A non invasive technique for transverse beam envelop matching and its consequence on the cryomodule layout

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SPL collaboration meeting

Outline

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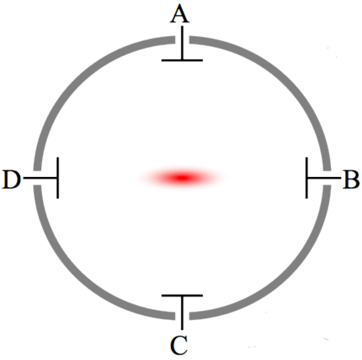
- Image currents induced by the proton bunch on the conductve vacuum pipe can be collected with the help of dedicated pickups.
- With four antennas and a little bit of mathematical gymnastic, the detected signals can be treated in order to obtain informations about the beam position or ellipticity.



Dipolar signal

$$\frac{B-D}{A+B+C+D} \propto \bar{x}$$

Quadrupolar signal

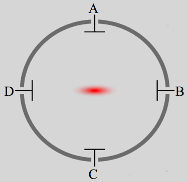
$$\frac{(B+D)-(A+C)}{A+B+C+D} \propto \sigma_x^2 - \sigma_y^2 + \bar{x}^2 - \bar{y}^2$$

Signal amplitude

- The signal amplitude goes like r^{-n} with n the moment order and r the distance between the antenna and the axis:

Induced current at B

$$J_B \sim \frac{i_b}{2\pi r}\left\{1+2\frac{\bar{x}}{r}+2\left(\frac{\sigma_x^2-\sigma_y^2+\bar{x}^2-\bar{y}^2}{r^2}\right)+\ldots\right\}$$



- Care has to be taken for the choice of r:
  - too large: your signal is in the noise,
  - too small: reduced transverse acceptance and possible contribution of high order terms.
- To extract the ellipticity, you need to measure first the positions.

Outline

Brief history and proposal

- The use of the quadrupolar moment of the BPMs have been proposed by Miller at SLAC (1983) to obtain the emittance by solving a matrix equation derived from the known transfer matrices between pick-ups.
- The use of the quadrupole pick-ups in rings has largely focused on determining the phase and the amplitude of the betatron and revolution frequencies in the raw pick-up [Chohan et al, EPAC'90].
- It is proposed to use the quadrupolar moment of the BPMs to match the beam transversely in periodic sections of a linear accelerator (linac). The idea is that the non invasive measurement of the BPMs can be used to match the transverse beam envelop if, at least, one BPM is located in a quadrupole of the lattice (FD0, FODO).

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Demonstration (1/2)

- The quadrupolar moment can be expanded in terms of the beam sizes $\sigma_{x,y}$, the betatron function $\beta_{x,y}$ and the emittances $\varepsilon_{x,y}$:

$$M_Q \propto \sigma_x^2 - \sigma_y^2 = \varepsilon_x \beta_x - \varepsilon_y \beta_y \quad (1)$$

- Taking into account the property $\varepsilon_x = \varepsilon_y = \varepsilon$ (relevant for high intensity linacs), the previous equation is reduced to:

$$M_Q \propto \varepsilon \left(\beta_x - \beta_y\right) \propto \beta_x - \beta_y \quad (2)$$

- If M_Q is constant for two consecutive periods, we have the following property:

$$\beta_x(s_1) - \beta_x(s_2) = \beta_y(s_1) - \beta_y(s_2) = \Delta \quad (3)$$

- As the BPM is located in a lens, α is null in one plane (let us say the horizontal one), it induces that $\Delta = 0$.
- If $\alpha_x = 0$ and $\beta_x(s_1) - \beta_x(s_2) = \beta_y(s_1) - \beta_y(s_2) = 0$, it can be shown that $\alpha_y(s_1) = \alpha_y(s_2)$.

Pick up position in the lattice

If the detector is located between the quadrupoles (to simplify integration or ...), one could think to use a null quadrupolar moment as a matching criterion, but this condition does not imply the matched beam case. Mismatch envelop modes can give this configuration (see after).

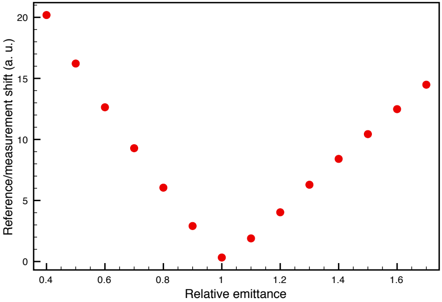
Outline

How to

- To match the beam with the help of the quadrupolar moment of the BPMs in lenses, several techniques may be used.
- In case the channel is almost constant (rare!), the simple condition M_Q = constant is enough. For example, to tune the beam at the entrance of the channel the sum of the square of the M_Q variations period after period can be minimized.
- In case, the channel varies significantly (beam energy evolution, phase advance ramp), one possible technique may be based on a a priori knowledge of the emittance evolution or its value.

