

# CONSIDERATIONS ON A NEW FAST EXTRACTION KICKER CONCEPT FOR THE CERN SPS

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## Abstract

A new 450 GeV/c extraction kicker concept has been investigated for the SPS, based on open C-type kickers and a fast-bumper system. The beam is moved into the kicker gap only a few ms before extraction. The concept is illustrated in detail with the LSS4 extraction in the SPS – very similar parameters and considerations apply to the other fast extraction system in LSS6. A similar concept could also be conceived for injection but is more difficult due to the larger beam size. The technical issues are presented and the potential impact on the machine impedance is discussed.

## INTRODUCTION

The present SPS fast extraction is in the horizontal plane. The kickers are ferrite C-core with a return conductor closing the gap, Fig. 1, which provide enough aperture for the injected beam at 14 GeV. An alternative extraction kicker concept, Fig. 2, is investigated with the idea to build an open C-type kicker and fast-bumper system, such that the beam is moved into the kicker gap shortly before extraction. In this note the concept is illustrated with the SPS LSS4 extraction [1] from the SPS – very similar parameters and considerations apply to LSS6 [2]. A similar concept could also be used for injection, with a fast bump to move the beam out of the kicker aperture; however, this is much more difficult due to the larger beam size, and is not investigated here in any detail.

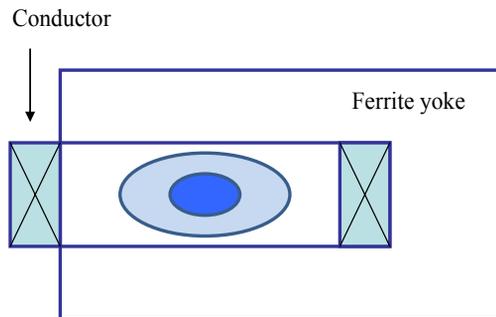


Figure 1. Schematic of present MKE kicker. The vertical gap height is determined by the injected beam size.

For a given magnet current, the kicker field is defined by the vertical gap; a smaller gap will be an advantage since more kick strength is available for a given Pulse Forming Network (PFN) voltage and system impedance. Kicker beam coupling impedance is an issue for beam stability, and having the beams present in the kicker gap for a short time only, and at high energy, could be a big advantage. Similarly, kicker heating from the real part of

the beam coupling impedance will be less of an issue if the coupling impedance seen by the beam is much less for most of the accelerating cycle. In addition, since a smaller vertical gap is required (for a given current), less installed kicker length will be required, which helps reduce the overall beam coupling impedance [3]. The smaller vertical gap and single conductor of the new kickers mean that the impedance per metre will, however, be higher.

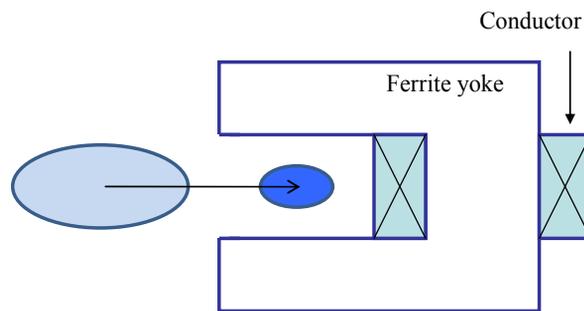


Figure 2. Schematic of alternative MKE kicker, where a fast bump moves beam into the gap. The vertical gap height is determined by the extracted beam size.

## CONSTRAINTS AND ASSUMPTIONS

The constraints and assumptions used in investigating the feasibility of such a concept are listed. These are initial estimates and clearly have scope for optimisation.

