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THE IMPACT OF COMPUTER CONTROL ON THE PERFORMANCE OF THE CERN INTERSECTING STORAGE RINGS

by

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Summary

The ISR control system has now developed to a state in which it relies heavily for both routine operation and machine development on the control computer. This gives significant benefits in security of operation, as well as easing the task of controlling a very complex installation. The computer has enabled the machine development team to concentrate on beam studies, without worrying overmuch about calibrations and reliability of individual components, so that they have been able in three years to surpass the original design objectives.

1. Initial Objectives

The basic design document for the Intersecting Storage Rings was the design study published in 1964. Planning of the control computer system started in 1967, at about the same time as the excavation work in the ring tunnel.

At that date, although some process plants were being controlled by computer, the experience in accelerator laboratories of computer control was not very encouraging. Small computers were only just changing in technology from discrete to integrated circuits, and the high reliability we not take for granted had not been proved.

Furthermore, the large proton storage rings would be unique, and it was feared that a long and arduous commissioning period might be needed to achieve any sort of useful performance. The computer system could not be allowed to present its own commissioning problems at the same time.

The computer system was therefore planned as a complement to the manual facilities, to be installed in parallel and used whenever its performance was superior.

In designing control systems for both computer and manual control, a number of compromises had to be accepted. For example, digital-to-analog converters for control of beam transfer line power supplies were made to accept decimal settings. Extensive general purpose control systems were ruled out, in favour of individual solutions for particular groups of hardware. To minimise the cost of the control system and to avoid undue duplication, the design principle adopted was of data transmission systems linking the control room to remote equipment buildings, having both a computer connection and a manual control panel in the control room. The bulk of the expense was in the command link and in the remote equipment, and as these were common to the manual and computer controls, they could be developed and tested in parallel with the computer system.

The equipment initially selected for computer control was that in which sheer quantity appeared likely to overwhelm operators, and in which individual monitoring or adjustment was inappropriate or excessively laborious. The main examples selected were power supply adjustment, in which nearly 300 power units had to be set, beam observation (e.g. of the closed orbit) and vacuum system supervision. This latter choice surprised some people at the time, but turned out to be very important indeed. The vacuum system had 300 pumps and a similar number of gauges, making an over-all appreciation of the vacuum situation difficult without reasonably sophisticated data reduction and presentation.

Flexibility of the computer software was taken very seriously and an elaborate file structure was adopted for all data, even when it seemed fixed, rather than incorporating coefficients into the programs. In this way, very drastic changes to machine operating conditions could be introduced without revisions to programs. This approach contrasted markedly with the suggestion made in the ISR design study for a function generator controlling tune through the pole-face windings, and is one of the key elements in the success of the computer system.

The mixture of manual and computer controls precluded a control room layout based on two or three computer consoles, and the solution adopted was to insert computer terminals in three positions in the operating area, which was nevertheless kept fairly small.

A long-term objective of complete computer control was agreed, to provide a framework for gradual development of the system, and all controls and instrumentation were designed with the future computer connection in mind.

In 1968, the problems and costs of setting up a network of computers appeared considerable. The gradual implementation coupled with a requirement for flexibility to meet unforeseen requirements caused us to choose a single computer of reasonably high power: a 24-bit machine with a 1-microsecond core store cycle. A fast-access disc store and a graphic display system were also specified. To permit continuous hardware and software development, as well as to assure a high level of serviceability, a second computer was included. The order was placed in November 1968 and the computers delivered 12 months later.

2. Early Experience

Tests of the first part of the beam transfer line from the CPS started in May 1970, and at the end of that month the Storage Ring Control Room (SRC) was first used. The computer had been installed some six months previously, and was used to take data from pick-up electrodes and compute beam positions. This work continued for the rest of the year. As the beam transfer system was commissioned, the power supply setting and checking programs were put into operation, and in September when the TT1 transfer line was first tested over its 350 m length, the magnet currents were set by computer, and a STEER command, requesting the computer to adjust the beam position at a particular luminescent screen, made the next proton pulse pass right through the line.

