EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

LEP/Note 564
PS/CO/Note 86-19
2.7.1986

Project: TIMING
Domain : UTILIT
Category: STUDY
Status : FINAL

ON THE SEQUENCING OF THE CERN MACHINES AND ON A UNIFIED PARTICLE TRANSFER PROTOCOL

G. Baribaud, P. Heymans

Geneva, Switzerland

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1. INTRODUCTION

The LEP Preinjector, in particular LIL, is now in the commissioning phase. The LEP main ring construction is well underway. The relevant controls systems are presently being implemented, respectively in an advanced stage of design. It is therefore time to consider the synchronisation of these machines with the intermediate PS and SPS.

The machines of the CERN-wide accelerator complex work in cycles, each cycle being a compromise between the beam(s) required and the constraints of the machine. The cycles of various machines therefore evolve independently except for a small fraction of the total time, when they interact during short intervals around the moments of beam transfer. For the latter, the magnetic fields, radiofrequencies and beam characteristics must meet stringent conditions on both sides and this subtle RENDEZVOUS requires the exchange of a number of signals.

Between transfers, the cycle of each accelerator evolves without input from the other ones, relying on its internal timing system which is peculiar to the specific needs of that machine and to the technology and thinking of the era in which it originated.

Several machines of the CERN-wide accelerator complex run interleaved cycles with different kind, quality, source and destination of the beams. They do so in periodic sequences called supercycles. These must be orchestrated in such a way that the appropriate cycles meet at the correct instant for rendezvous. At the PS complex, the orchestra conductor comprises two SEQUENCERS: the LINAC Beam Sequencer (LBS) which gives the beat and the Program Line Sequencer (PLS) which indicates to each machine what cycle is to be played next. Facilitating this, all cycle times are made multiples of one basic period.

In addition to its functions of cycle-to-cycle coordination and synchronisation, the PLS is provided with powerful and user-friendly editors and archive manipulation. These facilities have proved crucial for rapid changes in the programme of the PS complex. The forthcoming electron/positron fillings represent similar changes, which must be handled efficiently on a CERN-wide scale.

This working paper makes proposals for (i) a CERN-wide sequencing mechanism and (ii) a unified rendezvous protocol. It is attempted to use the same or similar methods throughout and to strip them to the essentials with an eye on easy implementation, operation and maintenance. The emphasis is on the principles, not on the technology.

It is not attempted to make recommendations for the internal timings of various accelerators. Either these are adequate as a whole or they are already being supplemented to meet the needs of the LEP operations, like at SPS. In case recommendations (i) and (ii) be agreed, some local adaptation may become necessary.

2. PROPOSAL (i): CERN-WIDE SEQUENCING SCHEME

2.1 The experience with the present PLS at PS

The positive experience with the PLS scheme at PS makes us propose a similar system at the CERN level, coordinating the existing PLS at PS and the MTG3 (in statu nascendi) at SPS[1], but only to the extent that this is necessary for common programmes. The local sequencers should remain in charge of more detail and must keep stand-alone capability during shutdowns or commissioning.

At this point we must introduce a few principles, best illustrated by the ones in the PLS[2]. The latter (Fig. 2.1) coordinates the accelerators of the PS complex by broadcasting messages (so-called PLS telegram) indicating the type of present cycle and of the next. The messages only contain WHAT should happen (e.g. cycle type); all detailed information on HOW it should happen is contained in tables in the process interface of each accelerator. At each cycle, the PLS telegram indicates which of those data are to be presented to the process equipment. The tables contain parameters such as magnet currents but also settings of preset counters governing the detailed timing of the cycle. Parameters in the tables can be adjusted from the consoles or loaded from archives. All cycles are usually multiples of one basic period and synchronisation is ensured by the SSC (start supercycle event), a so-called WHEN data from which all the cycles are triggered in sequence.

2.2 Sequencing the LEP Preinjector

Due to the e^+/e^- transfers from EPA to PS, the filling cycles of EPA must be synchronised in the supercycle of the PS accelerator complex. Many equipment have somewhat different settings and, in part, different equipment is activated for e^+ or e^- (e.g. LIL V, transfer lines, etc..); different filling and ejection schemes are possible. There is thus a "filling-to-filling modulation" (FFM) similar to the pulse-to-pulse modulation (PPM)[2] in PS, the EPA filling cycle taking the place of the PS magnet cycle. For LPI, too, the consoles must work on one chosen filling cycle (e^+ or e^-), excluding information from the other one, so as not to confuse the operator.

For the reasons mentioned above, the coordination of the LPI must then also come from the PLS in some form, i.e. by a separate PLS telegram for LPI. A further important reason for using the PLS is that this will allow homogeneous central programming of filling cycles as part of the PS supercycles. Powerful and user-friendly editing facilities for this are existing and standard interface modules are available.

The PLS telegram for LPI will say WHAT is going to happen, i.e. e^+ or e^- and which of the filling and ejection schemes. The details of HOW the fast timing is done are supplied by a dedicated microsequencer[3,4,5] according to the above-mentioned directives of the PLS, arriving every basic period of 1.2 sec. The microsequencer then coordinates intricate microsequences at a beat of 100 Hz (for LIL and EPA injection) and for ejection towards PS. The controls of the other equipment in FFM (e.g. power supplies, phasers) are done in accordance with the usual PPM techniques used at PS.

The PLS-telegram for the LPI will be generated in a new device called Telegram Slave Unit[6] (TSU in Fig. 2.2), rather than in the PLS computer itself as is the case for PSB and PS (Fig. 2.2). This avoids saturation of the present PLS computer and it yields four major advantages: (i) it allows stand-alone simulation of PLS input; (ii) it can be ADDED to the PLS, leaving the latter fully operational at all stages; (iii) it is a first step towards a generalised modular sequencing hierarchy (see sec. 2.3); (iv) it opens the way to extend the number of user groups beyond the present 8.

Physically, the TSU will be composed of standard interface modules as used for LPI, in particular the MC68000 microprocessor based auxiliary crate controller SMACC[7]. Prototype software is presently under test and a first full TSU is aimed for mid 1986.

2.3 Generalisation of the principle

The essence of the sequencing scheme being developed for the LPI is a hierarchisation of coordinating tasks, like in an organisation. At each level there is an input of directives from above, complemented by more detailed instructions generated locally, while reports are returned to the level above.

