THE INJECTION KICKER SYSTEMS OF LEP

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Abstract

The LEP injection system consists of 2 groups of 4 fast pulsed magnets, one group for e^+, the other for e^- injection. Each group is composed of 3 full aperture ferrite kickers equipped with metallized ceramic vacuum chambers and one ferrite kicker septum magnet, housed in a vacuum tank. The septum magnet is connected to its pulser via a fast pulse transformer. Kickers as well as septum magnets are energized by high repetition rate bursts of half sine wave pulses.

After a short presentation of the injection layout and the performance requirements, this paper discusses the electrical circuit of the burst pulse generators. It describes then the design of the air insulated kickers including a novel method of computer modelling the field attenuation caused by the metallization of the ceramic chamber. Thereafter the design of the septum magnets is presented. Finally the controls system is shortly described.

Introduction

LEP will be filled at an energy of 20 GeV from its preaccelerator, the SPS, by accumulating e^+ and e^- bunches over about 100 injection cycles with a minimum repetition time of 1.2 s. To achieve a high accumulation rate 8 lepton bunches will be injected per cycle in a fast burst of < 3 ms duration.

The 2 injection zones, one for e^+, the other for e^-, are located in the regular arcs about 500 m from either side of interaction point 1. The space for the injection elements, kicker and septum magnets, has been created by replacing the regular LEP dipoles of 4 lattice cells by an arrangement of double field dipoles. The injection is done from the inside of the arc, to avoid the septum being hit by synchrotron radiation.

The injection equipment consists of 3 full aperture kicker magnets and 1 septum magnet in each of the 2 injection zones. The kickers are located at a distance of about 80 m from each other near successive F-quadrupoles and create a fast local orbit deformation. The septum magnet is situated immediately downstream of the central kicker.

Performance Requirements

To deflect only the stored bunch to which the injected particles are to be added and to avoid deflection of counterrotating bunches a risetime of the deflecting field pulse of < 3.2 µs and a falltime of < 18 µs are required. Depending on the chosen mode of bunch accumulation in LEP, the repetition time between the injection of successive bunches may vary between 65 µs and 480 µs.

As the injection regions are located in the arcs of LEP neither alcoves nor service galleries exist close to the magnets to house the generators. Because of the limited space in the tunnel and its high radiation level all bulky and radiation sensitive equipment of the generators must be located in the service buildings which have a distance of about 1 km from the magnets. Table I summarizes the main performance requirements of the injection systems :

Table I

Performance requirements

Apertures:	Kicker magnet	hor.	200	mm
		vert.	49	mm
	Septum magnet	hor.	35	mm
		vert.	28	mm
Septum thickness			2	mm
Kick strength:	Kicker magnet		56	mT•m
	Septum magnet		366	mT•m
Pulse	risetime		< 3.2	µs
	falltime		< 18	µs
	flattop duration		> 0.2	µs
	repetition time		> 65	µs
Burst:	Number of pulses per burst		8	
	Burst repetition time		1.2	s
Length of transmission line		~	1	km
Bakeout temperature			150	°C

Technical Layout of Main Components

Electrical Circuit

The choice of the basic electrical circuit is determined by the pulse shape requirements, the short repetition time within the burst and the long distance between magnet and service building. All requirements are best met by a circuit consisting of a half sine wave discharge of a pulse capacitor close to the magnet in combination with a fast recharging system located in the service building.

The operation principle can be seen from the diagram of the septum magnet circuit shown in Fig. 1. A large capacitor bank C1 in the service building charges the pulse capacitor C2 in the tunnel resonantly by closing switch S1. Thereafter C2 is discharged into the magnet Lm by closing switch S2, creating the required quasi sinusoidal magnet current pulse. The discharge is stopped after half an oscillation by the unidirectional switch S2. The pulse energy is dissipated in matched resistors Rd at the input of the transmission line. The septum circuit is equipped with a pulse transformer, to adapt the rather different characteristic impedances of the charging and discharging circuits and to allow earthing of the center of the magnet. The kicker magnet circuit is similar to that of the septum, except that the transformer is not needed. Fig. 2 shows a burst of 8 pulses and Fig. 4 and Fig. 5 give calculated and measured shapes of the magnetic field pulse.

