IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

THE INTENSITY MONITOR DEVICE FOR PETRA

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Summary

The PETRA intensity monitor is a transformer with an iron tape core mounted on a piece of ceramic beam chamber. The inside of the ceramic chamber is coated entirely with a < .2 µm stainless steel film which on one hand is thick enough to present a continous metal chamber boundary to the high frequency components of the electromagnetic bunch fields (this coating is necessary to avoid excessive power losses due to higher order mode excitation). On the other hand the coating must be thin enough to measure currents up to 8 individual bunches of different intensities by picking up the lower frequency components of the injected or circulating beam. Design and performance are discussed.

Introduction

The intensity monitor device must give an instant display of the currents in the 8 individual circulating bunches. Sensitivity and dynamic range of the monitor must be good enough to detect small intensity increments for optimizing injection efficiency as well as extremely low intensity to determine changes of beam lifetime. To make the signals reproducible the following additional design criterions must be observed: beam position, coherent oscillations and change of the monitor temperature caused by HOML or synchrotron radiation must be of no influence to the output signals.

Principle of Operation

The frequency range of the monitor is determined by the following data:

Orbit time (T_0)/revolution frequency	7.68 µs/130.3 kHz
Number of rf buckets of circumference	3840
Max. number of equally distributed bunches	4 per direction
Design intensity	20 mA/bunch
Injection rates	0.1 ... 1 Hz
Actual injection intensities (single bunch)	$5 \times 10^8 \ldots 5 \times 10^9$ particles/bunch
Bunch lengths (half width)	100...200 ps

Intensity measurement can be based on a low pass filter response[1] rather than on the real bunch shape since the frequency contents of the bunch signal up to several GHz is rather independent of small changes of the bunch shape[2,8], though the PETRA bunches can be considered as a delta function of time and the measurement device as a Fourier analyzer. A toroidal transformer approaches very nearly the described response and incidentially does have a rather high sensitivity. To measure the intensity in a bunch we have to integrate

$$I_b = \frac{1}{T_0} \int_T 1b(+)dt$$

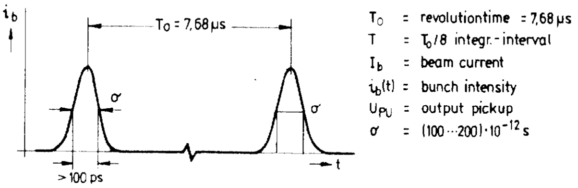

Fig. 1a: Bunch Shape in PETRA

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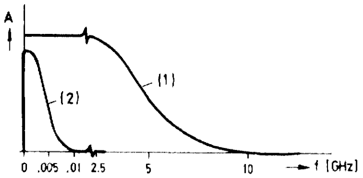

Fig. 1b: Bunch Spectrum (1) and Pickup Response (2)

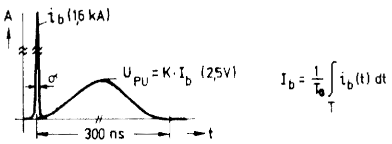

Fig. 1c: Realtime Bunch and Signal from Pickup

The maximum available integration time T for the lowpass filter[3] is

$$T = \frac{T_0}{8} = 0{,}96 \text{ ms}$$

if the monitors are positioned exactly in the midpoints between PETRA straight sections where the bunches appear aquidistant. For adequate signal separation we choose T' = 300 ns which leads to an upper cut off frequency of ≈ 3.5 MHz[4]. Thus the signal from high charge contained in short bunches are converted into low frequency output signals the amplitude of which can be directly calibrated in units of charge number of particles or average current.

Special Aspects in Design

By reasons of standardisation the same type of ceramic chamber should be used as it was already in use for the injection kickers. Inserting such a chamber into the conducting uniform vacuum ring of PETRA would mean an incisive break (gap) of the impedance that can excite excessive higher order mode losses (HOML). Though it is important that the PETRA ring in general does not have any avoidable source of HOML it is even more important to keep a stable environment for the transformer itself.

The chamber is already loaded by synchrotron radiation ∿ 7 W/cm, though the inside of the ceramic chamber is coated entirely with a thin metal film. The thickness of this metal film has to be just so that only lower frequency components of the electromagnetic bunch fields can penetrate through the metalization and may be picked up by a transformer outside the chamber.

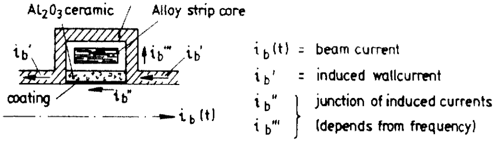

Fig. 2: Schematic Transformer

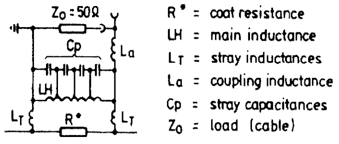

Fig. 2a: Equivalent Circuit

Particular calculations about this problem were made in[8] on a cylindrical model, but the special geometry of the PETRA chamber and the sputteringresults (see Fig. 3a) make direct calculations impossible.

