Magnets and Power Supplies for COSY

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Abstract

Corresponding to the ionoptical parameters of the Jülich Cooler Synchrotron COSY dipoles, quadrupoles and their power supplies have been designed and are under construction. The magnets cover an energy range from 40 MeV up to 2.5 GeV with a ramp rate of 1 T/s. The storage ring operation mode for beam cooling, experiments and slow extraction covers the full energy range. Special care was taken in the design of the dipole endfield shape and shimming to achieve the necessary identity of all 24 dipole magnets. The quadrupoles are figure of eight-type magnets with identical cross section and two different lengths. The status of the project is described in /1/; basic parameters are given in /2/.

Dipole magnet design

The magnet design was done with the Poisson group program /3/. Due to easy access to the vacuum chamber and additional pumping /4/ a c-type pole shape design was chosen. Shims are foreseen to reduce the pole width and to achieve the desired field homogeneity at $B/B = 2\cdot 10^{-4}$ within 60x200 mm at injection and and 24x180 mm at maximum energy. The magnets are grouped at the ring alternating, two with joke inside and two with joke outside the ring to compensate for tolerances to use the dipole magnets for experiments and to allow an easier injection-extraction scheme. To build all magnets identical and cheap the dipoles are rectangular straight box-magnets with flat pancake-coils.

With a maximum vertical beam size of 60 mm the gap height was chosen 90 mm due to the installation of heating and insulation for insitu bakeout of the vacuum chamber.

Fig. 1 shows the cross-section of a dipole magnet. Table 1 gives the basic data.

With a field ramp of 1 T/s a carbon free pure iron material of 1.5 mm thickness is used for the lamination. This material provides low coercive force and a large permeability over the full range of magnetisation.

The laminations are shuffled to equalize remanent field effects. The stack of laminations of a total joke is welded with strengthening plates and glued stacks of endfield blocks. These blocks are equipped with removable pole pieces to allow for shimming of the mechanical length of the magnets to achieve an identity of better than 2×10^{-4} of all dipoles. The excitation coils are simple rectangular pancakes from solid copper conductor 33x33 mm^2 with a 12 mm bore for one cooling circuit per coil. Each magnet is equipped with backleg windings for tolerance and orbit correction.

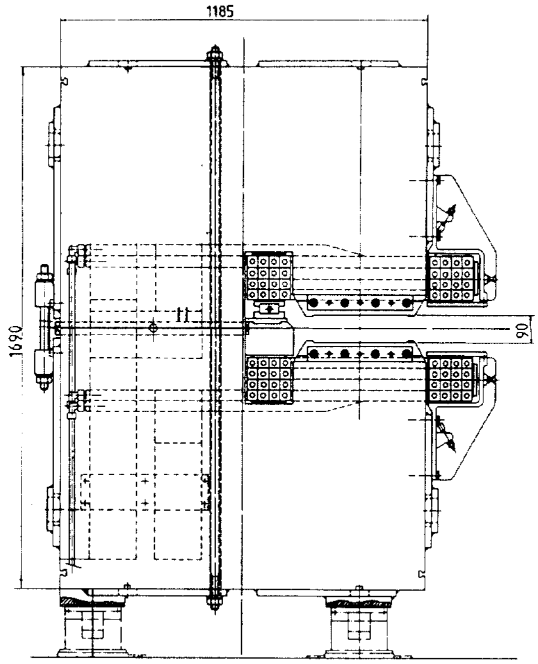


Fig. 1: Front view of a dipole

Table 1: Dipole parameters

Gap height	90 mm
Bending radius	7 m
Deflecting angle	15 °
Effective length	1833 mm
Flux	0.13 .. 1.58 T
Number of coils	2
Turns per pole	16
Max. current	5000 A
Current density	5.1 A/cm2
DC voltage	15.3 V
Peak voltage	52 V
Total weight	28 t

Quadrupole magnets

Two different quadrupole types are used in COSY. A 300 mm long one in the ring sections and a 570 mm type for the telescopes in the straight section. For ease in design and construction both quadrupoles are identical in the cross-section (fig. 2). The main parameters are listed in table 2.

A figure of eight type magnet was chosen due to limited space at injection and extraction. Shims will be used to obtain the large horizontal aperture region of +/- 100 mm for the long type and +/- 70 mm for the short type respectively.

