X-RAY MONITORS TO MEASURE BUNCH LENGTH AND VERTICAL PROFILE AT LEP

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Abstract

Special vacuum enclosures allow the direct exposure of solid state detectors to the main dipole synchrotron radiation, through a window of 400 μm Be. CdTe photoconductors have been chosen for their short carrier lifetime (10 ps). Two detectors are mounted together.

1. An array of straight photoconductors is measuring the vertical profile with a pitch of 100 μm, at each bunch passage.
2. A solid state circuit with imbedded matched lines is producing the autocorrelation of the longitudinal profile with 16 channels.

These two devices have been brought up to the state of final prototypes tested in the LEP beam; an appraisal will be presented of their performances so far achieved.

INTRODUCTION

The aim of the project is to monitor at a repetition frequency of 44 kHz the vertical [1] and longitudinal [2] distributions of electron and positron bunches in LEP. These particles emit, when traversing machine dipoles, a large quantity of synchrotron radiation in the X-ray region between 10 keV and 100 keV which can be directed onto monitors placed outside the machine vacuum.

Two special recesses have been placed in LEP vacuum chamber near the quadrupoles QD12, on both sides of LSS1. There the main dipole synchrotron radiation strikes the detector through a 400 μm Be window (see Fig. 1) covering a surface of about 1 mm height and 20 mm width.

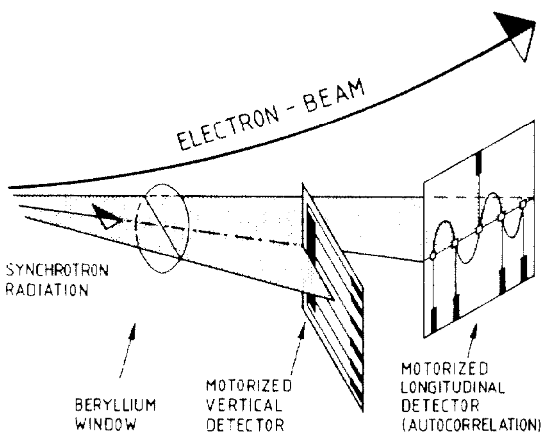

Fig. 1. Layout of X-Ray monitors

The mechanics and the detector vessel will be described, then the principle of each detector and the results obtained so far.

MECHANIC AND VACUUM TANK

When LEP is operated at 45 GeV, 100 W of synchrotron radiation is passing through the Beryllium window threatening the detector with corrosion. The detectors are therefore mounted on a mechanical support moving inside a vessel evacuated down to 10^{-6} Torr (to insure for the insulation of the high polarization voltage). One movement serves to take the detectors out of the X-Ray beam when not in use, the other is for fine vertical tuning (see Fig.2).

For the transmission of the movements by the servo-motors, which are at atmospheric pressure, to the inner vacuum, rotary FERROFLUIDIC feedthroughs were used. They are hermetically sealed by a ferrofluid kept under a magnetic field.

No polluting residual gas, even rarefied, is permissible, otherwise the window or the detectors could be corroded. So, the frictions were minimized with a stainless steel/polyimide contact for the gear wheels actuating the rotational motion, and stainless steel/titanium carbide for the ball screw, which provides the vertical motion.

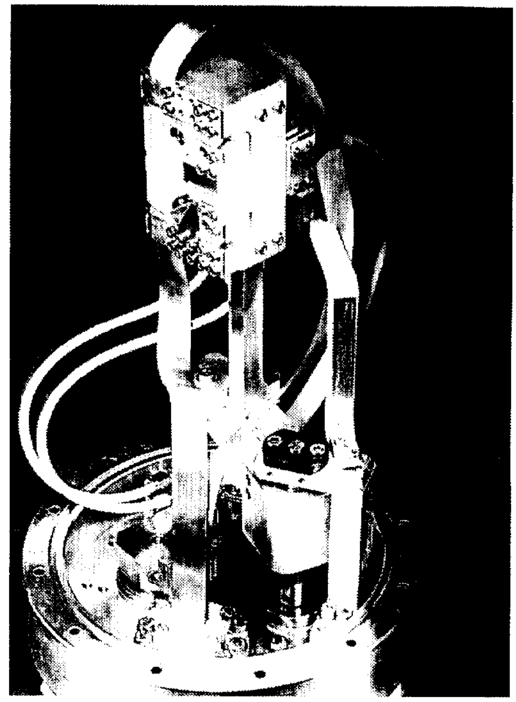

Fig. 2. Motorized support in vacuum for X-Ray monitors

The vacuum vessel, made of aluminium alloy, with its Be window, must be baked-out in situ. It was foreseen to to test it, prior to installation, with three cycles of bake-out at 150° C during 24 h.