- Extraction angle from kicker should be 0.5 mrad;
- Kicker vertical and horizontal gap should provide enough aperture for extracting CNGS beam at 300 GeV, and a sufficiently good field quality for this beam;
- The aperture of the kicker for the injected beam should not be less than at present;
- The flat-top ripple of the kick less than  $\pm 1\%$ ;
- The kicker rise- and fall-time should be 1  $\mu$ s for the CNGS (this can be longer for LHC, to a maximum of 6  $\mu$ s);
- The pulse-length should be enough for CNGS, i.e. 10.8  $\mu$ s;
- One design is used for LSS6 and LSS4 (the vertical aperture could be smaller for LSS6);
- Optics and beam size at kicker locations:
  - Maximum beta functions assumed are 100 m X, 35 m Y;
  - $12/8 \pi$ .mm.mrad normalised emittance for CNGS beam;
  - Dispersion at kicker location: 0.5 m
  - $\delta p/p$ : 0.1 %;
  - Orbit allowance:  $\pm 4$  mm;

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- Alignment tolerance:  $\pm 1$  mm;
- Acceptance:  $\pm 5 \sigma$ .

## REQUIRED KICKER APERTURE

Using the above values the minimum horizontal half-aperture is 14.9 mm, and vertical is 9.5 mm. A minimum full aperture for a 300 GeV CNGS beam is then assumed to be 30 mm horizontal, 20 mm vertical, Fig. 3. Note that vertically this is the same as the extraction gap in the downstream MS septa, which have larger vertical beta functions (they essentially fill the half cell), although the beam only makes one pass in the septum.

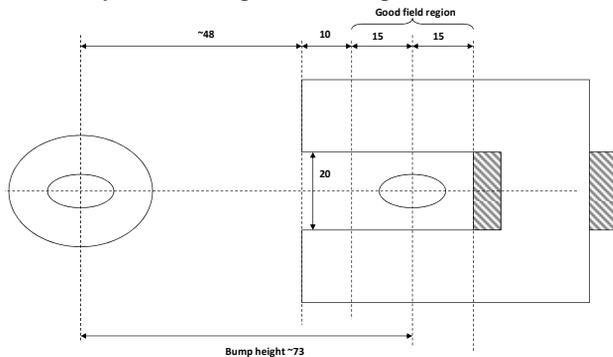


Figure 3. Possible geometry for a new SPS extraction kicker concept.

## CHARACTERISTIC IMPEDANCE, INDUCTANCE AND RISE TIME

For an impedance matched transmission line system:

- $I = U/2Z$
- $L = \mu_0(w/h) l_m$
- $B = \mu_0 I/h$

where  $U$  is the PFN voltage,  $L$  the magnet inductance,  $I$  the magnet current,  $Z$  the characteristic impedance of the (matched) system,  $w$ ,  $h$  and  $l_m$  are the aperture width, aperture height and magnetic length of the kicker magnet, respectively, and  $B$  the magnetic field.

The present system impedance, for the MKEs, is  $10\Omega$  – we assume this is kept, so that existing PFNs and generators can be re-used. The present PFN voltage, for MKE4 (a matched system), is about 50 kV giving  $I \approx 2.5$  kA: for the existing aperture heights of 32 mm (S-type magnet) and 35 mm (L-type magnet), the central fields are approximately 98 mT and 90 mT, respectively. For the aperture shown in Fig. 3, and 2.5 kA, the central field  $B$  in the aperture would be approximately 157 mT (note: the flux-density in the back-yoke of the ferrite C-core (presently 70 mm), at the centre of the magnet, would be reduced by  $\sim 40\%$  in comparison with the existing MKE4 kicker magnet, for a given pulse current).

Keeping the present magnet length  $l_m$  of 1.674 m, three magnets (five presently installed) then give 0.804 Tm, or 0.53 mrad deflection at 1503 Tm rigidity for 450 GeV.