All these functions can be done by an elementary building block as shown in Fig. 2.3. Our proposal relies on the generalisation of this principle. The logical description of the elementary building block is the same regardless of its position and it may be used at any level in a tree structure (Fig. 2.4).

The technology now being developed for LPI is potentially capable of being used at any level hence yielding an elementary building block. The hardware and software are of a generalised nature and have the flexibility for reconfiguration as needed by the changing physics programs. Only the specific operations must of course be programmed ad hoc. For this, powerful editing facilities are available centrally on the PS main operator consoles. More modest ones are foreseen for local interaction.

Two interacting accelerators have a good deal of independant life which may be programmed by a local sequencer, thus also yielding stand alone capability. At the moments of particle transfer, however, the machines must match predefined conditions. Also this may, by agreement, be programmed individually on both sides, but a common coordination device is so much more convenient, in particular for the frequent changes of programs known at CERN.

Although it would be favourable to have this standard sequencer at all relevant points in the tree stucture, this is not essential as long as the signals exchanged are agreed. For example, the SPS sequencer MTG3 can very well be integrated. The signals exchanged with PS will then be as described, but inside SPS and possibly LEP a completely different logic and technology may exist.

2.4 The hierarchical sequencer layout

Following the developments and considerations of the previous section, a two-layer hierarchical layout (fig.2.5) is suggested for CERN by the following argument. Up to now almost all particle beams are channeled through PS which acts as a pivot. In future the PS and SPS will make up the LEP injector chain and hence play a role similar to the PS today. Each of the two happen to have fully fledged controls systems catering for local needs up to now. It is logical to benefit from this state of affairs and only make the strictly necessary additions. The CENTRAL SEQUENCER will only deal with things common to both controls systems. Within each of the latter, the LOCAL SEQUENCERS of the second layer will control the local supercycles, using data coming from the main sequencer and data generated locally. In stand-alone mode the central sequencer signals are ignored and they are simulated to meet the local requirements.

Should the need arise, the implementation of a three layer architecture would also be feasible thanks to the recurrent nature of the elementary building block.

The generalised sequencer concept is shown on figure 2.6, it can be used either as a local sequencer or as a central sequencer. It contains the logical units which convert the incoming telegram and the local instructions into the outgoing telegram (the so-called TITO = Telegram In Telegram Out) and the local timer which generates the SYNCH OUT event and controls the moment of distribution of the outgoing telegram. The local built-in timer is triggered by the SYNCH IN event.

A central clock and a calendar facility will be distributed to all machines via the sequencer network. A 1 kHz frequency is a sensible value for the central clock.

We shall now give the main functions of the local sequencer and of the central sequencer.

2.5 The Local Sequencer

In our proposal there is one sequencer per machine (e.g. PS, SPS, PSB, LPI, etc.) with the exception of AA and ACOL which can both be controlled via the PS telegram, for the time being.

The local sequencer coordinates the detailed characteristics of the local supercycle. The data generated by the local sequencer are derived from in part the central sequencer, in part from local requests and machine stati (e.g. parasitic cycles for machine development).

The input parameters from the central sequencer are :

IN (1) the central clock and calendar;

IN (2) the START SUPERCYCLE event; all the WARNING CYCLE events (see OUT(2) below) of the machine supercycle will be derived from that event and from the central clock; usually the repetition rate of the start supercycle event is the duration of the longest supercycle;

IN (3) the WHAT data (relevant to the common programme). This may refer to the programme (set of supercycles) to be played or to some request (e.g. $\bar{p}$ transfer requested) leading to some minor cycle modification;

IN (4) the stati and requests of all the machines (including those of the machine controlled by the sequencer); if appropriately displayed, they may influence some operator requests;

IN (5) some complementary data such as :

- the value of the basic period (1.2 s for the time being)
- the supercycle number, etc.

IN (6) Finally, there is also input from the local interaction medium, e.g. a terminal.

The outputs of the local sequencer towards the machine are:

OUT (1) the central clock and calendar;

OUT (2) the WARNING CYCLE event(s) from which all the internal 1 kHz timing events are derived. The repetition rate of that event is usually a multiple of the basic period; (some fluctuations are foreseen for LPI). There is one such event per machine controlled by the sequencer;

OUT (3) the WHAT data of the cycle (slave telegram), they are presently the PLS telegram for the PS, the PSB, and in the near future the LPI;

OUT (4) the state and requests of all the machines;

OUT (5) some complementary data such as:

- the value of the basic period
- the cycle and the supercycle numbers, etc..

2.6 The central Sequencer

The role of the central sequencer is to coordinate the activities of the local sequencers.

The inputs are:

IN (1) the central clock and calendar for further broadcasting to the whole CERN accelerator complex; these data will be supplied by some commercially available hardware;

IN (2) the START CERN SUPERCYCLE event from which all the machine start supercycles are derived;

IN (3) the list of common programmes and antiprogrammes which are to be executed during the run by the CERN accelerator complex, according to the requests and states of the machines;

IN (4) the machine stati, indicating the present conditions of all the machines of the complex and the requests from machines or from MCR, asking for programme modification;

IN (5) The complementary data such as
- the value of the basic period
- the shift of all the supercycles with respect to the start supercycle event, etc.

If one excludes the stati output usually aimed at the above layer, all the outputs of the central sequencer are sent to all the local sequencers in parallel (cf. inputs to local sequencers in 2.5). The stati output may be used in the MCRs as input to the alarm systems.

2.7 The internal sequencer

In principle, within each machine a third layer is conceivable in order to allow the stand-alone operation of a subset of the machine, for example during shutdowns. Such a facility may be welcome by the hardware specialists who must test their equipment during short periods of time. This could be implemented using the generalised sequencer concept.

3. PROPOSAL (ii): UNIFIED PARTICLE TRANSFER PROTOCOL

3.1 General

In a particle transfer, a part or the whole of the beam of an emitting machine is tranferred into a specified space of the receiving machine. The transfer protocol does not depend on the direction in which the particles travel.

Presently the choice of signals exchanged by two machines at the time of beam transfer is somewhat different from case to case. Analysis shows that in principle a single protocol could suffice for all known cases. Such a unified protocol would only transfer the strict minimum of signals and eliminate all ad hoc redundancy. The advantage would be more transparency hence simpler diagnostics.