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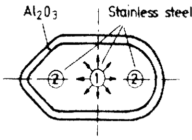
Technology of the Pickup

The ceramic chamber which carries the pick-up has a cross section very similar to that of the PETRA standard chamber. Its length is about 500 mm, so that there is room enough to install two or more independent monitors. The metal coat consists of stainless steel .2 μm and has been sputtered onto the inner surface[6,7] in an 1.5 Ah run.



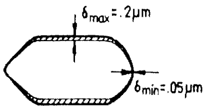


Fig. 3: Sputtering Method Fig. 3a: Deposition of Metal

Stainless steel has been preferred by following reasons:

1) sensitivity increases with higher gap resistance R*[8]
2) thicker metalization reduces the thermal load by induced wall currents[5]
3) material with low conductibility is easier to handle if a definite resistance must be tuned.
4) stainless steel does not tend to corrosions or gettering effects

A monitor is built up of 4 transformer sheaves. Each of these sheaves is put together of 2 C-figured cores which close up tightly to the outer boundary of the ceramic section. A remaining gap prevents direct thermic transitions. Gaps between the individual sheaves make an intensive air cooling feasible.

The synchrotron radiation is shadowed off by cooled ledges in the neighboured flanges.

The cores are made of 0.025 mm alloy strips. In preliminary trials with ferrite cores (3B4) a higher output indeed, but magnetostrictive effects and an increased sensitivity to strange fields had been observed. An alround cover of strong aluminium plates furnished with finger contacts accomplishes the necessary outer low resistance path.

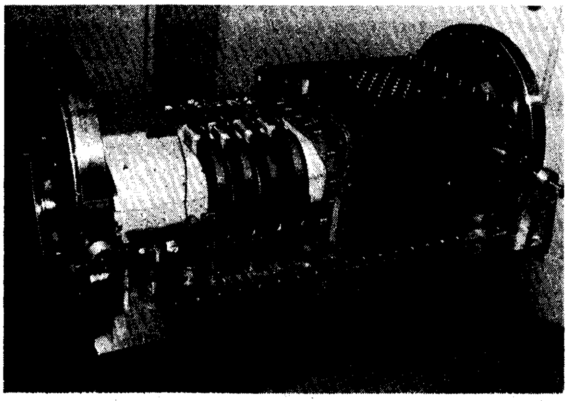


Fig. 4: Pick-up Electrodes M 1 and M 2

Field Distorsion and its Compensation

Bringing a conducting sheath between beam and pick-up causes field distorsions by eddy currents. Thickness, density and geometry of the sheath determine behaviour in frequency response and sensitivity, though the vacuum chamber gets to a contributory determinant in the performance of the monitor.

Nonlinearities or partial resonances become evident if the beam changes its position.

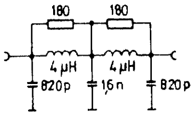
Compensating the inhomogenous damping

Irregulations in the thickness of the metal coat are inherent to the applied sputtering method. This effect has been successfully eliminated by

1) sparing out windings in zones of decreased damping
2) introducing external resistor loaded loops (fine tuning). Fig. 5a shows the remaining effect of beam position to output signal.

Eliminating the partial resonances

The transformer is loaded by R* and the Q of the alloy material decreases rapidly with increasing frequency. Partial resonances determined by stray capacitances and inductances are differently excited by beam position (wall effect)[9]. These difficulties were overcome by inserting a double π-low pass filter into transmission line with a cut off at 3.5 MHz and a flat "pulse taylored" response.



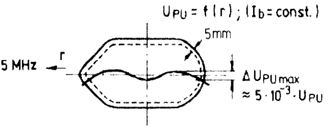


Fig. 5: Integrating π-Filters (domains the overall Cutoff) Fig.5a : Output versus Horizontal Position (Compensated)

A broadband amplifier with a gain of 26 db and a remote controlled step attenuator completes the monitor device for direct beam observation. First active lectronic is located in the experimental hall to avoid any direct cross talk from the beam.

Calibration

Pick-up signals are primarily calibrated in units of charge. Basic calibration must be done before setting up. Very short pulses of known area are fed into a matched wire which simulates the beam. The peak of the output signal is proportional to that pulse area. The calibration of the external test loop can be taken at the same moment to check the monitor when is is built in.

Electronic Equipment

Monitor M 2 is mainly used for instrumentation and processing. Separation of up to 8 individual bunch signals has been realized by 8 sample and hold (S&H) circuits connected in parallel and triggered by the PETRA Bunch Marker System (BMS). Associated S&H-circuits restore the missing dc-components. Hence it goes to the voltage to frequency converter followed by a rated counter. A buffered momory stores the actual signal and is refreshed every second. The digitized data are transferred then to the PETRA-computer NORD 10 by the Sequential Data Acquisition System (SEDAC). The entire system is shown by Fig. 6.

