PERFORMANCE OF WIRE POSITION SENSORS IN A RADIATION ENVIRONMENT

W. Coosemans, B. Dehning, M. Hildreth, A. Marin, J. Matheson, G. Mugnai, J. Prochnow, F. Roncarolo, E. Torrence

CERN, Geneva, Switzerland

Abstract

The large electron-positron collider (LEP) at CERN has been equipped with a spectrometer for beam energy determination. The spectrometer measures the bending of the beams in a dipole magnet using beam position monitors (BPMs) to reconstruct the beam trajectory. The stability of the positions of the BPMs themselves is monitored using a stretched-wire position system. We report our calibration and experience of the operation of the WPS in the synchrotron radiation field of LEP.

1. INTRODUCTION

At LEP, a spectrometer has been installed to determine the beam energy with a relative precision of 10^{-4}. A bending magnet is flanked by six beam position monitors, three on each side. These BPMs are used to determine the beam deflection angle due to the magnet. Knowledge of the angle and the magnetic field allows calculation of the beam energy. An accuracy better than 1µm on the beam position measurement and a relative precision of $3\ 10^{-5}$ on the integrated magnetic field is necessary to reach the desired accuracy on the LEP beam energy measurement [1].

Capacitive wire position sensors (WPS) [2] are used to determine the relative stability of the position of each BPM. The temperatures of all sensors and associated electronics are also monitored. The resulting information is digitised via a multiplexed high accuracy digital voltmeter [3], which is read out continuously during LEP operation.

Wire position sensor accuracy was tested in the laboratory with a displacement measuring interferometer, whilst relative accuracy tests have been performed in the LEP environment. The effects of synchrotron radiation on the wire position sensor performance have been observed. Several studies are presented which have been carried out in order to understand and minimise such effects.

2. SETUP OF THE WIRE SYSTEM

The wire system consists of three wires; the first extends over the whole spectrometer and is intended to observe movements of the arms of the spectrometer with respect to each other. Two further wires are installed, one on each arm for redundancy and also to distinguish between shifts and expansions of the BPMs (Fig. 1). The expansions, however, have a negligible effect on the beam position measurements. There are eighteen WPSs installed at the spectrometer: one on either side of each BPM and one at each mounting point of the wire. Those on the BPMs observe movements of the BPMs, with respect to the wire and those at the fixing points observe movements of the wire, with respect to the supporting limestone block.

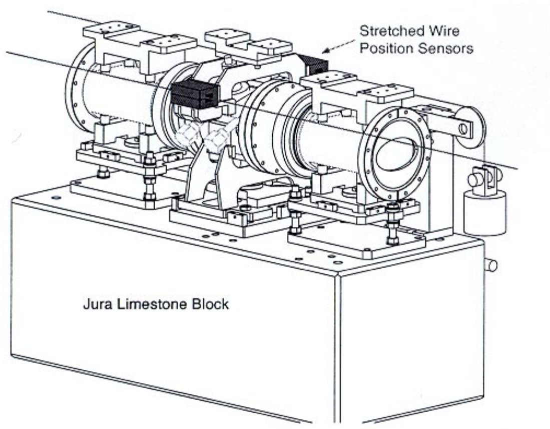

Fig.1: One of 6 BPM stations with the attached wire system and the BPM in the center.

3. PRINCIPLE OF OPERATION OF THE WPS

The principle of the position measurement is to determine the capacitance between opposite electrodes of the sensor and the wire. This is achieved by measuring the current from the electrodes while an alternating voltage of 10 V peak to peak at 4 kHz is applied to them relative to the grounded wire. The capacitance is to the first order inverse proportional to the distance in this geometry. To obtain the wire position, the analogue signals from opposite plates are subtracted.

