Using the Chopper as emittance exchanger

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Abstract

The propagation of pulses synchronized with the bunches on both chopper plates can generate a quadrupole like field in the Y-Z plane (transverse-longitudinal). The field distribution induced, depends on the length of these pulses, their voltage and their synchronicity with the bunches.

This particular field shape entails effects on the transverse and longitudinal beam emittances. If the polarity of the pulses is well chosen with respect to the particle charge, they can then act as emittance exchanger. In this note, we report the preliminary results.

This following study shows what are the effects of several generated fields on the beam distribution parameters. A particle tracking code was developed for this purpose. It allows simulation of a field distribution moving with the bunch velocity.

I Using a quadrupole field.

For proof-of-principle, we artificially generated an electrical quardupole in the Y-Z plane starting from a Superfish generated field map. This field map is extracted from a PMQ Superfish modeling, rotated by 45° (Figure 1).

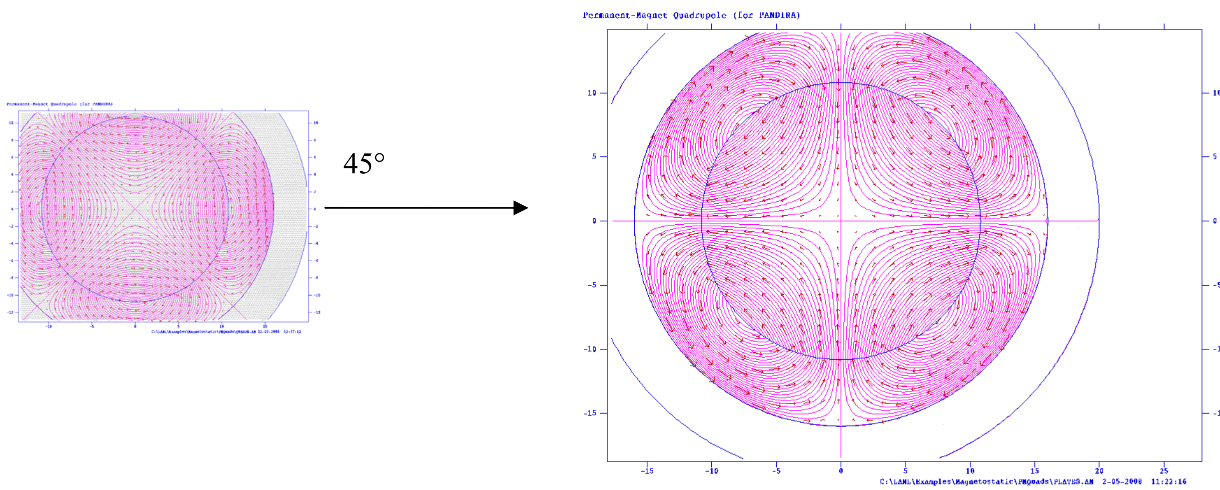

Figure 1 : Electric quadrupole Field.

The integration of this field is represented in Figure 2.

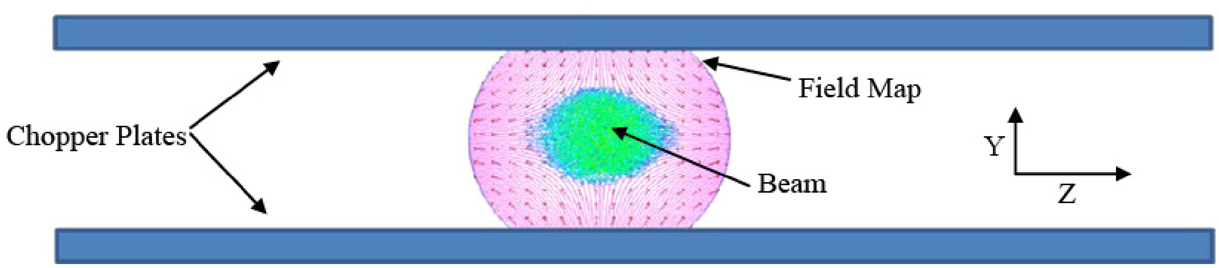

Figure 2 : Field and Beam integration in chopper plates

The first results obtained with this configuration are really encouraging. They show that we have emittance exchange between the transverse plane where we apply the field and the longitudinal plane. The relative emittance increase in the first plane corresponds to the decrease in the other one. Few configurations tried, varying the size of the beam, the travelling time and the strength of the field show that we can easily obtained a 10% variation in emittances values without any distortion of the beam.
The conclusion of this preliminary part tell us that if we are able to generate an electric quadrupole field applying pulses on the chopper plates, we can produce emittance exchange.