The electron-beam weld, between the window and its Al support, manufactured by ELECTROFUSION CORP. USA, must resist high stresses due to the differential expansion Be/Al. These elastic stresses proved greater than the strength limit of the weld! But a new calculation, using the program of Finite Elements Method : CASTEM, showed us very nicely (see Fig. 3) the plastic deformation of the material during the first heating, then, after creep, the elastic tangential stresses, alternating in compression and tension, at the next temperature cycles. Thus von Mieses stresses are acceptable.

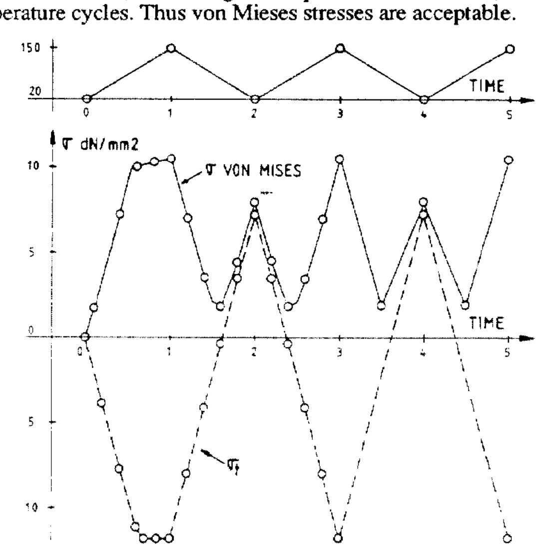

Fig. 3. Computer simulation of the stresses in Be/Al weld. The upper trace shows the temperature cycle, the dashed line gives the tangential stresses, the full line is the resulting von Mieses stresses.

X-RAY VERTICAL PROFILE MONITOR

A thin layer of CdTe (4μm) is deposited on a ceramic support, 127 μm thick, using the technique of metalorganic chemical vapour. One vertical bias line and 64 horizontal finger lines (50 μm wide) with a pitch of 100 μm, are made with vacuum deposit of gold. The bias voltage is applied on the gaps of 40 μm between the 64 finger lines and the bias line (see Fig. 4).

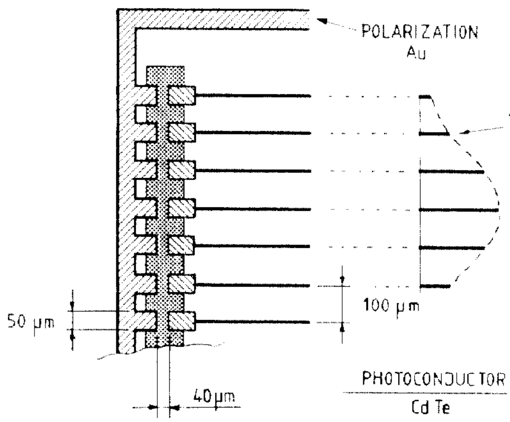

Fig. 4. Layout of the detector for vertical profile

Under the impact of X-rays the conductance of CdTe changes and the gap resistance decreases as a linear function of the photon flux [1, 2, 3] generating currents in the different lines which directly give the vertical profile.

Electronic system

All front end analogue electronics associated with the detector have been built with the prerequisite to use the digitizing and storage system already developed for the BOM (Beam Orbit Measurement System) [5]. And since the detectors are 300 m away from the digital processing system situated in the pit at intersection No.1 something had to be done in order to reduce the price for analogue signal transmission cables.

Because the BOM input flash ADC [5] was able to take data spaced by about 1 μs, it was decided to time multiplex 16 signals in the same cable in less than 22 μs (interval between LEP bunches).

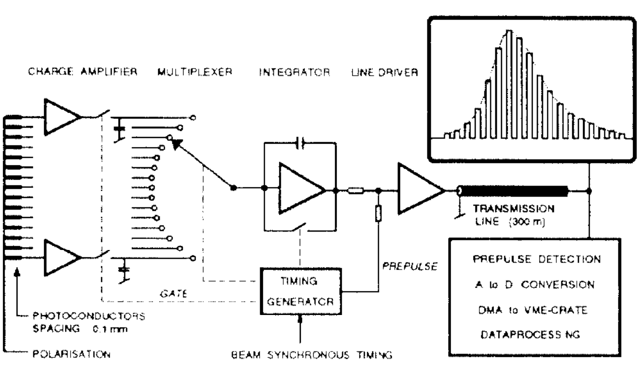

Fig. 5. Synoptic diagram : detector and front end electronics

No electronic module was available on the market to amplify, store and time multiplex 16 signals at that speed. Therefore, a VME module with 16 input channels was developed at CERN. In this module (see Fig. 5) the charge from each photoconductor is amplified, gated and stored by means of hybrid components. After gating (2 μs) the charges are multiplexed onto an integrator and mixed with prepulses preceding each channel.