4. PERFORMANCE OF THE WPS

One particular test to check for the correct behavior of the sensors was to change the temperature of the BPMs, whilst observing the movements measured by the WPSs (see Fig. 2). This test was performed on several occasions. The expansion of the BPMs (Δl) due to the temperature change ($\Delta T = 10\ ^oC$) determined by the WPS signals is in good agreement with the expansion coefficient of aluminum ($\alpha = 2.3\ 10^{-5}\ 1/^oC$), from which the BPMs are made:

$$\Delta l = l\ \Delta T\ \alpha \qquad \text{where } l = 30 \text{ cm}$$

$$\Rightarrow \qquad \Delta l = 70\ \mu m$$

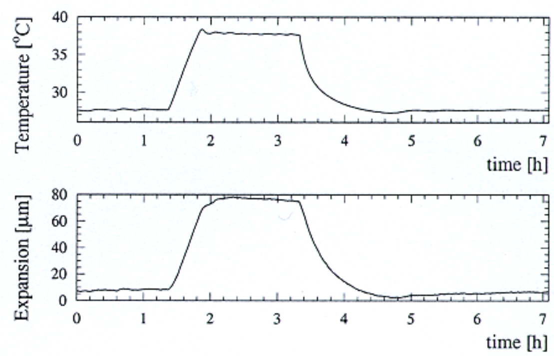

Fig.2: Temperature and expansion versus time.

The differences between successive readings of the WPS (12 s apart in time) are an indication of the noise level in the system, if it can be assumed that in such a 12 s period there are no wire movements. This assumption allows an estimate to be made of the upper limit of the noise. The distribution of the difference between successive readings was found to be Gaussian, with an RMS close to 150 nm (see Fig. 3). This is sufficient for our requirement of sub-micron resolution.

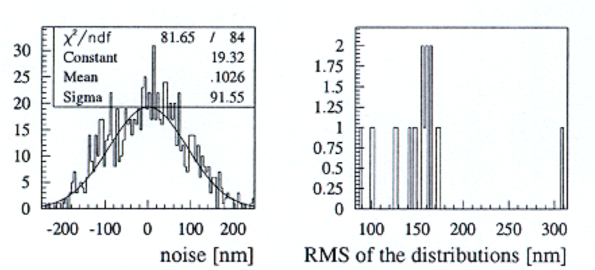

Fig. 3 : Left: distribution of the difference between successive readings for one sensor.
Right: Sigma of the distributions of the difference between successive WPS readings.

5. LASER TEST STAND

To test the accuracy of one WPS, a test stand as sketched in Fig. 4 was constructed. The principle is to compare the position measurement of the WPS with that of the displacement measuring interferometer.
The results will be published in Ref. [4].

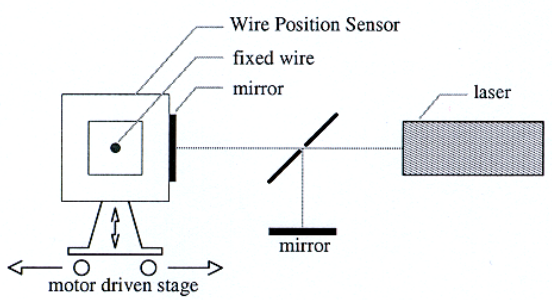

Fig. 4: Test stand to measure the accuracy of the WPS.

6. EFFECT OF THE LEP ENVIRONMENT ON THE POSITION MEASUREMENT

During a ramp of LEP the energy loss from the beams due to synchrotron light increases from almost 0 to 700 W/m for a beam current of 10mA. This affects the sensor significantly, as may be seen from Fig.5. The LEP filling structure is clearly seen in the raw signal of the WPS: At 4 h LEP was filled, the energy was ramped at 4.5 h, between 4.5 h and 8.5 h the beams were colliding and at 8.5 h the beams were dumped. Especially during a beam dump, there are fast position changes in the signal with a height of approximately 4 µm. There is a correlation between the height of these position changes and the position of the wire in the sensor (see Fig. 6). In the situation, where the wire is in the center of the WPS, no instantaneous position changes were observed. The jumps are just slightly smaller, when the electrodes are insulated with Kapton tape.
This correlation was still observed with the wire fixed temporarily to the frame of the sensor, showing that the jumps occurred even though the wire itself was stationary. This means that the effect is an artefact arising within the sensor itself and is not related to a wire movement.

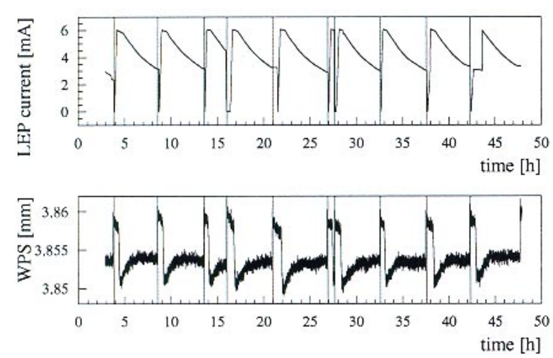

Fig.5 : Upper : LEP beam current over two days.
Lower : signal of a WPS.