The yokes are separated in the midplane and consist of a glued stack of lamination with welded strenghtening plates. The pole-ends are chamfered to meet the ionoptical specifications.

The coils are produced from solid copper conductor 8x15 mm^2 with a 4.5 mm hole for two cooling circuits per coil. There is a distance of 35 mm between the coils to enable the installation of diagnostic equipment.

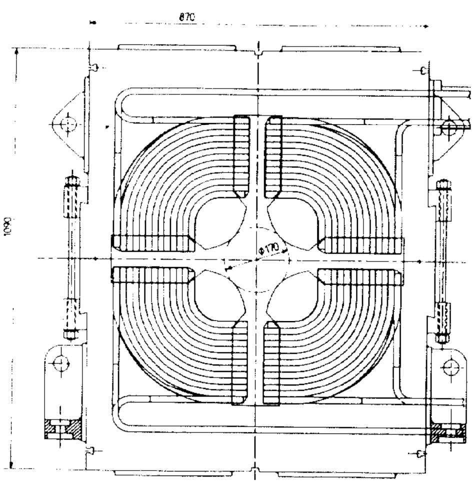


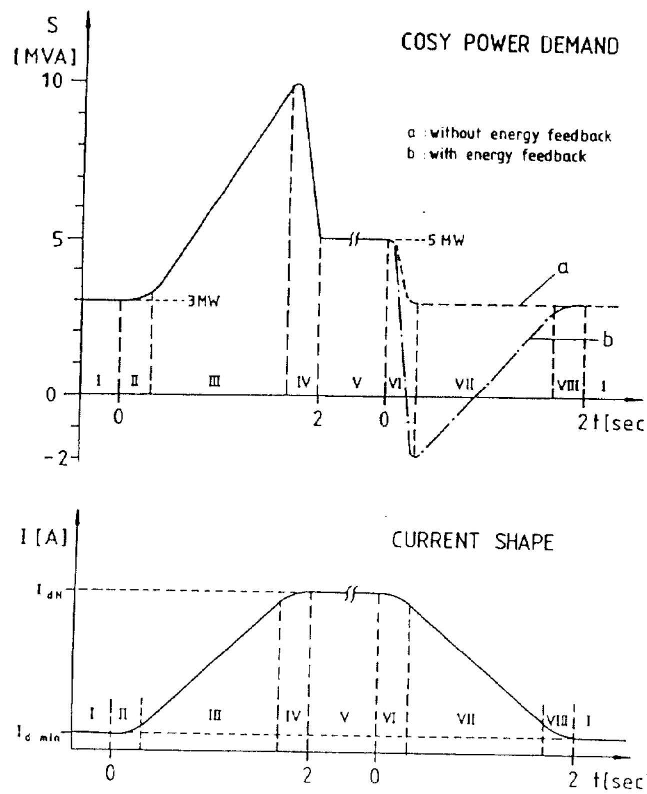
Fig. 2: Front view of a quadrupole

Table 2: Quadrupole parameters

	MQT		MQU
Number	32		24
Gradient	7.65 T		7.5 T
Aperture radius		85 mm	
Iron length	570 mm		300 mm
Iron height		1090 mm	
Iron width		860 mm	
Turns per pole		48	
Max. current		520 A	
DC voltage	37 V		27.4 V
DC power	19.3 kW		14.3 kW
Peak voltage	61.4 V		38.3 V
Peak power	30.7 kVA		19.5 kVA

Magnet power supply demands

All dipole magnets are connected in series. Thus they will be fed by one power supply which provides an output voltage of about 1300 V to produce a field slope of 1.6 T within 1.6 s during particle acceleration (fig. 3 phases II, III, IV. During particle injection and e-cooling (phase I, fig. 3) only a small dc current of 235 A is fed in corresponding to an output voltage of about 20 V and an output power of less than 1 % of the rated power. During the storage and extraction mode (phase V, fig. 3) very stable dc currents between 900 A and 5000 A have to be delivered at output voltages between 80 V and 450 V. The respective output power even at maximum dc current is 30 % of the rated power only, see table 3.



