EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN PS/84-02 (CO)
24.1.1984

A MULTI-USER MICROPROCESSOR-BASED MEASUREMENT SYSTEM FOR THE CERN PS ACCELERATOR COMPLEX

G.P. Benincasa, F. Giudici, N. Vogt-Nilsen

Paper to be presented at the IX. Triennal World Congress
of the International Federation of Automatic Control
IFAC, Budapest, July 2 - 6, 1984.

A MULTI-USER MICROPROCESSOR-BASED MEASUREMENT SYSTEM
FOR THE CERN PS ACCELERATOR COMPLEX

G.P. Benincasa, F. Giudici, N. Vogt-Nilsen

European Organization for Nuclear Research, CERN, CH-1211 Geneva 23,
Switzerland

Abstract. The accelerator complex produces charged particles in batches (acceleration cycles) at intervals of the order of 1 second. For measuring the performance of the accelerators, repeated measurements of certain beam variables may be required at instants chosen arbitrarily inside one acceleration cycle. The paper describes a scheme which allows several operator consoles - each independently - to select and reserve different sets of measurement instants of one and the same instrument, while the respective measured data are returned to the requesting consoles as if each of them were the sole user of the instrument. The scheme, which solves some stringent real-time and arbitration problems, is structured as a general purpose device so that it may be used for a variety of beam measurement instruments. It is successfully in use for 10 different instruments.

Keywords. Microprocessor; particle accelerators; on-line operation; multi-access system; pulsed process; real-time constraints; measurement channel; software standardisation.

INTRODUCTION

Amongst the main tools used to study the intimate constitution of the matter are the circular protons accelerators: protons are injected into accelerators at low energy, accelerated to high energy and ejected toward the different physics experiments. They work like batch processes, in acceleration cycles at intervals of the order of 1 second or more.

In the last few years, a sophisticated, multi-computer control system (Baribaud and co-workers, 1979; Benincasa and co-workers, 1979) has been added to an important part of the CERN installations called the CPS (CERN Proton Synchrotron) complex: it permits a centralised operation of three circular accelerators with the concerned proton transfer lines. The setting-up and the tuning of the accelerators largely depend on a series of delicate and precise measurements of different kinds: e.g. proton orbit measurements, proton beam losses monitoring, high frequency measurements, proton beam intensity detection, etc.

The beam measurement instruments concerned may be completely different from each other concerning the principles used and their specific hardware. On the other hand, they all have two characteristics in common: (i) the operational requirements and (ii) the strong real-time constraints imposed by the fast cycling process. It was decided to separate the hardware and software part required to treat adequately each specific kind of measurement from the part necessary to fulfil the common constraints. The latter part can be standardised in a way so as to produce a general frame that can support any kind of specific measurement system. The result is a hardware layout and a software package called MTIM (Multiple Trigger for Measurements) to which a measurement device can be attached independent of its complexity.

THE REAL-TIME CONSTRAINTS

As already mentioned, the proton accelerators are pulsed processes with short cycle times. Consecutive cycles can be very different from each other depending on the various uses of the proton beam: extraction for direct high energy physics, filling another accelerator, production of antiprotons, etc.

At the beginning of the cycle, protons are injected into accelerators, they are then accelerated during the increase of the magnetic field (that offsets the rise of centrifugal forces and is proportional to particle energy) and used at high energy. After that, the magnetic field decreases and a new cycle is started. In certain cases, protons are also decelerated during the decrease of the magnetic field and are used at low energy (Fig. 1).

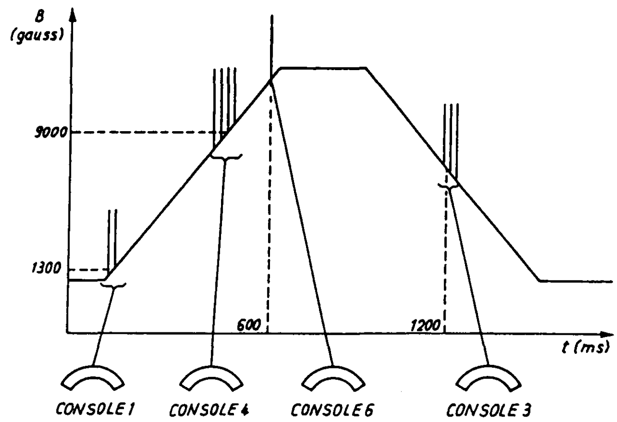

Fig. 1. Various measurements in the same cycle (Gauss & ms settings)

Measurements have to be made several times (up to 30) at precise moments in the same cycle and these instants can be specified in three different ways:

A) in real-time (millisecond) from the start of the cycle
B) in units of increasing magnetic field (increasing B pulses)
C) in units of decreasing magnetic field (decreasing B pulses).

