CHAPTER 24

TRANSFER LINE MAGNETS

24.1 INTRODUCTION

With an overall line length of 5.6 km and an overall deflection of 152° the magnet system of the LHC injection transfer lines TI 2 and TI 8 comprises almost 700 magnets, corresponding to almost the equivalent magnetic length of the SPS. Economy considerations led to the decision to use classical warm main dipoles and quadrupoles of compact design. The main dipoles, quadrupoles and the new correction magnets are supplied in the framework of the contribution of the Russian Federation to the LHC. Apart from three special dipoles all remaining magnets required for the new lines have been recuperated from closed down installations. These came mainly from the SPS-LEP transfer lines TI 18 and TI 12, together with the anticlockwise injection tunnel into the SPS from the PS, TT70. The main parameters of the magnets and the required quantities are described in this chapter.

24.2 MAIN DIPOLES, MBI

Since no set of dipole magnets existed to allow the required 152° total deflection in the available space, new main bending magnets had to be designed and constructed. Initial plans to use superconducting dipoles and quadrupoles were abandoned after analysis of the overall cost. On one hand a lot of cryogenic support equipment would have been needed for the two transfer lines and on the other hand, TI 2 and TI 8 will only be powered for relatively short periods during injection [1] and therefore keeping the electricity consumption rather low. The penalty of using classical magnets is that the limited strength has lead to substantially longer transfer tunnels. The final choice was therefore a solution using classical magnets having a length of 6.3 m and a field of 1.81 T [2]. Their cross section is given in Fig. 24.1.

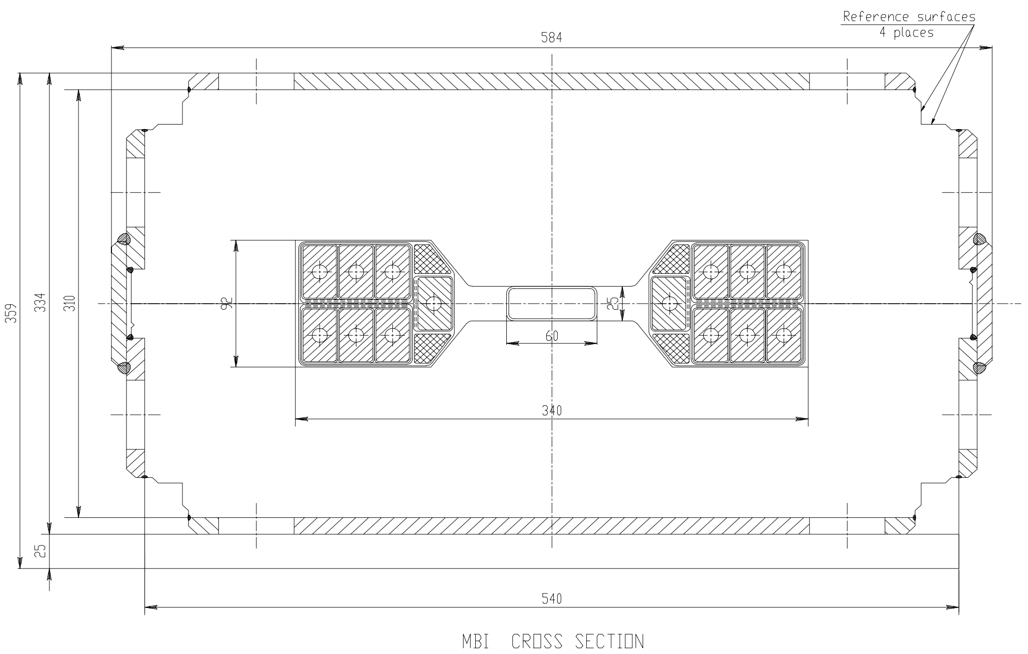

Figure 24.1: MBI cross section

Since the main dipoles in the transfer lines account for the bulk of the required electrical power, a careful optimisation of the parameters was required to minimise the power consumption and arrive at an economic solution. The main parameters of these magnets are summarised in Tab. 24.1.