At this point it may be helpful to recall a few principles of the transfer RENDEZVOUS.

The transfer is performed by three successive phases:

a) the preparation phase

b) the synchronisation phase

c) the execution phase.

3.2 The preparation phase

In most particle transfers pulsed equipment is used. This equipment must be prepared in advance. Presently, one machine called the Timing master (cf. below) sends a pulse to the other machine. This so-called FOREWARNING pulse starts the charging of power supply capacitors, for example. The time of arrival of the FOREWARNING pulse depends on the equipment. It is proposed to generate in each machine the appropriate FOREWARNING from the WARNING CYCLE event and from the central clock. A software link may then be foreseen between the two internal FOREWARNING generators.

3.3 The synchronisation phase

In case of bunch-to-bucket transfers, the bunches of the emitting machine must be placed in given buckets of the receiving machine. For this, the RF systems must be locked in frequency and phase, i.e. one of the machines must follow the other, a MASTER-SLAVE relationship must exist.

In principle either of the two RF systems could act as RF master. However, in practice the choice of the frequency slave will be for the machine for which it is easier to modify its frequency, e.g. empty machine or smaller machine (rephasing time varies as the square of the radius).

In case of MULTIPLE TRANSFER (e.g. e^-/e^+ from PS to SPS) the phase lock is interrupted while rephasing the bunch pattern in one machine before the next transfer takes place[8]. There are two subsequent rendezvous. In order to relate the bunches and buckets of the first and second transfers, the machines must also lock revolution frequencies during rendezvous. This is done through the closest common subharmonic, called FIDUCIAL, which the master sends to the slave. In SINGLE transfers the fiducial may be redundant. The rendezvous protocol must cope with many transfers within one machine cycle.

The value of the fiducial frequency is defined as[9]

$$Fi = \frac{(F\ Rev)master}{p} = \frac{(F\ Rev)slave}{q}$$

where p and q are the smallest integers which satisfy

$$\frac{Circumference\ master}{q} = \frac{Circumference\ slave}{p}$$

To allow a correct frequency and phase synchronisation, the frequency master sends its RF and the fiducial frequency or revolution frequency to the frequency slave. Those connections are not considered as timing connections, they are fully under the responsibility of the concerned RF specialists.

The phase of the fiducial frequency with respect to the bunches to be ejected or the buckets to be filled is determined by the RF master before each transfer.

The synchronisation process should reach a stable state roughly 10 ms before the particle transfer. The frequency master and the frequency slave send to their local timing an RF train which will be used as local timing clock. The frequency of the local RF train can be different from the RF frequency. The RF phase with respect to the bunches or the buckets is internally defined in the relevant RF system by the RF specialists.

In case the bunch structure of the beam is not considered in the transfer (e.g. Linac to PSB, PS to East experimental area), the synchronisation phase does not exist.

3.4 The execution phase

At the moment of transfer between two circular machines, the energies hence fields of the two machines must strictly match (not be equal). In a flat-top-to-flat-top transfer or equivalent this is adjusted by correcting the field of one machine and using the receiving one as spectrometer.

In a flat-top-to-ramp transfer or vice versa, the ramped machine usually sends to the other machine a prepulse (B.WARNING) at a fixed time before the field of the machine crosses the relevant level. Charging of kickers, etc. on both sides can be derived from this B-pulse; matching fields is by adjustment of the transfer moment i.e. by changing the B-pulse. The timing of the ramped machine is then the timing MASTER (it determines the moment of transfer) and the timing of the other machine is the timing SLAVE. The B.WARNING pulse is generated a fixed time before the particles are transferred. This scheme compensates for the fluctuations of the magnetic field. If the fluctuations of the magnetic field are small enough then the B.WARNING may be replaced by internal pulses derived from the central clock (see below).

In flat-top-to-flat-top transfers the timing is less critical and the transfer can be initiated from the central clock. In a flat-top-to-flat-top transfer there is no natural timing master like in the flat-top-to-ramp transfer. Either of the two machines could be chosen to be master, independently of whether it is emitting or receiving beam.

In case of bunch-to-bucket transfer, in both flat-top-to-ramp and flat-top-to-flat-top transfers, the physical particle transfer is finally triggered by a WARNING pulse, generated by the timing master and sent to the timing slave. The WARNING pulse is linked to the synchronised RF. All the individual high resolution pulses required by the internal equipment will be generated by preset counters started by the WARNING pulse and clocked by the local RF train.

In case the bunch structure of the beam is not considered in the transfer, there is no synchronisation phase (cf. 3.3) hence no WARNING pulse is required. The transfer is usually started internally from the B.train in case of ramp transfer (eg. Linac to PSB) or from some event derived from the central clock (e.g. PS to east experimental area).

When particles can be transferred in either direction[10,11] between two machines (e.g. PS and SPS, PS and AA) the same timing systems with the same frequency and timing masterships are used, delays (at present in the slave) will compensate for twice the time of flight of the particles between the two machines.

Recapitulating, there are four ways to trigger the execution phase :

i) the WARNING pulse alone. e.g. PS to SPS[12], EPA to PS[13], and PS to AA[11] transfers;

ii) the B.WARNING pulse alone;

iii) none of them, e.g. PS to PS experimental East area tranfer;

iv) the B.WARNING and the WARNING pulse, e.g. PSB to PS transfer[14].

However, on the long term, possibility (iv) should be avoided and replaced by a WARNING pulse generated about at the same moment as the present B.WARNING if the RF synchronisation process is stable early enough.

3.5 Layout of rendezvous protocol

From above considerations it can be concluded that in principle one layout as depicted in Fig. 3.1 can satisfy all known cases. However, as there is no fundamental reason why frequency master and timing master should reside in the same machine, a second layout as shown in Fig. 3.2 must be considered.

There are then maximum four signals transmitted: (1) the RF signal (analog), (2) in case of multiple transfers the fiducial (pulse train), (3) only in case of a flat-top-to-ramp transfer, the B-warning pulse and (4) the warning pulse linked to the RF. Some timing connections need only a subset of those signals.

The timing master receives from the local RF system, (a) the local RF pulse train, and (b) the fiducial pulse train or, in case of a single transfer, the local revolution pulse train. The timing master creates the B.WARNING pulse from its internal B train and the WARNING pulse by counting local RF pulse train, starting from the first fiducial (or revolution) pulse passing a gate opened by the chosen C-pulse or B-pulse. In each of the two machines there is the relevant fan-out from the warning pulse to all related timings, using preset counters counting the local RF train. The slave timing receives the latter train from its own RF system.