The circuit shown in Fig. 1 has several attractive operational and economic properties :

- The comparably long rise and fall times result in moderate operation voltages of < 25 kV allowing air insulation and the use of single stage thyratrons with an inherently short recovery time making a high repetition rate feasable within the burst. C2 and S2, the main components to be located close to the magnets, are housed

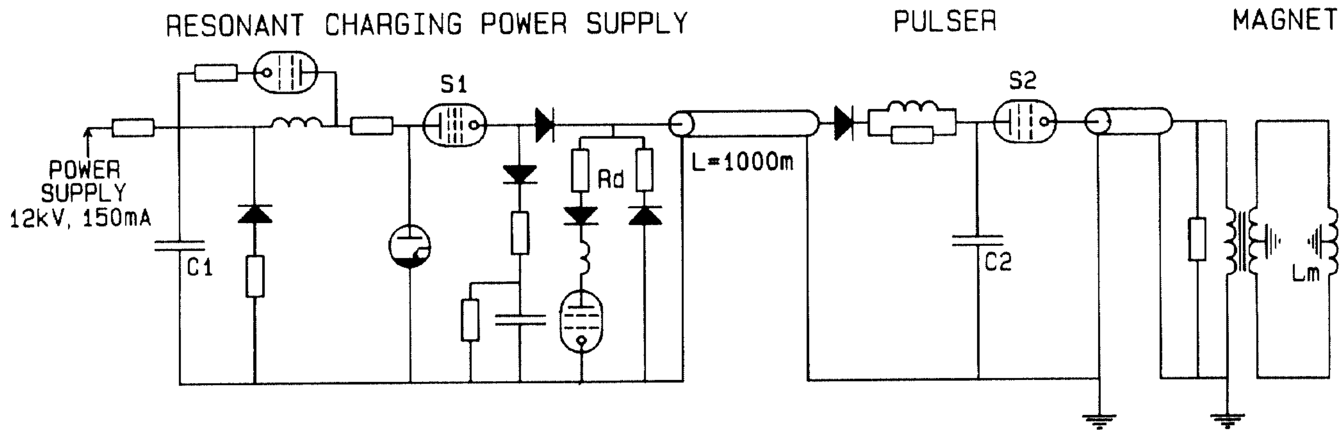


Fig. 1 Circuit diagram of the septum kicker system

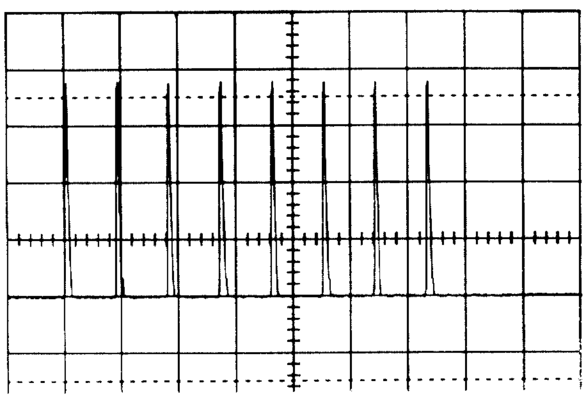


Fig. 2 Typical burst of 8 pulses
(Hor. scale 100 µs/div., vert. scale 400 A/div.)

in a compact, mobile and radiation resistant pulser that fits into the limited space between the rear side of the magnet and the tunnel wall.

- The transmission line does not transport the fast high intensity magnet current, but only the charging pulse of lower intensity and longer duration. High frequency attenuation on the cable is therefore not critical and an efficient high voltage design with semiconducting layers can be used, resulting in a small diameter and correspondingly low cost. Furthermore the cable does not need to be matched to the low characteristic impedance of the magnet discharge circuit eliminating the costly requirement to connect several cables in parallel. To avoid any electrical pertubation of low level signal and data cables running in parallel over 1 km on adjacent cable trays, the outer cable conductor is an Al-tube of 2 mm wall thickness which is large compared to the skin depth during pulsing. The solid conductor allows at the same time to meet the IEC 332-3/C norm concerning flame retardance.

A detailed description of the electrical circuits, the choice and performance of its main components including the pulse transformer is given in [1].