Depending on the nature of the measuring instruments, the minimum time interval between two consecutive measurements must be as short as possible: 2 or 3 ms is the usual requirement.

Each measurement requires the transmission of several words for command and acquisition :

a) for command, because the setting of the measurement devices can be different from the previous one.
b) for acquisition because usually before the execution of a new measurement it is necessary to read the results of the previous one: in certain cases this means the acquisition of some hundreds of words. The speed of the transmission system (a CAMAC serial highway) imposes a first constraint: in the best case (DMA) it is of about 100 μs/word. The second constraint comes from the process computer which shares the measurement task with other urgent tasks; due to possible peak loads, the settings and acquisitions cannot always be granted at the correct instant.

THE OPERATIONAL REQUIREMENTS

The operation of the PS complex is done using six general purpose consoles (Carpenter, 1978): i.e. each console can access any part of the accelerator system.

During the delicate phase of tuning the accelerators, one or several users (using several consoles) may want to access the same measurement device during the same machine cycle; e.g. a first one is interested in the proton injection, a second in the acceleration phase, a third in the ejection and so forth (Fig. 1). The access may be multiple.

As already mentioned, executing a measurement is not merely a question of acquiring data at a certain instant, but it is also necessary to previously set the command device to the required conditions; in other words the user, during the time of his measurements (including the setting interval times) must be the exclusive master of the hardware device.

This is complicated by the fact that the measurement instants in the cycle may be varied by the user during the beam tuning operation; in fact, one usual procedure is to attach the measurement timing to a rotating knob and to scan the cycle repetitively during e.g. 15 minutes. Inevitably, this kind of procedure produces conflicts with other users consoles due to possible overlap periods that must be adequately arbitrated.

THE ADOPTED SOLUTION

A straightforward solution to the exposed problems could be to multiply the measurement equipment to a number that could fulfil all the concurrent requirements. Besides the excessive cost of multiplying this sophisticated equipment, different measurement systems, though built the same way, have obviously slight differences in calibration, amplifier drift, etc. This may reduce the possibility to compare the measurements.

In the adopted solution there is thus only one measurement device, but it can be accessed via a certain number of "measurement channels" (12 in general but up to 30 in special cases) which are as much as possible, independent of each other. A "channel"is a way to access a measurement which makes the user the complete master of the device during a few milliseconds around the instant of the measurements. Except for very slight constraints (overlaps) he has the feeling of being the only customer of the equipment, while he may actually be sharing it with others.

The Hardware Layout (Fig. 2)

The multi-measurement system MTIM is located in a CAMAC crate (usually one crate per kind of measurement) belonging to the serial highway of a process computer.

The components of MTIM hardware are 4 CAMAC modules:

1) a module called Auxiliary Crate Controller (ACC) (Beck and co-workers, 1978) developed at CERN. It contains a TMS 9900, 16 bit microprocessor with 16K of RAM memory. The core images containing all programs for the ACC are created and stored in the process computer and are down-loaded into the ACC over the CAMAC serial highway. -
2) a module called Program Line Sequence Receiver (PLSR). This module is connected with another computer of the network which is in charge of the synchronization of the different accelerator cycles: it contains, at each moment, all information needed by the ACC to recognise which kind of magnetic cycle is executing and which will be the next.
3) Two modules called General Purpose Preset Counter (GPPC). Each module is a double one started by the same impulse (usually the start of the cycle): the first half module is fed with a real-time train (1 kHz), the second half with the B-up or B-down trains (one pulse for each fixed number Gauss).
   Set with a pre-defined value, the module counts pulses of a specific train and - when the count matches the preset value - it produces an interrupt (LAM) for the microprocessor and a trigger pulse for the actual measurement device.

The other slots of the CAMAC crate contain the modules specific for the measurement equipment in question; as already mentioned, it may be very different from one measurement to another.

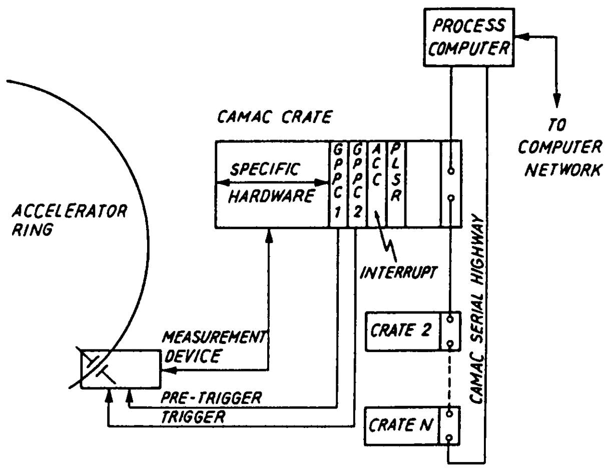

Fig. 2. General hardware layout of a measurement system using multi-trigger

The Software Layout (Fig. 3)

The software of MTIM is composed of two different entities:
- a set of real-time modules resident in the microprocessor (one identical set per ACC i.e. per kind of measurement);
- a module called Equipment Module (EM) resident in the process computer (only one module for all multi-trigger measurements).