The present MKE-L ( $w/h$ ) is 147.7/35, so  $L \approx 9 \mu\text{H}$ . Assuming that the fill-time is approximately given by ( $L/Z$ ), then the present fill-time is  $\sim 0.9 \mu\text{s}$  (note:  $L/Z$  underestimates the fill-time of the magnet as it neglects

the effect of the series inductance of the magnet cell capacitance on the cell cut-off frequency). For the same magnet length, and allowing for an effective width of ( $w+h/2$ ) because of fringe fields, ( $w+h/2$ )/ $h$  of 50/20 gives  $\sim 5.3 \mu\text{H}$ , or  $\sim 0.53 \mu\text{s}$  fill time – significantly faster than at present ( $\sim 0.9 \mu\text{s}$ ). Note that the effective width is taken as ( $w+h/2$ ) since the return conductor does not close the aperture and hence there is additional fringe field. It would be possible to either keep this rise-time margin or (probably better) build two longer magnets to give the same total deflection but with only 2 PFNs. For instance, two magnets each of 2.5 m long at 0.16 T gap field would have  $L \approx 9 \mu\text{H}$ , or  $\sim 0.9 \mu\text{s}$  fill time.

## BEAM COUPLING IMPEDANCE IMPLICATIONS

The kicker gap height would reduce from 35 mm to 20 mm. As an illustration, for a similar design as the present MKE, reducing the gap to 20 mm would increase the real part of the longitudinal beam coupling impedance by around a factor 2, depending on the frequency, Fig. 4. However, the total installed length of MKE kickers would decrease from  $\sim 13.6$  m (8 magnets) to  $\sim 7.8$  m (4 or 5 magnets), so the net increase in real longitudinal beam coupling impedance is only about a factor 1.2. It should be recalled that this increase is only for of the order of 100 ms or less, and only when the beam is at extraction energy. Similar scaling or detailed simulation would need to be made on a more realistic geometry for the longitudinal and transverse impedances, and detailed beam dynamics simulations should be made to understand whether this gives a net advantage.

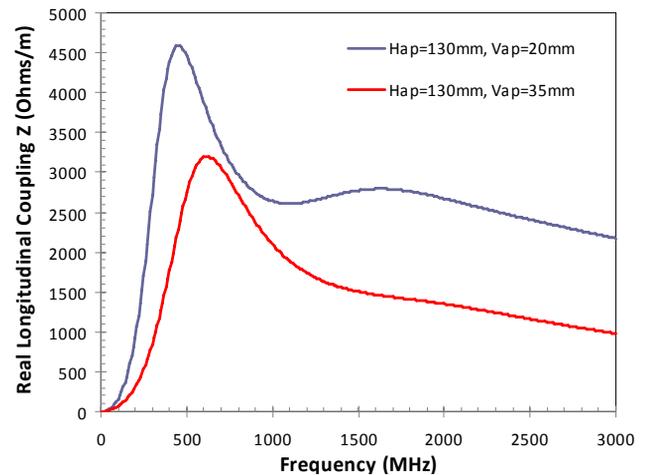


Figure 4. Theoretical real longitudinal beam coupling impedance, per m length, for different kicker gap heights.

If the beam coupling impedance is still too large, a possibility is to have a larger vertical aperture, increasing the number of magnets accordingly. This would either directly result in lower beam coupling impedance due to the larger gap, or more interestingly would allow space for shielding elements to be inserted, to carry the beam image current (e.g. as per LHC injection kicker magnets [4]). Alternatively the coupling impedance could be

reduced by a serigraphy on the surface of the kicker, although this has some other technical concerns.

### EXTRACTION BUMP

The extraction bump should provide an offset of about 68 mm at the entrance of the kicker, with an angle matched to the beam size envelope at the kicker location. The bump, Fig. 5, must also bring the circulating beam close to the TPSG/MSE for extraction. A long extraction bump with 5 magnets is needed, Table 1.

The existing MPLH magnets can reach 1.2 mrad, and the MPSH 0.6 mrad. Possibly bumpers HB3 and HB4 could be combined into one stronger magnet (similar to that used for slow extraction in SPS LSS2).

The bump rise time should be fast enough that the time spent by the circulating beam in the kicker aperture is short compared to the rise-time of the detrimental processes at high energies (vacuum, instabilities). A rise-time of ~200 ms, comparable to existing MPSH/MPLH, would mean around 50 ms during which the beam is inside the kicker aperture (2000 SPS turns). The CNGS beam will be an additional 50 ms inside the kicker for the 2nd batch. The possibility of reducing the bumper rise-time will be investigated.

