THE SPS FAST ACQUISITION SYSTEMS - BEAM POSITION, BEAM LOSS, CHARGE DETECTORS

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SUMMARY

The control of a large pulsed machine like the SPS needs the acquisition of a great number of data taken at precise timings along the cycle. To get this compatible with the facilities provided by the SPS control system, the fast acquisition systems are split into three stages: hardware acquisition, global data transfer to the computer, followed by selective treatment. Some examples are given for the three larger SPS systems of acquisition: beam position, beam loss and charge detectors.

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INTRODUCTION

The SPS accelerator is a large pulsed machine. The characteristics of the beam, circulating all round the 7 km of circumference of the machine and along the several kilometers of beam transfer lines, are given by a large number of beam monitors. For instance, along the SPS ring, are located 216 beam position monitors and 216 beam loss detectors. In the transfer lines, beam intensities, positions and profiles are measured by secondary emission devices using thin foils. Each foil, whose signal has to be measured, is linked to a charge detector. More than 700 charge detectors are installed along the West extraction and West beam lines out of a total of 2000 units needed for the whole SPS system.

As the SPS accelerator is a pulsed machine, the beam characteristics change during the cycle and could also change from cycle to cycle, therefore measurements in the cycle have to be made at specific times. For instance, the position of the beam on its first revolution in the SPS could be different from that of its closed orbit if the injection trajectory did not coincide with the closed orbit.

Also, the closed orbit is not the same at injection, during acceleration or at maximum energy. The pulse duration of the injected or fast extracted beam in the transfer lines lasts a few microseconds only, during which time all the measurements have to be made. Moreover, several measurements of hundreds of detectors have to be made in a cycle in order to set up or control, for instance, three different extractions for three different experiments in the same cycle.

The SPS control system\textsuperscript{1)} uses one general purpose computer for each sextant and some computers located in an auxiliary building (injection, extraction, RF, etc...) or in the main control centre (console, display, alarm, etc..), each dedicated to a specific function. All these computers are interlinked in a starlike configuration to a Message Handling Computer. They are controlled by a real-time operating system, which supports an interpretative language called NODAL\textsuperscript{2)}. Any interpretative language although
a very powerful tool for writing flexible application programs and transmitting programs written in one computer to be executed by another, is too slow for fast acquisition. The NODAL statement for one single acquisition requires about 4 ms. Avoiding the interpretative language and using the assembler language already takes more than 1 ms to access a single piece of hardware via the general purpose multiplexing system (MPX) and standard system routine. To gather data faster, it is necessary to take maximum advantage of the 'Direct Memory Access' (DMA) facility.

While the DMA is simply a digital transfer of data without any treatment, a preliminary work has to be performed in order to select the analog channel and convert the data from analog to digital. The selective mode for addressing the channels being time consuming, only a global and sequential mode is simple and compatible with the DMA.

It was therefore decided to split the fast acquisition and treatment of a large amount of 'instantaneous' data into three different steps:

1. **The acquisition** by itself, which has to be done at the same time for all the data. A pure hardware solution has been chosen for it, using external analog or digital memories.

2. **The transfer** of data to the computer, which has to be fast and precisely timed to release the external memories for the next acquisition. It is done globally through the DMA facility.

3. **The treatment** of data, which is selective according to the needs of several NODAL application programs. It is performed by special 'Data Module Subroutines' (DMS) written in machine code language and providing the maximum flexibility in accessing data transferred at different times.

The purpose of this report is to explain the principles of acquisition, transfer and DMS treatment of the three larger SPS systems of acquisition: beam position, beam loss and charge detectors. Some examples of applications are given.
1. **DATA ACQUISITION**

The control system of the SPS power supplies of the main dipoles and quadrupoles is stable enough to give a precise relation between the beam energy and time in a given cycle. Therefore by distributing a 1 kHz clock train synchronized with the SPS cycle, it is easy to refer an acquisition at a given energy to a given timing expressed in millisecond units after a given event, e.g. the injection event\(^3\). Timing modules can be preset to the values by using the MPX linked to the local computers\(^4\).

Once these modules are initiated by NODAL commands, they generate during each machine cycle either two pulses at the preselected timings or a time window of duration equal to the difference between the two pulses, starting at the timing of the first pulse. These pulses trigger the whole acquisition system.

