

EXPERIENCE WITH COMPUTER CONTROL APPLIED TO THE CERN INTERSECTING STORAGE RINGS (ISR)

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(presented by R. Keyser)

Abstract

The paper discusses briefly the computer system and its interfaces with the ISR and with operators. In this framework the applications of the computer in the ISR activities are described.

1. Introduction

When the control system for the Intersecting Storage Rings at CERN was being studied¹⁾, it was decided to incorporate a computer for the supervision of the large quantity of hardware involved. The computer functions are to present data, suitably processed, to the operators and to carry out changes in settings as requested. The computational activity in these two functions can be considerable, as the computer may be asked for example, to present data on beam orbits analysed into harmonic components of the ISR circumference, and then to apply a control correction aimed at reducing some of these components to zero. Thus, our computer system is made to perform closed-loop functions, at present closely supervised by the operators, and as experience is gained in the behaviour of the ISR, these and others will be performed as part of complete setting-up routines.

The major applications of the computer system are the control of 300 power supplies in the beam transfer lines and the storage rings, data collection from over 100 beam observation stations and data collection, recording and display on an extensive ultra-high vacuum system. These and other applications described in this paper are operational and routinely used by the operators.

2. Computer Hardware

The computer used is a Ferranti Argus 500 which has a 24-bit word length, 8 sets of accumulators for multi-programming convenience, 24,576 words of 1 μ s core store and a fixed head disc store of 640 000 words capacity. The 34 ms worst-case disc access time permits several programs a second to be run.

Operator communication is achieved by means of three teleprinters and a graphic and alpha-numeric display system, driving 4 display screens.

General purpose input systems comprise a digital scanner which reads up to 8000 contacts at up to 600 m from the control room, and puts all the data into the computer memory each 112 ms, and 12 analog scanners in the various equipment buildings, reading up to 3500 signals selected by a reed-relay scanner and digitised by integrating d.v.m. techniques.

There is no all-embracing output system, each major control system being interfaced as a separate computer peripheral. Minor requirements are met by using a general-purpose unit, together with a small range of digital input and output cards. A Camac system has been added in order to facilitate the interfacing of small control systems. A data link network between the computers used for ISR physics experiments and the Argus will use Camac hardware.

For maintenance back-up, and also for software and hardware development work, we have installed a second Argus 500, with only 20 480 words of core store, a disc store, a teleprinter and a card reader.

3. Software

A multi-programming executive has been developed at CERN³⁾. This contains drivers for the various input-output devices together with schedulers for the core store, the display module store and the disc. Under control of the executive, up to seven application programs may be in execution at a given time. Normally copies of all the application programs are kept on the disc and are brought into core store by the executive, according to requests by operators. However, there are a few programs which are core resident, primarily for monitoring purposes or as part of the interface between the operator and the system.

At present in the on-line machine, 12K of core store is dedicated to system coding, re-entrant routines, input-output buffers etc., and 4K to core-resident application programs leaving 8K available for sharing among disc-kept application programs. About half of the disc storage is so far filled with data and programs.

The decision taken early in the project to purchase a second computer has been fully justified by later experience. Although one important justification for the second computer was hardware back-up for the on-line computer, the main use of the second computer has been in permitting program development in parallel with hardware development or ISR runs. New application programs can be largely debugged in the second computer, although it is usually necessary to complete the check-out with access to the specialised instrumentation and sometimes under operational conditions (e.g. the presence of a beam).

To date all programs have been written in assembly language, the programming being confined to a small number of specialists rather than a larger number of occasional programmers. About 7 man-years

of programming effort have been invested, equally divided between system development and application programs.

4. Computer - ISR Interface

Rather than using general-purpose computer input-output systems for all control applications, we have preferred to regard each major sub-system as a peripheral, which is independent of the others as far as the computer interface. Where possible, manual control facilities are switched into the sub-system at the computer end of the data transmission link. Thus for little extra cost manual control facilities are provided the check-out of which largely tests the computer control mode. Our experience has been that where for economic or technical reasons this philosophy could not be followed the development has been more difficult than otherwise.

In purely monitoring applications, such as vacuum pressure display or orbit measurement, general-purpose scanning systems have been used. Here, we have found it highly desirable to allow the computer full access to all relevant status data, and to allow such operations as calibrations to be performed automatically by the computer.

5. Interface between the System and the Operator

The operator communicates with the computer via one of six terminals. Each terminal consists of a keyboard, printer and/or CRT. The operator commands a particular function by typing a line of the form

label : program name, clauses (parameter list)

The label, clauses and in some cases the parameter list, may be omitted. For example,

XSET (FS 26)

would set the auxiliary power supplies to the values contained in the file FS 26. All programs and files are identified by means of names of four characters.

Clauses in the command allow the operator to specify where his output should be sent or can request the command to be repetitively carried out at given intervals of time or on given PS pulses. For example,

LSVG, FP, IN = 1S(1M)1H (S11)

would run the program LSVG to list on the Fast Printer (FP) every minute for the next hour, the pressures in Sector 11 as given by the vacuum gauges.

