MECHANICAL DESIGN, SIGNAL PROCESSING AND OPERATOR INTERFACE OF THE LEP BEAM CURRENT TRANSFORMERS

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Abstract

Four assemblies comprising DC, individual bunch and single turn current transformers are installed in LEP. The mechanical design is described. The data acquisition is made at the revolution frequency in the VME standard through 16 bit ADCs with 128 kwords buffer memory. The beam lifetime is computed and a transient recorder facility is implemented. Various displays are generated for the operators. The performance of the system is outlined.

1. MONITOR LAYOUT

Four identical transformer assemblies are installed symmetrically around point one, two are immediately downstream of each injection point and two are in straight sections at 163 m from point one. The assemblies can be equipped with toroids [1] suitable for fast (ST), bunch to bunch (BB) or DC measurements, see Fig. 1 for details.

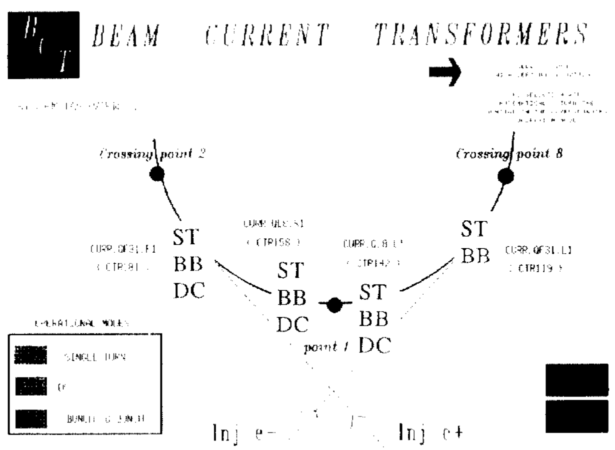

Fig. 1 : Current monitors layout.

The first two are essentially meant to work in SINGLE-TURN (ST) mode where the current of each injected bunch is measured. The two other monitors are used in MULTI-TURN (MT) mode, and are equipped with a DC transformer measuring the sum of both circulating beams and eight bunch to bunch (BB) channels providing the current of individual bunches (four e+ and four e-); so far only one of the MT monitors has been used operationally. The other one is used for development purposes. The DC transformer is used to calibrate the sum signal of the eight BB channels.

2. MECHANICAL DESIGN

The monitors are located in standard elliptical aperture vacuum sectors and a length of 390 mm is available for them. The design goals for the monitor mechanics were to provide the usual gap and external bypass for the image currents, to induce minimum higher order mode losses, to withstand the synchrotron radiation power deposition, to be bakeable to 150°C and to use standard components for economy and reliability.

These criteria led to an elliptical "RF chamber" being used to ensure a smooth environment for the beam. In the first design, which was used for tests in CESR at Cornell and installed in LEP for the positron injection tests in July 1988, the "RF chamber" was a piece of standard LEP aluminium chamber bolted to the vacuum housing. This design is not acceptable in the arcs for LEP phase 2 because of its higher outgassing rate under synchrotron radiation heating; consequently, a monitor with a copper "RF chamber" made of two 3 mm thick copper tubes having an elliptical cross-section was designed and will be installed in all locations (Fig. 2). These tubes are vacuum-brazed to two copper blocks with the same aperture on which two stainless steel cooling circuits are brazed.

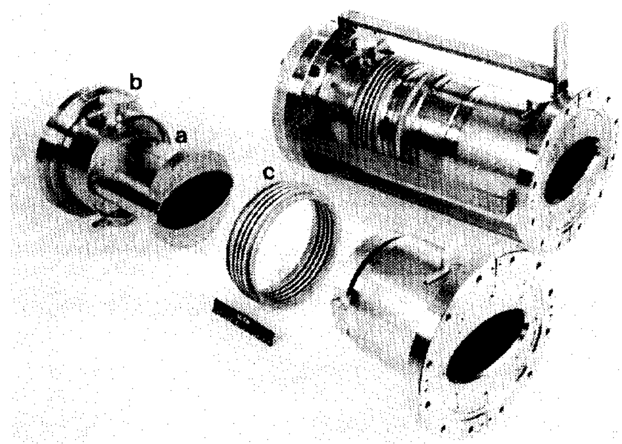

Fig. 2 : Assembled monitor housing with some constituants in the foreground : a) copper "RF chamber", b) cooling circuit, c) bellows.

