UPGRADING OF THE SPS INJECTION KICKER SYSTEM FOR LHC REQUIREMENTS

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Abstract

The present SPS injection kicker system is composed of 12 travelling wave magnets connected in pairs to six pulse generators. The eight most upstream magnets ('S'-type) have a kick rise time (2-98%) of 145 ns and the remaining four ('L'-type) of 215 ns. The flat top ripple of the kick is ±1%.

In the future, this system will also inject protons and ions for the LHC, with a bunch spacing of respectively 220 ns and 125 ns, and a flat top ripple requirement of at most ±0.5%. Important modifications, concerning both magnets and generators, are then required to meet these goals.

For ion injection only 'S'-type magnets will be used. The reduction of the kick rise time will be achieved by shortening the magnet length and increasing the characteristic impedance. To compensate for the loss in total kick strength, four new magnets and two new pulse generators will be added. At the moment it is not intended to modify the 'L'-type magnets.

Most of the pulse forming networks (PFN's) must be adapted to the higher characteristic impedance of 16.67 Ω. The internal structure of all PFN's will be upgraded to reduce the flat top ripple and improve the turn-on characteristics.

INTRODUCTION

The future role of the SPS as injector for the LHC requires an important upgrading of the SPS injection kicker system, designed more than 20 years ago for the needs of a fixed target accelerator. The main new requirements are a reduction of the kick rise time by 25% for heavy ion injection, and a decrease of at least 50% of the ripple on the flat top of the magnetic field pulse, which is actually about ±1%.

The present layout and originally planned upgrading measures are described in detail in [1]. This paper gives further simulation and pulse response studies resulting in additional upgrading measures.

1 THE PRESENT LAYOUT

The SPS injection kicker magnet system is composed of 12 travelling wave magnets with a total length of more than 12 m. The magnets are connected in pairs via a 190 m long transmission line to six pulse generators [2]&[3]. Because of the considerable total length of the system the eight upstream magnets ('S'-type) have a different aperture and kick rise time than the four downstream magnets ('L'-type). The magnets are housed in groups of four in three vacuum tanks. Table 1 gives the main parameters.

Table 1: Main parameters of the actual SPS injection kicker magnets

	'S'-type	'L'-type	
Deflection angle at 26 GeV/c	0.341	0.381	mrad
Kick strength at 26 GeV/c	29.6	33.1	mTm
Kick rise time (2-98%)	145	215	ns
Horizontal Aperture	101	141	mm
Vertical Aperture	61	54	mm
Magnet length	0.7		m
Operating voltage at 26 GeV/c	48.6		kV
Magnet impedance	12.5		Ω
Generator impedance	6.25		Ω
Number of magnets	8	4	
Position	1 to 8	9 to 12	
Housed in tank number	1&2	3	

The magnets are of the delay line type. Their inductance is divided into 22 elementary ferrite sections which are matched to the characteristic impedance by parallel plate capacitors inside the vacuum tank. The resulting flat top ripple of the magnetic field is about ± 1%.

The matched transmission line between each magnet in the accelerator tunnel and its pulse generators at surface level is composed of four coaxial cables in parallel, each with a characteristic impedance of 50 Ω.

The pulse generators are lumped element Pulse Forming Networks (PFN's) with a maximum operation voltage of 60 kV and a maximum continuously adjustable pulse duration of 12 μs.

2 THE NEW REQUIREMENTS

For the operation of the SPS as LHC injector new requirements are added to the parameters for fixed target operation. The main parameters for the magnetic field pulse are summarised in Table 2.

Table 2: Requirements for the future SPS inflector system

Mode of operation	Protons for LHC	Ions for LHC	Fixed Target	
Inject. momentum	26	12.97*	14	GeV/c
Deflection angle	3.92	4.56	3.92	mrad
Rise time	≤ 220	≤ 115	<~1000	ns
Pulse length	2.1	0.5	10.5	µs
Kick ripple	≤ ±0.5	≤ ±0.5	≤ ±1	%

* Proton equivalent

3 FUTURE LAYOUT

The most stringent upgrade that needs concern is the rise time of the magnetic field pulse. The future requirements are given by the injection scheme for ions which demands a kick rise time of less than 125 ns, about 25% lower than the rise time of the actual ‘S’-type magnets. Only ‘S’-type magnets will be used for ion injection. ‘L’-type magnets have due to their large aperture aspect ratio a too long filling time, difficult to adapt to the required value.

The kick rise time is mainly composed of the magnet filling time τ. For a given aperture, which fixes the inductance, τ is proportional to the length of the magnet, and inversely proportional to its impedance. Originally it was envisaged to achieve the rise time reduction by increasing only the characteristic impedance from 12.5 Ω to 16.67 Ω. The new impedance is chosen such as to build-up the matched transmission line from three instead of four parallel coaxial cables of 50 Ω. However, additional measurements on a prototype magnet have shown that a length reduction of the magnets is also necessary. The shortening can be chosen such that five instead of actually four magnets are housed in the vacuum tanks.

The loss in deflection strength, mainly due to the impedance increase, will be compensated by adding two further ‘S’-type magnets in a small, available, vacuum tank.

Four unshortened ‘L’-type magnets will remain installed and together with the twelve ‘S’-type magnets be used for the injection of LHC-protons at 26 GeV/c. The future parameters are given in Table 3.

