A NEW HARDWARE DESIGN FOR PSB KICKER MAGNETS (KSW) FOR THE 35 mm TRANSVERSE PAINTING IN THE HORIZONTAL PLANE

L. Feliciano, C. Bracco, L. Ducimetière, A. Fowler,
G. Grawer, R. Noulibos, L. Sermeus,
W. Weterings, C. Zannini, CERN, Geneva, Switzerland

Abstract

The changeover from Linac2 to Linac4 in CERN's injector chain will allow increasing the injection energy into the PS Booster from 50 MeV to 160 MeV [1]. Transverse phase space painting will be performed in the horizontal plane, by means of four stacks of four KSW kicker magnets. The KSW magnets are located outside the injection region and will produce a 35 mm closed orbit bump, with falling amplitude during the injection to accomplish transverse phase space painting to the required emittance. New magnets with two different types of coils are being built using the existing design. The magnets are made of two halves, which are assembled together around a vacuum ceramic chamber. In order to reduce the beam impedance, the ceramic chamber is internally coated by a thin titanium layer. A new multiple-linear waveform generator has been developed to provide the high flexibility in the KSW kicker magnets current decay to fulfil the requirements of all the different users (LHC, nTOF, ISOLDE, CNGS, etc.).

INTRODUCTION

In the framework of the Linac4 – LIU (LHC Injectors Upgrade) project the European Organization for Nuclear Research (CERN) is designing a new layout for the transverse painting in the horizontal plane with kickers (KSW). The 160 MeV H^- ions beam from Linac4 will be distributed to four superposed rings of the PS Booster (PSB) and a new multi-turn H^- charge exchange injection system [2] will allow increasing the beam intensity in the PSB. A series of 4 horizontal kickers (KSW), outside the injection region, will produce a 35 mm closed orbit, with falling amplitude during injection, and uniformly fill the horizontal phase space (transverse painting) and move the circulating beam away from the stripping foil; this will allow the reduction of the emittance (ε_x) blow-up induced by space charge effects and scattering processes.

KICKER REQUIREMENTS

Two types of KSW magnets will be installed in the PSB layout to produce the transverse painting bump. Optics studies showed that, since the magnets are not symmetrically distributed around the stripping foil, each type of magnet has to give a slightly different kick to perfectly close the bump and prevent any orbit leakage around the ring. All the magnets will thus be individually powered.

A high flexibility in the KSW current decay waveform is needed to fulfil the requirements of all the different users. A multiple-linear waveform is chosen for the KSW generators as schematically shown in Fig 1.

For an "ideal painting" (red line in Fig 1), an initial fast decay over few turns (called in the following Slope 1) has to be followed by an almost constant slope (Slope 2) until the end of injection. This allows filling first the centre and then the outer area of the transverse phase space reducing the charge density in the core of the bunch and thus the space charge effects. Once injection is finished, the circulating beam is moved away from the foil (Slope 3), as fast as possible, until a negative bump of -9.2 mm (fixed for all the users) to avoid any further interaction with the foil. At this point also the chicane starts decaying and the KSW bump goes to zero in 1 ms.

For small emittance beams (i.e. LHC beams), no painting is applied during the full injection process, the bump stays constant at 35 mm (I_0 green line in Fig 1). This could vary between 10 μs and 20 μs, depending on the current delivered by Linac4. During injection, the deviation from the reference waveforms must be always kept smaller than 1%. After injection the beam has to be moved away from the foil as quickly as allowed by the HW. Studies with ORBIT [3] were performed assuming the fall of the injection bump from 35 mm to zero in 10 μs (cyan line in Figure 1; a 2 μs margin was considered to take into account possible delays induced by the eddy currents in the Titanium layer of the vacuum chambers as explained in above). Such decay speed allows keeping the number of foil crossings low enough to limit the emittance blow-up.

For the high intensity and large emittance beams (i.e. ISOLDE, nTOF, etc.) the "ideal painting" will be performed. In case of 40 mA average current delivered by Linac4 up to the PSB, the maximum target intensity ($2.5\text{x}10^{13}$ protons per ring for ISOLDE) can be accumulated in 100 μs. The eventuality of a non-optimum performance of Linac4 (reduced current) and the consequent need to extend the injection process up to 150 μs to reach the target intensity is taken into account [4].

The envelope conditions for the KSW current decay (ΔI), depending on the user, are the following:

- “Slope 1”: ΔI = 10 % - 60 % in 5 - 30 µs respectively.
- “Slope 2”: ΔI = 1 % in 5 - 145 µs.
- “Slope 3”: ΔI/Δt = 10 µs for all the different waveforms (fastest decay).

Another limit condition is that the KSW generator current can vary from I_0 to 0 A in 150 µs while keeping the <1 % tolerance limit.