Performance

Direct Observation Channel M 1

For instant surveying the signals from monitor M 1 are displayed on a scope in front of the PETRA operator. Individual intensities can be measured directly from the scope's screen (see Fig. 7). Even in the case of non-accumulation the trace intensity is sufficient to look for the first turn at injection rates ≥ 1 Hz. A wave analyzer combined with a biasable pen recorder is helpful for optimizing the injection efficiency or to write small decrements in current for lifetime measurements.

Data of Pick-up

Sensitivity	1 μA ≙ 4×10^7 particle/bunch
Noise	2 mV_{pp}
Band width	3.5 MHz
Scaling factors	0.5/1.6/5/10 μA/mV/50 Ω
Temp. coefficient	- 0.03 %/C° (25°...55° C)
Nonlinearity	± 0.25 % (full aperture - 5mm)
Droop.D	< 2 %
Coat resistance R*	1.6 Ω

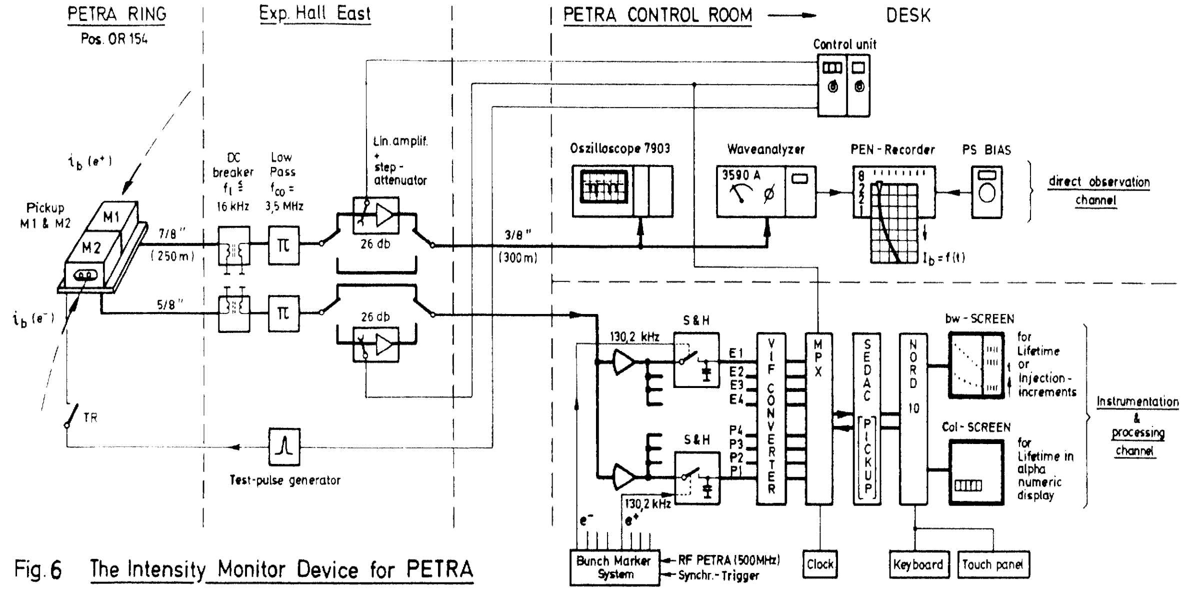


Fig. 6 The Intensity Monitor Device for PETRA

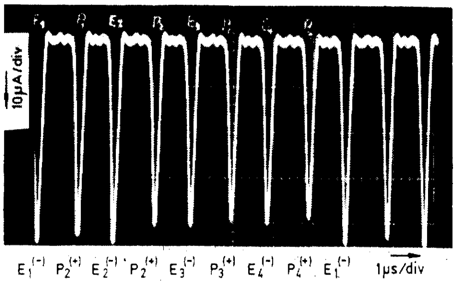


Fig. 7: Monitor M 2: 8 occupied Buckets ($4xe^-$, $4xe^+$) in PETRA. Total Current .33 mA. Sept. 3,78

Mechan. length	50 cm
Electrical length	8 cm
Number of turns	8x24 (per pick-up)
Material	3601K2 Permenorm VAC

Instrumentation and Processing Channel M 2

Lifetime measurements of a preselected bunch can be called up on to a coloured screen (Fig. 6). Two fixed refreshing intervals of 1 and 10 seconds are available.

Definition of life time is $L = I_b \cdot \frac{\Delta t}{\Delta I_b}$ (s)

Δt = interval between last two measurements
ΔI_b = decrements " " " "
I_b = actual current

The longer interval is preferred at longer life time or lower intensities. At currents > .5 mA and life times < 3 hours at full gain the accuracy of prediction is within ± 20 %. On a separate bw-monitor screen a continously refreshed graphic in floating zoom mode and in a column the last 24 measured intensities in numeric mode are displayed. Both are very helpful for the operator when optimizing the injection efficiency. A new kind of signal processing (linear regressive method) is being under development in order to improve accuracy and dynamic range and to discharge the PETRA computer from processing.

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