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AUTOMATIC PROCEDURES IN THE CPS MULTITURN SHAVING EJECTION

A. Krusche, H. Riege, G.C. Schneider*

Summary

Protons are supplied from the CERN PS to the SPS with the multiturn shaving ejection, which is one of the most complex CPS ejection processes. Computer control is not only used to provide the basic switching and adjusting functions, but also to introduce automatic feedback procedures. Whenever the actual state of certain ejection system components, including the proton beam, deviates from the desired state, such procedures are initiated by the computer control system. Automatic recovery of ejection equipment is started after power failures and intermittent faults. The ejected beam intensity is tuned and the shaving ejection efficiency is maximized by closed-loop real-time optimizations. Experience shows that successful procedures of this kind depend strongly upon reliable diagnostic instrumentation and on-line real-time diagnostic software. Fast convergence and safe behaviour are prerequisites. The merits of these automatic procedures are weighed against the considerable implementation effort.

Introduction

The continuous transfer (CT) system delivers protons from the CPS to the SPS by a fast shaving multiturn ejection, which has been described earlier[1,2]. The equipment involved and the principles of the CT are schematically shown in Fig. 1. The key function consists of a programmable fast staircase orbit bump[3] (FOB), by which slices of the proton beam are switched across an electrostatic septum deflector (ES31) in a number of steps each lasting one PS revolution. This results in an ejection spill three to ten times longer than the revolution time of the circulating beam. The basic objective is to fill the SPS in one or more batches with a beam as uniform and stable as possible.

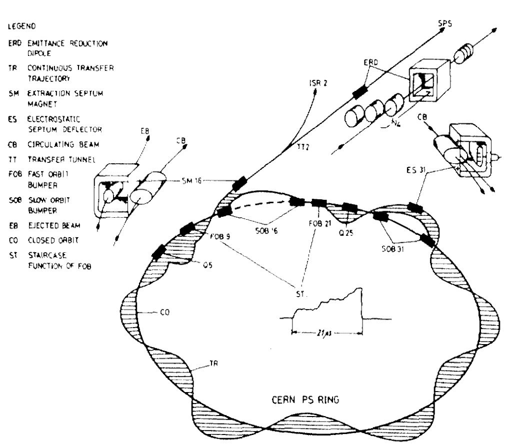

Fig. 1 - Synoptic diagram of continuous transfer process.

Automatic Procedures

Environment and principles

The control system which has been designed for the CT ejection is described in Refs. 2 and 4. It is built around a PDP 11/40 computer with a CAMAC interface to the ejection equipment and several CRT terminals and TV screens forming the man-machine interface. The control software is embedded in an RSX11-M real-time system. To a large extent it is written in an interpreter language. The basic control philosophy consists in mapping the desired reference status of the ejection parameters (equipment and beam) into a data base distributed over the different CT subsystem control tasks. This allows comparison of the actual, measured parameters with their desired reference states at any time and speedy recovery from deviating situations by automatic correction. Automatic procedures are defined here as closed-loop correcting or improving processes which are carried out by the control system without operator interaction.

The digital control of beam and equipment parameters in on-line closed-loop feedback systems is based on the precision and stability of the instrumentation elements involved. The beam diagnostic monitors have sufficient redundancy incorporated. The analog and digital signal processing modules have been designed for minimum adjustment, recalibration, and maintenance time. This was achieved by periodic automatic self check and self-adjusting techniques, when the necessary accuracy and stability could not be obtained by standard feedback techniques. To give an example, the temperature and time-dependent input offset drift of the fast gated signal integrators is periodically and automatically compensated at the hardware level[5]. Without a highly reliable instrumentation of the beam diagnostics and the fast bumper control hardware the closed loop beam optimizations described below would have given less valuable results.

Automatic recovery

Automatic recovery procedures provide for fault tolerance in different parts and levels of the CT ejection system. They represent a kind of "self-repair" of system functions after intermittent faults such as power failure, spurious parasitic effects due to the very noisy high current and voltage pulse environment, and slow drifts of equipment parameters (voltage or current levels). The basis for auto-recovery is the regular on-line surveillance of the relevant key parameters. Automatic recovery can be dangerous and even make certain operations virtually impossible, if applied under all circumstances. In the CT system auto-recovery is generally initiated a few times; if unsuccessful, the system remains in the fault condition and the operator's intervention is required.