In each of the two machines there is a timing system. This timing system deals with RF, B and central clock timings. The connection between the two timing systems are limited to a maximum of two (hopefully one in the future) specific signals, this feature will allow a more efficient exploitation and fault diagnostics. The users of the internal timings are then fully decoupled. This scheme is generally applicable and in particular between SPS and LEP where this point has not been finalised yet. However, the synchronisation scheme between SPS and LEP RF systems was specified and accepted[15].

The RF systems and the timing systems in both machines receive if necessary the relevant WHAT data (e.g. PLS train), the central clock and the WARNING CYCLE event from their local sequencer, and the other clocks (e.g. B train) from internal sources.

The present timing and frequency masterships are shown in Table. 3.1.

4. DIAGNOSTIC FACILITIES

4.1 Fast timing fault finding

Timing faults can plague the operation of accelerators, usually they are difficult to diagnose especially within a PPM environment. With a hierarchical structure of the proposed timing architecture, it will be necessary to install some diagnostic tools at the appropriate places. One type of tool is proposed for the monitoring of the sequencers, a second type is foreseen for the monitoring of the particle transfer between two machines, a third one for the internal timing pulses.

4.2 Timing monitoring of the sequencers

Every sequencer receives an event and generates a series of events to the lower layer (e.g. a WARNING pulse to every machine it controls). In order to diagnose quickly any error, it is suggested to attach a timing monitor to each sequencer. Any error in the distribution of events in the relevant supercycle will be reported to the above layer, then to the MCR. A similar standard monitoring module could also be used to diagnose the faults of internal sequencers if any.

4.3 Timing monitoring of the transfer

The monitoring of all the events involved in the transfer is more complex than the previous one since it also deals with some parameters of the machines. In fact, this timing monitoring relies on two types of actions, namely:

a) observation of analogue signals on scopes (also used for timing calibration). Within the PS the standard Signal Observation System (SOS) will be used where possible. Between PS and SPS the PS circulating current, the currents in the transfer lines and the kicker currents will be available in the SPS[12].

b) measurement at each transfer of the characteristics of the WARNING pulse (cf. Fig. 4.1 and 4.2). This is done by measuring (i) the time of arrival of the WARNING pulse in the machine cycle, (ii) the time between the WARNING pulse and the physical passage of the beam in the relevant transfer line, (iii) the time shift of the WARNING pulse with respect to the fiducial frequency and (iv) the time shift with respect to the local RF train.

The resolution of the last two measurements is within a few nanoseconds, they may have to be made in PPM (e.g. PS to SPS transfer).

If the measurements exceed some predefined limits then an alarm is generated, the results of the measurement must be available in both machines concerned (e.g. PS and SPS for PS to SPS transfer, this implies a data transfer between the two computer systems; alternatively, the reporting facilities of the sequenceers could be used).
The analogue signals are available but the measuring device has to be found. It is proposed to have one measurement device at each end of each transfer channel. This does not exclude other internal timing monitoring devices specific to some equipment. The connections of the WARNING pulse monitor are shown on Fig. 4.3.

4.4 Internal timing pulse monitor

Though this note does not deal with internal timing, it must be stressed that some systems to monitor the internal timing pulses are urgently needed. The existing intervallometers in the PS do not meet the AA requirements concerning antiproton transfers.

A pulse monitoring system must be able to measure the time interval between key pulses and a reference pulse over each machine cycle. To achieve this, an acquisition value must be derived from each key timing pulse (not normally the case at present; only set value can be read back). Any missing key pulse, or key pulses, generated at the wrong moment, must be reported to the MCRs. So far, most pulses require a measurement resolution of about 20 ns. However, the LPI needs a resolution of 1 ns.

Timing pulses are generated all over the site; so will the timing pulse monitors in order to save cables.

5. TIME SCALE AND RESOURCES FOR IMPLEMENTATION

5.1 Status

So far, we have delt with only principles. Detailed definition of both hardware and software still needs to be written down for implementation and future exploitation.

At the present PS implementation of PLS train and standard pulse distribution must be updated to take into account some new LPI request, the opportunity could be taken to replace it stepwise by a new version using new technology.

The possibility of using a commercial local area network (LAN), as opposed to CERN developments for the distribution of timing data needs also to be investigated with the CERN specialists.

Our limited resources militate in favour of a two-phase implementation.

5.2 Early implementation

5.2.1 TSU for LPI

This unit is being implemented (cf. sec. 2.2), it should be ready for stand-alone applications in mid 86 and for applications from the MCR by the end of 1986. No hardware needs to be developed and the software effort is about two man-years.

5.2.2 PS to SPS connection

The SPS will start the installation of their internal timing as from June 1986 to test SPS timing in January 1987[16]. To do so they need the Start Supercycle pulse, the PS PLS telegram, the C.train and the WARNING pulse (the FOREWARNING pulse will be suppressed in Summer 1986), all those signals are already available in the SPS; they can cope with finishing by Spring 1987.

5.2.3 Internal timing pulse monitor

This unit is in the phase of final specification; prototypes are expected by the end of 1986. Some units are required for ACOL in Spring 1987.

5.3 Final implementation

The final implementation will heavily depend on the human resources dedicated to this project. The main points to be treated are:

i) The general TITO implementation (cf. 2.4)

The software effort is estimated between 1.5 and 2 man-years; for the time being it is competition with the LPI-TSU implementation.

ii) The timing data distribution system

In order to use the most appropriate technology for the generation and transmission of timing data a small working team should be set up to specify in detail the correct transmission medium. The results could be expected in Autumn 1986 if resources are available. The total effort could be in the range of 2 man-years if commercial modules cannot be found.

iii) Timing monitoring of the sequencers (cf. 4.2)

The monitoring of the CYCLE WARNING events can be built from standard equipment. The software and the tests may require in the order of 0.5 man-years.

iv) Timing monitoring of the transfer (cf. 4.3)

The monitoring of the WARNING pulse may require the development of a new hardware. The hardware of the WARNING pulse monitor and the relevant software implementation effort still need to be investigated.

v) Central clock and calendar

It is hoped that such a unit can be built from commercial modules.

vi) Coordination of the project

Last but not least, the coordination of the project requires setting up a team of specialists and users for detailed definition and follow-up. It is estimated that 1 to 2 man-years must be collectively invested in the next few years.