A thermal analysis has shown that the temperature will not exceed 70°C at any point of the chamber for beams of 3 mA x 3 mA at 100 GeV. A 2 mm gap in this RF chamber stops the flow of image currents. Two stainless steel flanges are brazed to the copper RF chamber to minimize the power coupling to the rear volume. The vacuum vessel itself is made of a 140 mm diameter stainless steel tube welded to a 22mm long ceramic ring assembly followed by a hydroformed bellows to minimize the stresses on the ceramic. The assembly is terminated by two flanges, one of them being a rotational type. To limit the RF leakage the ceramic gap is covered by a copper strip in galvanic contact with the vacuum chamber on one side and isolated from the other side by a Kapton film. The overall capacitance of the two gaps is about 100 pF. The vacuum chamber is covered on each side of the gap by two heating jackets for bake-out. Following a thermal insulation there is a water cooled copper tube on which the measuring toroids are mounted. The rigidity of the monitor is maintained by four stainless steel bars connecting the two end flanges. The assembly is surrounded by a shield made of three concentric cylinders of magnetic material isolated from each other by Kapton films and the total assembly is enclosed in a 2 mm thick copper shield (Fig. 3).

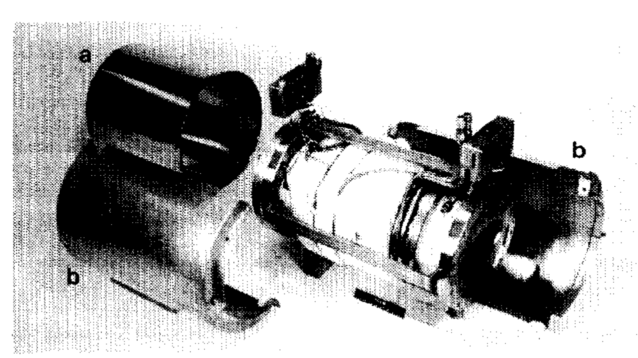

Fig. 3 : Finished current monitor with the three toroids (BB, ST, DC), the magnetic (a) and the copper (b) shields.

No loss factor measurement of the assembly has been made, but from previous experience this is estimated to be less than 0.05V/pC.

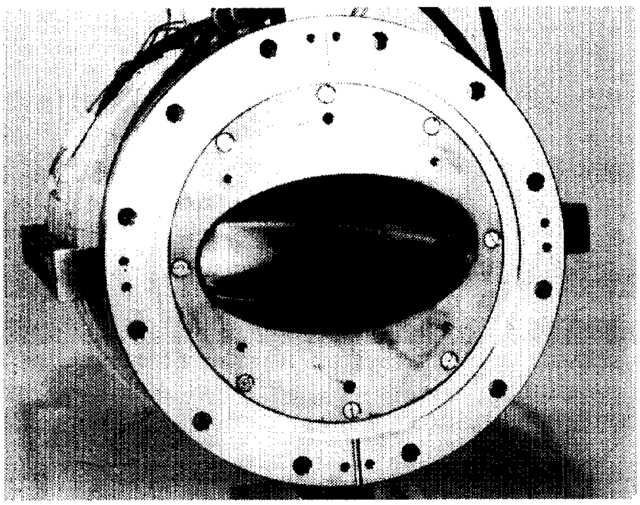

Fig. 4 : The transformer assembly as seen by the beam.

3. SIGNAL ACQUISITION AND PROCESSING

The signal processing for the DC, BB and ST transformers (Fig. 5) is controlled through a VME crate (Equipment Control Assembly: ECA) running under the RMS68K operating system standardised for the LEP Beam Instrumentation Group equipment [2]. The program in the ECA is written in Pascal and assembly language.

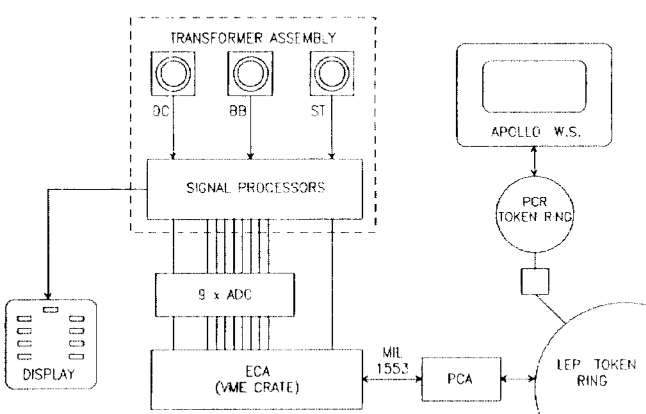

Fig. 5 : Acquisition system of the current transformers.

The ECA continuously monitors the LEP currents and communicates to a local PCA (Process Control Assembly) using the MIL/STD-1553 protocol. Apollo work stations, linked to the PCA through an IBM Token Ring, are used to further process the data and to display the results in the PCR (Prévessin Control Room).