The electrostatic septum deflector ES31[6] (Fig. 1) is an example for a CT subsystem, which undergoes a fully autonomous recovery after power failures, temporary vacuum rise, over-current faults due to spurious sparking, or slow HV voltage drifts. A recovery process may take more than 10 minutes and imply a sequence of thousands of CAMAC commands resulting from the properties of the septum and the electrostatic Van de Graaf band generator power supply.

Regular on-line diagnostics detect any deviation of CAMAC register contents, and correction routines restore valid reference values after intermittent faults. Examples are the 30 dual preset counters of the CT timing subsystem[7]. Other CAMAC modules, such as display drivers, are sometimes accidentally blocked. Constant surveillance allows reset commands to be sent from recovery routines whenever this happens.

* CERN – Geneva, Switzerland

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A final example is taken on the software level. The whole control system is synchronized to the PS cycle by event driven interrupts. In case of faulty multiple interrupt sequences the SW system can arrive at a state which leads to a total system crash. Automatic identification of such states allows the control system to be shut down properly and an automatic cold-start of the CT computer to be initiated.

CT beam intensity optimization

The shaving process is normally described in the horizontal phase plane. The ejected beam intensity is a function of beam size, particle distribution and orbit deformations, mainly stemming from the fast staircase orbit bump and can hardly be expressed in analytical form. Manual adjustment for a constant ejected intensity is laborious, because the operator has to approach this aim by successive trials, one step after the other, and to average cycle to cycle beam fluctuations and intensity modifications. The automatic ejected beam intensity optimization program acts upon all staircase steps at once and is able to converge within 20 to 30 PS cycles to an optimum. This, ideally, would be a constant intensity over the whole ejection length. Fig. 2 is a schematic lay-out of the closed loop. Fig. 3 shows a well adjusted staircase bump current, together with the respective ejected beam spill. The ejected beam intensity measured by a beam current transformer is conditioned by a specially developed filter, which integrates over time intervals corresponding to one PS revolution. This method eliminates the sensitivity to intensity modulations and allows the digital acquisition by one fast sampling ADC.

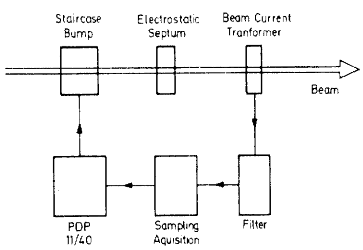

Fig. 2

Basic loop of CT beam intensity optimization procedure.

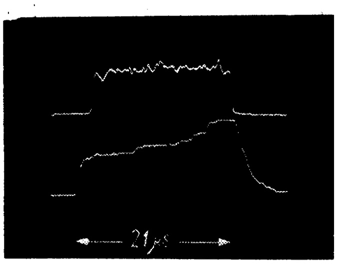

Fig. 3

a) Ejected beam (optimized) signal from beam current transformer.

b) Fast bump current signal.

After a set of 4 measurements "bad" beam pulses are rejected in comparison with the best pulse, which is the one nearest to the calculated mean value. Furthermore, the number of acquisitions is made a function of the beam fluctuations in order to improve the statistics under unstable conditions. The feedback algorithm is a linear approximation of the shaving process and takes into account the interdependence of the ejected turns.

The loop gain was maximized by relating it to beam size, which in turn depends on beam intensity. Before sending new reference values to the staircase bump generator all values are checked against hardware limits. In general, however, hardware checks could be reduced to a minimum, since the beam behaviour represents a much more sensitive check of the optimization procedure. Therefore, computing power resources are not over-stressed and modifications to the equipment require minimal software changes.

CT Extraction efficiency optimization

The ES31 deflector (see Fig. 1) acts as a peeling device (Fig. 4a) and its septum represents an obstacle to the proton beam during the shaving process causing proton losses on the septum and secondary losses around the PS ring. These unavoidable losses depend strongly on the relative angle α between the septum and the beam direction (Fig. 4b). Hence for all beam conditions an optimum angle exists which leads to minimum losses.

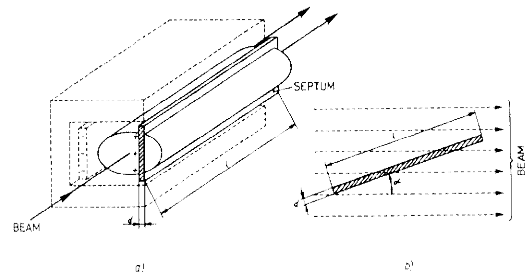

Fig. 4 - a) Beam shaving with the electrostatic deflector ES31.

b) The septum acts as an obstacle to the beam with an effective cross-section proportional to $d + \ell|\alpha|$ (for small angles α).