Kicker Magnets

For magnetic field pulses of the required performances kicker magnets are normally housed in vacuum tanks and use ferrite as yoke material. The short, high intensity lepton bunches would however excite gyromagnetic resonances in the ferrite, resulting in bunch lengthening and excessive heating of the ferrite, as was observed in SPEAR in 1974 [2]. The magnets are therefore built around ceramic vacuum chambers that are coated with a metallic film. The metallization provides a conducting path for the wall currents of the bunches and screens in combination with the chamber dielectric the ferrite against the wake fields of the bunches [3]. The layer is chosen thin enough to let pass the low frequency field of the kicker pulse.

A cross-section of the kicker magnet is shown in Fig. 3. The magnet has a length of 1 m, a window frame ferrite yoke in air and an insulated two-turn excitation coil. The yoke and its coil consist of two axially mirror symmetric halfs that can be opened radially to allow the installation of the vacuum chamber and its bakeout jackets. In closed position the half cores are separated by a thin copper plate, to avoid any closed magnetic flux path of the bunch field through the ferrite. The monolithic ceramic vacuum chamber has a length of 1.3 m and an aperture of 200 mm x 49 mm. Circular ceramic flanges are glass bonded to the chamber end faces, allowing a clamped UHV connection to stainless steel flanges of the standard metallic LEP vacuum chamber, bakeble to 200 ° C. The inner wall of the chamber is metallized with a 1.7 µm thick titanium layer by means of magnetron sputtering. The ceramic chamber and the coating procedure are discussed in more detail in a separate paper at this conference [4].

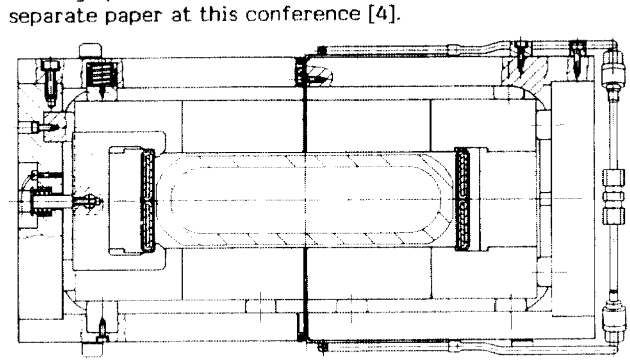
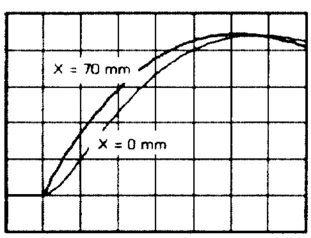


Fig. 3. Cross-section of the kicker magnet

The pulsed excitation of the kicker magnets induces eddy currents in the metallization, resulting in attenuation and phase shift of the magnetic field pulse depending on the radial position in the chamber. As the pulse deformation is strongly influenced by the chamber width we have chosen in the curved vertical parts a metallization thickness of only about .8 µm, taking into account that the bunch field is weak in this region. Attenuation and eddy current losses are thus considerably reduced.

The eddy currents induced in the metallization have been calculated by an equivalent electrical network which simulates the effect of the metallization. The equivalent circuit is established by subdividing the metallization layer into several concentric loops, corresponding to the concentric eddy current paths. The ohmic resistance and the inductance of these paths can be determined, as well as the mutual inductances between them. These loops are then considered as secondary windings of a transformer, the primary winding being the excitation coil. The resulting circuit can be calculated with PSpice [5], a computer code equipped with a model for multi-secondary transformers. This approach has the advantage that the equivalent circuit can directly be introduced into the computer code of the overall electrical circuit of the system. The calculation is therefore performed with the correct shape of the excitation pulse and takes furthermore into account the counterreaction of the metallization on the pulse generator. With the known eddy current distribution, the magnetic field pulse at different radial positions can then be calculated. Fig. 4 shows the result of the magnetic field pulse computation for 2 radial positions (x = 0 mm and x = 70 mm) and Fig. 5 gives the corresponding measured field, showing that the calculation simulates well the measurements.



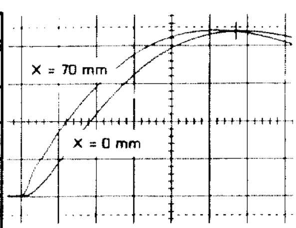


Fig. 4 Fig. 5
(Hor. scale 500 ns/div.)