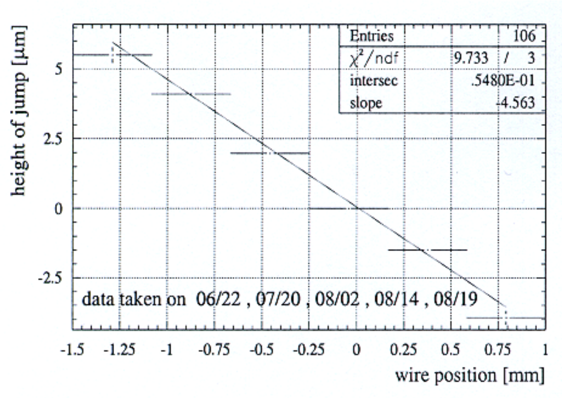

Fig. 6 : Correlation between the height of the jump and the wire position.

During one particular fill, the particle acceleration was interrupted and LEP stayed for 10min each at six different energies between 22 and 92GeV. It was seen that the sensors showed larger movements than expected from the temperature change alone as can be seen from Fig. 7. The size of the unexpected movement was observed to increase with the LEP beam energy to a power greater than one.

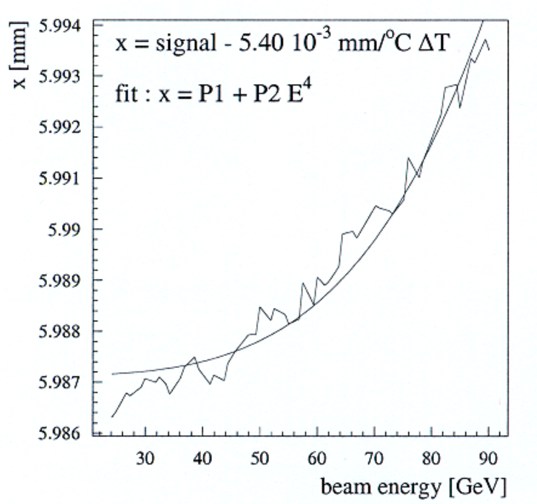

Fig. 7 : Normalised WPS signal ploted against beam energy.

To investigate whether this effect is a result of charge collection induced by synchrotron light, a DC voltage of 19V was applied to one of the alignment wires and the current flowing through this wire to ground measured during the acceleration time. This current was also found to increase with the LEP beam energy to a power greater than one.

Both observations are consistent with the fact that the synchrotron radiation power from the beam increases with the beam energy to the fourth power.

Working on the assumption that the correlation of the sensor signals with the LEP beam is due to synchrotron radiation, the sensors were shielded with around 2cm of lead. This measure was successful on those sensors where space considerations allowed adequate shielding. Those sensors which could not be shielded entirely still show jumps in their signal of around 1.5µm. These jumps are, however, no longer correlated in size with the wire position as can be seen in Fig. 8.

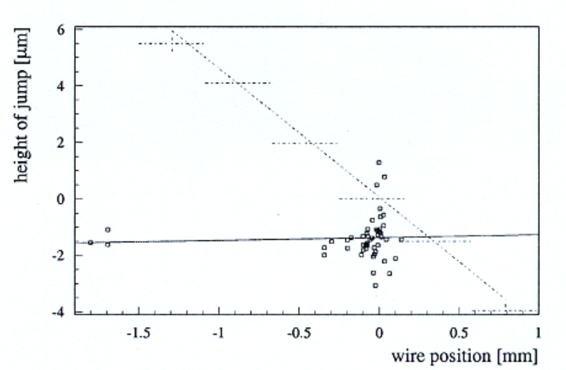

Fig 8 : Height of the jumps against the position of the wire after the sensors were shielded plotted on top of Fig. 6.

It was considered that the behavior of the sensors might be improved by collecting the free charges using electrodes made from copper sheet at the openings in the sensor head. Such a solution was attempted with a

DC voltage applied to the electrodes. However this did not alleviate the undesirable correlation of the sensor readings with the LEP current.

