on possible beam current loss. The secondary-emission grid monitors can be examined by the computer when matching or emittance measurements need to be carried out.

Fifty four RF pick-up stations for horizontal and vertical beam position measurements in each ring, are provided in the ISR. The radio-frequency group is responsible for constructing the pick-up stations and provides a wide band video display system in the SRC. The analogue output from these devices, some 216 signals per ring, will be scanned by the computer. Injection and stacking impose a high accuracy on orbit measurement over the full 150 mm radial aperture. The overall system is capable of measuring the beam position on any one selected revolution with a precision of a few millimeters. When integrating over many revolutions for closed-orbit measurements the precision will be better than 1 mm.

The computer will be used to correct and normalise the readings, and to print out or display the orbit data. A variety of displays can be generated, for example (1) on the first turn for injection adjustment and rough magnet correction, (2) on the second or on a later turn, (3) the closed orbit, (4) the difference between the first turn and the closed orbit in order to see betatron oscillations caused by incorrect injection.

Two high precision current monitors with an operating frequency range from d.c. to at least 50 kHz are installed in each ring. They measure the beam current at injection and throughout the entire stacking operation and up to a circulating beam current of 20 amperes.

A wide band beam current transformer with lower absolute accuracy and pass band from d.c. to more than 50 MHz is foreseen. It will complement the high frequency information obtained from the capacitive pick-up stations and should be useful for beam diagnostics.⁶

Occasional measurements of the intensity distribution of the stacked beam versus momentum will be performed by causing the RF system to pass an "empty bucket" through the stack.⁷

Steering of the colliding beams in the intersecting regions so as to optimise interaction rate may be performed by observation of interaction rate monitors: this technique is useful for measurements of the effective beam heights.⁸

Development work is in progress on a gas ionisation profile monitor to measure position and size of the stacked beam.⁹

Magnet Power Supplies

The beam transfer system magnets are powered by about 100 d.c. power supplies. As parts of this system are shared by the ISR and by the West Hall, it must be possible to set-up to a new energy quickly and accurately. Each power supply is controlled by a digital-analogue converter with 4 or 5 decimal digit setting and a drift of a few parts per million per month.¹⁰

The two main ISR power supplies, used to drive all the bending magnets in each ring in series, are also equipped with 5 digit digital-analogue converters.

In each ring, about 90 auxiliary supplies are required to drive pole-face windings, orbit correction magnets, sextupoles etc. A high degree of coordination is needed for the adjustment of these auxiliary power supplies, for such functions as adjustment of Q, orbit correction and acceleration of the stacked beam.

This coordination requires that all the power supplies can be adjusted simultaneously so as not to lose the stacked beam. Therefore, a different type of digital analogue converter is used, with an incremental drive, analogous to a potentiometer driven by a stepping motor.

All power supplies will be provided with local manual controls, with direct manual controls in the SRC, and with control possibilities via the computer. These latter range from simple instructions to adjust one supply in incremental or absolute terms, to more complex functions such as gradient adjustment. The role of the computer will be to deal with these direct commands from the operator, to memorise and repeat settings, to compute new settings and to monitor power supply performance.

Orbit Correction Controls

There are 36 separately-energised correction windings on the main magnets in each ring for radial orbit correction. Vertical correction is achieved by vertical displacement of pairs of bending magnets, to move adjacent focussing and defocussing units in opposite senses. Again, 36 such pairs are provided, so as to achieve efficient correction for closed-orbit distortions up to the ninth harmonic, to which the machine is most sensitive.¹¹

The Computer System¹²

A dual Ferranti Argus 500 computer system is on order. These computers have a 24-bit word length, multiple accumulators and multiple index registers, and a 1 μ s store cycle time. Each computer has 16,384 words of core store, and a 640,000-word disc store of the sealed, fixed-head type.

Data collection systems include a digital scanner which can interrogate 8,000 contacts, eight times a second, and a random-access analogue scanning system using several voltage-frequency converters and running at a total of about 600 readings per second. These systems, and some control channels, make extensive use of the diode-matrix technique for simple and reliable transmission of M x N signals over an M + N core cable.¹³

The computer will be interfaced to many of the control and display panels in the SRC, in addition to driving printers, a digital plotter and a versatile graphical display system. This latter is able to drive several screens at once, and will form the primary display for ISR orbit data, vacuum system status and pressure readings, and other extensive systems. One display will be transmitted through the closed-circuit television network for remote display.

Control commands passing via the computer system will use either special-purpose control panels or general-purpose equipment. In the latter case; instructions may be given to the computer in a high-level language for easy programming of special requirements.

Personnel Protection System¹⁴

Special problems arise in design of the personnel protection system (PPS) due to the presence of a stored beam and the many modes of possible operation. These modes will be changed frequently, and the system must be flexible enough to cope with this without loss of operating time. The ISR and beam transfer tunnels have been divided into four zones (Fig. 1) with interlock and safety conditions defined for each. Access to these zones is independent. Access to zone 1 (the rings themselves) must be prohibited as long as useful beam is stored, since the beam cannot be quickly restored after interruption. This is in contrast with normal accelerators, where access can be granted by momentarily interrupting operation.

Acknowledgement

We wish to thank the various groups in the ISR Division for their cooperation.

References

- ¹ K. Johnsen, "The CERN Storage Rings Project" IEEE Trans. NS 14, No. 3 1161 (1967) - Proceedings National Particle Accelerator Conference.
- ² W. Schnell, "The CERN Intersecting Storage Rings", ISR-RF/68-29.
- ³ B. Sagnell, "A Distributed Multi-Channel

Communications System for Flexible Remote Control and Telemetry", CERN 64-21.

- ⁴ B. Sagnell and K. Unser, "A Distributed Data Acquisition System", ISR-CO/67-35.
- ⁵ D.A.G. Neet, "Beam Profile Monitors for Fast and Slow Extracted Proton Beams", Paper H-32 at 1969 Particle Accelerator Conference.
- ⁶ K. Unser, "Beam Current Transformer with DC to 200 MHz Range", Paper H-39 at 1969 Particle Accelerator Conference.
- ⁷ W. Schnell, Private Communication.
- ⁸ S. van der Meer, "Calibration of Effective Beam Height in the ISR", ISR-PO/68-31.
- ⁹ B. Vosicki, "Beam Profile Indicator", ISR-VA/BV/ck, April 1968.
- ¹⁰ J. G. Pett, "A Digital to Analogue Converter for Controlling Magnet Power Supplies in the ISR Beam Transfer System", ISR-BT/68-9.
- ¹¹ L. Resegotti, "Provisions for the Correction of Closed Orbit Distortions in the ISR", ISR-MAG/68-30.
- ¹² D.A.G. Neet, P. Wolstenholme, "Proposal for Use of a Digital Computer for Data Handling and Control in the ISR Project", ISR-CO/68-6.
- ¹³ B. Sagnell, P. Wolstenholme, "Remote Data Collection Systems for the ISR", ISR-CO/68-24.
- ¹⁴ P. Rieben, "Proposal for a Personnel Protection System for the ISR", ISR-CO/68-39.