1.1 **Beam position detectors**

Each beam position detector consists of two electrodes\(^5\). The difference ($\Delta$) between the two signals coming from the two electrodes and their sum ($\Sigma$) are generated down in the tunnel by a passive hybrid ring on the accelerating frequency (200 MHz). After several treatments (frequency change, amplification, demodulation) in two separate electronic chains, each signal $\Delta$ and $\Sigma$ is sent to a voltage to frequency converter whose output is sent to a CAMAC counter. A special CAMAC module called 'sequencer', driven by a time-window, opens simultaneously the input gates of all counters connected to the beam position detectors at the same time and for the same duration (fig. 1). After the end of the time-window, each counter will contain a digital word proportional to the $\Delta$ or $\Sigma$ signals. By setting the window duration to 23 $\mu$s (one SPS revolution) or 1 ms ($\sim$ 40 SPS revolutions) the $\Delta$ and $\Sigma$ data correspond to a one-turn trajectory or to the closed orbit. With three timing modules, the counter gate can be opened three times each cycle, thus providing three separate acquisitions (fig. 2).

1.2 **Beam loss detectors**

A beam loss detector consists of an ionisation chamber located near the vacuum chamber in front of each main quadrupole\(^6\). The signal is
integrated during each cycle, and the integrator is considered as an analog memory which can be acquired 4 times in a cycle as described in Chapter 2.2. Two timing modules provide 4 pulses triggering 4 acquisitions, via the Sequencer Module. A third timing module provides the Start and Reset of the integrators (figures 3 and 4).

1.3 Charge detectors

Each signal coming from a secondary emission monitor is integrated by a charge detector. The principle is similar to the beam loss integrator with four possible acquisitions per cycle, plus a start and reset of the integrators. In addition an internal clock, obtained by dividing the 1 kHz SPS clock by 20, acts on the integrator in order to hold the value during 5 ms every 20 ms while the signal is allowed to reach its integrated value during the 15 remaining ms (figure 5). With the acquisition timings being given in units of 20 ms, the 5 ms holding time ensures that the conversion and transfer of all data is done at the same effective timing corresponding to the beginning of the 20 ms period, independent of the channel.

2. THE DATA TRANSFER

As indicated in the introduction, DMA modules take care of the data transfer for each system. A DMA module has four programmable registers. One register is the word count, set at initialisation to the maximum number of data to be transferred at a given timing, and decremented by one after each data transfer. The second register holds the address of the location in the computer where the data has to be transferred. It is incremented by one after each transfer. At initialisation it is set at the address of first location in the current acquisition table. The third register contains the requested mode of operation of the DMA and its status after each transfer. The fourth one contains the CAMAC command to access the module which holds the data to be transferred. Full hand-shake synchronizes the operations of the sequencer, the DMA and CAMAC modules which gather the data. The latter are counters for beam position detectors (fig. 1) and FET multiplexer units (FET MPX) followed by 10 bits analog to digital converters (ADC) for beam loss and charge detectors (figure 3).
When the word count register reaches zero, an interrupt (LAM) is sent to the computer which executes a real-time program to re-initialise all involved CAMAC modules so that they are ready for the next acquisition. Of course, there is one real-time program for each DMA.

To increase flexibility and ensure synchronization with the cycle another interrupt is sent by each acquisition system to the computer via a CAMAC module (JIR 10) once per cycle. The associated RT-program resets all CAMAC modules so that they are ready for the first acquisition. The JIR 10 module consists of a 16-bit interrupt register and a 16-bit mask register. By setting or not a bit of the mask register, the corresponding input interrupt is enabled or disabled. Being enabled, an interrupt (LAM) is sent to the computer which, by a dedicated driver, branches to the real-time program associated with the corresponding input interrupt. The JIR 10 driver is common for the 16 possible input interrupts while there is one real-time program by interrupt. A detailed explanation of this driver is given in the Annex.

2.1 Beam position detectors

The CAMAC system used for beam position detectors is shown in fig. 1. The sequencer and module JIR 10 take care of the triggering of data transfer and synchronization with the machine cycle. The sequencer, when driven by a timing pulse, triggers the DMA module which reads sequentially as many counters as are preset in its word count. When the latter comes to zero an interrupt is sent to the computer, which starts a RT program. Its task consists in resetting the counters and restoring the DMA registers. Thus the DMA is able to respond to the next trigger of the sequencer.