Table 24.1: MBI main parameters

	Value	Units
General		
Gap Height	25	mm
Nominal Field	1.81	T
Dimensions		
Overall Length	6.7	m
Core Length	6.3	m
Overall Width	584	mm
Overall Height	367	mm
Coil		
Resistance (at 20°C)	1.935	mΩ
Inductance	2	mH
Excitation		
Nominal Current	5340	A
Rms. Current	2314	A
Dissipated Power	11	kW
Cooling per Half Coil		
Pressure Drop	2	Bar
Water Flow	7	l/min
Temperature Rise	11	°C
Weight		
Coils (copper)	735	kg
Core	7900	kg

The coil parameters were chosen so as to allow to re-use the (relatively high-current) main LEP power supplies. All 112 main dipoles in TI 2 will be powered as a series from one power converter unit. The 236 magnets of TI 8 will use two power supplies [3]. To limit costs the upper and lower half coils feature a half-integer number of windings. All upper half coils are directly connected in series constituting the go conductor. The return conductor is formed from the lower half coils which are also connected in series. This design avoids the need for a separate return line, or bus bar system, along the dipoles.

To limit costs further, a gap height of just 25 mm was chosen. This forms the strongest aperture constraint in both lines. With the vacuum chambers installed the resulting physical full vertical aperture for the beam is 20.4 mm [4]. A rather elaborate correction scheme is therefore needed to keep the beam within this aperture.

The MBI magnets have been constructed at the Budker Institute of Nuclear Physics (BINP) in Novosibirsk in the framework of the Cooperation Agreement between CERN and the Russian Federation concerning Russia's participation in the LHC project. All 360 MBI magnets, including 12 spare magnets and 13 spare coils, have been delivered to CERN and are ready for installation.

24.3 MAIN QUADRUPOLES, MQI

As for the MBI magnets a classical solution was chosen for the 178 lattice and matching quadrupoles needed to equip TI 2 and TI 8. With a core length of 1.4 m these magnets have a nominal gradient of 53.6 T/m [5] at a nominal current of 530 A. Their inscribed diameter is 32 mm. A cross section can be found in Fig. 24.2. Their main parameters are summarised in Tab. 24.2.

All focusing and defocusing lattice quadrupoles of TI 2 will be powered in series by three power supplies recuperated from LEP. Two supplies are employed in TI 8 since MQIF and MQID magnets will use different settings for optics reasons. Matching elements will use a number of individual power supplies which have also been recuperated from LEP [3].

Like the MBI, the MQI quadrupoles are being constructed by BINP. All 184 MQI magnets, including 6 spare magnets and 12 spare coils, have been delivered to CERN and are ready for installation.

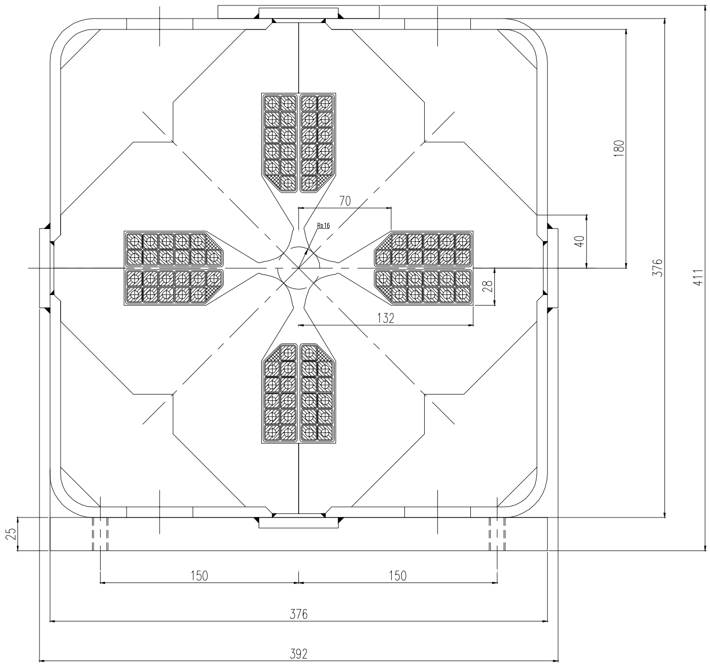

Figure 24.2: MQI cross section

Table 24.2: MQI main parameters

	Value	Units
General		
Radius of inscribed circle	16	mm
Nominal Gradient	53.6	T/m
Dimensions		
Core Length	1.4	m
Overall Width	392	mm
Overall Height	411	mm
Coil		
Resistance (at 20oC)	36	mΩ
Inductance	13	mH
Excitation		
Nominal Current	530	A
Weight		
Total Weight	1070	kg

24.4 OTHER MAGNETS

Almost all other dipoles have been recuperated from installations which were no longer used after LEP operation had come to an end. These came mainly from the electron injection line into SPS, TT70, and the electron and positron injection lines into LEP, TI12 and TI18. In total the recovery, refurbishment and re-use of 56 B340 magnets, 11 B280 and 2 MBB magnets was necessary. The cross section of the B340 magnets is shown in Fig. 24.2 and their main parameters in Tab. 24.3. The corresponding cross section and parameters for the B280 magnets are given in Fig 24.4 and Tab. 24.4 respectively. The MBB magnets are one of the two SPS main magnet types. Their characteristics can be found in [7].