In this way 16 channels of the vertical profile are sent as a 16 μs long train of pulses containing trigger information for the flash ADC 300 meters away.

The detailed description of the circuit will be given elsewhere [6] but its main characteristicsare as follows. BOM flash ADCs used for digitization have only 8 bits of resolution which is not sufficient to give a satisfactory dynamic range. Thus the front end module has been designed with two outputs: the low sensitivity one being attenuated by a factor 8. The high sensitivity output gives 4 V amplitude for a charge of 5.10^{-2} pC received in a pulse of 100 ps full width half maximum. Since the noise level is strongly related to the capacitance of the input cable a special development was made of a 32 channel kapton strip-line of 2 m length with only 200 pF per channel. Thanks to this precaution the noise level has been reduced to 3.10^{-3} pC peak to peak.

Results obtained in real beam conditions

One detector has been installed in LEP during the last shutdown and has survived many days of irradiation. This is a crucial result because the power deposited by X Rays in the 4 μm of CdTe can be estimated to 40 mW/mm^2, for a beam of 1 mA. Therefore the dose accumulated in several days amounted to more than 10^{11} grays, still no damage has been noticed which is exceptional for a semi-conductor detector.

The first results obtained recently with a final detector can be seen in Fig. 6. This picture is obtained with an oscilloscope triggered on LEP revolution frequency and receiving directly the multiplexed signal from 16 fingers of the detector. During the film exposure the same bunch was seen 150 times but there is not much smearing since the beam was stable. The short prepulses seen in Fig. 6 are made on purpose to trigger the digital acquisition electronics not yet in use. Since 32 finger signals are interlaced in two 16 channel modules, the binning in Fig. 6 is 200 μm and σ=0.6 mm can be deduced with hardly any systematic error to worry about. The relationship between X-ray image and electron beam emittance was examined in Ref. [1].

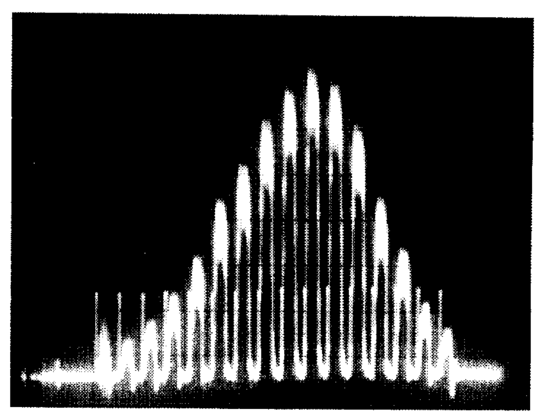

Fig. 6. Time multiplexed signal received from a vertical profile detector and observed on an oscilloscope (200 mμ per channel)

BUNCH LENGTH X-RAY PROFILE DETECTOR

The aim of this detector is to monitor the autocorrelation of the longitudinal profile. This system is patented and its principle has been described in Ref. [2, 3], therefore the method will be briefly summarized and the present status of realization given.

Realization of the detector

Developing a final prototype of this detector has been a long venture managed in collaboration with an industrial research institute in Grenoble [7]. The whole circuit is made on a thin quartz plate, 127 μm thick, 50 mm × 20 mm. Folded delay lines (see Fig. 7) are produced with a precise vacuum deposit of aluminium. On a horizontal row, at the height of the beam, fast CdTe photoconductors are connected to the delay line. All semi-conductors are illuminated simultaneously by intense synchrotron X-ray pulses.