II Generation of the field with Superfish.

We have used superfish to simulate the field induced by pulses propagating down the chopper plates.
The pulse length has to match both to the longitudinal size and the velocity of the beam they have to act on. For more simplicity, we decided to use the 3 MeV beam of chopper line. This beam was taken at two different strategic positions: at the RFQ output, where the transverse dimensions are the smallest and at the chopper plates entrance, where they are the largest.
For a 3 MeV beam at 352MHz, the beta-lambda is approximately equal to 8cm. Both chosen beams have a longitudinal size of 1cm.
The following figure represents the electric field obtained by applying pulses on the chopper plates for 1cm and 3cm pulse length that corresponds to pulse lengths of 0.4ns and 1.1ns. The voltage of the pulses is +/- 500V.

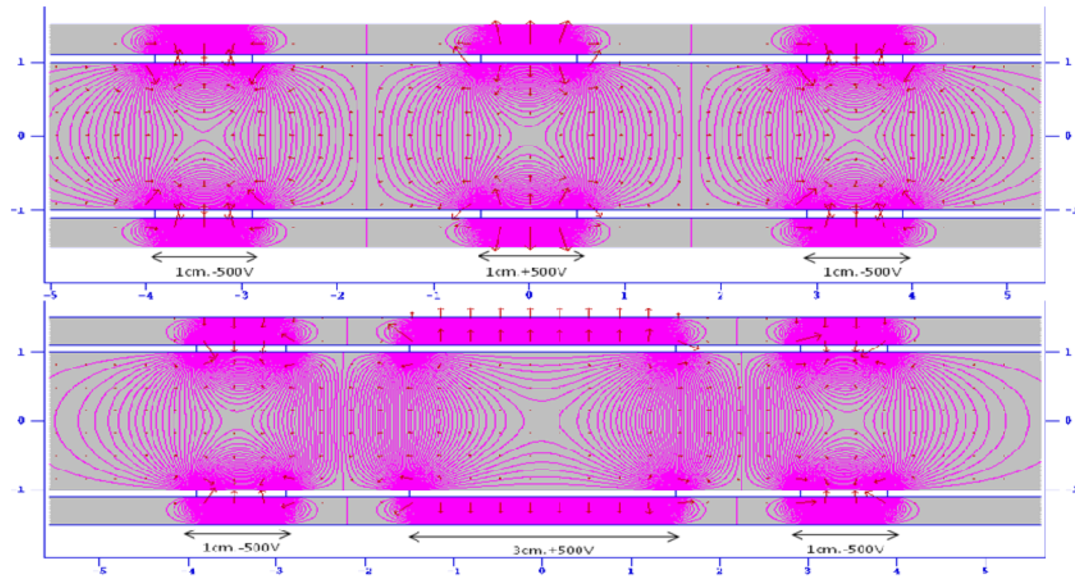

Figure 3: Superfish plots of the two configurations

If we zoom in the middle area, we can clearly see that the field distribution is very similar to the quadrupole shape field used in the previous chapter (Figure 4).

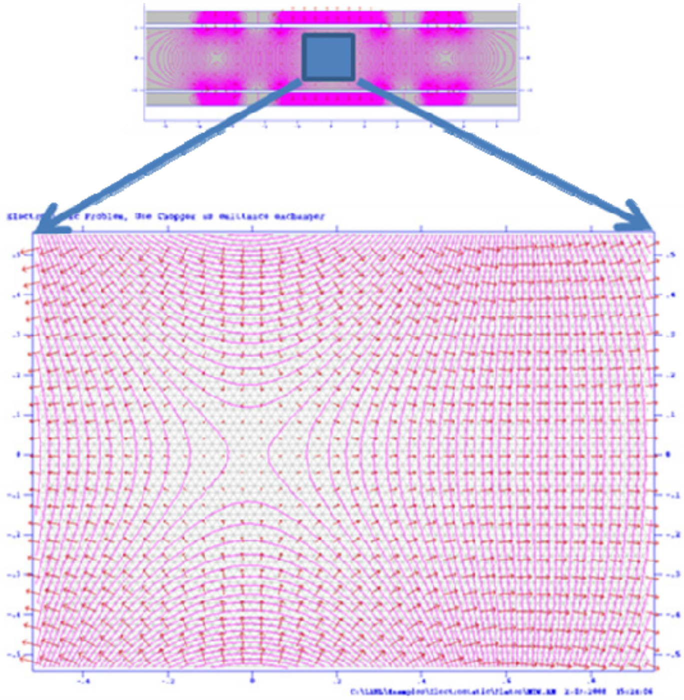

Figure 4: Field distribution in center area.

