A RESONANT FIRST TURN BPM FOR THE POSITRON INTENSITY ACCUMULATOR (PIA) AT DESY

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Abstract

The Positron Intensity Accumulator PIA at DESY is used to accumulate the intensity and damp down the emittance of the positrons produced in the Linac II before they are injected into DESY II. Up to 13 shots are collected and damped. During the damping process the (base band) peak current is increased by about a factor 4. Therefore the signal from the circulating beam can be up to 50 times bigger than the injected beam and hence overload any first turn detectors. The injected beam however is bunched by the 3 GHz RF of the linac. By filtering the 3 GHz component of the antenna signal and subsequent demodulation it is possible to set up a BPM system detecting exclusively the injected beam.

INTRODUCTION

The Linac II at DESY is an electron-positron linac delivering beams of 450 MeV. In order to reduce the transversal and longitudinal emittances of the beam it is injected into the accumulator and damping ring PIA [1]. PIA is a small ring with approximately 28 m of circumference. The revolution frequency therefore is 10.4 MHz. It is an octagon with 2 stretched and 2 shortened straights. Injection takes place in one of the short straights. The eight dipoles are combined function magnets and in addition there are 4 horizontally focusing and 4 horizontally defocusing quadrupoles. Each of the dipole chambers contains a button BPM. These BPMs and their readout however are optimized for measuring the closed orbit with 10.4 MHz bunches. Sufficient accumulations and damping are required in order to obtain a usable signal.

For monitoring the energy at the end of the Linac it is desirable to measure the beam position of the injected beam at a position with large dispersion. A suitable position for this is the first long straight, approximately 7 m from the injection septum. Here the dispersion is the largest and there is sufficient space to install a new BPM. It was decided to use a BPM of the PETRA III type [2]. This is a button type BPM with a large bandwidth.

SETUP

In order to separate the signal of interest from noise and the low frequency signal of the circulating beam, the pickup signal is first band-pass filtered (Figure 1). With a cavity-type BPM this could have been achieved directly at the source. But this would have required a completely new design while the PETRA III type BPM could be used with only minor modifications. The BPM has a diameter of approximately 98 mm.

The buttons are arranged with an angle of 45° to the usual coordinates of x and y. In this way the electrodes are less likely to be hit by stray particles from the low energy tail of the injected beam. The beam position then has to be calculated from a linear combination of the rotated coordinates.

By mixing with a 3.375 GHz reference the signal is converted to 375 MHz. The exact frequency and phase of the reference is not important as long as it is the same for all buttons. The signal is further improved by low-pass filtering and subsequent amplification. Finally it is fed into the actual BPM electronics.

The beam position is processed by readout electronics of the AM/PM type [3]. It was originally designed for the FLASH linac. In the AM/PM electronics a difference in voltage is translated into a phase difference of two normalized signals. In this way the BPM signal becomes independent of the beam current over a large dynamic range.

Given the high operating frequency of 3 GHz a phase shift between the individual buttons is likely. With a simplified model of the BPM it was calculated that a phase shift between corresponding buttons causes a reduction of the linear range of the BPM. The tolerable phase shift however was found to be up to 60° which can be achieved with a careful setup. With this phase shift the deviation of the measured from the real beam position increases from 1 mm to 2 mm at a beam position of 10 mm.

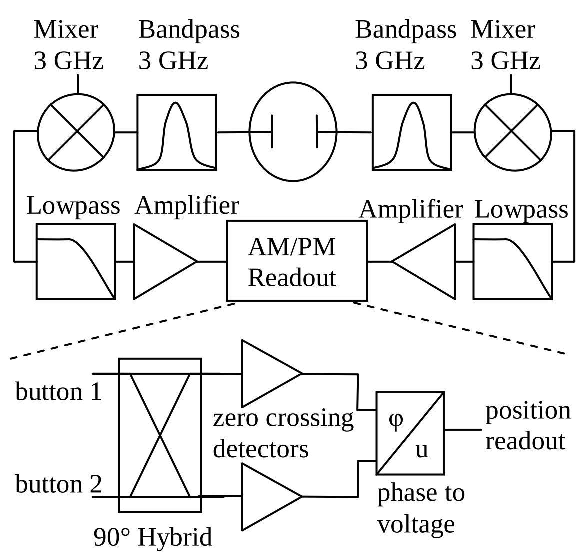

Figure 1: Block diagram of the BPM readout.

