

A Non Destructive Way to measure Betatron Mismatch at Injection

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Abstract: Betatron mismatch between a chain of proton (or ion) accelerators blows up the emittance of the beam. Following the ideas of Ref. 1, we study the use of Residual Gas Ionization Profile Monitors to measure this mismatch without disturbing the beam. A turn by turn readout can be performed by electrical or video readout. The sensitivity of the monitor is adjustable over a few decades by a local gas bump. First studies at DESY III will be presented.

Introduction:

Beam emittance preservation in a chain of proton accelerators is essential to reach the highest luminosity at the experiments. Each blow up of the emittance in the chain leads to a reduction of the luminosity. Mismatched injection into a circular proton accelerator will lead to a fast emittance blowup within the first few turns. An off orbit injection can be detected by oscillations of the beam center with BPMs while a betatron mismatch leads to transverse shape oscillations. This type of oscillation can be detected by a turn by turn profile measurement. Ref. 1 proposes a sophisticated CCD readout of a thin screen (phosphor or OTR) which is moved into the beam. But the screen itself produces an emittance blowup as well as significant secondary particle background. This destructive method is thus not suitable for use during normal acceleration operation. Residual Gas Ionization Profile Monitors (IPM) are used in many accelerators (Refs. 2-4) as a non destructive tool. They used the ionized residual gas in the vacuum chamber to produce a measurable beam profile signal. The signal amplitude is proportional to the vacuum pressure at the location of the monitor and to the beam current. Most of them use an anode strip readout with an integration time of down to $1 \mu\text{s}$ (Ref. 2) which is adequate for turn by turn measurements also in small accelerators. At DESY the IPMs are readout by sensitive video-cameras watching a phosphor screen (Ref. 5). This has the advantage of a "visible" beam and a simple data acquisition by frame grabbers. With a standard video camera the readout frequency is limited to the video standard frequency of $f_{TV} = 40 \text{ ms/frame} = 25 \text{ Hz}$. With higher frequencies by faster cameras, the signal

amplitude becomes smaller by the same amount. In the following we discuss a way to increase the signal to overcome this problem and we present some preliminary measurements.

New Readout:

The existing IPMs provide a light readout only. A fast and simple device which offers a very fast readout frequency together with high efficient light detection is a Linear Image Sensor (or Solid State Line Scanner). It consists of a row of 128 up to more than 1024 photodiodes depending on the type. The photo-current is integrated on an associated junction capacitance and read out by multiplex switch. Pixel-sizes from $a = 14 \times 14 \mu\text{m}^2$ up to $a_S = 36 \mu\text{m} \times 2.5 \text{ mm}$ exist. The large pixel size has the advantage that much more light is collected than in the equivalent area of a TV camera tube ($a_{TV} = 25 \times 16 \mu\text{m}^2$) or a TV CCD camera ($a_{CCD} = 16 \times 16 \mu\text{m}^2$).

Theoretically one will gain a factor of about $a_S/a_{TV} = 225$ in sensitivity when using a large pixel size sensor instead of a TV tube. Unfortunately the noise of a solid state sensor is somewhat larger than the noise from an electron tube and the spectral response is slightly different.

We have compared the response of a Newvicon tube camera (Type Grundig FA 76 with a 1 inch Newvicon tube XQ 1440) and an old¹ linear sensor with 256 pixels each size of $36 \mu\text{m} \times 2.5 \text{ mm}$ and (Type Hamamatsu PCD S2301-256 Q). Fig. 1 shows the same profile from a green (520 nm) phosphor screen observed by the TV camera and the sensor. Comparing the noise and the signals, it follows that the overall gain is $g_s \cong 6$ only. One can gain an additional factor of 10 by cooling of the sensor and/or using newest types.

Application to HERA:

The IPM in HERA delivers profiles with the following parameters: The vacuum pressure at the monitor is $P = 10^{-10} \text{ mbar}$, the gain of the MCP (Type: Hamamatsu F 2805-03) is set to $g_{MCP} \approx 10$ (at 300 V) at 30 mA beam current (60 injected bunches). The phosphor screen consists of P31

¹ 10 years old, Hamamatsu now offers a newer type S3901. However, we have had it already in our lab.

