Summary of session on beam-beam compensation schemes

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Abstract

This paper summarizes the presentations and discussions in the session on beam-beam compensation held during the workshop on beam-beam effects at Fermilab on 25 to 27 June 2001. The presentations and discussion were focused on two main topics: linear and non-linear compensation with electron lenses in the Tevatron and a compensation scheme for long-range effects in the LHC using a pulsed wire.

1 INTRODUCTION

In high luminosity hadron colliders the beam-beam effect eventually limits the bunch intensities. Recently schemes have been proposed to compensate part of the detrimental effects. During this session three presentations were made:

- Correction of the long-range beam-beam effect in LHC using electromagnetic lenses; by J.P. Koutchouk, CERN
- Simulation of the LHC long-range compensation; by F. Zimmermann, CERN
- Study of the Tevatron compensation; by D. Shatilov, BINP

The presentations were discussed and some issues of general interest for beam-beam compensation that were raised during this session are presented here.

2 COMPENSATION OF LONG-RANGE EFFECTS

Recently the long-range beam-beam effects have been more and more recognized as important factors for the stability of the beams in lepton and hadron colliders. Both, active or passive compensation of at least part of these effects may be essential for machines with many bunches.

2.1 Pulsed wire for compensation of long range effects

The proposal to compensate the long-range beam-beam effects (LRE) was made after initial tracking studies have shown the importance of long-range effects on the dynamic aperture. It was realized that for large enough beam separation the long range forces decrease with \( \frac{1}{r} \), where \( r \) is the distance between the beams. Such a field can also be produced by a thin wire. For the bulk of the long-range encounters this assumption is valid and the separation is typically between 7 and 10 \( \sigma \). Furthermore, most of these encounters happen where the beams are still approximately round and at a phase advance of \( \frac{\pi}{2} \) from the collision point. It can therefore be justified to lump all interactions into a single one. The linear part of the long range forces is largely compensated by the alternating crossings in the LHC interaction points. The size of the beam-beam tunespread (footprint) can be strongly decreased [1] by a wire running along the beam. The current times length of such a wire requires approximately 80A \( \cdot \) m. The size of the footprint can be decreased by a factor 10. Effects on the closed orbit are corrected simultaneously.

The bunch filling scheme of the LHC causes a difficulty, producing so-called PACMAN bunches which experience only part of the beam-beam effect and therefore need only part of the correction. To account for this it is proposed to pulse the current in the wire at the beginning and end of a batch, i.e. produce smaller compensating fields for the PACMAN bunches.

Preliminary considerations have shown that such a scheme is technically possible, using commercially available equipment.

The wire is operated in the vacuum of the machine and therefore needs a cooling system. Such a cooling is technically difficult for a wire of 1 mm diameter and alternatives have been proposed where a much thicker wire with cooling inside is used and the surface of the wire is shaped to obtain the correct \( \frac{1}{r} \) dependence.

2.2 Simulation of long range compensation with pulsed wire

To evaluate the above compensation scheme, a study was launched to simulate the effect on the beam. A second aim was to work out the tolerances and the sensitivity of the proposed setup to imperfections. For that purpose a weak-strong simulation was developed, assuming a linear transport in the arcs and at the interaction point a head-on collision and on both sides long-range collisions together with a wire. The wire was assumed at a distance of 9.5 \( \sigma \) and producing a \( \frac{1}{r} \) force. The tests were made on possible betatron phase errors, as well as on wire positioning and strength errors. For the evaluation the footprints and the diffusion rate was used. Without errors the footprints were reduced almost to the size of the head-on footprints alone since the compensation in the program is almost perfect. Already in earlier studies it was shown that the dif-
fusion rate increases steeply for particle amplitudes above 6σ (without wire). With a wire the increase of the diffusion sets in about 1.5 to 2 σ later, i.e. a significant increase of the available stable region. With phase errors of 2° to the wire, the improvement is still 1 to 1.5 σ. Only for errors larger than 10° the original steep increase is observed again. However such phase errors are not expected for a reasonably well behaved insertion optics. Studying the effect of static wire strength errors it was found that errors in the range [-40%, +20%] still give a good correction.

The positioning of the wire with respect to the beam is an important issue that may need some further thoughts, a consensus reached during the discussion. The simulation of positioning errors in the range [-40%, +60%] showed a dependence with acceptable compensation in the interval [-5%, +40%]. I.e. in case of positioning errors, an error away from the beam is preferable. While studying a scheme with a single wire compensating the long-range effects from both sides of the interaction point, it was shown that a scheme with two separate wires has advantages.

During the discussion it was agreed that no obstacle was identified up to now and the participants of the workshop strongly recommend to continue with this scheme.

### 3 STUDY OF TEVATRON COMPENSATION

Another simulation study aimed to evaluate the linear and non-linear compensation with electron lenses in the Tevatron, and possibly to define some strategies for the operation. For that purpose a weak-strong beam-beam code was developed (LIFETRAC) for the Tevatron that is fully symplectic in 6D and can use various noise sources, such as tune modulation or beam separation at the collision point.

The main purpose of the linear-beam-beam compensation is to suppress the bunch-to-bunch tune spread in the Tevatron. In a first step, good and bad working points are determined with the program. In the second step all bunches at bad working points are moved to the good working points with linear electron lenses. varying the parameters of the lenses and including perturbations this strategy can be tested. After the application of the linear lenses, the distributions of antiprotons at originally bad working points are practically the same as on good working points. Different electron lens profiles were investigated, studying the antiproton tune-shift and the luminosity. The difference was found to be rather small. Injecting noise on the electron beam led to exponential emittance growth.

The purpose of the non-linear compensation is to reduce the intrabunch tune spread, i.e. the tune footprint. The footprint of long range beam-beam interactions show a characteristic 'folding' for particles at amplitudes close to the beam separation. If this appears close to low order resonances it is considered dangerous since there we have \( \frac{dQ}{dA} \approx 0 \). Bad lifetime of tails must be expected. The effect of the non-linear lens is to scale down the footprint, thus moving the folding over area to smaller particle amplitudes. This may now lead to a blowing up of the core of the bunches that must be avoided. The recommended procedure now used in the simulation is to reduce the footprint moderately, i.e. by a factor of two in the first step. A linear lens should then be used to shift the bunch to a better working point where the reduced footprint is in an area free of dangerous resonances. Therefore the non-linear and linear compensation must be applied simultaneously.

In the discussion it was acknowledged that the study helped to understand better the requirements and to define the parameters for the compensation. However more experimental data is desirable. While the linear compensation looks very promising, it is recommended to further study the non-linear compensation. A consensus was reached that a small tune footprint (i.e. tune spread) alone does not guarantee a safe running. It must be considered a necessity but it is not sufficient.

### 4 CONCLUSIONS

Compensation schemes for head-on as well as for long range beam-beam effects have been discussed. Both approaches were found promising and well under way and the workshop strongly recommends to continue.

### 5 REFERENCES

