FAST LIFETIME MEASUREMENTS OF STORED e⁺/e⁻ SINGLE BUNCHES IN PETRA AND CORIS II

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Summary

A monitor for fast lifetime measurements has been developed and successfully tested. The monitor pick-up consists of a standard broadband transformer device in a ring position with equidistant bunch spacing. It has an upper cut-off frequency of about 4 MHz which allows to measure simultaneously the lifetimes of up to 8 individual bunches in PETRA (2 in DORIS II). In the electronic section the ac-signals are separated, baseline-restored, stretched and finally digitized in a highly stable 16 bit ad-converter. The output data are fed then into a microprocessor that computes the average currents and their time derivatives. As a result lifetimes of up to 3x10⁴ s can be measured in less than 2 seconds. Some measurements are reported.

Introduction

The lifetime of stored beams is an indicator of the overall condition of a storage ring because it is adversely affected by misalignments, technical faults or instabilities. Additionally, PETRA is faced with the problem of energy-ramping. During ramping up, different optics have to be passed through, and the stored bunches must carefully be kept away from satellite resonances, which cause particle losses. Therefore, rapidly updated lifetime information is most helpful to support the operator. Such measurements are also important for machine studies, especially with scrapers.

General Design Considerations

For machine tuning a lifetime monitor must accurately measure a long lifetime. For investigating the transversal dimensions of the bunches with scrapers at distances of 5 m away from the beam center it must quickly measure a short lifetime. Lifetime τ here is defined as:

\[ \tau = \frac{\text{average beam current} \times \text{measuring interval}}{\text{current decay}} \]

In order to maintain accuracy even at longer lifetimes the more accurately the \( \Delta T \) in current has to be measured. The interval time \( \Delta T \) can be considered as constant because it is derived from the quartz controlled rf-oscillator. In principle the high repetition rate of the current signals allows determining the lifetime out of a large number \( m \) of samplings, e.g. 10/4.04 s. Thus a reduction of the measuring error by a factor of \( \sqrt{m} \) is obtainable.

Basic Device Description

Broadband transformers serve as monitor pick-ups. The transformers are mounted in ring positions with equidistant bunch spacings.

PETRA - Ring Pos 50.1153 (Gap: Accelerator-Controlroom BKR/Electronicsroom) Control Desk

A low pass filter inserted into the transmission line next to the pick-up station determines the shape of the current signal to be analyzed later in the processor section. Immediately afterwards follows a remote controlled step attenuator and a linear amplifier in order to extend the dynamic range (0.1-100 mA FS). A long rf-cable connects the amplifier output with the input port of the electronic section located 400 m away near the main control room BKR. In this electronic section the current signals are separated, stretched and baseline restored by means of combined sample and hold-circuits (S&H). The sampling trigger for the S&H are derived from the rf-synchronous bunch marker systems (BMS, DBM). The output port of each S&H-group is directly connected to a highly accurate and stable 16 bit A/D-converter (ADC). The output data of the ADC's are fed directly into wired \( \mu \)-computers (TI 9995) which continuously sum up the digitized current signal amplitudes \( I_b \) during the entire measuring interval \( \Delta T \). The final results \( \Sigma I_b, \Sigma n*I_b \) are temporarily laid down in a multichannel mail box (RAM). An additional \( \mu \)-computer (TI 9995) acts as a central administrator processor and reads out the mail box registers, decides on an appropriate attenuation range and provides the displays, recorder, printer, etc., with actual lifetime data.

Design Criteria and Technical Layout

The Pick-up Electrode (PU)

A type of standard current transformer which has been in use for years serves as source for the current signal \( I_b \). The transformer core is made of permalloy tape with a thickness of 0.05 mm and carries 23 windings. It has an upper cut-off frequency of about 10 MHz if terminated with 50 Ohms. The lower cut-off given by R/L is about 5 kHz. On one hand a higher low cut-off decreases the influence of RF-interferences, but on the other hand it increases the crosstalk from the other bunches because the signals from these bunches have not gone to zero before the next bunch signal arrives. Because of the chopped data acquisition the lower end of the noise spectrum has to be investigated carefully. Induced transients or ripple from the main magnet currents can jeopardize the performance of all. At the end of the transmission line high noise level of 2 mVpp without any significant accentuation has been
measured. So a maximum spread of $\sigma(I_b)/I_b = 5 \times 10^{-4}$ can be taken into account.

The Low Pass Filter (LP)

The LP has a flat response and determines the minimum risetime for the following analog electronics. The upper cut-off is a compromise between pile-up and noise. In order to avoid any pile-up, the entire bunch signal length should not occupy more than half of a available bunch spacing.

Step Attenuator and Linear Amplifier.

The attenuator is a binary controlled type and spans 63 dB in 1 dB steps. The linear amplifier has a gain of 26 dB and can drive 100 mA at 4 MHz and 50 Ohms without noticeable compression distortions.

Transmission Line

The transmission line is a rigid 5/8 inch rf-cable to avoid pick-up from the environment along the cable duct.

