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MAN-MACHINE INTERFACE VERSUS FULL AUTOMATION

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Abstract

As accelerators grow in size and complexity of operation there is an increasing economical as well as an operational incentive for the controls and operations teams to use computers to help the man-machine interface. At first the computer network replaced the traditional controls racks filled with knobs, buttons and digital displays of voltages and potentiometer readings. The computer system provided the operator with the extension of his hands and eyes.

It was quickly found that much more could be achieved. Where previously it was necessary for the human operator to decide the order of the actions to be executed by the computer as a result of a visual indication of malfunctioning of the accelerator, now the operation is becoming more and more under the direct control of the computer system. Expert knowledge is programmed into the system to help the non-specialist make decision and to safeguard the equipment.

Machine physics concepts have been incorporated and critical machine parameters can be optimised easily by the physicists or operators without any detailed knowledge of the intervening medium or of the equipment being controlled. As confidence grows and reliability improves, more and more automation can be added.

How far can this process of automation replace the skilled operator?. Can the accelerators of tomorrow be run like the ever increasing robotic assembly plants of today?. How is the role of the operator changing in this new environment?.

Paper presented at the
Computing in Accelerator Design and Operation Europhysics Conference
Berlin, September 20-23, 1983

1. Introduction

The operation of present day accelerators relies heavily on the use of computers. Their impact on accelerator control can be appreciated by noting how few operators are required on shift in spite of the considerable increase in amount and complexity of equipment to be controlled. The operators interface with the machine has been eased and made more sophisticated and some processes have been handed over to the computer for automatic control.

Using examples from the operation of the SPS this paper will show how the man-machine interface has been improved in all operations tasks, the directions in which automation have been made possible and those areas of operation for which there is still a long way to go.

2. What is accelerator operation

The Cyclotron was one of the first accelerators and was manually operated before the introduction of computers. The philosophy of operation and the controls were much the same as was to be found in any production process plant in industry. The equipment was patrolled and surveilled by the operator and values recorded or adjustments made as he did his tour of the building. He decided what needed to be adjusted and interacted with the individual elements of the accelerator : a multifaceted role which required considerable and varied skills.

Today our accelerators have much more equipment than before, and is distributed over a greater area, sometimes in inaccessible and hostile places. The number of parameters in the process has increased considerably and the modes of operation and the performance requirements are invariably at the limit of what is technologically feasible. Even the cyclotron of today is heavily dependent upon the use of its computer ¹⁾ with its needs for different energy/particle modes of operation beam matching, etc.

The accelerator operation itself is multiphased, with separate yet overlapping control requirements. These phases include the initial and subsequent commissioning phases, the steady daily production and the study and improvement phase.

Used in its most general meaning, the term "Operator", means, a person interacting with a physical system. Today's accelerator operator is not only the classical machine minder, but also the equipment specialist and the machine physicist. The man-machine interface and automation must assist him in carrying out his separate operational tasks.

The question therefore for today's accelerator designers is not whether or not the computer should be used but rather in what way they should be used to control the accelerator complex. Among the many questions to be answered by the designer and user is to what extent the operator must be part of the control loop or how successfully can the computer replace him. The balance to be found is between the open and closed loop systems of control, the man-machine interaction versus full automation.

3. Use of computers, extended hand and eye

The SPS consist of more than 10 km of tunnels on average of 40 meters below the ground containing thousands of individual elements. They are controlled by a network of computers to constrain, accelerate and deliver protons for the use of the European Particle Physics community. Protons at various energies up to 450 GeV are extracted for collision with stationary targets in external halls, caused to collide at 270 GeV with antiprotons inside the accelerator itself.

Individual computers are responsible for the control of the equipment in local zones or for particular parts of the process (acceleration, extraction, etc.) and communicate with the Main Control Room through the system of data links. The man-machine interface at the centre is a computer driven console whose programmes are in a tree structure and activated by means of a touch panel. The displays are all standard raster TV generated by microprocessor controlled CAMAC modules.

There are at present 35 computers in the network of NORD 10's and NORD 100's arranged in nodes which serve the Main Control Room of the SPS. A high level interpreted language called NODAL is used for the operations programmes which are written mostly by the equipment groups and the operations team.

How these many systems were brought together and used to control and operate the accelerator has been described in detail elsewhere.²⁾³⁾⁴⁾

The SPS is an example of how computer control of accelerators is being approached today.

- a) The operator no longer has to patrol the building to check the state of the machine and change the equipment settings. An effective surveillance and alarm system checks the state of the equipment every few seconds and reports any variation from the desired state to the operator. The operator then calls up the control of that element on his console and makes the necessary adjustments. This has been referred to as "the extended hand and eye" function of the control system.
- b) Files of equipment settings, can be saved on the computers, loaded and compared with previous sets. Complicated equipment functions are easily generated and modified according to operational requirements.
- c) Operator training and skills are greatly improved by the use of console programmes written by system experts or by members of the operations group. Protection against faulty manipulation is assured by limitations built into the software at the computers-equipment interface.
- d) Machine physics concepts are included in the computer programmes in a natural way and the operator, is able to correct the orbit, adjust Q, chromaticity, etc without the need to know what current is being sent to which dipole, quadrupole or sextupole in the ring.

