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MEASUREMENT OF THE MEAN RADIAL POSITION OF A LEAD ION BEAM IN THE CERN PS

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A system was thus designed for simultaneous acquisition of revolution frequency and magnetic field. The frequency measurement uses a direct digital synthesiser (DDS), phase-locked to the beam signal from a special high-sensitivity pick-up. The magnetic field is obtained from the so-called B-train. From these two values, the MRP is calculated. The precision depends on the frequency measurement and on the accuracy of the value for the magnetic field. Furthermore, exact knowledge of the transition energy is essential.

This paper describes the hardware and software developed for the MRP system, and discusses the issue of calibration, with a proton beam, of the B measurement.

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1. INTRODUCTION

The PS closed orbit measurement system uses rather small electrostatic electrodes [1] which are not sensitive enough for the small charge contained in the Pb^{53+} bunches. There is a high-sensitivity pick-up to measure the Pb-ion beam at just one place and to drive the radial beam control loop. However, the mean radial position (MRP) can be determined, without measuring the position all around the ring, from high precision measurements of the revolution frequency and the magnetic field.

2. THEORY

The theory of such an MRP measurement for proton beams is treated in [2], but a new way of measuring the revolution frequency allows a simpler procedure. The determination of MRP is based on the differential relation between revolution frequency f, orbit radius R and magnetic field B [3]

$$\frac{dB}{B} = \gamma^2 \frac{df}{f} + \left(\gamma^2 - \gamma_{tr}^2\right)\frac{dR}{R} \qquad (1)$$

with γ_{tr}, the transition energy.

At the PS, protons pass transition during acceleration whereas ions are ejected before reaching it.

R_0 corresponds to the central orbit, such that

$$\Delta R = R - R_0 \text{ and } MRP = \overline{\Delta R} \qquad (2)$$

Using equation (1) we analyse the influence on the MRP of measurement errors of the different quantities, one at a time, keeping the others constant.

The B-value is given, with 0.1 G resolution, by the "B-train", derived from a field measurement in a reference magnet, connected in series with the magnets in the ring. Whereas the reproducibility is about 1 in 10^5, the error on the absolute value can be higher than 1 %. To calibrate the B-train, we measure the MRP of a proton beam, injected on a cycle for ion acceleration, by taking the average of the 40 pick-ups of the closed orbit acquisition system. This is precise to ± 0.1 mm. Reading at the same time the revolution frequency, we calculate the theoretical B-value and compare it to that indicated by the B-train. Figure 1 shows the resolution in G, for a precision of 30 Hz in the measurement of the 20^{th} harmonic of the revolution frequency. This is the error observed on the loop during a sweep of the input frequency from 3 to 10 MHz.

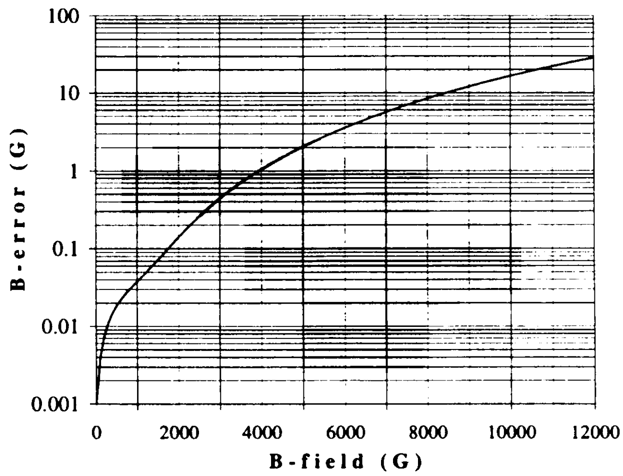

Fig. 1 : B-calibration error due to 30 Hz loop ripple and 0.1 mm MRP error from orbit acquisition.

When this B-calibration and the 30 Hz frequency error of the loop are applied to the position calculation of proton and ion beams, we get the measurement error as a function of the B-field (fig. 2). Since the measurement error increases close to transition, γ_{tr} must be known with great precision.