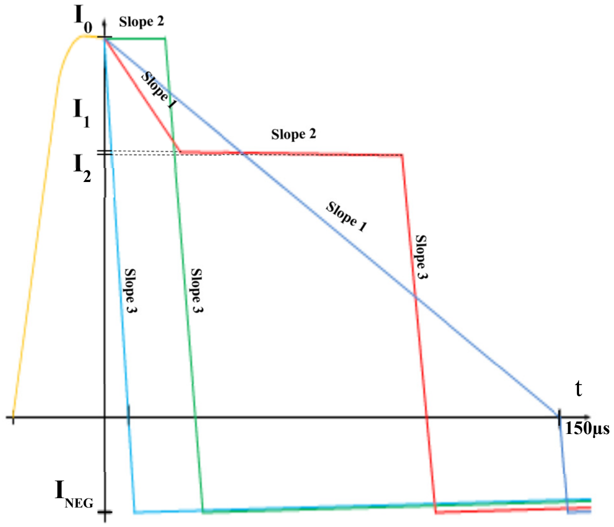

Figure 1: BI.KSW current waveforms for different users.

MAGNETS

Mechanical

Two different types of KSW magnets are being built, one for the inner magnets (2L1 & 16L1), and one for the outer magnets (1L4 & 16L4). This guarantees the same kick shape for all magnets of a similar type. However, due to their position, the kick strength required will be slightly different for each magnet, (see Table 1), and each magnet will be powered individually.

Table 1: KSW Magnet Parameters

	unit	1L4	2L1	16L1	16L4
Kick	mrad	1.15	5.41	5.85	0.83
Magnetic field	mT	6	28	30	4
Gap height	mm	132	132	132	132
Gap with	mm	132	132	132	132
Length	mm	370	370	370	370
Inductance	µH	390	39	39	390
Number of turns		48	16	16	48
Repetition rate	Hz	1.1	1.1	1.1	1.1

Electrical

The construction of the new KSW Kicker magnets is based on the previous design. The magnet is composed of two halves and is opened to install a ceramic vacuum chamber. A magnetic circuit is used to homogeneously distribute the flux density inside the aperture. It is made of Ferroxcube Ni Zn ferrite, grade 8C11. The magnet will be excited by a multi turn winding in which the current will vary according to Fig. 1. Each half magnet is then partially epoxy cast after assembly to impregnate the coil. A 3D view and schematic cross section of the KSW Kicker magnet is shown in Fig. 2. For each position the four magnets will be mounted on a mechanical support to form a stack.

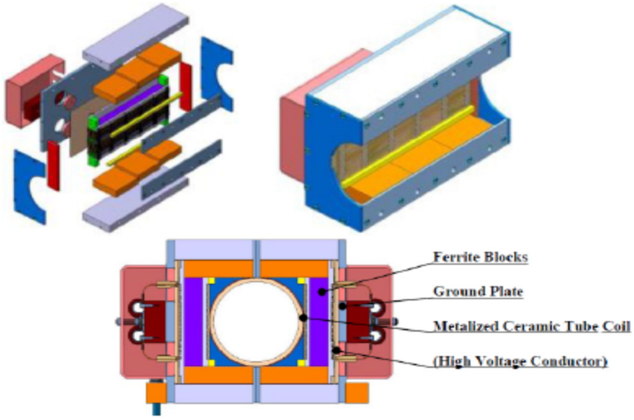

Figure 2: 3D models and schematic cross-section of the KSW magnet.

The predicted KSW magnets field distribution in the ceramic vacuum chamber presents a homogeneity of ±3 % (Vector Fields computation), as illustrated in the Fig. 3. The current amplitude to reach the required integrated field is around 400 A for the outer magnets (40 A in the case of the inner magnets).

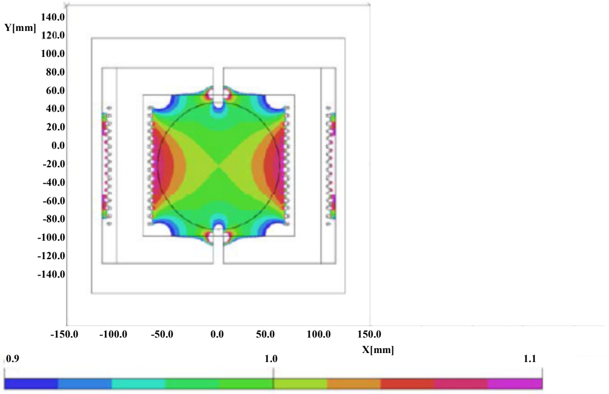

Figure 3: Predicted field homogeneity of KSW magnet.

Ceramic Chamber

All 8 new magnets, as well as future spares, will be equipped with new ceramic vacuum chambers as illustrated in Fig. 4.

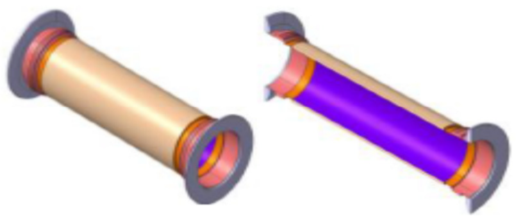

Figure 4: 3D and section views of the new KSW ceramic vacuum chambers.