These are some of the more obvious ways in which the man machine interface has been improved by the introduction of computers and the increased complexity of operation compared to our early cyclotron model has been made possible.

4. Development of use of computers towards automation of operation

A. Automation in the setting of the machine mode of operation

The setting up of the accelerator from a previously optimised state by loading files of equipment settings is a familiar feature of computer control. In addition sequences of programmes can be run by the operator, or more likely automatically, to change from one machine state to another. This is used in cyclotron operation when a sequence of energy scans is needed and in synchrotrons (for example Petra) when it is necessary to move from one working point to another via intermediate points to avoid resonances.

It is clear that the accelerator must be operated as an integrated process. All equipment must function not only reliably but in the way requested by the central control room. The required mode of operation must be communicated to the equipment and the equipment must be able to report back any deviation from this state.

In the SPS the Engineer in Charge chooses the machine mode from a list of possible modes of operation based on precomputed magnetic cycle of the main power supplies. From his choice a Master File is generated which can be accessed by all the equipment systems software. The master file contains all the information concerning the machine physics parameters, times in the cycle of injection and extraction, which zones will receive beam and when, etc.⁵⁾ The applications programmes for the individual equipment systems have a button "Update to Master" which adapts all the settings for the equipment thus changing voltages, currents and timings accordingly. In addition the machine mode requirements are distributed to all the local computers so that the required states of the elements are defined, surveilled and communicated back to the control centre in case of any malfunction.

The changeover from one state to another within a given overall mode of operation was a problem highlighted when the SPS runs in collider mode. Up to 24 hours were needed to produce enough antiprotons in the Antiproton Accumulator (AA) for a reasonable fill of the SPS for Physics.

The processes for ensuring their reliable and efficient transfer had to be well defined and implemented with the minimum of equipment malfunction and human error.

Antiproton transfer to and acceleration in the SPS is the most critical period and so a series of preparatory states of operation before the final transfer were identified.

The first was to extract protons from the SPS and transfer them to the CPS up the line that the antiprotons would use later. The second was to transfer pilot pulses of antiprotons and accelerate them. Finally the day's production of antiprotons would be transferred in 3 bunches at 26 GeV, accelerated and made to collide with 3 dense bunches of protons at 270 GeV within a time interval of about 25 seconds.

The change from one state to the next was carried out by a sequence of programmed tasks and checks in each local computer which was initiated from the centre. As operating experience grew so did the list of checks to be carried out and with it the efficiency and reliability of the transfer operation increased. A synchronous sequence of checks took care of the synchronisation of the 3 machines, AA, CPS and SPS.

This automatisisation of the transfer process was very successful: there were no losses of antiproton bunches due to the malfunction of equipment covered by this procedure. More details of the "Sequencer" are reported elsewhere in this conference by C. Saltmarsh.⁶⁾

However we are still a long way from the operations managers dream of a single button "SWITCH ON" which eliminates all the problems encountered after a long shutdown.

B. Automation of the steady state operation

After a setting up or commissioning period the accelerator normally enters a phase of steady running. In this production phase the operation looks most like other industrial production processes.

Minor optimisations of the particle production occur during this time, the status of equipment and values are recorded, usually automatically by the computer system, and the alarm/surveillance system informs the control centre of any abnormalities.

The steady state is a desired state of operation but often it is not achieved due to equipment failure or operational faults.

Frequently the time taken to diagnose a fault is far greater than the time required to correct it. The fault diagnosis and remedy for the cyclotron operator was far simpler than in our present day complex accelerator. However today with a good, well maintained alarm and surveillance system the operator is kept well informed of the state of the equipment and from his experience - aided by the control system text facilities for example - he is able to decide on the correct cause of action to be taken. Most alarm systems have the facility to eliminate consequential alarms to some degree hence highlighting the root cause of the malfunction. Other more advanced systems based on previous known fault conditions offer the operator a recommended course of action; not many systems correct the fault themselves fully automatically. There are particularly interesting developments in the nuclear power industry, post Three Mile Island, on fault diagnosis and correction. In the field of the automation of fault diagnosis

the computers can contribute in the future to improve efficiency of operation. With accelerator downtime at between 10 and 20% there is a strong incentive for further development of this application.

Production performance, equipment parameters recording, automatic log book entries are all aspects of the steady state operation that can and are being helped by the computers but are not yet fully automated. Control by voice commands seems a long way in the future. Perhaps the accelerator control would be a suitable test bed for the Fifth Generation Computers.