Emittance monitoring

- The idea is to minimize the shift between a reference evolution of the M_Q and its measurement.
- One may think that this a priori knowledge is the weakness of the technique but it is exactly the opposite. By varying this reference, the matching procedure offers the possibility to measure the real emittance value or evolution.



Outline

Benchmark strategy and channel parameters

- To benchmark the technique, it is proposed to use a typical section of a high power linac to perform a statistical study of performances of different beam enveloppe tuning procedures in presence of unperfect focusing elements.
- The focusing period is based on a FDO lattice and the O represents a block of three resonators to provide acceleration from 180 MeV up to 520 MeV (11 focusing periods).
- A proton beam with a peak current of 75 mA is used.
- Defaults for the quadrupoles (position and gradient) and the cavities (amplitude and phase) have been randomly generated in order to simulate 2000 different linacs.

Five cases

1. Minimization of the discrepancy between the measured size and a reference size law. It is assumed that a beam profiler can be used.
2. Minimization of the mismatch factor (smoothing size evolution with the help of beam profilers).
3. Obtain a measured quadrupolar moment equal to zero with the QPU between the quads.
4. Minimization of the discrepancy between the measured quadrupolar moment and a reference quadrupolar moment law with the QPU inside a quad.
5. Do nothing because you don't want to spend money for transverse matching diagnostics in your linac...

Results for the rms size at the exit

A non invasive technique for transverse matching

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Pick up signal

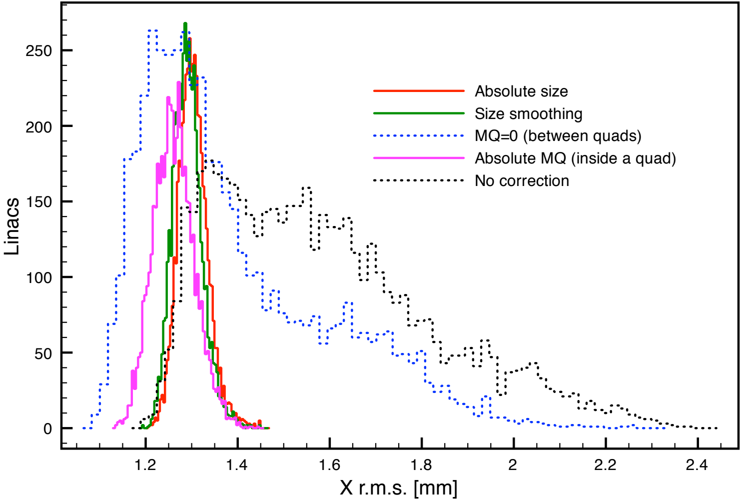
Bibliography

Demonstration

Emittance monitoring

Benchmarks

Conclusions



Results for the halo at the exit

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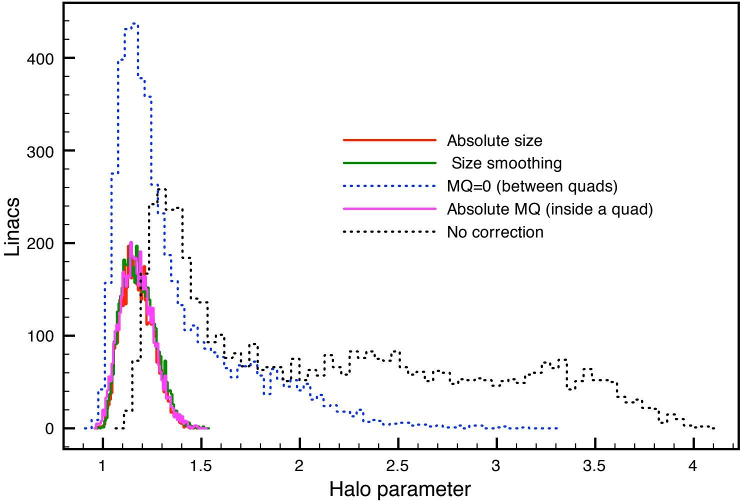
- Pick up signal
- Bibliography
- Demonstration
- Emittance monitoring
- **Benchmarks**
- Conclusions



Outline

Conclusions

- The use of QPU is an opportunity to match transversely the beam envelop at each focusing period. It is a non invasive technique which is particularly relevant for proton (e- laser stripping can be used only for H-).
- Because the use of QPUs is anyway mandatory for the alignment, the extra cost to measure the Q moment should be modest compared to the addition of a dedicated device.
- Care has to be taken for the optimization of the aperture.
- Because this technique implies that the detector is located inside one quad per focusing period, one could imagine that the design of the quadrupole is more complicated.
- Open question: does it work if the detector is located just before or just after the quad (FODO)?