The module JIR 10 sends an interrupt to the computer when the reset pulse distributed by the master timing arrives. A RT program is then started to initialize fully the whole CAMAC system. Thus whatever happened in the previous cycle, the acquisitions are resynchronized with the new cycle.
2.2 Beam loss detectors

The CAMAC system used for beam loss detectors is shown in fig. 3. The tasks of the sequencer and JIR 10 module are very similar to those carried out by the corresponding modules described in previous section, so much alike that JIR 10 module is physically the same. However the data transfer is a little bit more complicated because the data are available as analog signals and not as digital data as is the case for the beam position detectors.

Thus the sequencer must first trigger an ADC which samples the first channel of the first FET multiplexer and which at the same time forces the latter to select the next channel. When the conversion is terminated, the ADC informs the sequencer that the data is ready to be fetched out. Then the sequencer triggers the DMA which transfers the data from the ADC register to the computer and at the same time forces the ADC to start a new conversion. This interleaved timing sequence ensures the fastest data transfer and it is specially vital for the secondary emission detectors. The effect of the zero reaching in the DMA word count register and of the reset pulse are similar as in the previous section, the only difference being in the number and type of the CAMAC modules to be reset.

2.3 Charge detectors

The layout and operation of the CAMAC system used for charge detectors is the same as for the beam loss detectors, the only difference being in the number of sub-systems, most of the time larger than one per computer. Moreover there are only two acquisitions for charge detectors installed in the injection line, beam dump line or in the main ring. The other detectors are acquired four times to allow easy monitoring of different extractions in the same machine cycle.

3. THE DATA TREATMENT

It has been shown that, once the transfer is done, all the data are sequentially available in a resident table associated with a given acquisition. The data treatment, which is selective according to the user's needs,
is based upon the principle of Data Module Subroutine (DMS)\(^1\) which is a subroutine written in machine code language and addressable by NODAL. The DMS gives access or control - one at a time only - to any equipment defined by its 'N-value', and several characteristics of the equipment are available by defining the property ('\# PTY'), according to the typical statements to read or write a property: \(> \text{SE A} = \text{DMS (N, \# PTY)} \) or \(> \text{SE DMS (N,\# PTY)} = A.\)

There are 3 DMS, one per type of detector, called DETP (Beam position), DETL (Beam loss) and DETN (charge detectors). As any DMS, they are not resident but located in a core-load kept on the local drum. Moreover they are designed to communicate with the resident tables and enable or disable the real-time programs in response to a specific property (i.e. \# ENB). They may also provide the difference between two acquisitions belonging to the same cycle.

For instance, a statement such as \(> \text{SE A} = \text{DETL (N,\# 41)} \) will give to A a value equal to the difference between the 4th acquisition and the first. If the first acquisition is done before the beam injection and the fourth after the beam dump, A represents the total dose whatever the integrator's offset may be. \(> \text{SE A} = \text{DETL (N, \# 32)} \) could correspond to the 'instantaneous' dose around a fast extraction.

The acquisitions may be taken at three timings for the beam position monitors and at four for the beam loss and secondary emission monitors. The performances and flexibility of such a system are shown in the following examples of application.

3.1 Closed orbit displays

The first timing used for the beam position monitors is fixed at the injection to permit beam observation at this critical moment.

All the other timings may be changed on request, using the facilities provided by the application program TSLOT (see fig. 2). The second and third timings available for the beam position monitors are used to explore
the beam behaviour at different moments of the machine cycle (fig. 7),
and the difference of two orbits at two different instants. In particular
the second and third acquisitions give precious information on the bump
excited during the slow and fast extractions (fig. 8).

3.2 Beam loss display

The first and fourth timings used by the beam loss monitors are fixed
so that the automatic sum-up of the differences between the fourth and first
acquisitions gives the total radiation doses over a certain number of machine
cycles. Thus the first timing is set before the injection and the fourth
after the beam dump.

The remaining two timings available for the beam loss monitors are
used mainly to explore losses incurred between two instants (fig. 9) of
the cycle.

3.3 Profile display from secondary emission monitors

All the four timings available for the secondary emission monitors
used in the extractions and transfer lines may be changed at will. As
shown in fig. 5, the program TSLOT gives the user the possibility of fram-
ing three extractions in the cycle (typically a slow, a fast-slow and a
fast). Figure 6 gives an example of a profile averaged over the complete
slow extraction and obtained by displaying the differences between the
second and first acquisitions.