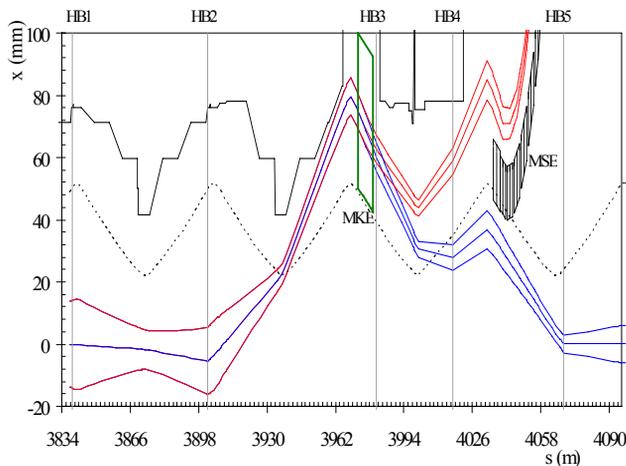


Figure 5. Bumped (blue) and extracted (red) beam envelopes ( $\pm 3 \sigma$ ). The locations of the bumpers (HB), kicker (MKE) and septum (MSE) are indicated. The nominal aperture at injection is shown dashed.

Table 1: Bumper locations and deflections.

| Bumper | Location | Strength [mrad] |
|--------|----------|-----------------|
| HB1    | 412      | -0.05           |
| HB2    | 414      | 0.73            |
| HB3    | 416      | 0.21            |
| HB4    | 417      | 0.67            |
| HB5    | 420      | -0.05           |

### EXTRACTION TRAJECTORY, ORBIT IN QUADRUPOLES AND APERTURE

The extraction trajectory is also shown in Fig. 5. Assuming three magnets of the present MKE length, the extraction kicker strength needed is about 0.18 mrad per magnet, which should be possible with a similar maximum current to the present MKE4 operating at 52 kV ( $32/20 * 0.112 = 0.179$ ), and corresponds to 0.16 T in the aperture. The maximum excursion in QFA418 is 90 mm for the  $3 \sigma$  edge of the beam, which is acceptable.

Because of the larger negative angle from the bump than for the present extraction this pushes the extraction septum inwards by about 2.5 mm compared to the present situation, which reduces slightly the aperture available for the injected beam at the extraction septum. The horizontal aperture at the septum for the injected 14 GeV FT beam decreases from 5.49 to 5.21  $\sigma$ .

### OTHER SYSTEMS

Additional enlarged quadrupoles QFA and QDA would be needed at positions 416 and 415, respectively. Four enlarged quadrupoles in total would be needed to equip both extraction straight sections. There are only 4 spare magnets of this type in existence, one of which needs rebuilding (no tooling exists).

Apertures of other elements (correctors, pickups etc.) in the LSS between Q15 and Q17 will need to be large enough horizontally – similar to those already used in the extraction and injection regions of the SPS near the enlarged quadrupoles. This might entail the construction of some new beam instrumentation.

The two MBA dipoles in 416 just before the kicker will need to be displaced by about 10-12 mm towards the outside of the SPS, to give enough aperture for the bumped beam. This is already done in 418 for the extracted beam.

### CONCLUSION

The new concept for fast extraction kickers for the CERN SPS looks feasible on paper, and could possibly provide a means to reduce the beam coupling impedance, especially at injection and during the energy ramp. Some potential issues with the proposed concept need some follow-up in order to prove the feasibility.

- Quantify the kicker aperture width, shim and height requirements from field quality calculations, and determine the required ferrite cross-section;
- Simulate the kicker magnet equivalent circuit, with realistic parasitics, to predict field rise-time;
- Define maximum allowable field in ferrite/aperture and required magnetic length;
- Investigate bumper rise-times and powering;
- Simulate beam coupling impedance for new kickers compared to existing ones;
- Investigate potential impedance/stability issues for 2000 turns of beam inside kicker gap (4000

turns for the 2nd batch of CNGS double-batch extraction).

### ACKNOWLEDGEMENTS

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