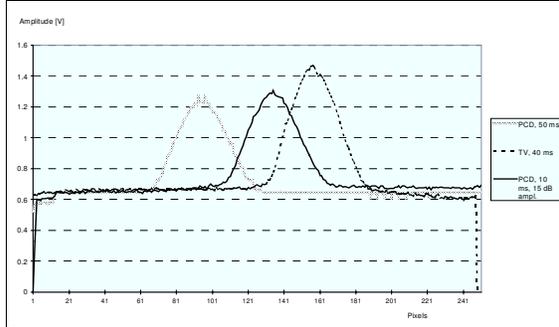


Fig. 1: Comparison between a Newvicon TV camera (center) and a Linear image sensor (without gain at 50 ms (left) and with 15 dB amplification at 10 ms (right))

phosphor with a decay time of $\approx 10 \mu\text{s}$. It is read out by a SIT camera which is $g_{\text{SIT}} / g_{\text{Newv}} = 90$ times more sensitive than the Newvicon camera (Ref. 7). Using a large linear sensor instead of the SIT camera and the maximum gain of the MCP ($g_{\text{max}} = 3.8 \cdot 10^4$ at 1000V) one gains a factor of $g_s \cdot (g_{\text{Newv}} / g_{\text{SIT}}) \cdot (g_{\text{max}} / g_{\text{MCP}}) = 250$ and should be able to change the readout frequency from $f_{\text{TV}} = 25 \text{ Hz}$ to 6.3 kHz . This is still about 7.5 slower than the revolution frequency of HERA ($f_r = 47 \text{ kHz} = 21 \mu\text{s}$). Unfortunately the large area sensors² have a maximum readout frequency of $5 \text{ MHz/pixel} = 39 \text{ kHz}$ for a 128 pixel sensor. But a readout every second turn will be still adequate to measure betatron mismatch oscillations. However, an additional gain of about 3.75 is needed for the readout. This can be done in two different ways:

- 1) Adding a image intensifier in front of the sensor. There are sensors with a fiberoptic window² to which an intensifier can be coupled directly.
- 2) Increasing the vacuum pressure. A factor of 10 can be easily reached by switching off the pumps around the IPM. With a controlled gas leak one can adjust the pressure over some decades.

Application to PETRA:

The IPM in PETRA delivers profiles with the following parameters: The vacuum pressure at the monitors is $P = 1.5 \cdot 10^{-10} \text{ mbar}$. The phosphor screen consists on P31 Phosphor, too. It is read out by a Newvicon camera. The gain of the MCP is set to $1.5 \cdot 10^3 (=700 \text{ V})$ to measure profiles at 20 mA (10 bunches injected into PETRA). The revolution

² For example: EG&G Reticon Solid State Line Scanner SB Series Type RL0128SBF-011. Note that this type has a factor 10 less dark current (=more sensitivity) than our tested sensor.

frequency of PETRA at injection is $f_r = 131 \text{ kHz}$ ($7.6 \mu\text{s}$). This is too fast for the large area scanner as well as it is too fast for the decay time of the phosphor screen. In principle there are faster types of phosphor (P46) and faster sensors. A scanner with an adequate readout frequency is the IL-C9 from DALSA with 512 pixels (60 MHz pixel rate and 110 kHz scanning rate) with an area of $a_{\text{DALSA}} = 14 \times 42 \mu\text{m}$. The area is smaller than the large sensor but the dark current should be smaller, too. However, more investigations are needed to apply this readout at PETRA.

Measurements in DESY III:

The revolution frequency in DESY III at injection is 294 kHz ($3.4 \mu\text{s}$) which is too fast for large area scanners³. But in DESY III we were able to prove the calculations above: The IPMs in DESY III were installed in 1989. They do not have an internal MCP, therefore the amplification has to be applied outside of the vacuum. An image intensifier (Proxitronic type BV 2502 McG 15) is coupled with a fiber-optic spacer directly onto the fiber-optic window of the SIT tube Type (4804 HP1 WOCP) of a video camera (Type Bosch TYC 9A). The intensifier is run with a voltage of 4.15 kV, which corresponds to an amplification gain of $g_a = 2$. With this gain we measure profiles with $1.5 \cdot 10^{12}$ protons in 11 bunches circulating in DESY III at a vacuum of $2 \cdot 10^{-9} \text{ mbar}$. Instead of the SIT camera we installed our original linear sensor from HAMAMATSU (Type Hamamatsu PCD S2301-256 Q) with a pixel size of $36 \mu\text{m} \times 2.5 \text{ mm}$ and 256 pixels. The maximum readout frequency of this device is $f_{\text{max}} = 500 \text{ Hz}$. We were able to adjust the vacuum pressure by a controlled leakage. This was performed by powering a piezoelectric precision leak valve (Type Veeco PV-10) and injecting dry nitrogen.

Following the same formalism as that for HERA we have to increase the pressure by a factor of $g_a \cdot (g_{\text{SIT}} / g_{\text{Newv}}) \cdot (f_{\text{max}} / f_{\text{TV}}) = 600$ to measure profiles with the sensor at a frequency of 500 Hz. Fig. 2 shows a mountain range display of the evolution of the beam profile in steps of 2 ms of 10^{12} protons at injection. The vacuum conditions were adjusted to about $2.6 \cdot 10^{-6} \text{ mbar}$ at the monitor. The gas bump was kept localized within $\pm 10 \text{ m}$. The profiles are well usable to determine the emittance of the beam. This is shown in Fig. 3 for the first 200 ms after injection.