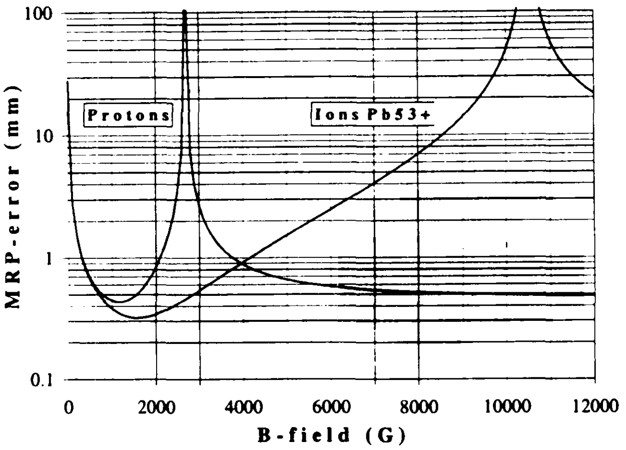

Fig. 2 : MRP measurement error for proton and ion beams using B-calibration of fig. 1, 30 Hz frequency measurement error, and 0.1 G B-train resolution.

3. MEASUREMENT PRINCIPLE AND HARDWARE

The frequency measurement uses a direct digital synthesiser (DDS), phase locked to the 20th harmonic of the bunch signal from a wall current monitor. Such a system was already developed for the PS beam control [4]. A simplified block diagram is shown in fig. 3.

Since the details of this loop have been described in ref. [4] we only give some important characteristics :

- whereas the frequency resolution of the DDS is 40 MHz / 2^{24} = 2.38 Hz, the LSB of the correction word from the ADC is applied to the 3rd bit of the frequency word which corresponds to 9.54 Hz,
- the local oscillator f_{RF} + 10.7 MHz is generated by a mixing process which, over its frequency range, produces sidebands at particular frequencies [5],
- the look-up table for the frequency program is stored in an EPROM memory for proton acceleration.

For ion beams, the B-train is adapted by a binary rate multiplier (BRM), which approximates the charge/mass ratio of Pb^{53+} ions. This leads to a maximum error of about 200 Hz around 1500 G.

4. MEASUREMENT RESULTS

The B-train was calibrated with protons, injected on the machine cycle foreseen for ion acceleration. As expected from the previous simulation results, when this B-correction was applied to the ion beam, the MRP appeared to deviate up to 15 mm at high energy, contradicted by the measurement with the high-sensitivity pick-up. Consequently, the B-correction curve was adjusted and a polynomial fit of third order used for further processing (fig. 4).

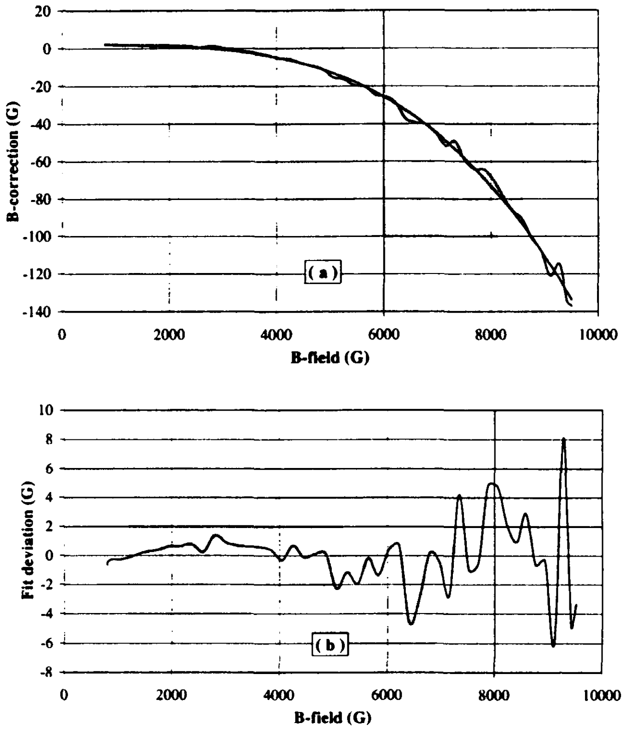

Fig. 4 : a) Measured B-correction values and their polynomial fit. b) Difference between the two curves.