A simple DVM display is connected directly to the signal processor units for local monitoring of the 8 bunch currents and total current. This display is also transmitted over the CCTV network to the PCR.

3.1 DC and Bunch Currents

The system has been built to acquire at least 1000 values of the DC and bunch currents at the beam revolution frequency.

Analog signals proportional to the total current and the bunch currents are available from the transformers [1]. The nine signals are each connected to processing chains consisting of ADC cards and memory buffers (Fig. 5). The ADC's are continuously self calibrating 16 bit modules with cycle times of less than 40μs which permit two acquisitions per turn. They are in single Europe format and are housed in a separate crate with galvanic isolation from the VME system. Laboratory tests on the ADC cards gave integral nonlinearity of ± 60 ppm (parts per million of full scale), a temperature coefficient of 30 ppm/°C, and a long term stability better than 90 ppm per week. The noise resolution is a function of the averaging and is shown in Fig. 9 (ADC card). The memory buffers are VME compatible and each channel has a capacity of 128 K x 16 bit words, i.e. current readings.

The fast timing signals for controlling the signal processors, ADC's and buffers are indirectly derived from the Beam Synchronous Timing (BST) and Programmable Delay Modules (PDM) [2]. Timing pulses related to each of the bunch passages are passed to the appropriate modules under control of the CPU. Blocks of readings (length programmable) are acquired in the buffer memories for subsequent processing in the ECA. Equipment status, calibration and range changing are made through a commercially made VME input/output module (Adas ICV196).

3.2 Single Turn Injections

A fast transformer is used to monitor single turn injection. Signals from the signal processor are acquired by a fast Integrate and Hold circuit and an ADC. The ADC is a commercially available VME module (Adas CV150) having a conversion time of 4 μs and a resolution of 12 bits. Information from the ADC is read directly into the memory of the CPU on a pulse to pulse basis. At present successive measurements can be made at about 100 μs intervals.

Gating and control signals for the Integrate/Hold and ADC are derived from the BST, PDM and I/O modules.

4. DATA PROCESSING

A limited effort was available to optimise the software. The present status is given below. The system performance can be further enhanced with more effort in this area.

The organisation is the same for the DC and the BB monitors. There is acquisition and storage at each LEP revolution (88.9 μs) and then averaging over a determined number of revolutions.

Each current value results from a cycle during which the acquisition time and the processing time (transfer and averaging) are approximately equally shared. If an injection occurs into LEP, the on-going cycle is restarted to keep synchronism and consistency. In order to keep the PCA available for other tasks the ECA/PCA transmissions have been limited to a set of 5 values every 4 s for each of the nine channels. For good 50/150 hz noise rejection each value is the average of 675 acquisitions. Tests have shown that a much faster rate could be used. Fifty values sent every second would give good tracking of the loss mechanisms during delicate machine operation phases (filling, energy ramping...).

Each time a transmission occurs, the application program in the Apollo reads the new values, stores them, and averages them to obtain the new current readings.

5. FACILITIES PROVIDED

All these various options are accessible through a single program via a mouse selection, starting from the overall layout display of Figure 1.

5.1 DC **CHANNEL:** this channel provides :

- the sum of the two beams updated at 4 sec intervals,
- the lifetime derived from a least square fit of Ln[I(t)] over a sampling interval which depends on the machine mode and varies from 15 s during ramping to 10 mn when the beams are stable. Over 100 values are processed during stable beams

which gives a precision of about 1 %. This value is also updated every 4 s (Fig. 6).

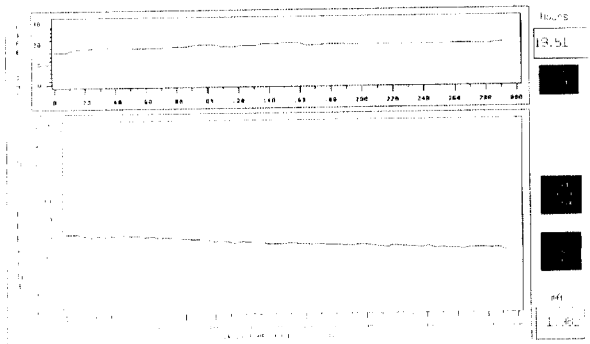

Fig. 6 : Total current (bottom) and lifetime (top) display.

a transient recorder: each individual value transmitted is saved in memory. A facility exists to retrieve any part of this data at a given time (Fig. 7). The memory capacity is of 600 transmissions which represent 40 minutes of information at the present sampling rate. Tests are under way to stamp any of these values with a pre-selected timing event so that particular current recording periods and injection or stacking efficiencies can be retrieved.