In conclusion the final implementation will require an investment in the order of 5 man-years or more.

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ACKNOWLEDGEMENT

The expertise about timing is highly dispersed throughout CERN, our main task was to collect and analyse these data. Our colleagues are too many to be thanked individually; however, we are very grateful to G. Beetham, J. Boillot, R. Garoby, J. Lewis, J.P. Potier, J.P. Riunaud and J.D. Schnell for their valuable remarks.

We thank particularly B. Kuiper for his continuous encouragement and help and K. Hübner for his remarks on the manuscript.

TRANSFER	FREQUENCY MASTER	FIDUCIAL	TIMING MASTER	WARNING	B.WARNING
LIL -> EPA	EPA	Frev EPA	EPA	Y	N
EPA -> PS	EPA	Frev EPA/5	PS	Y	N
PS <-> SPS	SPS	Frev SPS	PS	Y (-70us)	N
SPS <-> LEP	LEP	Frev LEP/7	SPS	Y	N
PS <-> AA	AA	Frev AA/4	PS	Y (-100us)	N
PS -> LEAR	PS	Frev PS	PS	Y	
PSB -> PS	PS	RF PSB	PS	Y	Y (-14ms)
LIN -> PSB	NA	NA	PSB	N	Y (-2 ms)
LIN -> PS	NA	NA	PS	N	Y (-2 ms)
AA <-> ACOL					

TABLE 3.1

FREQUENCY AND TIMING MASTERSHIPS

NA : Not applicable

Y : Yes

N : No

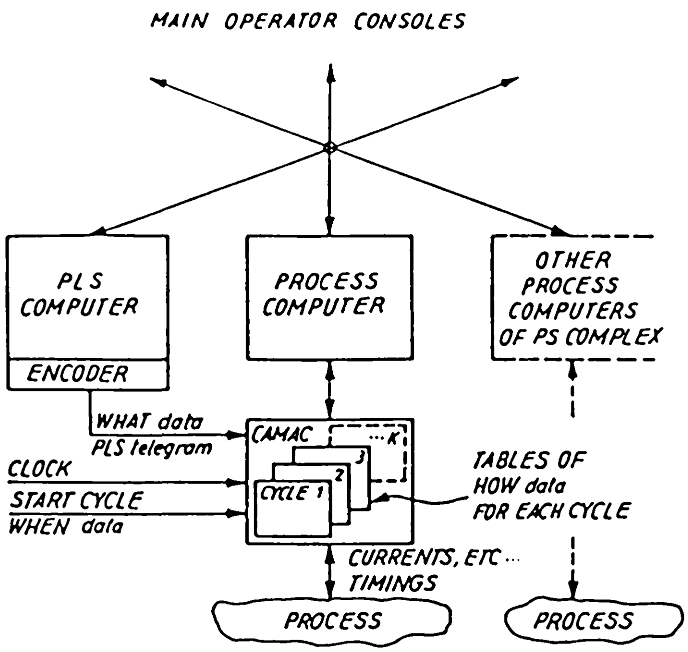

Fig. 2.1. The PLS System coordinates the cycles in the supercycle of each accelerator in the PS complex by broadcasting the PLS telegram which indicates WHAT cycle is going to be played next. Detailed information on HOW each cycle is composed is stored in data tables in the CAMAC interface. HOW data may be adjusted from the consoles or loaded from archives. Synchronisation is by counting clock pulses from each START CYCLE pulse (so-called WHEN data). The PLS system allows interactive composition of supercycles on the main operator consoles, using powerful display and editing facilities.

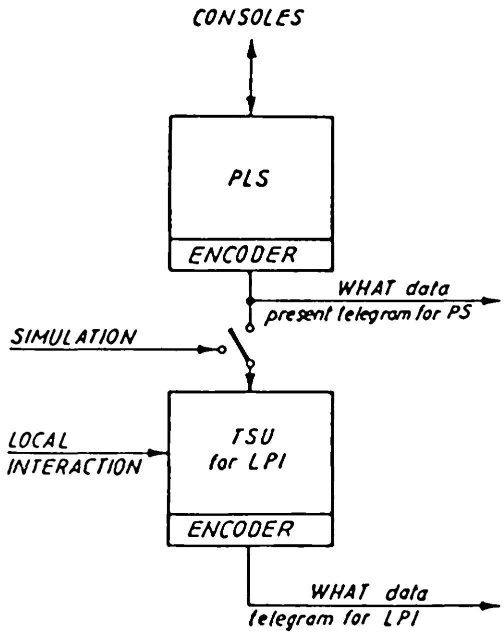

Fig. 2.2. The Telegram Slave Unit (TSU) creates and broadcasts the telegram for LPI, using the output of the PLS as input. This allows to avoid saturation of the present system and has four major advantages: (i) it facilitates stand-alone operation during shutdown and commissioning, simulating the PLS input and allowing local interaction; (ii) it can be added to the PLS, leaving the latter operational at all stages; (iii) it is the first step towards a generalised modular sequencing hierarchy and (iv) it opens the way to extend the number of user groups.

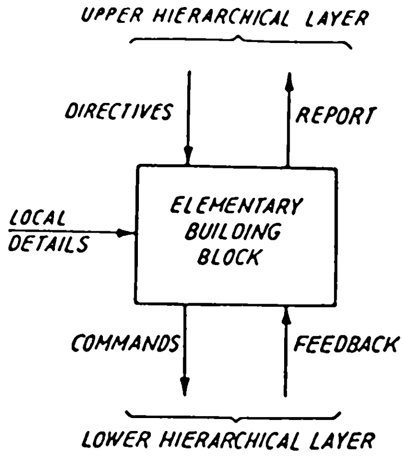

Fig. 2.3. In analogy to human organization, the elementary sequencer building block gets general directives from the upper hierarchical layer and some more specialized or detailed instructions locally. The output is an appropriate commande message to the lower hierarchical layer. It must be possible to observe the results through a feedback path and to report to the upper hierarchical layer.