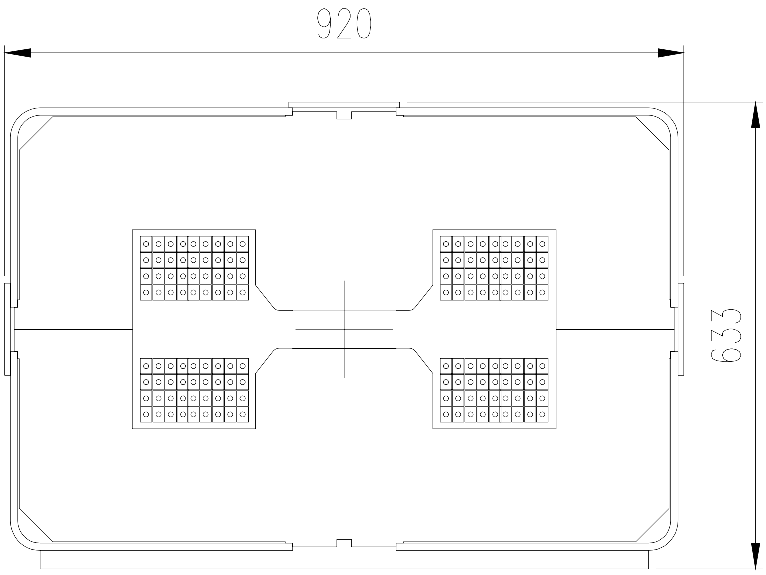

Figure 24.3: B340 cross section.

Table 24.3: B340 main parameters

	Value	Units
General		
Gap Height	52	mm
Nominal Field	1.6	T
Dimensions		
Core Length	3.412	m
Overall Width	920	mm
Overall Height	633	mm
Coil		
Resistance (at 20^{o}C)	37.6	mΩ
Inductance	120	mH
Excitation		
Nominal Current	1000	A
Rms. Current	433	A
Dissipated Power	7	kW
Cooling per Half Coil		
Pressure Drop	6	Bar
Water Flow	36	l/min
Temperature Rise	15	^{o}C
Weight		
Coils (copper)	1360	kg
Core	11900	kg

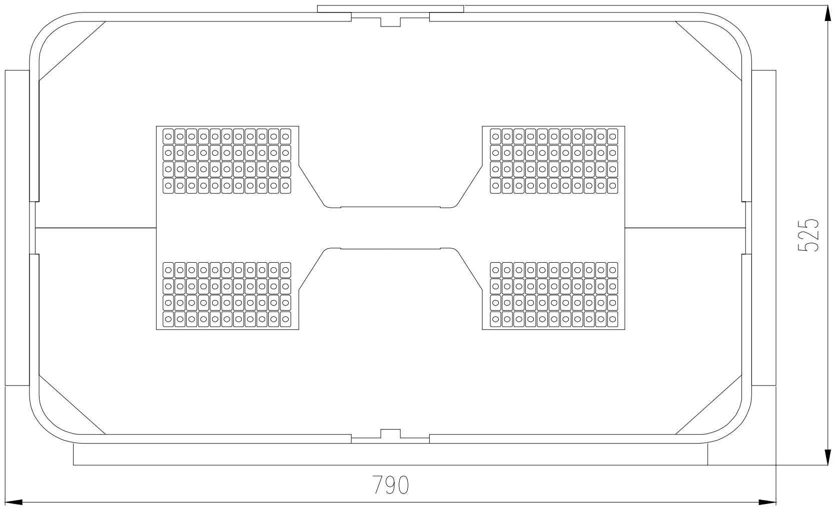

Figure 24.4: B280 cross section

Table 24.4: B280 main parameters

	Value	Units
General		
Gap Height	48	mm
Nominal Field	1.7	T
Dimensions		
Core Length	2.8	m
Overall Width	790	mm
Overall Height	525	mm
Coil		
Resistance (at 20^{o}C)	66.3	mΩ
Inductance	103	mH
Excitation		
Nominal Current	822	A
Rms. Current	356	A
Dissipated Power	8.5	kW
Cooling per Half Coil		
Pressure Drop	6	Bar
Water Flow	25.6	l/min
Temperature Rise	30	^{o}C
Weight		
Coils (copper)	805	kg
Core	6000	kg

In addition to the recuperated dipoles mentioned above three special C-type dipoles (denominated MBHC) have been built. These were needed in the extraction channel towards TI 8 near LSS4 (at this point the line is called TT 40). The cross section of these magnets is given in Fig. 24.5 and their main parameters in Tab. 24.5.