While there are many mnemonics that an operator has to learn, together with their parameter lists, this is inevitable with a process that has so many diverse aspects as an accelerator. Naturally, the tasks of the operator is made as easy as possible and a number of aids are at his disposal.

Brief specifications of the programs associated with each system are available for display on the CRT screens. Often used commands can be associated with a set of buttons; pressing the button is equivalent to typing the command.

Editing facilities are available (back-space and delete). Further, there are instructions which will abort a program in execution or remove repetitive commands waiting to be completed.

It has proven to be essential to re-assure operators that everything is normal if any action takes more than a few seconds. Such messages are conveniently displayed on CRT screens.

6. Functions Already Implemented

6.1 Beam Transfer Channels

Magnet power supplies are set up by the computer for each run according to lists of values stores on the disc. The routines incorporate switch-on, magnet cycling and checks for correct functioning. Steering of the beam can be performed by specifying to the computer the number of mm the beam has to be displaced at a certain position detector (e.g. luminescent screen). It was in this way that the first beam was steered through channel T11. Further programs can record settings, or check them against a list and signal discrepancies to the operator.

Beam currents are monitored, and beam positions at the beginning and at the end of each channel are computed, by a program which takes calibrations of individual pick-up electrodes into account and performs periodic measurement of electronics' offsets. Beam currents, percentage losses and beam positions can be displayed or recorded as convenient.

Profile data from secondary emission grid monitors are read by the computer and can be used to compute beam emittances.

6.2 Injection

A standard set-up procedure is the optimisation of injection into a storage ring using closed-loop control to minimise the betatron oscillation amplitude. This is done by adjusting injection position and angle and predicting the minimum (the apex of a cone) in about five steps. The computer program quickly achieves excellent results and releases the operator from a delicate tuning procedure.

6.3 Monitoring of the Ultra-High Vacuum System

An important task of the computer is the supervision of the vacuum instrumentation. A variety of programs are used for producing lists or c.r.t. displays of sputter-ion pump currents, valve positions etc. The operator is able to shorten the lists by imposing restrictions such as currents greater than a given value, valves closed etc. Graphical displays

of the pressure around the rings are produced from the ionisation gauge readings (see Figure). Moreover, the computer can automatically calibrate the gauges by switching their modulator potential. Groups of gauges may be turned on or off.

6.4 ISR Working Line Adjustment ⁴⁾

The computer is able to set pole-face windings and other correction currents to a list corresponding to a specified Q_H-Q_V locus over the ISR aperture. Each list is established or modified by a program which computes and applies saturation compensation at high main magnet field, and programs which permit the operator to change Q and its derivatives.

6.5 Closed Orbit Analysis and Correction ^{5,6)}

The computer proved to be an indispensable tool in the presentation to the operator of orbit data. As in the beam transfer system, calibration of the pick-up stations and recording of the offsets in electronics can be performed by the computer. On request, 224 readings are taken from either ring, the beam positions are calculated and the orbit displayed.

Further programs are used to analyse the beam orbit into its harmonic components. A set of these harmonics may be selected by the operator, and correction magnet currents altered to reduce the amplitude to zero. A further orbit measurement and analysis will check the corrected orbit. The loop is at present closed in a number of stages by the operator, but it could be done by the computer in one action, should it be operationally desirable.

In this way, orbit corrections have been performed vertically and radially. Vertical correction has also been carried out by adjustment of magnet positions. Orbit analysis programs compute the required jack movements. The adjustments are controlled by the operator, supervised by the computer, which displays the positions of the magnets concerned. It carries out checks during the adjustment, exercising a veto on further movement if limits would be exceeded.

6.6 Orbit Bumps

The computer is used to produce vertical or radial bumps of a given amplitude. To do this, the necessary power supplies must be adjusted in a constant ratio to one another, in order not to disturb the stacked beams outside the bump area. This procedure is standard when setting up colliding beams for optimum luminosity.

6.7 Power Supply Supervision

The computer is used extensively in checking the correct operation of about 180 ISR power supplies and 80 beam transfer power supplies, both during a run when it checks for faults, drifts etc.

and in preparation for a run to establish correct performance of all functions, check that zero offsets and maximum currents are within tolerance, etc.

6.8 Logging Functions and Alarm Monitoring

During the ISR runs the computer sums the numbers of protons injected, dumped or lost due to various causes. This helps in compiling statistics on operation and in radiation monitoring.

Beam transfer and ISR magnet power supplies are monitored regularly and warning of faults, drifts, etc. are presented on a reserved alarm printer. Other important items, such as clearing electrode voltages, were incorporated in monitor programs as the need arose.

6.9 ISR Development

In addition to use of standard operational facilities, programs have been prepared for particular investigations, as for example beam current decay rate evaluation and current loss related to beam scraper position.

7. Further Development of the Computer System

Work is being carried out under four main headings :

- automatic setting up of the machine conditions. This is generally a two-stage process, the setting of standard conditions in a number of components followed by a fine tuning procedure. For example, the setting of the transfer line magnets is followed by optimisation of injection for minimum betatron oscillation. To automate the set-up of the ISR so as to achieve reproducibly high beam quality is one of our main goals.
- improvements and extensions to logging and alarm monitoring facilities.
- communication with ISR physics experiments. This project will link about a dozen computers on the CERN site through Camac modules.
- assistance in ISR machine studies. Further automation of measurements will give useful assistance to physicists and speed up their experiments.

