INJECTION AND EXTRACTION MAGNETS OF COSY–JÜLICH

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The injection of the proton beam into the COSY ring will be achieved by the stripping injection of an H_2^+ beam. The beam is injected by a septum magnet and will be shifted across the target by means of 3 bumper magnets. The bumper magnets with their associated power supplies, that produce a 2..10 ms bump, are described. The beam will be extracted by an electrostatic septum followed by 2 magnetic septa. Because of the high field of about 1 T in the magnetic septa a high current density of more than 80 A/mm² is needed. The designs of the septa are given.

Bumper–Magnets

Three window frame bumper magnets produce a 10 mrad kick that shifts the beam across the stripping target. One long bumper (type A) is located in the target straight section. It has a big gap height due to the cross section of the vacuum chamber in this section. The maximum field of this magnet is only 29 mT to yield moderate electrical supply conditions. So a magnetic length of about 0.7 m is necessary to generate the required kick. Two short bumpers with medium gap heights, a maximum field of 58 mT, and therefore smaller magnetic length (type B) are located in the injection/extraction arc section of the COSY ring. The main data of these magnets are given in table 1.

dimens.	Apert.height	Apert.width	length
Magnet A	180 mm	229 mm	644 mm
Magnet B	100 mm	220 mm	400 mm

Mag.data	Field	Error	Slope	Eq.length
Magnet A	29 mT	<2.5%	14.5T/s	700 mm
Magnet B	58 mT	<2.5%	29.5T/s	350 mm

El. data	Max cur	RMS cur	resist.	induct
Magnet A	209 A	29 A	25 mΩ DC	0.5 mH
Magnet B	232 A	33 A	18 mΩ DC	0.5 mH

Table 1 Bumper Magnet Data

Rep rate	Rise time	Flat top	Fall time
1 sec	10 msec	10 msec	2..10 msec

Table 2 Current Waveform Data

The laminated iron cores of the magnets are made of transformer sheets (Si–Fe, 0.35 mm). Thus the current waveform requirements given in table 2 can be met with negligible eddy current effects in the iron core. The kick during injection is generated while ramping down the magnets linearly over a time duration variable between 2 msec and 10 msec.

The high operating current limits the number of turns from 20 to 40 turns per magnet. The small maximum duty cycle of 1/30 ... 1/50, that may occur in the synchrotron mode, leads to moderate rms–currents of about 30 A for both types of magnets, thus allowing the use of a glass–tape–epoxy insulated rectangular copper conductor 8.6·4 mm² without a cooling channel. The result is that a simple coil design, with a double layer for the short bumper and a single layer for the long bumper, has been proposed. The 2 mm mass insulation consists of glass fibre reinforced epoxy resin (figure 1).

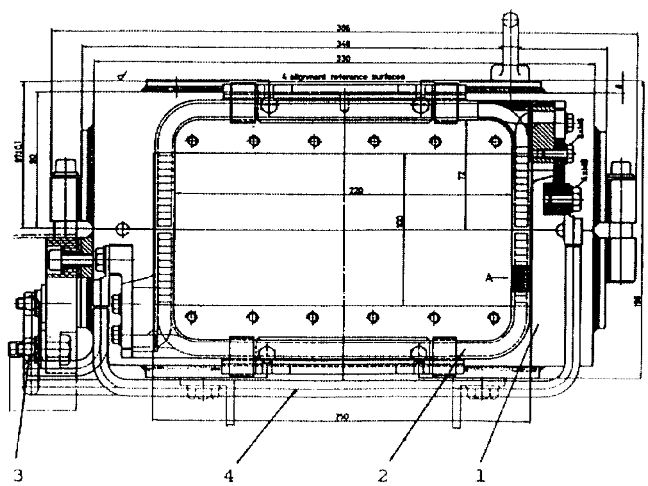

Fig. 1 Bumper magnet

1 iron core 2 winding 3 current terminals

4 winding to winding connection

An essential feature is the split design of the magnets for easy removal during bake out of the vacuum chamber. The core consists of two u–shaped halfs being fixed together via 2 two centre pins using 4 screws. Four reference surfaces allow an easy aligning of the magnet in the ring. The winding is also split into 2 half windings, each being attached to its respective half core. The winding–to–winding connection consists of single insulated cables with ring terminals being screwed to the flat contact terminals of the half windings (figure 1).