III Simulations results.

In order to access the effects of the field we tracked the beam through the field map obtained. Two different beams: one "small" and one "large" in the Y-Z plane.

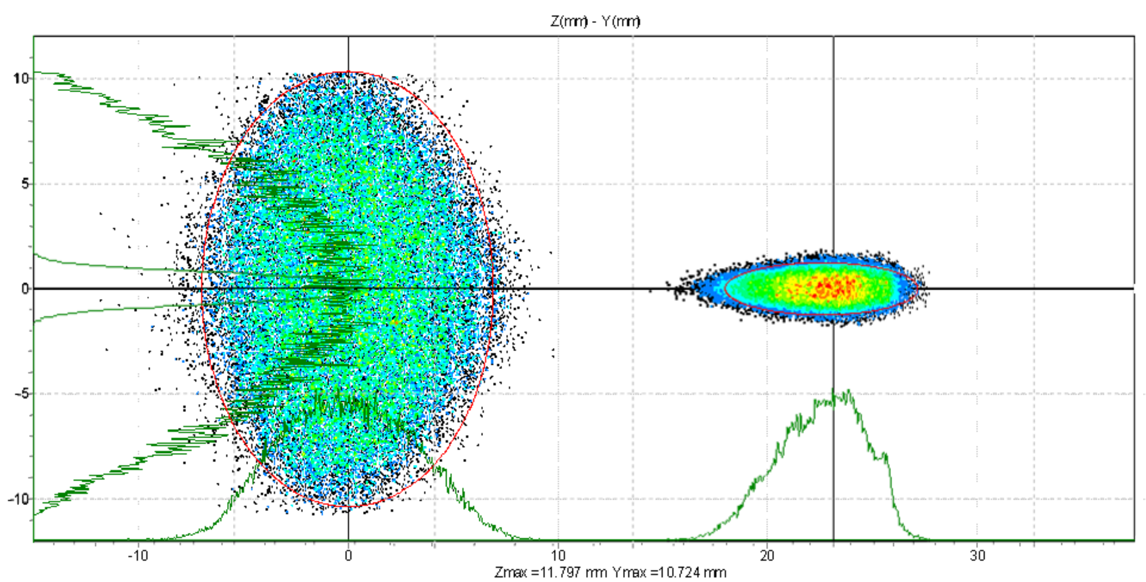

Figure 5: Beam distribution of "small" and "large" beam.

1 Using the First Field map – 1cm pulse length

We use the first field map with the 0.4ns pluses.
For both beams, we have applied the field during different durations: 10, 20 and 30ns.

	10ns		20ns		30ns	
	$\Delta\varepsilon_y$ (%)	$\Delta\varepsilon_z$ (%)	$\Delta\varepsilon_y$ (%)	$\Delta\varepsilon_z$ (%)	$\Delta\varepsilon_y$ (%)	$\Delta\varepsilon_z$ (%)
Small Beam	-0.07%	+0.38%	-0.55%	+1.3%	+41%	+5%
Large Beam	+17%	+0.95%	+48%	+7.5%	High Losses	

For the small beam, the emittance exchange works until 20ns. After 20ns the beam starts to become distorted and there is no more benefit. For the large beam, it does not work at all. This is probably due to the fact that for a large beam and a short pulse length, the field seen by the beam is not quadrupolar. The next figure illustrates the defocusing effect that the field can have in some areas.