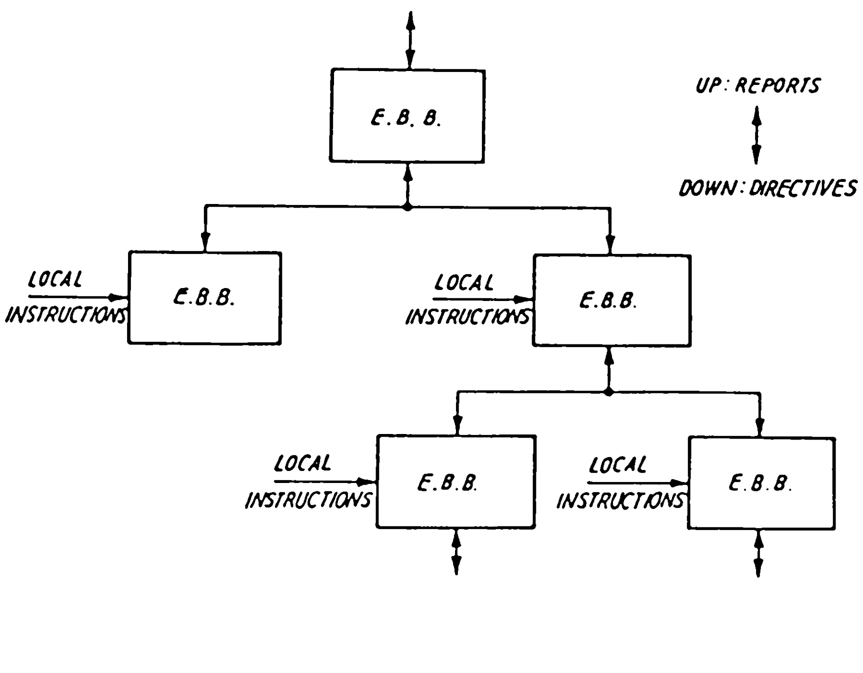

Fig. 2.4. The elementary sequencer building blocks can be used to construct a hierarchical sequencer architecture. Any sequencer transforms the directives from the upper hierarchical layer, complemented by local instructions, into a message for the lower hierarchical layer and reports back to the upper layer. The logical description of the sequencer does not depend on its position in the hierarchy.

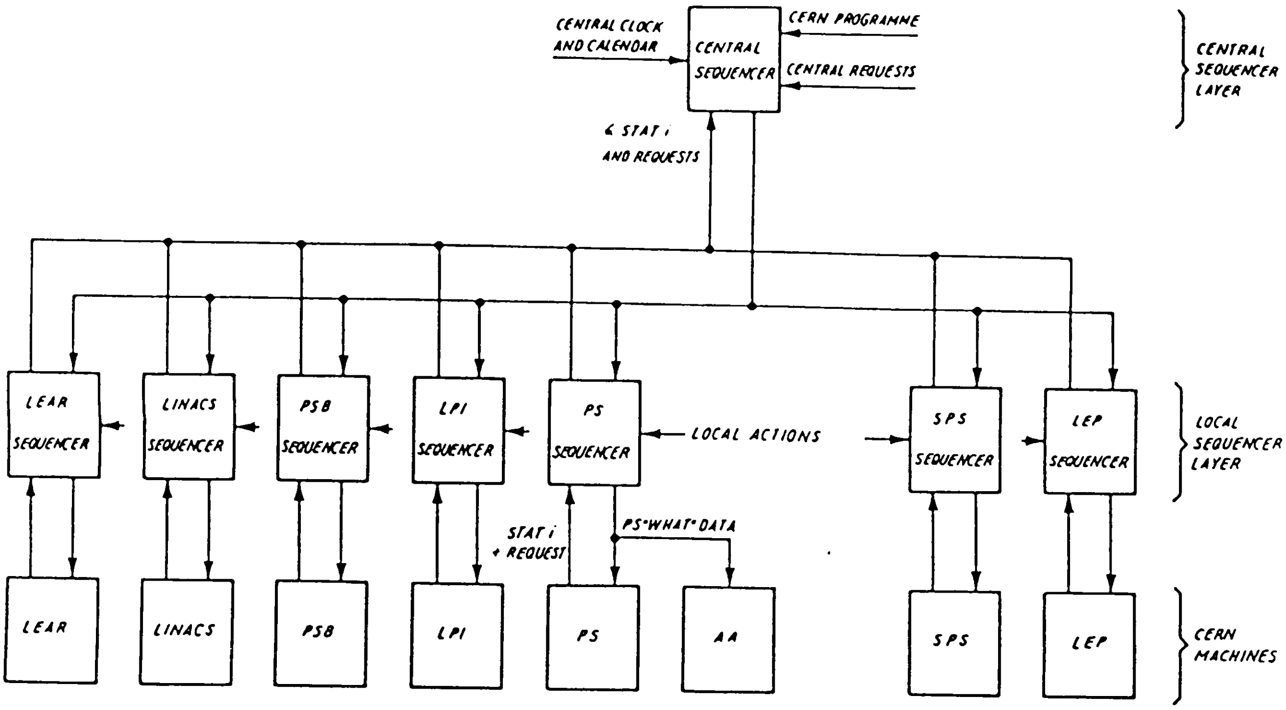

Fig. 2.5. Proposed Sequencing Architecture
The sequencing of the CERN machines could be ensured by two layers of the standard sequencers. There is one local sequencer per machine with the possible exception of AA. Within the SPS the exact number and the technology of local sequencers is still open to discussion. The central sequencer coordinates the activities of all the CERN machines via the local sequencer according to the CERN programme, the local request and the states of the machines. The central clock and calendar are distributed to all machines via the sequencers.