In November, some tests were performed on one storage ring, and in the following January both rings were put into operation. Initial tests were at low momentum (15 GeV/c) at which the magnet profile should have given the design conditions. During the next few months, working points in the Q_H-Q_V diagram were tested, followed by working lines. By April 1971 there was data for ten lines stored in the computer for 15 GeV/c and rather fewer for other momenta. After quite an amount of trouble with the power supply control system, it settled down to become reliable and the development of working lines went ahead smoothly. A suite of programs was made available for manipulation of the machine tune, and development progressed rapidly[1].

During the same period, orbit measurement and correction facilities were put into operation. It was realised that the orbit measurements could not be used as a basis for setting up collision of the beams at the intersections, and a procedure was established for sweeping the two beams vertically across each other at the intersection, and monitoring the interaction rate. This permitted a steering resolution to better than 0.5 mm and also provided a measurement of effective beam height and hence of luminosity.

From the very beginning, steering in the beam transfer system was performed through the computer, which was told to make certain corrections at particular monitor positions, and worked out which correction element to use and by how much to change it. At the injection point to a storage ring the adjustments are very delicate, as the residual betatron oscillations about the closed orbit must be minimised. As the manual estimation of injection errors was rather subjective, and because of the four adjustments required per ring (angle and position, referred to a standard point, in radial and vertical senses) an automatic procedure was instituted, performing in a few minutes an operation which initially could take up to an hour. This closed-loop adjustment by the computer remains a major task at present, and efforts are continuing to improve its accuracy, which limits ISR luminosity directly.

Later in the year, currents of a few amps were stored in the ISR, and the vacuum was found to be very critical in limiting the current achievable. The computer had been connected to monitor pump currents and gauges because of the immense complexity and size of the vacuum system, and because the calculation of true pressure for each Bayard-Alpert u.h.v. gauge required an elaborate calibration sequence. Soon, programs which had been expected ro run a few times a day were in operation every 15 seconds, monitoring pressure rises at the beams were stacked, and the programs had to be revised to allow them to run even faster. The computer terminal installed by the vacuum racks in a corner of the control room became the centre of attention.

By the end of 1971 the computer was performing many of the operational and machine-development functions, and since then its use has been extended and consolidated.

3. Beam Control

Many essential functions of the computer may be grouped under this one heading, which will be discussed as an illustration of our current position.

Periodically, after a long shut-down or a realignment, a major orbit correction is needed. The procedure for orbit measurement is assigned to a set of push-buttons, and the measurement is made on five successive pulses from the CPS and averaged. If a correction is thought necessary a data file is sent to the CERN central computers for analysis, and a list of corrections is sent back to the ISR for application by the control computer. A further check of the corrected orbit is made, and this is normally satisfactory[2].

At the start of each run, when beams are to be set up for physics, the orbit is again checked and the small errors in vertical position at each intersection are taken out. This establishes a reasonably accurate collision of the beams when they are later stacked.

The main magnets and the correction windings have been set up to standard values selected from many alternative tables stored in the computer, and provided that injection has been optimised, the stacks can be built up. If a high luminosity is required, the "8C" working line may have been selected: this calls for adjustment of the working line at intervals while the stack is being established, so as to compensate the curvature introduced by space charge[3].

Alternatively, the stack may be established at 26 GeV/c, and then accelerated (by phase-displacement) to 31.4 GeV/c. In this case a dialogue is established between the programs which progressively alter the main magnetic field and correction winding currents, and the radio-frequency system, the whole procedure being automatic[4].

A luminosity check is commonly required, and in this case we either perform a high-accuracy calibration at one intersection region, or a steering adjustment at about six of our intersection points simultaneously. At first, the orbit bumps were introduced by means of equal energisation of two magnets (per ring) placed approximately one quarter-wavelength upstream and downstream of each intersection, but now we use four-magnet bumps which have minimum second-order effects outside the intersection of interest, and we also correct the coefficients from our knowledge of the actual betatron wavelengths at central orbit. The bump amplitude can be perturbed by space-charge effects, and these are also compensated for.

When it became necessary to minimise background by altering the angle at which the beams passed through the intersection, a set of coefficients was calculated and the existing program was able to handle the manoeuvre, replacing millimetres by milliradians.