Bumper Power Supplies

We show in table 1 that both magnet types have similar electrical data. So 3 identical power supplies can be used for the bumpers. Two criteria govern the design of these converters:

- exploit the small duty cycle by using a storage capacitor as voltage source in order to reduce the input power.

- generate the required current ramp with bipolar Darlington power transistor, operated in the linear mode as a variable current source.

Figure 2 shows the principle scheme of the power supply. It consists of a charging unit (70V, 5A), of an electrolytic capacitor with C = 0.15 F as an intermediate dc link, and of a series transistor arrangement for current regulation. The power unit needs about 2 sec to charge the capacitor up to the 70 V maximum, which then acts as the energy source for creating the current pulse at the load (R_L = 25 mOhm, L = 0.5 mh).

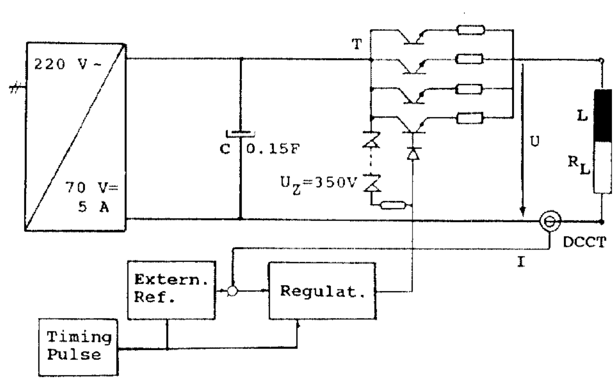

Fig. 2 Bumper power converter - schematic

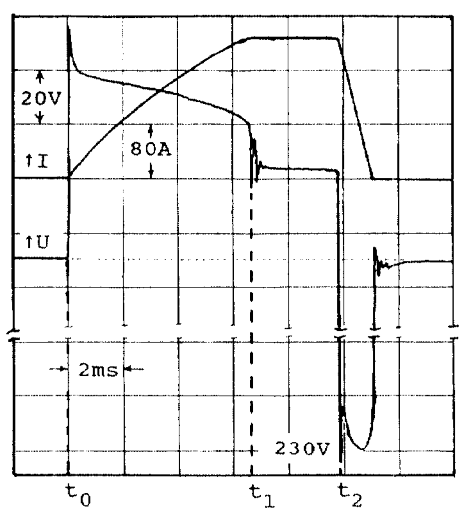

Fig. 3 Bumper test pulse

Figure 3 shows a typical load pulse generated with the protype power supply at a dummy load. The pulse can be divided into 3 different phases starting at t_0. First the load inductance, L, is charged up to a maximum current, I, of 230 A by an aperiodically–damped discharge of C, which is initiated by turning on the transistor. The capacitor provides the energy for the ohmic losses and for the magnetic field. Thus the voltage U across the load drops to 50V. Between t_1 and t_2 the transistor T acts as a current source, keeping current I and voltage U constant. The ohmic losses are covered by the capacitor energy. At t_2 the linear ramp down is started for generating the 2 .. 10 msec bump. The transistor, T, operated in the current source mode, acts as a variable resistor of more than 1 Ohm thus producing a negative voltage jump at the load of more than 200 V. During the fall time $t_3 - t_2$ the 'transistor resistance' even has to be enlarged for compensating the decreasing voltage drop at the load resistance R_L. Nearly all the energy in the circuit – the remaining energy in C and the energy of the bumper magnet L – has to be dissipated in the transistor T. The ohmic losses between t_1 and t_2 amount to 90 J, assuming a resistance of 0.1 Ohm for the cable connection between the power converter and the magnet. This results in maximum of 280 J (of the 370 J capacitively stored energy) to be dissipated in the transistor during the fall time. With a repetition rate of 1..2 sec, 150..300 W have to be continuously withdrawn. These values show that the proper choice of the transistor T is very important. In this case, 4 Darlington power transistors, operating in parallel were chosen, each transistor being capable of 800V, 300A (see figure 2). The actual current value for the current control is measured by means of a DCCT, making use of a hall element. More than 100.000 test cycles have been performed without failure at even harder conditions i.e. shorter charging times and a fall time of 1 msec (see figure 3).

Septum Magnets

The magnets of the extraction septum for COSY are similar to those used for e.g. in the CERN LEAR–ring. It consists of one electrostatic septum followed by two magnetic septa after half a unit cell.