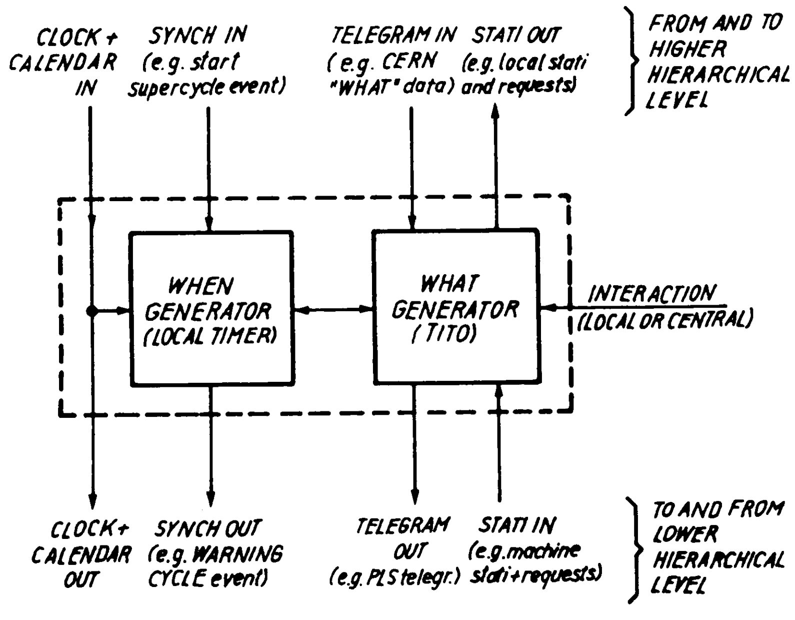

Fig. 2.6. Generalised Sequencer Concept
The standard sequencer contains the logical unit which merges the telegram from the upper layer with the data, stati and requests into the telegram for the lower level. It also contains the local timer which - using the SYNCH IN event, the CLOCK and appropriate delays - generates the SYNCH OUT event and the instant of the outgoing telegram. The examples shown in brackets refer to a local sequencer. The structure of the standard sequencer does not depend on its position.