Finally it is important to note that the software has been written
so as to ensure that the acquisition used in computing the required differ-
ences, belong to the same machine cycle, regardless of the moment when the
NODAL application program comes to fetch them up.
REFERENCES


5. R. Bossart, L. Burnod, The SPS beam position and closed orbit control (to be published).


Interrupts management

The CAMAC module JIR 10 is used to manage the interrupts required to synchronize a large number of equipments with the machine cycle. These equipments are the power supplies for the orbit correction dipoles, the function generators and all the fast acquisitions.

The JIR 10 module has 16 slots which have been allocated as shown below.

<table>
<thead>
<tr>
<th>Slot</th>
<th>Interrupt attached</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Function generator stop acc.</td>
<td>Function generators</td>
</tr>
<tr>
<td>2</td>
<td>Function generator stop ext.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Function generator test stop</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1st pulse for COD</td>
<td>Closed orbit correction</td>
</tr>
<tr>
<td>5</td>
<td>2nd pulse for COD</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>COD acquisition</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Beam position reset</td>
<td>Beam position</td>
</tr>
<tr>
<td>8</td>
<td>Beam loss reset</td>
<td>Beam loss</td>
</tr>
<tr>
<td>9</td>
<td>1st SEM reset</td>
<td>Secondary emission detectors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>8th SEM reset</td>
<td></td>
</tr>
</tbody>
</table>

A mask register is used to enable or disable each slot. When one or more interrupts occur, possibly at the same time, the module sends a demand ('LAM') to the computer on the hardware level 10. Thus the JIR 10 management routine is activated and executes the following steps:

(a) The 16 slots (input register) are read as one word and at the same time disabled, if previously enabled (automatic mask).

(b) Updating of a specific program location containing a '1' for each slot if an interrupt had been detected since the last enable. Thus one is able to check whether or not an interrupt has occurred.
(c) The corresponding RT-programs are linked to the execution list of the system monitor.

(d) Reset of the active slots and of the corresponding bits in the mask register (selective reset).

(e) Reset of PIO module to enable new LAM coming from the JIR 10.
FIGURE CAPTIONS

1. Hardware layout for beam position detector acquisition and transfer.
2. Example of beam position acquisition timings along a SPS cycle.
3. Hardware layout for beam loss and charge detectors acquisition and transfer.
4. Example of beam loss acquisition timings along a SPS cycle.
5. Example of charge detector acquisition timings along a SPS cycle.
6. Example of profile averaged over the complete slow extraction.
7. Example of a typical closed orbit near injection.
8. Example of the difference of two orbits before and during extraction showing the extraction bumps.
9. Example of display of beam losses incurred between two instants.
Fig. 1 - Hardware layout for beam position acquisition and transfer.

BP SYSTEM - TIME SLOT SELECTION
TIMINGS ARE REFERRED TO EVENT 0

1ST ACQ. | 0  | 0  | 0  
2ND ACQ. | 2000  | 0  | 0  

Fig. 2 - Example of beam position acquisition timings along a SPS cycle.
Fig. 3 - Hardware layout for beam loss and charge detectors acquisition and transfer.

BL SYSTEM TIME SLOT SELECTION TIMINGS ARE REFERRED TO EVENT 0

<table>
<thead>
<tr>
<th>TIMING (NSEC)</th>
<th># OF CYCLES</th>
<th>SECTION #</th>
</tr>
</thead>
<tbody>
<tr>
<td>START</td>
<td>-300</td>
<td>0</td>
</tr>
<tr>
<td>1ST ACQ.</td>
<td>-100</td>
<td>0</td>
</tr>
<tr>
<td>2ND ACQ.</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>3RD ACQ.</td>
<td>2100</td>
<td>0</td>
</tr>
<tr>
<td>4TH ACQ.</td>
<td>6470</td>
<td>0</td>
</tr>
<tr>
<td>STOP</td>
<td>6920</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig. 4 - Example of beam loss acquisition timings along a SPS cycle.
Fig. 5 - Example of charge detector acquisition timings along a SPS cycle.

Fig. 6 - Example of profile averaged over the complete slow extraction.
Fig. 7 - Example of a typical closed orbit near injection.

Fig. 8 - Example of the difference of two orbits before and during extraction showing the extraction bumps.
Fig. 9 - Example of display of beam losses incurred between two instants.