The ceramic vacuum chambers are composed of an isostatically pressed alumina tube with brazed sleeves, which are welded to standard flanges. The ceramic will be coated by a thin titanium layer on the inside in order to minimise the beam coupling impedance. The metallisation thickness has been chosen to be equivalent to 2 µm (R=0.3 Ω flange to flange) to provide sufficient longitudinal impedance shielding (mitigation of the beam induced power) and low transverse impedance for beam stability. A lower coating resistance would degrade the pulse shape.

POWER GENERATOR

The main parameters of the KSW circuit are given in Table 2.

Table 2: KSW Magnet Parameters for Operation

	unit	16L1	16L4	1L4	2L1
Max. V	kV	1.0	1.0	1.0	1.0
Max. B	mT	36	9	9	36
Max. I_0	A	400	40	40	400
Nom. B	mT	30	4	6	28
Nom. I_0	A	395	17.5	26.5	367
Fall time (min)	µs	10	10	10	10
Pulse duration	µs	0-150	0-150	0-150	0-150

The KSW kicker magnets will operate with many different waveforms depending on the beam user (Fig. 1). Before beam injection, the current rises to I_{Max} and then starts to fall down to I_{Neg} during the injection with 1, 2 or 3 different linear slopes. The final slope, from I_{Neg} to 0 in 1 ms, is identical for all waveforms. The outer magnets in position 16L1 and 2L1 have an I_{Max} of 400 A while the inner magnets in position 16L4 and 1L4 have an I_{Max} of 40 A. Therefore two different types of generators have to be built. All four generators of one ring must work synchronously and deviation from the reference waveform shall be less than 1 %.

The principle of the generator operation is schematically shown in Fig. 5. To produce the magnet current rise or fall a voltage proportional to the required di/dt of the current is applied. Pre-charged capacitors are used as voltage sources and are switched one after the other to the magnet. A generator includes four capacitor switching stages in series, each supplying voltage of one polarity. The current can flow in both directions.

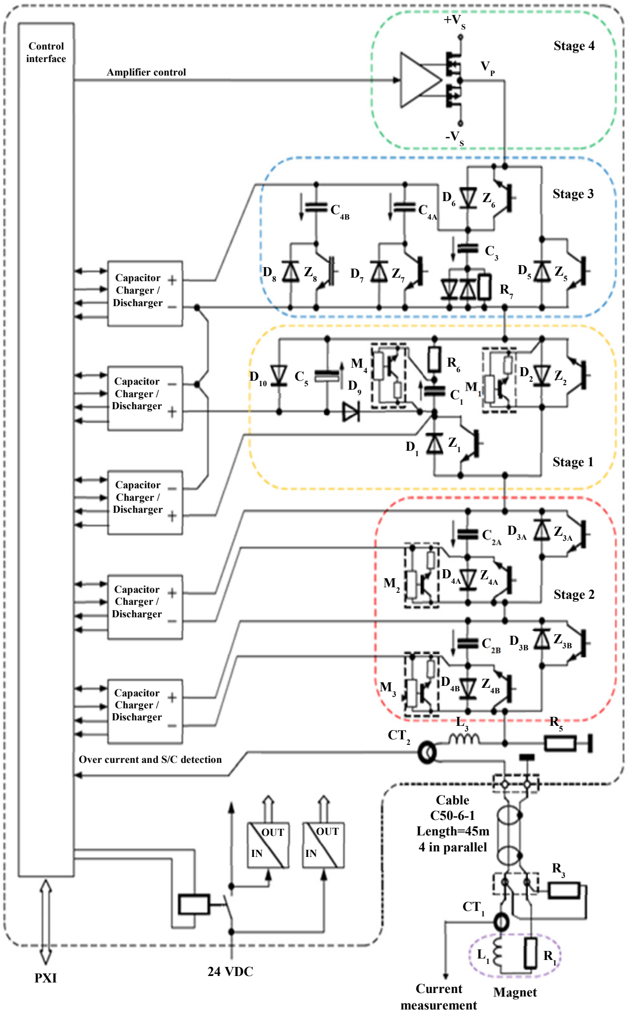

Figure 5: Schematic of BI.KSW 400A pulse generator.

SUMMARY AND STATUS

Good progress has been made for the magnet production. Both supporting structure have been produced, as well the 16 half magnets. The epoxy impregnation of the coils is ongoing. Ceramic chambers were produced and the metallization process is just about to start. A high current version prototype of the pulse generator was built and is ready for testing. The low current version prototype is currently under development and is expected to be ready for testing by mid-2015.

REFERENCES

[1] L. Arnaudon et al., "Linac4 Technical Design Report", CERN-sLHC-Project-Note-0020, CERN, Geneva, Switzerland, 2010.

[2] W. Weterings et al., "Status of the 160 MeV H-Injection into the CERN PSB", New Orleans, LA, USA, 20 - 25 May 2012, pp.2041.

[3] J.D. Galambos et.al, "ORBIT User Manual version 1.10", 1999.

[4] "Injection Line and PSB Injection Systems", LIU PSB 1.10" 1999.TDR, CERN-ACC-2014-0337.