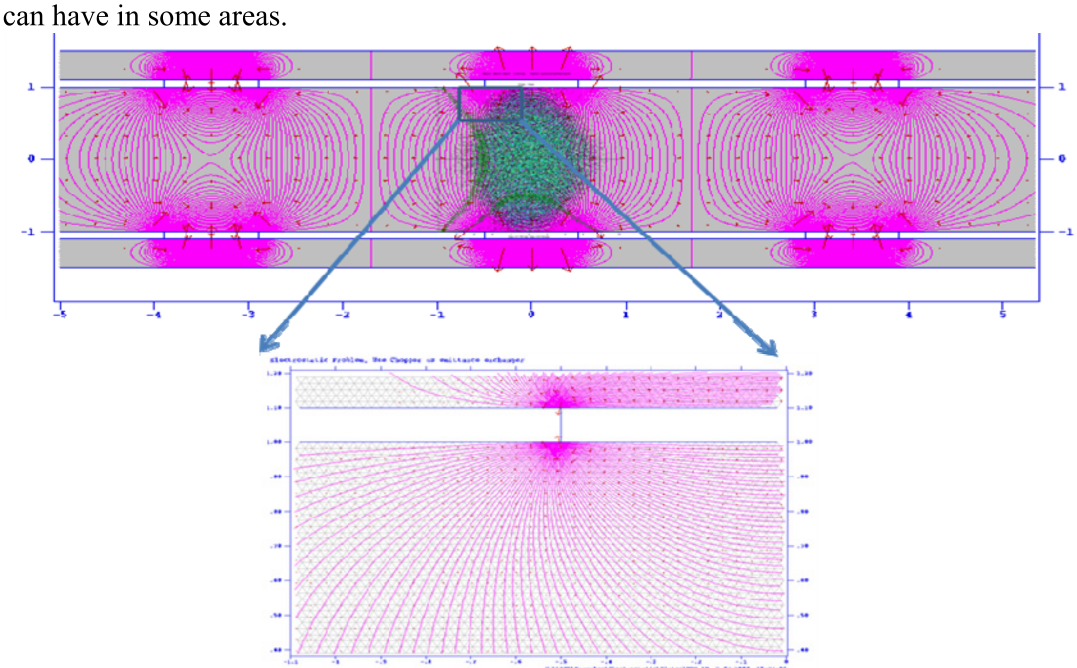

Figure 6: Field distribution in the "edge" area.

We clearly see that the beam covers more than the "quadrupole" area. For this reason, it works with the small beam but not with the large one.
According to these results, we decided to increase the pulse length from 1 to 3 cm in order to avoid this effect.

2 Using the Second Field map – 3cm pulse length

The results are summarized in the following table :

	10ns		20ns		30ns	
	$\Delta\varepsilon_y$ (%)	$\Delta\varepsilon_z$ (%)	$\Delta\varepsilon_y$ (%)	$\Delta\varepsilon_z$ (%)	$\Delta\varepsilon_y$ (%)	$\Delta\varepsilon_z$ (%)
Small Beam	-0.04%	+0.15%	-1.4%	+0.38%	-5.2%	+1.1%
Large Beam	-0.71%	+0.51%	-1.1%	+1.4%	-0.89%	+2.6%

For the small beam, the emittance exchange works really well. The results are really encouraging whatever the duration of the field is. For the large beam, it works well until 20ns. Then we start to reverse the process after 30ns, the losses are too big and the beam too distorted to take the values into consideration.
We also noticed that, while the emittance exchange works well (until 20ns for large beam and 30ns for small beam), we did not introduce any coupling between the transverse and longitudinal planes.

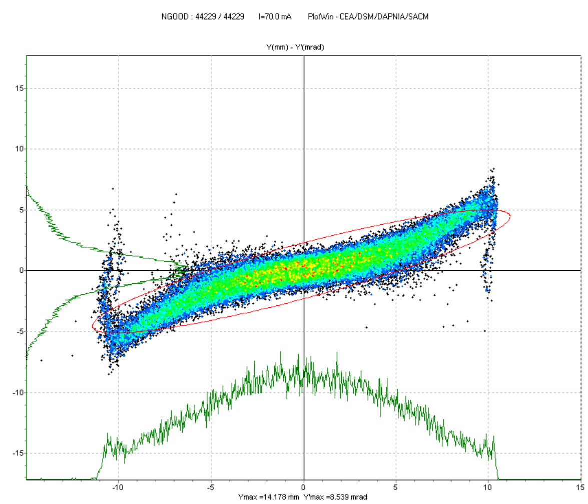

Figure 6: Beam distribution of a "distorted" beam.

Conclusion.

The purpose of this study was to explore the possibility to use the chopper plates as an emittance exchanger. We showed that it was possible and its efficiency depends on the beam size and on pulse duration. In fact the beam sizes (transverse and longitudinal), the pulse length and voltage, distance between the plates, length of the plates with respect to beam velocity, etc… are as many other parameters to consider carefully in order to achieve a good efficiency. Taking all these details into account, a further optimization studies are necessary to explore the optimum parameters for emittance exchange.

Acknowledgements

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 “Structuring the European Research Area” programme (CARE, contract number RII3-CT-2003-506395)