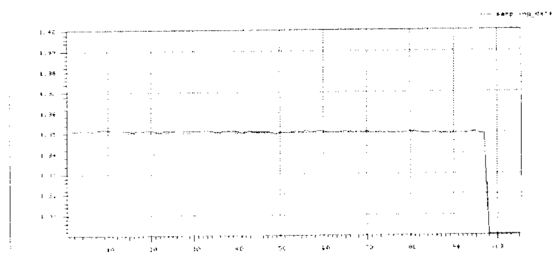

Fig. 7 : Transient recorder output of a current loss.

a loss-monitor : an interlock is foreseen, based on the continuous processing of di/dt in the ECA, which can provide via the fast timing loop (BST) and within two LEP turns (178 μs) a signal to stop a given process; although not yet fully implemented, successful tests have been performed at the ECA level.

5.2 BB CHANNELS : each bunch signal is treated in the same way as the DC signal; the currents of individual bunches are displayed and plotted with the same updating frequency: Fig. 8.

As a short term development, it is foreseen to compute the individual lifetimes of the eight bunches.

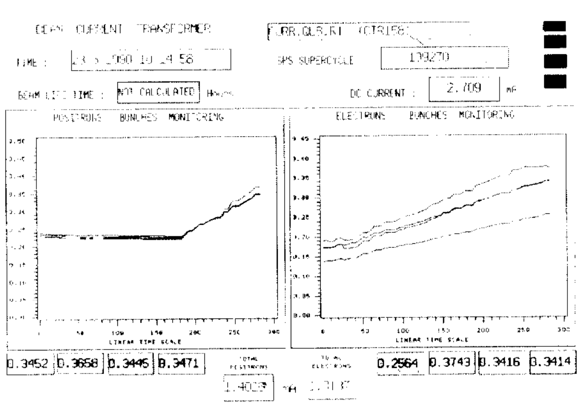

Fig. 8 : Display of positron and electron bunch currents.

6. PERFORMANCE

The measured average rms noise levels of the DC and BB channels, as a function of the number of averaged points taken at the revolution frequency, are shown in Fig. 9.

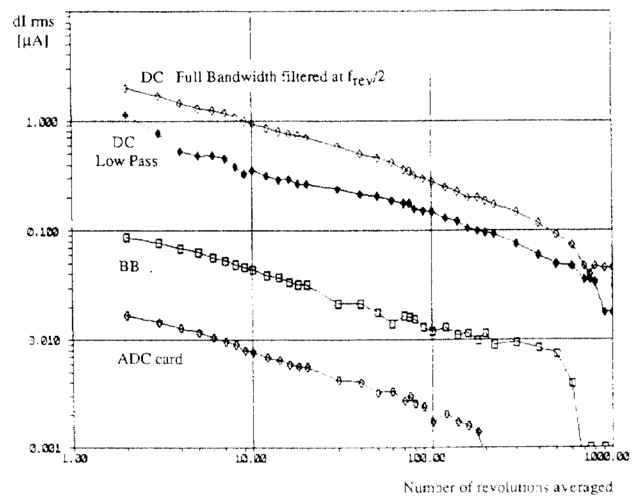

Fig. 9 : Rms noise levels measured as a function of the number of averaged revolutions for the DC channel (Full bandwidth and Low Pass), a BB channel and the laboratory test of the ADC card.

6.1. DC CHANNEL : the monitor uses the 10 mA full scale Low Pass filtered output from the processor (0.5 ms rise time). It is calibrated with its built-in absolute test source. The fluctuations observed on the Apollos in the PCR are less than 1.2 μA peak to peak over periods of 5 to 10 mn . Offset variations of a few μA have been observed and are suspected to be caused by electromagnetic and thermal effects on the toroids.

6.2. BB CHANNELS : the full scale is 2.5 mA. The channels are equalised with a test generator and the sum of all bunches is normalised with the DC monitor. A single bunch circulating in the machine has also been used to calibrate each channel against the DC monitor. The display has a resolution of 0.1 μA (i.e. $5.5*10^7$ particles). At present, the time interval, at the transformer, between the passage of an electron bunch and the nearest positron bunch is 1.1 μs, this causes cross-talk of 1 to 3 % on the positron channel.

6.3. ST CHANNEL : This facility was used extensively during the injection test of July 1988 and at the start-up of LEP when one bunch was injected on each lepton cycle. A resolution of $5*10^7$ for a full scale of $5*10^{10}$ has been obtained. As it is no longer considered essential for operations, the monitor has not yet been fully tuned for four bunch injection per SPS lepton cycle.

ACKNOWLEDGEMENTS

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