Sample & Hold (S&H)

In the first two "fast" S&H's (MP 271) the peak value and the baseline shift are stretched. The sum is passed to the slower S&H (MP 261) which holds the value dropfree during the conversion time of the ADC. The first S&H must be able to track fully the input swing up to 3 V.

A/D-Converter (ADC)

Stability and quality of the ADC essentially contributes to the desired resolution of 5x10^{-5}. Basic and selecting measurements have been carried out by means of a de-standard, a precise lifetime simulator and a special µ-computer program. As a result of these tests we chose the 16 bit ADC MP 8016 from Analogic.

Differential Nonlinearities. As to nonlinearities in the I/O characteristics, less than 10 isolated steps with deviations < 2 LSB's were found in the entire range.

Output Signal Spread. This is caused by internal noise and has been confirmed to be 50 µV. At a quantization step (LSB) of 150 µV it may be neglected. Incidentally some noise interference smoothes the quantization effect and allows lifetime measurements even at small decrements (see Fig. 3).

Short Term Stability/Drift. During the measuring intervals the stability of the ADC must be better than the overall resolution of the device!

Conversion Time. It is minimized to 25 µs and is limiting the utilisable signal rate to 26 kHz which is corresponding to every 5th revolution for PETRA and to every 40th for DORIS II.

Processors (µC)

The TI 9900 has been applied because it is standardised type in our lab. The CPU-time (25 µs) is always less than the ADC-time.

Data Processing

For a sufficient approximation to the actual "trend" the lifetime is evaluated with a linear regression method. The first µ-C sums up the incoming current data $I_{nb}$ in preparing forms:

$$ I_{nb} = \text{32 bit word length}$$

$$ I_{nb} = \text{40 bit word length}$$

The program is synchronized by the EOC command of the ADC and stops if $n$ equals $m$. Afterwards the results are stored into a RAM. The administration processor gets access to those stored data and computes the individual lifetimes $t_1, \ldots, t_4$ according to:

$$ t = \frac{\Delta t \cdot m - 1}{m} \sum_{n=1}^{m-1} I_{nb} $$

$$ \Delta t = \text{time space of single measurements} $$

$$ \Delta t \text{= zero time of single measurements}$$

$$ t_1, t_2, t_3, t_4 $$

The total interval time $\Delta T$ results from:

$$ \Delta T = m \cdot \Delta t, \text{presettable in 0.4 \ldots 1.6 s} $$

The individual lifetimes (PETRA: 4, DORIS II: 2) are simultaneously indicated in hours in four-digit-displays in decimal mode. Output ports for scopes, printer, recorder and computers are also available (see Fig. 2).

Error Estimation

Presuming normal-distributed data, the expected deviations are as shown on the left side of Fig. 5; and assuming that $\sigma(I)/I$ is in the order of 5x10^{-4} one gets the results as shown on the right side of Fig. 5:

$$ \sigma[I]/I = \sqrt{\frac{\Delta T}{m \cdot \Delta t}} $$

$$ m \gg 1, \Delta t \approx \frac{\Delta T}{m} $$

$$ \sigma[I]/I = 5 \times 10^{-4} $$

Fig. 5 Measuring Errors as a function of Lifetime.

These deviations are in good agreement with observations during long machine runs on PETRA and DORIS II.

Measurements

Some measurements are presented to point out the achieved capability and the versatility of the device. Lifetime due to vertical scraping is shown in Figs. 6a-b. These curves have been taken at the end of a 19.3 GeV luminosity run with 1.5 mA/bunch and two bunches per direction in PETRA. When the scraper approached the 5 degree distance a normal distribution has repeatedly been measured for the $e^-$ bunches. According to Kohaupt:

$$ t = 3 \cdot m \cdot \text{damping time in ms} $$

$$ 4.67 \text{ is the damping time in ms} $$
since \( n = z/\sigma_z \) = \textit{scraper position} / \textit{standard deviation} \\

one obtains from the measurements \\
\( \sigma_z \approx 0.3 \text{ mm} \) \\

The loss of beam during the measuring time (> 5 min) was < 0.4 mA/bunch.

It clearly appears from the curves that the lifetime instantaneously corresponds to the scraper position. Another measurement (see Fig. 7) was made at 7 GeV with a horizontal scraper.

It shows the significant influence of the vacuum pressure on the transverse tail of the beam. The tails of the beam > 5 cm away from the beam center obviously do not have a normal distribution. This effect is not well understood yet. Probably the collisions with the gas molecules lead to extremely strong particle oscillations driving them into nonlinear regions. A similar effect was simultaneously measured in the vertical direction.

The last picture (Fig. 8) illustrates the sensitivity of the device. The initial lifetime of about 13 hours decreases already when the scraper is still rather far away (30 mm) from the beam center.

\section*{Conclusion}

This new lifetime monitor has been very useful at DESY. Particularly useful is the reliable information about the trend of the lifetime even at longer lifetimes up to more than 10 hours. When PETRA operates for colliding beam experiments, minimizing the losses often correspondingly reduces the background.

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