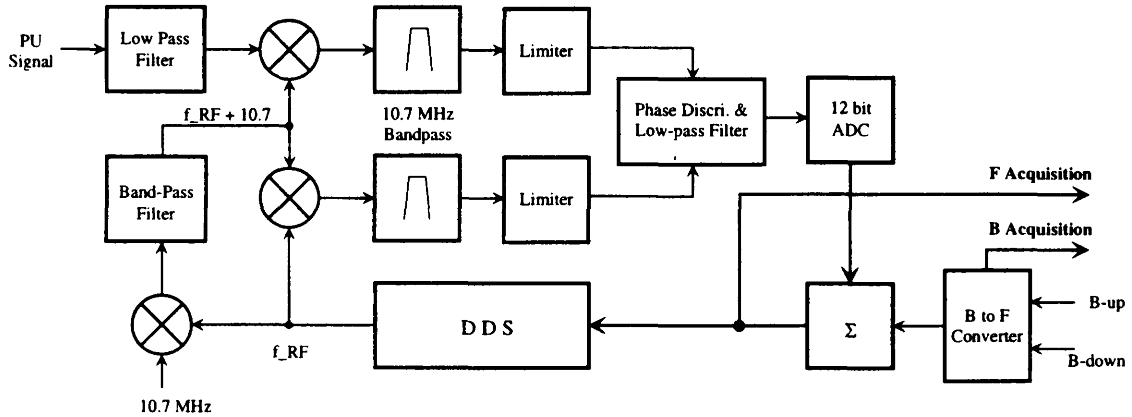

Fig. 3 : Block diagram of the MRP measurement system.

The results obtained with this polynomial correction are shown in fig. 5, together with the demodulated pick-up signal used in the beam-control system.

Since the B-correction is now a smooth function, and the position evolution given by MRP and high sensitivity pick-up agree throughout the cycle, the entire ripple, of less than 4 mm at high energy, can be attributed to the frequency ripple in the loop, namely 6 Hz, better than was obtained during earlier lab tests.

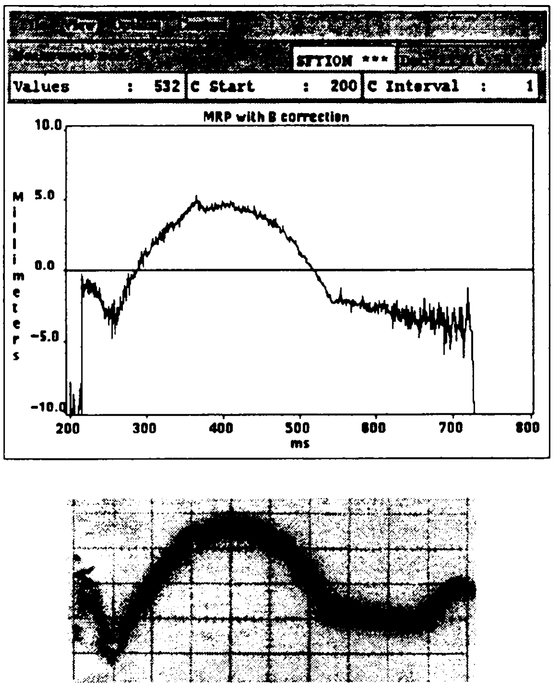

Fig. 5 : MRP acquisition and demodulated signal from the high-sensitivity pick-up.

5. SOFTWARE

Three real-time tasks are used to carry out the MRP measurement in a front-end VME system : control, acquisition and treatment. The control task sets the hardware parameters, such as the particle type and harmonic number. The acquired B and f values are stored, at 1 ms intervals, for the whole cycle in a dual-port RAM. Finally, the treated values are processed and made available to higher level application programs, via a standard controls "equipment module" software.

6. CONCLUSION

Whereas the system is precise enough to measure proton beam MRP to better than 1 mm at high energy, a more accurate frequency measurement is needed for ion beams. Several improvements are underway :

- use of a high dynamic range commercial receiver chip (Analog Devices, AD608),
- a new 32-bit DDS (Analog Devices AD9955) with a higher frequency clock (80 MHz) for 0.02 Hz resolution,
- a second DDS, in place of the local oscillator, to substitute the analogue process by digital addition,
- increased resolution of the ADC to 14 bits,
- replacement of the EPROM look-up table and the BRM by a RAM table which can be loaded for any particle and harmonic number used in the PS,
- insertion of an averager on the DDS control word to reduce the ripple coming from both the ADC and the B/f-converter. This element will influence the loop response.

Improvement of the precision of the closed orbit measurement system through multiturn acquisition is also envisaged [6].

Finally, new software will make B-calibration easier.

7. ACKNOWLEDGEMENTS

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