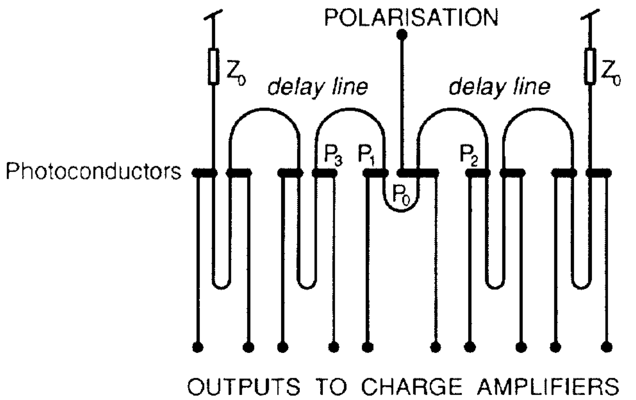

Fig. 7. Layout of the autocorrelation circuit for longitudinal profile

The photoconductor P_0 polarized with a d.c. bias voltage sends through the line an electric signal V(t) proportional to the incident light pulse $j_0(t)$. This signal propagates in the two delay lines and biases the other semi-conductors with various delays τ_i. Any photoconductor P_i generates a current proportional to the product of the light pulse and of its delayed image $V(t+\tau_i)$. And the delivered charge Q_i :

$$Q_i = k \int_{-\infty}^{+\infty} j_0(t)\, V(t+\tau_i)\, dt$$

gives one point of the autocorrelation profile, corresponding to the delay τ_i.

The readout electronic is the same as the one used for the vertical profile, see Section above. Thus, a 16 channel module integrates, stores and time multiplexes the data into one single transmission cable every 22 µs.

Results obtained with subpicosecond laser pulses

The evaluation of the performances of CdTe photoconductor and of the single delay line circuit was made in a laser laboratory in Paris [8]. With the help of an optical delay line, one part of a subpicosecond laser pulse was sent to the bias photoconductor P_0 and the other part to any photoconductor situated on the electrical delay line. The integrated charge was then measured for different optical delays between these two pulses, and the result of the autocorrelation signal is given in Fig. 8.

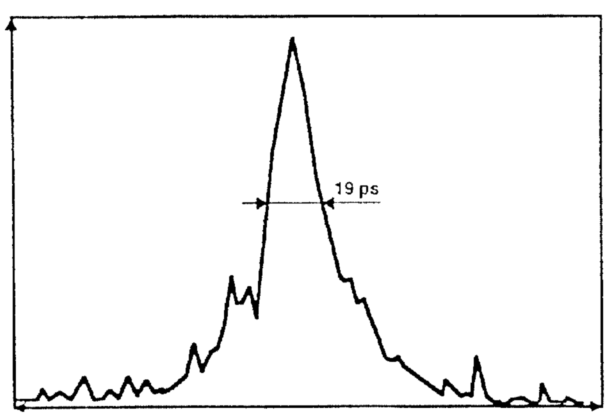

Fig. 8. Time autocorrelation obtained for one channel of the circuit tested with a subpicosecond laser pulse and a variable optical delay

The FWHM of this autocorrelation curve is 19 ps which corresponds to about $\sigma \approx 8$ ps. Moreover, Fig. 8 is typical for any channel of the circuit shown in Fig. 7, even those with the longest electrical delay, which demonstrates the perfect adaptation of the delay lines in the monolithic circuit.

Results obtained at LEP

The first prototype of the monolithic circuit had only a few working channels because several defects had developed during the 29 steps of its production . It has nevertheless been installed in LEP in Octobre 1989 and led to the first observation of autocorralation signals from short X-ray pulses. The signals are clean and have the right amplitude but, due to the missing channels, they do not allow to draw a pulse shape.

Unfortunately, the second prototype broke during installation. in March and the next trial will be done this summer with a third circuit.

CONCLUSIONS

Both prototypes of vertical profile and autocorrelator detectors along with their associated electronics have very interesting features. They permit the realization of :

- Non intercepting beam detectors;
- Real time single shot measurements;
- Measuring bunches at a rate of 44 kHz;
- The vertical resolution is not diffraction limited;
- There is no critical timing needed to trigger the system

When the acquisition and software control has been implemented, X-ray monitors will be entirely remote controlled and should provide a simple tool for the operators. Commissioning of the vertical profile monitors is on the way and the final prototype of the autocorrelator will be installed and tested this summer.

Finally we should mention also the very unique characteristics of CdTe photoconductors :

- They accept extremely high radiation doses;
- Also thanks to their very low dark current they are able to handle very high voltage (many kV);
- The actual speed of our detector is fast enough for LEP bunch length measurements. But elsewhere the speed obtained recently with similar deposition process of CdTe was 480 fs [9].

Both types of devices, vertical profile and bunch length monitors, beyond their possible use with other particle accelerators, will certainly find useful applications in the near future in high intensity laser monitoring, single shot X-ray or plasma detector or picosecond electric pulse generation or detection.

ACKNOWLEDGEMENTS

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