Kicker Septum Magnets

For the septum magnet circuit, a novel fast pulsed system has been chosen with the same type of pulse generator, transmission line and electronics as used for the kickers. This standardisation reduces considerably design effort and cost. The septum can then be designed as a simple metallic plate acting as eddy current screen and requiring neither cooling nor connection to the excitation circuit. For mechanical reasons we have chosen a 2 mm thick copper plate. With a maximum skin depth of 0.2 mm as generated by the excitation pulse, the plate provides an excellent screening of the magnetic field. The magnet yoke is built from ferrite because of the high frequency content of the fast pulses. As the required kick strength is moderate, the low saturation induction of ferrite is acceptable requiring a magnetic length of 1.7 m. Contrary to the kickers, the ferrite of the septum magnet can be screened against the electromagnetic field of the circulating bunches by an appropriate extension of the septum plate. The septum magnet is therefore housed in a vacuum tank.

A cross-section is shown in Fig. 6. The stored bunches circulate in a metallic tube with a cross-section similar to that of the standard LEP vacuum chamber, to limit the higher order mode losses in the vacuum tank.

To avoid electrical flashover across the ferrite between the excitation bar at high voltage potential and the septum plate at earth potential, a fast stepdown transformer with 9 and 4 turns is inserted between generator and magnet [1]. The transformer allows furthermore to earth the center of the excitation bar, such that one end of it has positive the other negative potential. This reduces the voltage across the ferrite to a save value. In addition the central earthing point provides a symmetry that cancels any electrostatic stray field as seen by the circulating bunches and likely to occur in a fast pulsed system. The resulting measured longitudinally integrated leakage field is < 0.1**%**. This value contains however still a considerable portion of pick-up due to the large signal to noise ratio during the measurement.

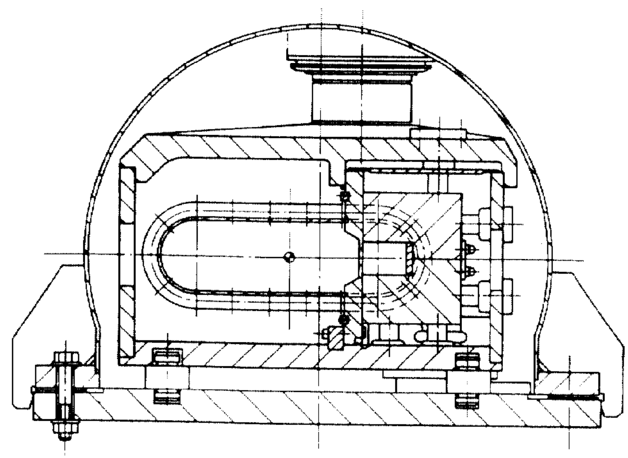


Fig. 6. Cross-section of the septum kicker magnet

Controls

Each group of 4 kicker magnet systems is connected to the LEP controls network (MIL 1553) via a control processor which transfers and coordinates messages from µP-based sub-controller for charging, timing and interlocks. Control processor and sub-controller are built in standard G 64 and communicate via RS 232 links.

- The charging sub-controller performs all functions for power supply control, voltage setting and acquisition of ouput voltages.
- The timing controller contains sets of precise digital delay units and gated 200 MHz clocks with an accuracy and resolution of 3 ns. These timing units trigger power MOSFET pulsers which supply 1000 V pulses for the triggering of the thyratrons.
- The interlock controller contains fault detectors surveying the correct functioning of the kicker systems. Detailed fault reporting is provided by a data logger.

Conclusion

Several of the kicker and septum magnet systems, including their generators and resonant charging supplies, have been assembled and extensively tested under high voltage. The septum magnets and ceramic vacuum chambers have undergone repeated bakeout cycles at 170 °C and 200 °C respectively. All systems operate reliable according to the expected performances.

Acknowledgments

The project described is the result of a common effort of the SPS Fast Pulsed Magnets Section. Major contributions were made by J.L. Bretin, R. Chappuis, Ch. Niqueletto, R. Tröhler and H. Verhagen.

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