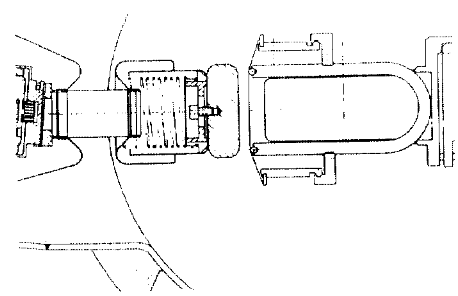

Fig. 4 Electrostatic septum – cross section

The electrostatic septum (figure 4) is a C–shaped grounded anode with a 0.1 mm molybdenum septum foil and a solid titanium cathode with a maximum voltage of 200 kV. An electrostatic field of 120 kV/cm is sufficient to extract the protons with an energy of up to 3.3 GeV/c. To yield optimum position, anode and cathode are moveable in radial and in angle position with respect to the circulating beam. The whole assembly is in situ bakeable up to 300 °C to meet the specified vacuum conditions. The parameters of the electrostatic spetum are given in table 3.

For final extraction into the experimental beam lines two identical septum magnets with 5° deflecting angle each are used to be able to build straight cores and coils. According to the extraction scheme only 13 mm space are available for the septum width including tolerances and mounting width resulting in a current density of 88 A/mm². Figure 5 shows the cross section of the septum magnet together with the vacuum chamber at the entrance of the first magnet. Each turn of the coil is split into two cooling circuits for efficient cooling, the septum loop and the return loop. Three independent systems: thermal clicks, differential pressure drop, and the voltage drop across the winding are used to supervise the conductor in order to prevent melting of the coil.

The magnets can be removed from their working position at the vacuum chamber by a special supporting system to enable the necessary bake out of the chamber. Table 4 gives the main magnet parameters.

max. particle momentum	3.3	GeV/c
deflection angle	3.5	mrad
effective length	1000	mm
max. voltage app.	120	KV/cm
gapwidth	15	mm
radial displacement of anode	±20	mm
radial displacement of cathode	±20	mm
angle resp. to closec orbit	±2	mrad
anode material	molybdän	
anode thicknes	0.1	mm
anode height	60	mm
cathode material	titanium	
cathode thicknes	30	mm
cathode height	90	mm
vacuum pressure	< 10^{-10}	mbar

Table 3 Parameters of the electrostatic septum magnet for COSY

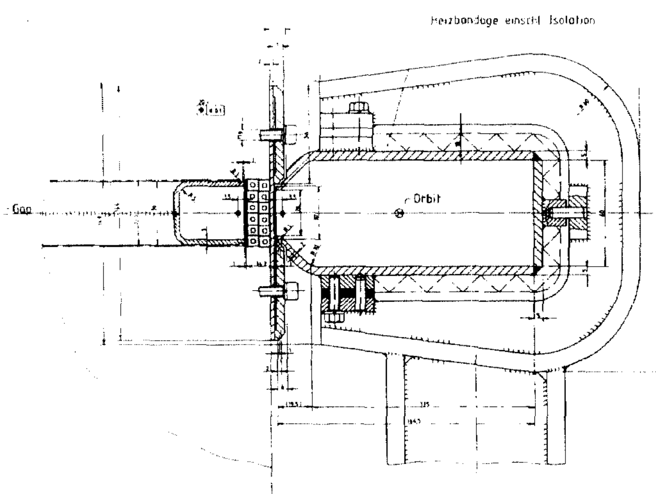

Fig. 5 Septum magnet and vaccum chamber – cross section

Mechanical	Overall length	1000	mm
	Overall height	400	mm
	Overall width	640	mm
	Iron core length	935	mm
	Iron core hight	400	mm
	Gap hight	37.5	mm
	Gap width	125	mm
	Approximate weight	1150	kg
Electrical	Magnetic field	1.1	T
	Magnetic length	952	mm
	Number of turns	12	
	Coil current	2740	A
	Coil resistance	13.2	mΩ
	Operating voltage	36	V
	Power dissipation	99	kV
Cooling	Water flow rate	51	l/m
	Differential water pressure	13	bar
	Water temperature difference	27	°
	Copper temperature difference	39	°
	for septum conductors:		
	- Water velocity	11	m/s
	- Burn out time	1.2	s

Table 4 Parameters of the magnetic septum magnet for COSY