The communication between the EM and the different ACCs is performed with an exchange of data blocks via the CAMAC serial highway. The two entities together realise two functions: the execution of the measurements that must be synchronous with the process cycle, and the setting of the requests, coming from the user, that are totally asynchronous.

The software of MTIM in the microprocessor is accompanied by a set of real-time user routines, called by MTIM, that are specific to each application.

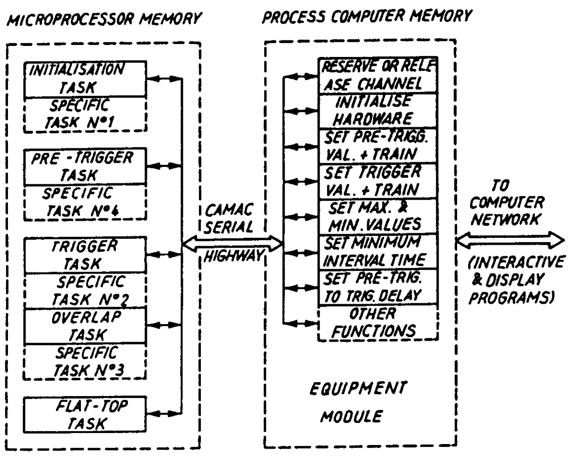

Fig. 3. Block representation of "MTIM" software

The MTIM real-time tasks (Fig. 3 & 4). These tasks, resident in the ACC, are triggered by two external interrupts and two LAMs:

1. the first interrupt tells the ACC that a new accelerator cycle has started. It triggers the following task:
   - initialisation of both hardware and software for a new series of measurements;
   - reading the content of the PLSR module to identify the kind of accelerator cycle;
   - checking the measurements which are required in the current cycle and organising them in three tables of increasing real-time values: one table for the requests in milliseconds, one for those in the increasing B-field and the last for the decreasing B-field. This is necessary because the measurement channels (12 in general) are allocated to the different users in a dynamic way and the corresponding setting times may be chosen arbitrarily.One important task of the ACC is then to order the measurements in increasing execution times and to create at each cycle a table of pointers to the corresponding channels (and users).
   - selecting the first two measurement settings, one in ms and the other in the increasing B-field, and charging with these values the two concerned half preset-counters;
   - calling the task initializing the hardware, (Specific Task No. 1).

2. When the first measurement instant (in ms or in B-field) arrives, the concerned preset counter produces a LAM and another task is started in the microprocess:
   - the first action is to inhibit the other preset counter (the B-field counter if the actual measurement is in milliseconds and the preset in millisecond in the opposite case) to avoid that another measurement disturb the present one;
   - the subsequent action is to set in the same preset counter the next measurement value;
   - the task for the measurement proper is called (Specific Task No. 2);
   - the last action is to verify if during the few millisecond of the described treatment another request has arrived that has not been serviced (overlap). The treatment of overlap is an important feature of the system; it must be done in real-time because the slope of the magnetic field can assume any value and is changing from cycle to cycle. It is then impossible to know, a priori, the relationship between milliseconds and Gauss. Jn case of overlap, the corresponding channel is appropriately flagged;
   - if an overlap occurs, a specific measurement task is called (Specific Task No. 3).

3. A second LAM can be generated by a second preset counter called pre-trigger. This counter is not used in all measurements but only when the device concerned requires a special setting before each measurement (e.g. changing sensitivity, select horizontal or vertical plane etc.) In that case the second preset is set to a value of 1 or 2 milliseconds inferior to the measurement instant to permit these settings.

   The associated MTIM task essentially calls a specific measurement task (user task No. 4).

   The sequences described for points 2. and 3. are repeated for each measurement.

4. The second interrupt (Flat Top Interrupt) tells the microprocessor that the increasing B-field is finished and then the measurement in decreasing B-field (if any) can start.