Furthermore another type of sensor (Fig. 9) was brought into the LEP tunnel. With this sensor it is possible to measure the capacitance between two plates, with and without air between them. The jumps occurring during the beam dump are reduced by a factor of 7, when the sensor is put under vacuum, as can be seen in Fig. 10.
In Fig. 10 one can also see that the size of the signal while the sensor is under vacuum is similar to the situation where LEP is running and there is air between the electrodes.

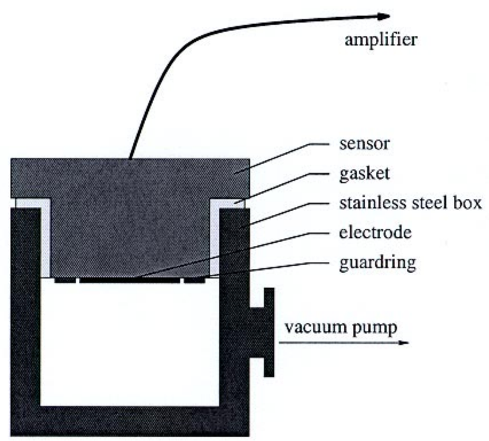

Fig. 9: Cross section of a capacitive distance measuring sensor.

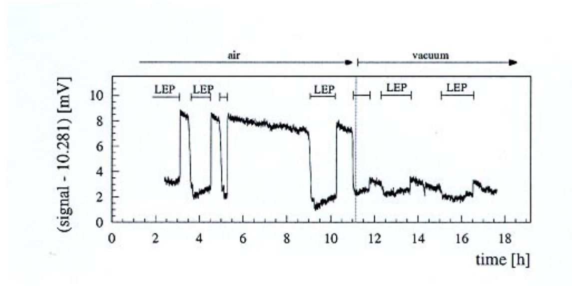

Fig. 10: The signal from the sensor (inversely proportional to the distance) after offset subtraction against time.

The synchrotron light coming from the beams ionises the air surrounding and within the sensor head. This leads to the creation of free charges. Furthermore the N_2 and O_2 molecules are split [5]. This seems to result in a decrease of the dielectric constant ε_r ($=1+\delta$, $\delta = 5.94\ 10^{-4}$: dry air) as seen in Fig. 10.

One can write the following equation, where x is the distance and C the capacitance between sensor and target and S the surface of the electrodes:

$$Signal \sim C = \frac{\varepsilon\varepsilon_r S}{x} = \frac{\varepsilon S}{x} + \delta\frac{\varepsilon S}{x}$$

While LEP is running or the sensor is under vacuum, the second term in the equation is zero (δ=0).

The signals from opposite plates in the WPS are subtracted. Thus we do not expect any net signal from the sensor when the wire is in the center and the field lines are symmetrical (Fig. 11a). If the wire is off center (Fig. 11b), one would expect a different contribution from each plate.

For the WPS the formula looks quite similar, where C_i is the capacitance between the wire

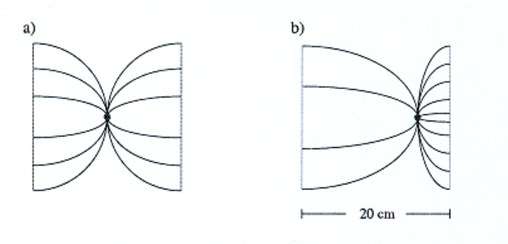

Fig. 11 : Field configuration inside the sensor.
a) centered wire
b) off centered wire.

7. CONCLUSION

We have determined that the WPSs have a resolution better than 200 nm. Systematic errors correlated with beam current have been shown to be due to synchrotron light. This ionises and splits the molecules of the air within the sensor heads, but has been suppressed by means of lead shielding where possible. Those sensors which are insufficiently shielded due to lack of space still show beam current related jumps of the order of 1.5 µm. However, the shielding has removed the dependence of the bump size on the wire position.

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8. REFERENCES

[1] : C. Menot et al., CERN-SL-99-007 DI

[2] : FOGALE nanotech :
190 Parc Georges-Besse
30035 NIMES Cedex 1 France
Tel. (33) 04.66.38.14.85
Fax (33) 04.66.38.14.59
email: fogale@mnet.fr

[3] : Keithley DVM 2002

[4] : J. Prochnow, CERN-SL-00-XXX BI

[5] : M. Hoefert et al., CERN SL/95-08 (DI)