Some of the standard daily optimisation processes are being nearly fully automated and as an example of this evolution consider the steering of a beam down a beam line. In the SPS, this programme displays the position of the beam in mm in the horizontal and vertical planes each time it passes the monitors in the two independent planes. The operator chooses one position and corrects the displacement by changing the current through the corresponding steering magnet upstream of the point selected by the computer. The process of operation has been well modelled to make it simple for the operator to understand what is required from him.

However there are certain limitations in the model:

- a) there is no guide to the operator as to how much current should be put into the magnet corresponding to a given mm displacement at one point.
- b) his action at one place can cause displacements to be worse at others.
- c) throughout the time that he is steering with this programme the quality of the beam is reduced because of some blowing up of the beam by the monitors.

The skill and experience of the operator is relied upon to carry out the task quickly and efficiently. The task in fact has not been sufficiently well modelled and for this we have to return to the design of the beam line and include in the model more of the underlying machine physics.

An automatic programme has now been implemented which takes the measurement of the beam properties, emittance etc., and the displacement of the beam at all positions down the line. Knowing the lattice transfer matrix and its inverse, the required currents to be modified are computed. The whole line is then resteeered. The model is sufficiently good that the steering process can be completed with two iterations taking only a few pulses of the machine.

At the SPS the operator is still offered the final decision to accept the new currents although with added confidence in the programme and equipment reliability this man machine interaction can be eliminated. The next step would be to let the control system fully optimise the line whenever it sees the need. The necessary algorithms for this step have not yet been worked out.

C. Automation, machine physics and modelling

There are immediate reactions from machine physicists and others when one talks about the automation of studies on the accelerator. After all, studies by definition, imply an uncertainty in direction and results. There is a logical sequence of studies first then automation. Nevertheless, machine physics investigations on the accelerator require man-machine interactions and with the power of the computers available, the potential for easing the burden on the machine physicists is as great as for helping the other accelerator operators. In the end we will not expect to see full automation in this field but will surely see much more and more powerful man machine interaction.

The machine physicist would like to communicate with the accelerator in his own particular way. His design model centres around the behaviour of the beam in terms of betatron Q values, bucket sizes, chromaticity, etc. He does simulations on larger computers which allow him to interact in terms of these beam parameters and produce "normalised" machine parameters which the equipment specialist translates into hardware. Once the hardware becomes a reality in the form of an accelerator, the machine physicists are again called upon to help commission and develop the machine. The machine physicists need to measure and modify the beam parameters using the control system to translate these requests into volts and amps in particular items of equipment. The modelling used for designing the accelerator can be then usefully transferred directly for its control and operation.

Take for example the correction of chromaticity in the SPS:

The machine physicists' model identify three major components in each plane contributing to the chromaticity of the machine, the natural chromaticity which is constant through the cycle, a term which reduces with increasing energy coming from remanent field effects and a term proportional to the rate of change of field, the eddy current contribution. Sextupoles in arranged family groups, are used to correct these and any other unknown effect which individually contribute to the horizontal and vertical chromaticity correction depending upon their physical location in the accelerator.

The computer, via the applications programme, automatically converts the desired correction into particular currents in the sextupoles at well defined times through the cycle. Once this relationship is established and programmed the machine physicist or operator can ignore the existence of sextupoles (the alarm surveillance system will warn him of any equipment faults) and can interact with the accelerator only in terms of his familiar machine parameter, chromaticity.

To set the chromaticity the physicist must first make measurements on the beam.

These measurements require the concerted use of kickers and beam monitors, timing modules and computers, data links, CAMAC and multiplex. There are many possible sources of error which can lead to faulty measurements results. The principles of control used for setting the machine in a given mode need to be applied to these measurement subsystems. The computer system is better adapted to this complicated routine task than the human operator. The machine physicist should need only to specify his measurement and the system should guarantee the correct result. Until this becomes operative, no automatic correction will be possible.

Conclusion

The computer has made possible the efficient operation of today's accelerators and the operator role has considerably changed from the pre-computer days. The man-machine interaction has become more than just the ability to bring the control of equipment to the operator in the central control building. The tools for understanding the working of the accelerator have become more sophisticated and the accelerator equipment can be controlled as an integrated process. Many of the routine operator tasks are carried out by the computers and the operator relieved of the drudgery is thus freed to study those aspects of development of the machine performance not yet covered by the system with a view to including his findings in tomorrow's automation.

References

- The computer aided control system of the VICKSI Accelerator
W. Busse, IEEE Trans Nuc Sci Vol NS-26 No.2 April 1979
- The Design of the Control System of the SPS
M.C.Crowley-Milling, CERN 75-20
- Experience in the Control System of the SPS
M.C.Crowley-Milling, CERN 78-09
- Controlling an Accelerator - The operation viewpoint
V. Hatton & G. Shering, CERN SPS/80-12 (AOP)
- Master file 1983
R. Lauckner, SPS/AOP/Note/82-9
- A Multi-Processor, Multi-Task Control Structure for the CERN SPS
C. Saltmarsh, SPS/AOP/Note/83-8, This Conference