The future injection scheme is not compatible with positron injection and can therefore only be implemented after the end of LEP operation.

Two additional pulse generators of 8.33 Ω characteristic impedance must be constructed and the impedance of the generators of the shortened ‘S’-type magnets must be correspondingly increased. The synchronisation of the eight generators must be achieved with an accuracy of less than 10 ns. This requires the development of a new power triggering method for the high voltage thyratrons, together with a substantial improved surveillance electronics.

Table 3: Future parameters of the magnets

	‘S’-type	‘L’-type	
Deflection angle - LHC prot.	0.196	0.392	mrad
Kick strength - LHC protons	17	34	mTm
Operating volt. - LHC protons	50		kV
Deflection angle - LHC ions	0.380	--	mrad
Kick strength - LHC ions	16.4	--	mTm
Operating voltage - LHC ions	48.4	--	kV
Kick rise time (0.5-99.5%)	115	220	ns
Magnet length	0.5	0.7	m
Magnet impedance	16.67	12.5	Ω
Generator impedance	8.33	6.25	Ω
Number of magnets	12	4	
Position	1…12	13…16	
Housed in tank number	1,2,3	4	

The second upgrade necessary is a reduction of the ripple and the droop on the flat top of the magnetic field pulse. The ripple has three main causes on which improvements will be done:

- Bandwidth limitations of the magnet;
- Wave reflections generated by mismatch between the impedance of the PFN, the transmission line, the magnets and the termination resistors. The mismatch is to some extent unavoidable because of transitions from lumped elements, like PFN’s and magnets, to devices with distributed constants like transmission lines;
- Slight differences between individual cells of the PFN, causing non-negligible ripple due to reflections of the discharge wave, which travels forwards and backwards through the PFN.

4 EQUIPMENT MODIFICATIONS

4.1 General

The SPS injection kicker system is in continuous operation and can only be upgraded after the closure of LEP in October 2000 when an eight months shutdown will commence. After the shutdown the upgraded system must again be available for fixed target operation and studies with the LHC-type beam. The shutdown period is too short to dismantle, modify and reinstall this complex inflector. The individual components to be upgraded will therefore be prepared and tested as much as possible in advance. A detailed planning and upgrading scenario is under study.

4.2 Kicker magnets

The short ‘S’-type magnets will be built-up in advance from components of the obsolete pbar injection kickers of ‘L’-type. The length reduction requires the complete dismantling of the magnets, modification of the ferrite aperture and modification or remanufacture of mechanical items such as the high voltage conductor, the beryllium return conductor and the frames. Furthermore, the base plate of two Ω-shaped vacuum tanks will be rebuilt to allow installation of five short magnets.

For the impedance increase of the magnets the value of the matching capacitors must be lowered. This will be achieved by suppressing one of the two ground plates of the capacitor, and adjusting the size of the remaining one.

The frequency response of the magnets will be smoothed by damping the resonance frequencies. This will be achieved by means of resistors, connected in parallel to the cell inductance. Simulations and frequency measurements have been carried out and shown an optimum effect for a resistance of 50 Ω.

An RF screen will be installed between the different magnets in the vacuum tanks to create a better beam impedance continuity.

4.2 Pulse generators

Several options have been studied to improve both the ripple and, specially for ion injection for LHC, the current rise time. Among these were:

- Adding a short and more stable PFN or a Pulse Forming Line (PFL) of 2.1 μs duration dedicated for LHC beams.
- Improving the existing PFN of 12 μs duration to allow the three types of injection as specified in Table 2.

For cost and maintenance reasons, the last option has been retained.

For the ripple reduction of at least 50% it is intended to apply methods developed recently during the design of the prototype of the LHC injection kicker system [4]&[5]. Instead of a separate coil for each cell of the PFN, which has the disadvantage of small differences between the individual cells and poor mutual coupling, a continuous coil will be used for the first straight part of the PFN. This section is large enough to produce the 2.1 μs long pulse needed when the SPS is operated in LHC injector mode. The continuous coil is wound onto a precision-machined insulating support tube to assure high geometrical accuracy, needed for inductance and coupling stability, and for accurate reproduction of the calculated parameters. A 100 Ω damping resistor, which is effective at helping to further reduce the ripple, is connected in parallel with each PFN cell. An R-L-C cell is also added at the main switch end to improve the current rise time.

The design developed in [4] takes into account all known stray elements and, for the coil, the skin, field and proximity effects for frequencies up to 10 MHz. The ripple is then minimised by the PSpice "Optimizer" code [6].

Conduction losses along the coil result in a droop on the flat top of the magnetic field pulse. These losses can be compensated by grading the capacitors such that they increase in value starting with the main switch side of the PFN. Linear grading is suitable and the natural production spread of the capacitors can be used. Losses in the transmission line also help to compensate for the droop.

OUTLOOK

The upgrading of the SPS injection kicker magnet system is a demanding task and requires a full scale test system including the power switches and the complete length of the transmission line, checked at full operation voltage. Spare equipment to be modified is available and the transmission line has been purchased. The pulse response of a spare magnet of increased impedance has been tested at low voltage. A complete upgraded kicker system should be ready for testing at the end of this year.

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