A fully automatic on-line optimization has been implemented as part of the CT control system[8]. By continuously varying the septum angle around its initial reference value and measuring the efficiency together with the momentary angle value at each ejection instant, the optimum angle can be deduced from the measured data (see Fig. 5) by a least squares fit. Checks are performed on the optimization and other relevant equipment data to exclude dangerous angle settings in the case of abnormal beam fluctuations, equipment failures, or other doubtful situations. The efficiency optimization delivers an accurate result in less than 5 min , with negligible disturbance of the beam. Normally this optimization procedure is scheduled to run automatically every 4 h. However, it can be initiated or interrupted at any time.

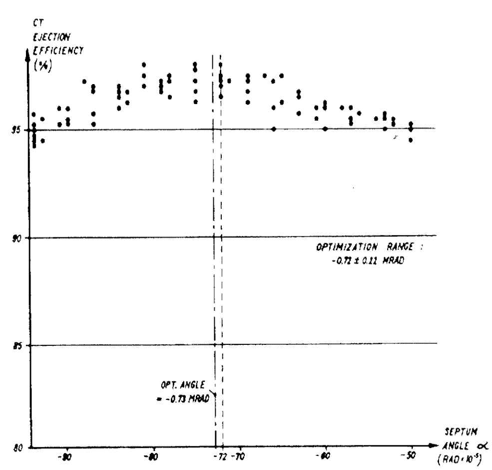

Fig. 5 - Plot of efficiency distribution measured during two angle-scan cycles around nearly optimum position.

Experience

CT System reliability and performance

The unavailability of the CT ejection system measured during 5000 hours of scheduled CT operation time was less than 30 h [9]. The unavailability of the CT control system during the same period during which many developments took place rated less than 0.3%. This figure was even reduced to about 0.1% when the ejection and control equipment, as well as the control software remained unmodified. The considerable decrease of down-time can be clearly traced back to the implementation of the automatic recovery procedures in the control system.

The beam intensity optimization was the program most frequently initiated by the operators (70% of all requests!). It strongly contributed to the CT performance improvement and to the SPS satisfaction. Experience with the extraction efficiency optimization shows that 1 to 2% of efficiency are gained when the procedure is scheduled regularly. In other terms this gain represents a mean reduction of 20 to 50% of the total CT extraction losses. The regular application of the efficiency optimization also decreases the long term variations of measured efficiency from 1% to 0.2%. The recently introduced multibatch filling of the SPS at high proton intensities underlines the merits of the optimization for reducing radiation and increasing equipment lifetime in the PS.

Safety and convergence

The development of automatic procedures can be justified only when a net gain in safety and performance during routine operation is obtained. In the PS-SPS environment, where proton production time is precious, such procedures may represent a considerable risk, if convergence towards reasonable end results under most circumstances is not provided. This kind of convergence not only implies a well converging mathematical algorithm for the relevant process, but also has to protect the equipment from faulty automatic settings. Surveillance of beam and equipment behaviour before and during the automatic process provides the necessary security.

An important aspect of automatic optimizations in process control is the speed with which optimum conditions are reached. If the procedure takes much more time to arrive at an acceptable result than would a skilled operator, the procedure can be considered doubtful.

Conclusions

The merits of the automatic procedures developed for the CT ejection system have clearly been demonstrated. Based on a reliable lay-out of beam diagnostic and equipment instrumentation, as well as on the systematic implementation of on-line diagnostic software, the automatic recovery and optimization processes maintain high availability and performance of extraction. Routine operation is simplified, speeded up and the risk of faulty operator manipulations minimized. These advantages are not without some drawbacks. The development of automatic procedures costs serious effort in terms of instrumentation and software. On-line diagnostics SW represents 30 to 40% of the total CT control system SW. Temporary risks of deterioration in the ejection process could not be excluded during implementation and test periods of the order of months.

Automatic recovery and on-line optimization are considered as the most rewarding outcome of the CT control system. Weighing merits against drawbacks such procedures should be repeated, even more extensively, on any similar future system.

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