Operating modes

I : Injection, Cooling — II - IV : Acceleration

V : Storage mode — VI - VII : Ramp down

Fig. 3: Power demand and current shape

The stability and ripple requirements of the dc currents during flat top and flat bottom are in the range of 10^{-4} related to the respective actual value (fig. 4). These requirements become very severe with respect to the low output power and output voltages. The local utility prescribes a 12-pulse-system for power converters in the MVA-range. This is achieved by the parallel or series connection of two 6-pulse-bridge rectifier systems which are phase shifted against each other by 30 electrical degrees. Such power converters combined with low pass filters can meet the required tolerance range in principle taking into account the integrating behaviour of the magnetic load.

An additional tolerance margin of the output current in the range of 10^{-4} .. 10^{-3} (fig. 4) is required during the current rise in the accelerating phase with respect to the current shape of the quadrupole. If the dipole current or one of the quadrupole currents exceeds this tolerance range the beam will be lost at least partially. Consequently the dipole current shape is chosen as a master and half of the tolerance margin is given to the dipole magnet power supply.

Table 3: Supply data

MD: Dipole mag. MQU: Quadrupole mag. unit cells
MQT: Quadrupole mag. target cells

System	Output	Injection	Accel.	Storage
MD	Voltage	18 V	1400 V	350 V
	Power	4200 W	7000 kVA	1650 kW
MQU 1	Voltage	15 V	465 V	285 V
	Power	380 W	233 kVA	143 kW
MQU 2	Voltage	10 V	310 V	190 V
	Power	250 W	155 kVA	95 kW
MQU 3	Voltage	5 V	155 V	95 V
	Power	130 W	78 kVA	48 kW
MQT 1/8	Voltage	7 V	250 V	135 V
	Power	170 W	124 kVA	68 kW

The tolerance margin in the accelerating phase governs the requirements for the set value transfer to the power supply and for the control loop of the power supply. Normal power supplies with proportional integrating control loops produce actual current values being time delayed against the set value. This time delay is also known as following error which can be accepted if it is stable and well known before starting the accelerating ramp. In this case the following error can be compensated by a pretrigger of the starting time. Unfortunately following errors are not stable but have a jitter which may be a function of the load and of the starting conditions. The situation becomes even more complex if the shape of the ramp with different slopes and flat tops is considered.

To overcome this following error problem power supplies with fast semiconductor power elements combined with a fast proportional control loop are suggested and in use. Both solutions are investigated for the dipole power supply.

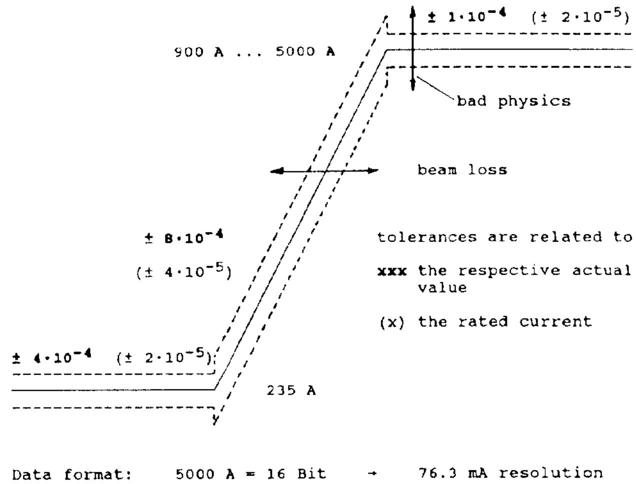


Fig. 4: Tolerances of the Dipole Magnet Currents

Concerning the set value a fast transfer with 16 Bit resolution is planned. This affords a large amount of computing power in the control interface to the power supply.

The quadrupole magnets are split into

- 8 identical families for the target cells, each family consisting of 4 magnets connected in series,
- 3 different families for the unit cells, the single families consisting of 4, of 8 and of 12 magnets connected in series.

Each of the 11 quadrupole families is fed by one power supply delivering a rated dc current of 520 A. The output voltages of the single power supplies rank from 155 V to 465 due to the respective number of quadrupole magnets to be fed (see table 3). The tolerance margins for the accelerating ramp are equal to those of the dipole current. But the tolerance requirements are strongly reduced during the injection and the storage mode compared with those of the dipole currents.

References

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