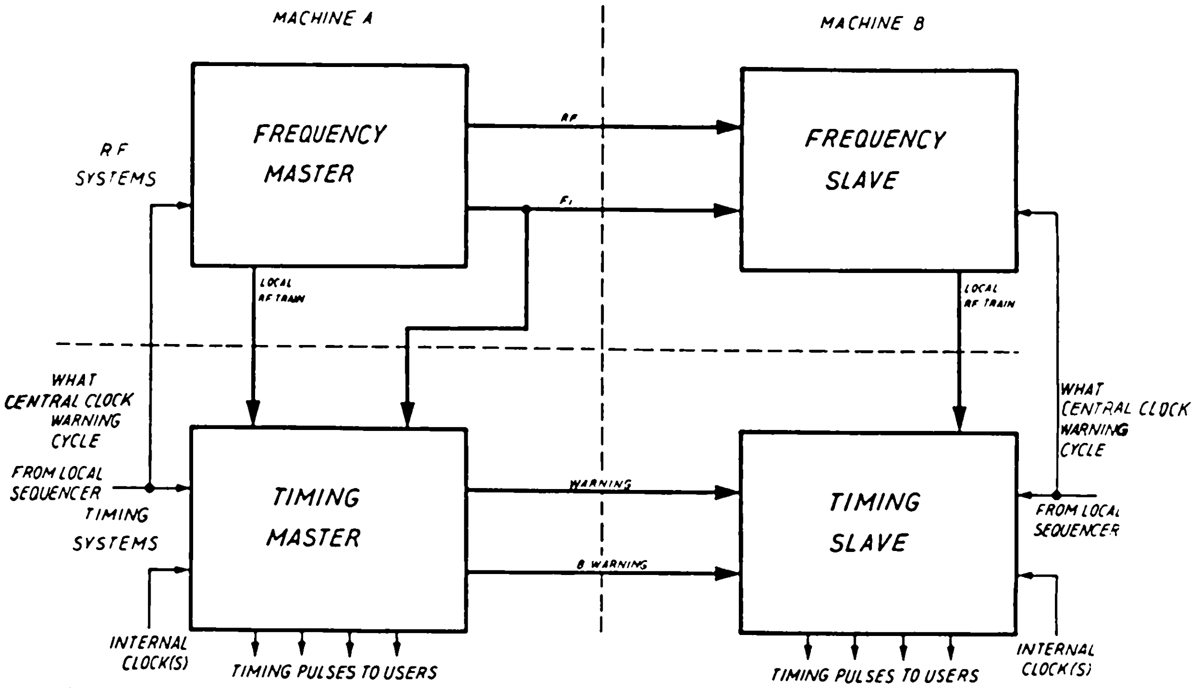

Fig 3.1 FREQUENCY MASTER AND TIMING MASTER IN THE SAME MACHINE

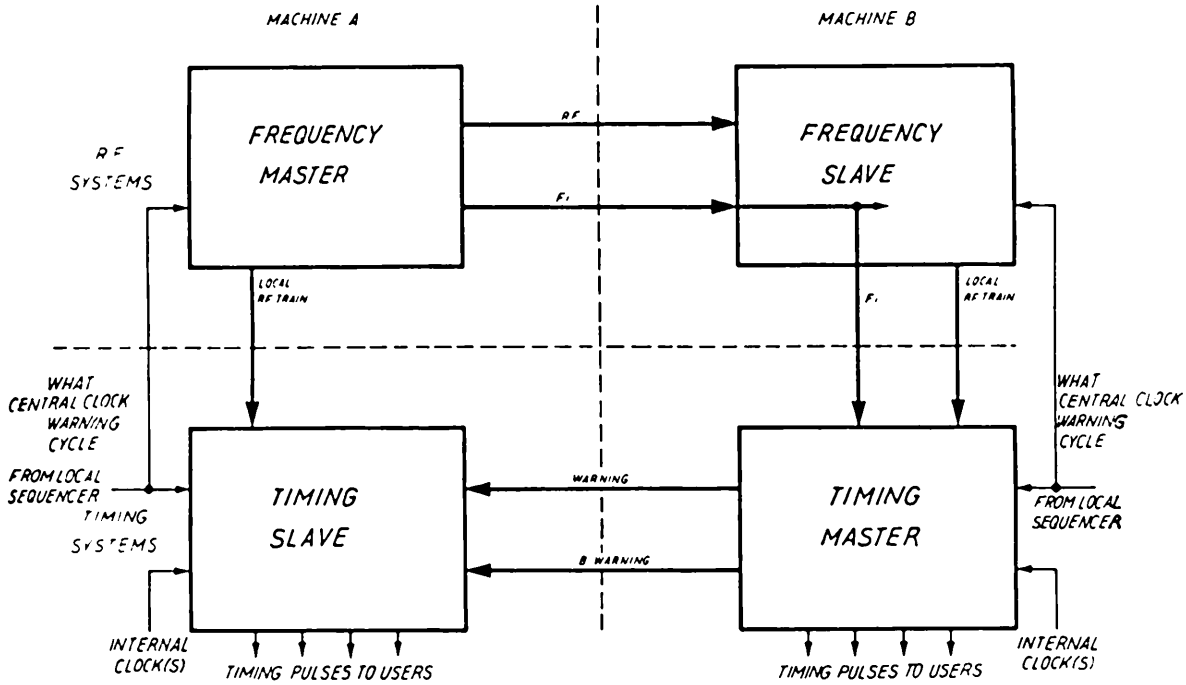

Fig 3 2 FREQUENCY MASTER AND TIMING MASTER IN DIFFERENT MACHINE

The frequency master sends the RF and the FIDUCIAL frequency to synchronise the slave. These two connections are under the responsibility of the RF specialists. As the frequency master and the timing master do not necessarily reside in the same machine, two cases must be envisaged. The timing master is synchronised by the frequency master either (i) directly or (ii) via the frequency slave . The timing master sends a maximum of two signals to the timing slave. In principle this connection could be reduced to one single signal. Each timing system serves its local users, thus decoupling the users of the two machines. Each timing system receives the WHAT data, the WARNING CYCLE event and the central clock from its local sequencer. Other internal clocks may be used.

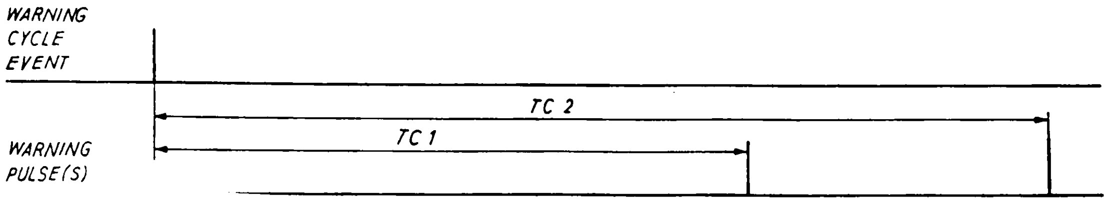

Figure 4.1 <u>Monitoring of WARNING PULSE in the machine cycle</u>.
The time of arrival of the WARNING PULSE (or pulses since there may be several within one machine cycle) is measured with respect to the WARNING CYCLE event. Usually, this measurement will be made in ppm. The resolution is about 10 µs. The WARNING PULSE monitor stores the measurement and triggers an alarm in case the results exceed some predefined limits.

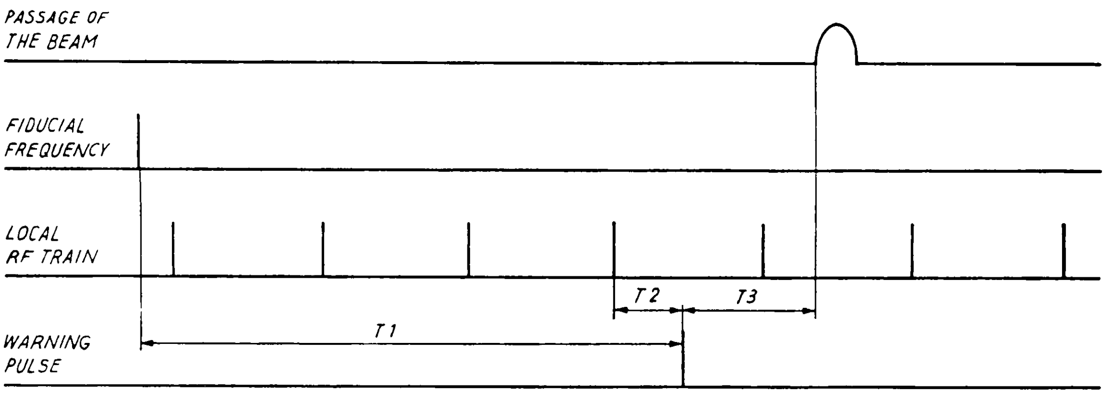

Figure 4.2 <u>Monitoring of the WARNING PULSE at the moment of transfer</u>.
The time differences between the WARNING PULSE and the passage of the beam in the relevant transfer line, the fiducial frequency and the local RF train are measured and compared with reference values. In case the measurements exceed some predefined limits, an alarm is generated. The measurements depend on the type of cycle. The resulution of measurement may be as low as one nanosecond.

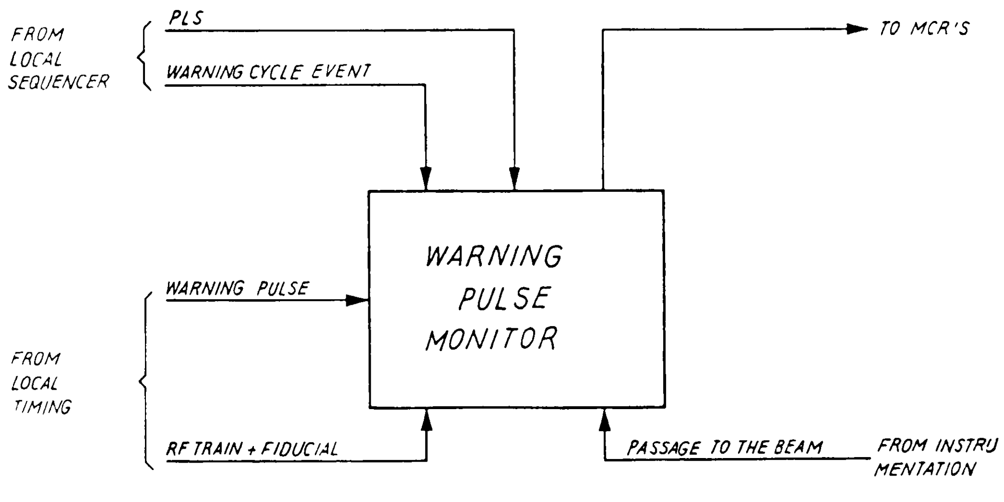

Figure 4.3 <u>The WARNING PULSE monitor</u>.
The hardware of the WARNING PULSE monitor receives the WARNING pulse and the reference elements from the local sequencer, the local timing and the local instrumentation (e.g. to supply a current transformer output). The results of the measurements are available for all cycles concerned by all the users. There is such a device at both ends of a transfer tunnel between two machines.