8. Concluding Remarks

The computer has shown itself to be an essential part of the control system. It has proven very reliable. In this context, one may mention that files are kept on disc for many months and it is rare that their contents become damaged.

Since the commencement of running-in tests the computer has been used by the operators. The com-

missioning of the computer programs closely followed the installation and testing of ISR components. The computer system is now used extensively, both in operation and in testing of equipment.

For successful computerisation of an apparatus, it has been found essential that both hardware and software be complete. Incomplete computerisation of a control system often causes dissatisfaction. The last link may only require a small effort but may greatly enhance the performance.

The total investments including engineering and programming effort has so far stayed below 2% of the ISR construction cost.

Acknowledgment

On the human side, we have encouraged active involvement of other groups in the computer project, which is essential if full benefits are to be realised from the investment in time and money. We wish to express our gratitude for the many contributions from our colleagues.

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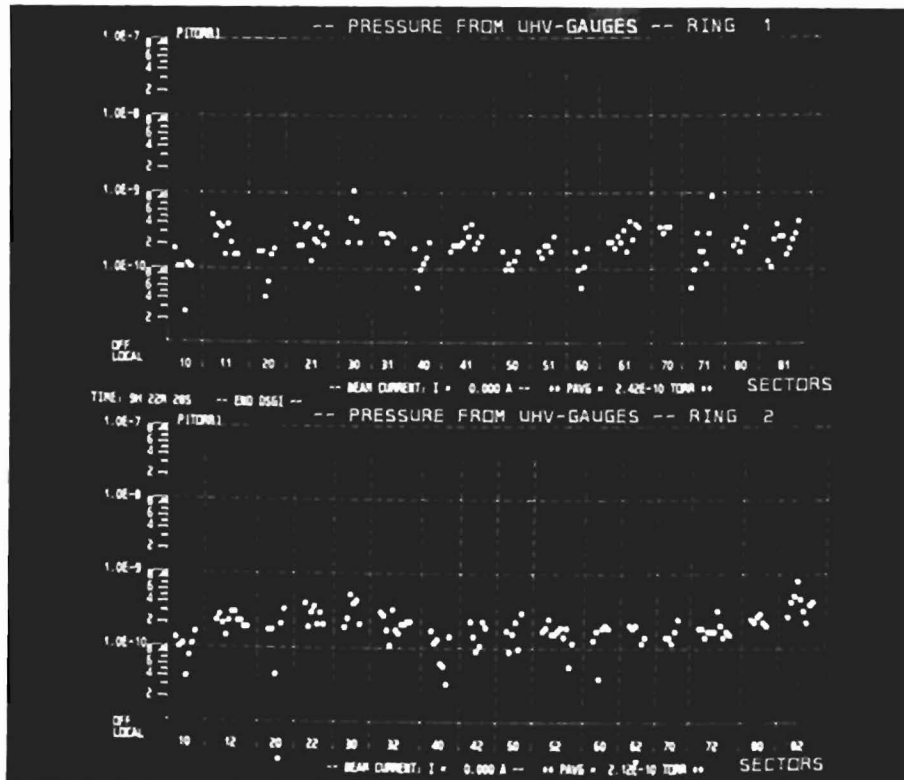


Figure
CRT display of pressures read from Ultra-high vacuum gauges.

DISCUSSION

M.J. KNOTT : In your "multi-programming system", do you mean to imply that more than one program can simultaneously time-share the C.P.U., or that many programs are simply "on call" by the operator ?

R. KEYSER : The system is a time multi-programming system, scheduling up to seven programs in core.

M.J. KNOTT : Can you also do off-line (background) tasks such as compiling at the same time ?

R. KEYSER : Since one of the seven tasks I mentioned above could be the assembler, the answer is "yes".

K. MALLORY : I am pleased to find that the ISR, being like SLAC essentially a "steady-state" machine, puts little emphasis on fast response from user programs.

G. SCHAFFER : We cannot consider the ISR as a steady-state machine in all respects, for example, not with respect to beam-vacuum interactions. We need to implement some fast triggered correlation study programs in order to analyse the situation on vacuum pressure instabilities and the mechanisms

that cause sudden beam losses. The development of our data-acquisition system towards faster response is included in our program of future work.

A. MILLICH : To what extent should one monitor beam quality rather than hardware which influences beam behaviour ?

R. KEYSER : At present, it is difficult for the computer to be told how to quantify the quality of the beam. If, for example, a badly stacked beam is produced, the experimentalists soon tell us and we restack. How it is determined that a stacked beam is deteriorating may be solved by asking the experimenter's computers over the data link that I mentioned. When some ideas are known about what causes deteriorations, then we may know what to monitor.

VAN DER BEKEN : The question of monitoring the beam or the hardware depends on the machine involved. For ISR, the loss of the beam might have severe results; therefore, monitoring the hardware might be wiser. In the case of the CPS, one pulse lost is less drastic and monitoring the beam might be acceptable.