By means of the standard procedures outlined above, we have been able to establish beams of the required characteristics, with low decay rates, at any required energy, and to place them exactly in the intersection region, to achieve high luminosity, as a routine operation. To illustrate the effort this represents, it can be remarked that there are 35 programs for dealing with the set of 200 ISR power supplies (excluding beam transfer and experimental magnets) and there are 87 data files of settings for these power supplies stored in the computer memory. To relate this to the over-all project, the total number of programs available to run on the control computer exceeds 400.

4. Faults

When dealing with an intricate machine, the question of fault-finding is important. In the computer system, all control programs have been made to follow a rigorous protocol. First, status signals are examined, to see whether the requested actions may be performed. If conditions are incorrect, the operator is warned. Next, it is usual to check on present settings and to calculate the new settings: the details vary with the system. The correction is then made, and after a short delay a new series of measurements and checks is initiated. Sometimes a fine adjustment is required, and this can be automatic, but if it seems excessive the operator is warned of a possible calibration problem.

This may seem very obvious, but it is one of the major differences between digital computer control and pure hardware control, in which checking of outputs is rare. There are several available techniques for achieving the sort of coordinated adjustment of multiple outputs which we often need, the digital differential analyser being admirably suited to present-day technology, but the computer retains the great advantage of reporting on failures in the external world and becoming obviously paralysed by internal failures.

In a project such as the Intersecting Storage Rings, where a simple test of new operating conditions may easily require two hours, security of operation is of the greatest importance in facilitating machine development. One must be quite certain that perturbations introduced are exactly those desired and that their amplitudes are recorded.

It is fair to state that, although in such a complex machine as the ISR we have had our share of hardware faults, the computer has very often signalled and identified these at once, so avoiding waste of time checking a large mass of equipment to localise the fault, or worse still continuing in blissful ignorance.

A further aspect of computer operation is the routine supervision of equipment, with the aim of reporting on failures and drifts. At the ISR we have about 30 programs dealing with various classes of equipment, which run at appropriate intervals during the standby periods, filling, physics experimental runs, and machine development. These programs report to an alarm printer. This is a little unconventional, in that control computers in accelerators or nuclear power stations often use cathode-ray display tubes for alarm presentation. At the ISR, perhaps on account of the very long time cycle of refilling the machine, we have chosen to print all alarm messages and to keep them for some time.

5. Operator Communication

At present, we have four computer terminals in the control room. Each has a key-board, a small printer and a text display screen. These facilities are supplemented by a graphics display system with two screens, four fast printers (for alarms, logging of routine happenings, vacuum and general purposes) and various data processing peripherals.

At each terminal, so as to ease the task of the operator, there is a set of 12 buttons: four of these are for special purposes such as stopping the program currently executing at that terminal, and eight are general-purpose buttons to which can be assigned any named file of eight commands. At present we have 165 such files of commands in the computer store, and the system is intensively used.

One noticeable omission is the knob. We have no digital computer-linked knobs at present. The characteristics of the storage ring seem to make knob-twiddling undesirable: there are very few control knobs in the entire control room. When an adjustment is desired, it is usually necessary to calculate its magnitude and then to apply it exactly, and it may well be an elaborate quantity involving setting of 40 parameters in a smoothly coordinated fashion.

6. Conclusion

At the ISR, computer control is well established, to the extent that the simpler routine operations would be virtually impossible without it, and complex operations now common would be ruled out altogether.

As our knowledge of the machine improves, and as the machine performance is pushed ever higher, the flexibility and security achieved by computer techniques becomes ever more important.

In three years of operation, the storage rings have been brought to performance levels exceeding the design objectives, and the operational procedures now handled as routine are in advance of early predictions. The computer has played a vital role in permitting the accelerator physicists to concentrate on studying the beams without being confused by irregular or unknown behaviour of the hardware. The development time saved by adopting this tool can only be guessed, but must certainly be appreciable.

7. Acknowledgements

I must express my appreciation of the hard work and continued enthusiasm, despite many early discouragements and difficulties, of the staff of what is now the ISR Computer Group, and also for the co-operation and trust of the entire staff of the ISR Division.

8. References

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