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CHARACTERIZATION

Before beam operation the BPM was tested with a network analyzer connected to various pairs of buttons. It was found that the buttons have a high-pass characteristic with a cut-off at approximately 300 MHz. Because of the large diameter of the beam pipe the RF can propagate into the pipe above a frequency of 1.87 GHz, the lowest waveguide mode. While this will not influence the direct interaction of the beam with the electrode, it allows parasitic modes and wakes from nearby parts of the machine to couple to the electrodes. A great deal of ringing has to be expected.

In order to preserve the large acceptance of the ring it is not possible to change for a smaller beam pipe radius. This prevents the most obvious way to suppress interaction with signals from other parts of the machine.

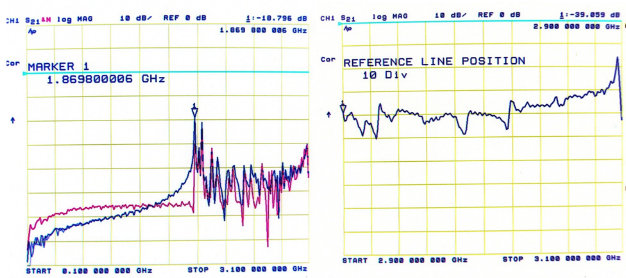

Figure 2: Frequency Response of the BPM.

The raw signals of the buttons have been investigated with a spectrum analyzer in zero span mode (Figure 3). The spectrum analyzer was triggered with a PIA trigger and the sweep was set to 320 ms, a full cycle of the PIA accumulation. The center frequency was first set to 2.998 GHz, the linac frequency. This way the 13 injections are clearly visible with a spacing of 20 ms. The power at the peak of one such pulse was measured with -57 dBm. Switching to 125 MHz one sees the accumulation of intensity in the ring. After 13 injections -47 dBm are measured. At the end of the accumulation cycle the 12^{th} harmonic system is switched on for better bunch compression. At this point the intensity increases by approximately 8 dB.

The second measurement was taken at 125 MHz because the high-pass characteristics of the buttons suppress the lower frequency signals. The difference between 2.998 GHz and 125 MHz amounts to 10 dB at the last injection. Considering that there is a factor of 13 between the injected and the accumulated beam one would expect a difference of approximately 20 dB. Indeed this is the case after compression when the power spectrum shifts towards higher frequencies.

It was also checked that the signal at injection really correlates with beam. When the trigger of the linac gun is removed, the signal is gone. Noise sources like the kicker magnet nearby the BPM continue pulsing in this case. The signal-to-noise ratio therefore can be assumed to be at least 10 dB.

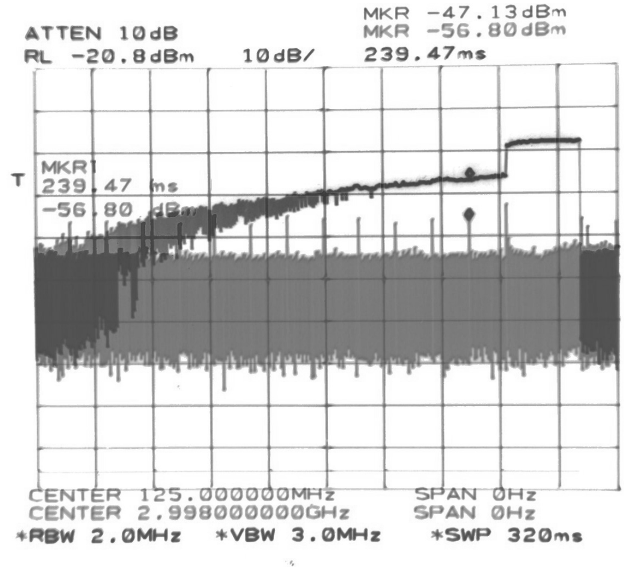

Figure 3: Frequency selected response of a single button, photographed from a spectrum analyzer in zero span mode. Two frequencies are shown, 125 MHz and 3 GHz.

MEASUREMENTS

The Beam Position Signal was measured with a positron beam. In the electron case the situation is more favourable. Therefore it was assumed that it would surely work if the positron case did.

Figure 4 shows the response of the BPM to an injected pulse of $8{\cdot}10^8$ positrons. As expected there is considerable ringing visible. The beam pulse has a maximum duration of 50 ns. The following single values were taken circa 30 ns from the onset of the pulse.

During the measurement there was a timing jitter of a few nanoseconds. Therefore the measurements were post processed by shifting them to an equal rising edge. With the timing jitter removed the signal had a RMS variation of 13 mV.