³ The sensor IL-C3 from DALSA with 128 pixels and an area of $14 \times 14 \mu\text{m}$ provides a readout rate of up to 400 kHz.

The measured emittance blow up is a result of the strong space charge forces acting on the beam at the low energy injection. We calculate that the gas bump contributes less than 10 % / 0.2 s to the blow up, even at the low injection energy of DESY III (310 MeV/c).

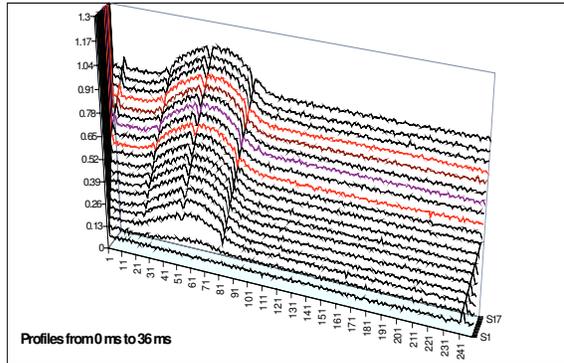


Fig. 2: Evolution of the beam profile in DESY III after injection in steps of 2 ms. The dips in the profile are results of the fiducial marks (1 cm spacing) on the phosphor screen of the IPM

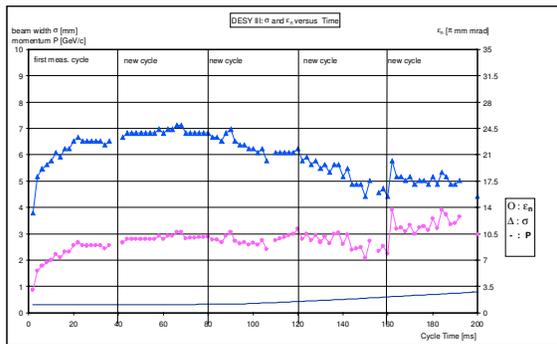


Fig. 3: Evolution of the normalized emittance (lower trace) and the beam width (upper trace) in DESY III measured with a linear sensor.

Of course we cannot measure betatron mismatch oscillations because the revolution frequency is still 588 times higher than the readout frequency as well as the decay time of the phosphor (P31) is too long. Therefore the resulting profile is a result of an integration of 588 turns. But it shows that the IPM in HERA and in other large machines can be used as a non destructive tool to measure the betatron oscillations at injection with the modifications and factors discussed above. Note that the light optics (focal length, aperture, lenses) was the same for all types of readout for this experiment. With the present light optic (enlargement = 5.9) we have a theoretical resolution of the beam profile of $\sigma = \text{pixel size} \cdot \text{enlargement} = 150 \mu\text{m}$ which adds

quadratically to the beam size. This is still adequate to measure a 10% modulation of the beam size. The noise of more modern sensors will be about a factor ten less than the present one. Therefore the contribution of the noise will be much smaller than in the present measurements.

Conclusions:

We have studied a way to use the IPMs at HERA for non destructive measurements of betatron mismatch oscillations at injection. The change to faster (turn by turn) readout can be done by using large size linear image sensors. The high efficiency of the sensors combined with various sources of light amplification such as local gas bumps and/or image intensifiers allows a turn by turn detection of the beam profile. The measurements in DESY III proved the theoretical gains needed for the fast measurements. In the near future we wish to test the behavior of an additional image intensifier in front of the linear sensor. This may remove the need of a local gas bump.

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References:

- Ref. 1: C. Bovet, R. Jung; LHC-Project-Report 3 (1996)
- Ref. 2: W.S. Graves et al.; A nondestructive fast beam profile monitor; Nuclear Instruments and Methods A 364 (1995) pp. 13-18
- Ref. 3: T. Kawakubo et al.; Non-Destructive Profile Monitor using Micro Channel Plate; Particle Accelerator Vol. 29 (1990) pp. 233-238
- Ref. 4: J.-L. P. Vignet et al.; Beam Monitors Based on residual Gas Ionization; GANIL P 96 16 (1996)
- Ref. 5: K. Wittenburg ;Experience with the Residual Gas Ionization Beam Profile Monitors at the DESY Proton Accelerators; 3rd European Particle Accelerator Conference, 24.-28.3.1992, Berlin, Germany
- Ref. 6: T. Schotmann; Das Auflösungsvermögen der Restgasionisations-Strahlprofilmonitore für Protonenstrahlen in PETRA und HERA; Diploma thesis, DESY-HERA 93-09
- Ref. 7: G. Samulat; Stahlprofilmessungen in den HERA-Protonen-Beschleunigern unter Ausnutzung der Restgasionisation; Diploma thesis, DESY-HERA 89-18