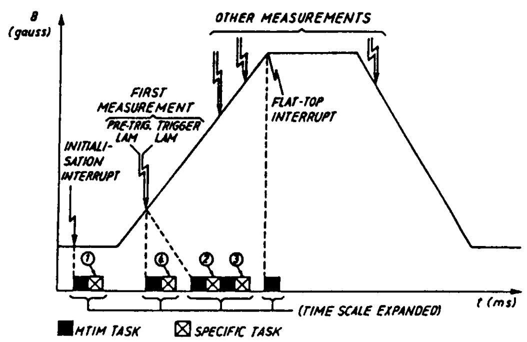

Fig. 4. Measurements in an accelerator cycle

The specific real-time tasks For each measurement device, a maximum of 4 tasks must be provided. These tasks communicate with MTIM using only two flags that represent two fixed addresses in the ACC memory:

- the first flag contains, at each instant, the channel number of the current measurement;
- the second flag indicates if the current measurement overlaps or not with another user.

Apart from these two flags, no other communications are required between MTIM and the specific tasks; the latter can be written in a totally independent way.

The four specific tasks are (Fig. 3) :

a) the task No. 1 initialises the specific hardware at the start of each cycle.
b) The task No. 2 executes the actual measurement. Using the mentioned flag, the results of the measurement are put into the appropriate channel.
c) The task No. 3 is called in case of overlap. In that case the user can decide either to accept the values measured for the overlapping user or simply invalidate his current measurement. This decision usually depends on the time precision required on the specific measurement.
d) The task No. 4 sets the measurement device to the conditions for the next measurement, if required.

If one or more user's tasks are not required for a specific measurement, they are replaced in MTIM by dummy calls.

The MTIM equipment module. It is a software interface module between the interactive operator applications and the real-time tasks.

The various setting information is transferred in the form of Module calls with specific parameter values. The most common actions performed by the EMs are :

1. It permits to allocate to each user the number of channels requested for his measurements. The channels are reserved for the requesting user and released again at the end of the measurement period. Searching for free channels is done in a dynamic way, i.e. if a user X asks for N channels, the EM will allocate to him the first N channels (in general not consecutive) that are not yet reserved by other users. The channel allocation process is completely transparent to the user; the EM keeps the account of which channel is assigned to whom.

2. For each measurement the EM communicates to the real-time task the required instant and the selected pulse train.

3. For each device, the EM permits to adjust the minimum time interval between two successive measurements with the same train, and the minimum delay between the pre-trigger and trigger, if required.

4. It follows from point 3 that the EM can immediately reject a measurement trigger that overlaps with another one of the same pulse train; this leaves the real-time task only to treat the overlaps between measurements of different pulse trains (see before).

CONCLUSION

MTIM is running since about one year and it is in charge of 10 different measurements on the accelerators.

Its main advantages are economy through standardization:

a) in software: the MTIM frame (EM + RT tasks) has cost about 4.5 man-months of skilled programming. In addition each of the 10 user applications have cost about 2.5 man-months.

The experience with a previous system (Benincasa, Carter, Rinolfi, 1979) shows that if the user software also contains the real-time and the multi-channels facilities, it easily costs twice as much, i.e. ~ 5 man-months.

b) in maintenance: in a control system with thousands of hardware and software modules, this point is very crucial.

c) in implementing user programs: i.e. the various general-purpose high-level programs displaying the results of measurements on consoles;

d) in expandibility: a new measurement device can quickly be added to the system: the MTIM real-time tasks are ready and the characteristics of each device, i.e. the minimum setting time, the delay between pre-trigger and trigger, etc., all are parameters that are interactively adjustable using the Equipment Module.

REFERENCES

Baribaud, G., S. Battisti, G.P. Benincasa, J. Boillot, M. Bouthéon, R. Cailliau, B. Carpenter, J. Cupérus, G. Daems, A. Daneels, R. Debordes, P. Heymans, I. Kamber, H. Kugler, B. Kuiper, F. Perriollat, J.P. Potier, W. Remmer, Ch. Serre, P. Skarek and A. van der Schueren (1979). The improvement project for the CPS controls. IEEE Trans. on Nucl. Science, Vol. NS-26 nr. 3, p. 3272.

Benincasa, G.P., J. Cupérus, A. Daneels, P. Heymans, J.P. Potier, Ch. Serre and P. Skarek (1979). Design goals and application software layout for the CERN 28 GeV Accelerator Complex. IFAC-IFIP, Symposium SOCOCO, Prague, June 1979.

Carpenter, B.E. (1978). Computer topology for the new PS control system. CERN/PS/CCI/Note 78-7.

Beck, F., C. Guillaume, H. Kugler, M. Rabany and R. Rausch (1978). Auxiliary CAMAC crate controller using a 16 bit microprocessor. ESONE Conference, Hamburg, September 1978.

Benincasa, G.P., C. Carter, and L. Rinolfi (1979). A microprocessor-based system for frequency measurements under critical constraints. Real-time Data Handling and Process Control, North-Holland Publishing Co., ECSC, EEC, EAEC, Brussels and Luxemburg, 1980.