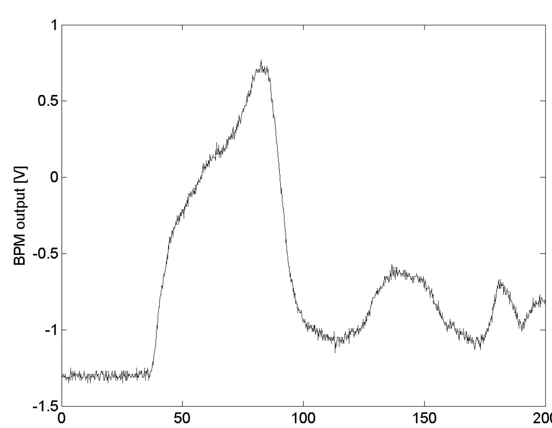

Figure 4: Beam Position Signal.

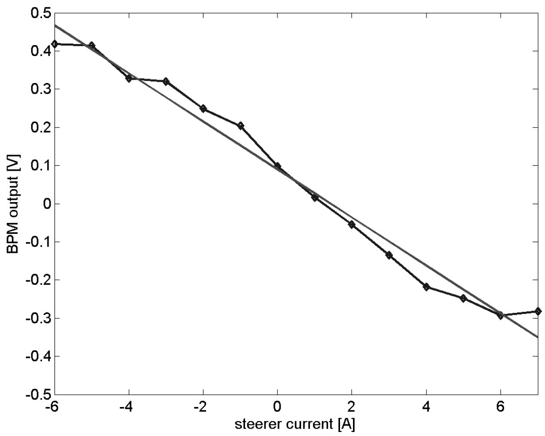

Figure 5: Vertical movement by a steerer magnet 5 m upstream the BPM. Outsize this range beam loss occured.

Since the coordinates of the BPM are rotated by 45° from the machine coordinates each pair of buttons is equally sensitive to horizontal and vertical movement. First the BPM was calibrated with a vertical steerer approximately 5 m upstream. Figure 5 shows the result. The steerer moves the beam 1.5 mm/A at the position of the BPM. So the total displayed range is 19 mm. Beyond this range the beam intensity is reduced by beam loss. The corresponding measurements were ignored.

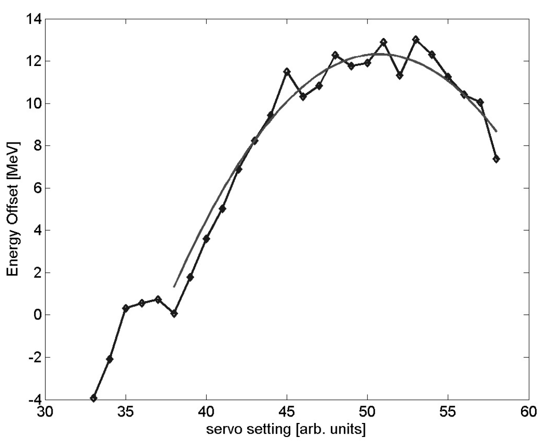

Figure 6: Energy variation by adjusting two acceleration sections of the linac. The nominal setting is 45.

The slope is 63 mV/A, hence 42 mV/mm. This is the calibration regarding the actual vertical displacement of the beam. Along the axis of the BPM the displacement is actually larger. The RMS jitter of 13 mV mentioned above then translates into 300 μm. This is not the resolution of the BPM but includes actual beam jitter.

The same calibration constant can be used for the horizontal axis. With this and together with the known dispersion at the location of the BPM it is possible to measure the energy variation of the injected beam. The beam energy is adjusted with the so called "servo". This is a phase shifter moving the phases of the two last acceleration sections of the linac against each other. The abscissa in figure 6 is the setting of the servo, by coincidence it is close to the actual phase-shift. At the time of the measurement the optimal setting of the servo was 45. As can be seen the linac is operated close to the maximum of the servo. All measurements were cross-checked with a nearby viewscreen.

In figure 4 a slope can be observed on the BPM signal in the range of interest between 50 ns and 80 ns. This was attributed to an energy chirp of the beam pulse. Indeed the pulse is cropped when the energy is moved towards the acceptance limits of PIA.

CONCLUSION

A first turn BPM has been installed in PIA. By RF-filtering it cleanly separates the injected from the stored beam. Due to the necessary large aperture of the BPM the cut-off frequency of the beam pipe is lower than the bunch frequency and hence the operating frequency. It does – however – deliver reasonable results that are good enough to be used for setting up the machine and possibly for automating the energy control of the linac.

REFERENCES

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