Two QTR and one QTL type quadrupoles have been re-used in the TT 40 part of TI 8 due to the larger aperture requirements of the CERN Neutrino to Gran Sasso (CNGS) line TT41. Details of these can also be found in [7].

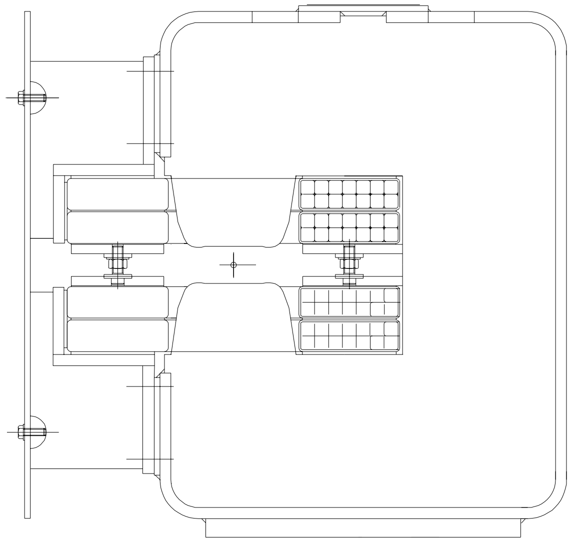

Figure 24.5: MBHC cross section

Table 24.5: MBHC main parameters

	Value	Units
General		
Gap Height	50	mm
Nominal Field	1.52	T
Dimensions		
Overall Length	5.4	m
Core Length	5.0	M
Overall Width	585	mm
Overall Height	586	mm
Coil		
Resistance (at 20^{o}C)	61	mΩ
Inductance	67	mH
Excitation		
Nominal Current	900	A
Rms. Current	600	A
Dissipated Power	23.5	kW
Cooling per Half Coil		
Pressure Drop	6	Bar
Water Flow	20	l/min
Temperature Rise	15	^{o}C
Weight		
Total weight	9000	kg

24.5 CORRECTOR MAGNETS

An in-depth study was carried out [4] to establish the necessary number and placement of corrector dipole magnets in order to keep the deviation of the beam trajectory within the available aperture. Apart from the correctors which were already installed in the TT60 beam line and a few cases where ordinary bending magnets could also be used for trajectory correction, the rest were provided by a new series of MCIA corrector magnets. A total of 91 MCIA correctors are needed to equip the two transfer lines and have once again been constructed at BNIP. In order to minimise the costs and spares the design of the horizontal and vertical correctors was chosen to be identical [6]: the positioning of the magnet on the supports defines the type of deflection. The Cross-section of an MCIA (in the orientation as a horizontal corrector, MCIAH) is shown in Fig. 24.6. The main parameters of the MCIA are given in Tab. 24.6.

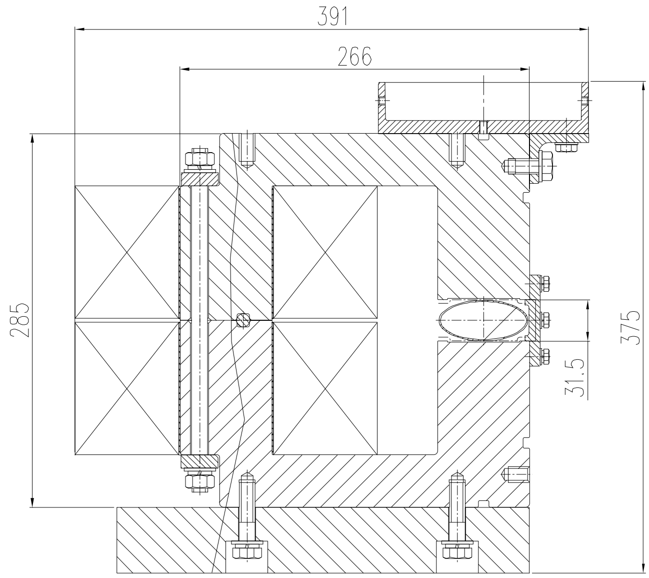

Figure 24.6: MCIAH cross section

Table 24.6: MCIAH main parameters

	Value	Units
General		
Gap Height	32.5	mm
Nominal Field	0.27	T
Dimensions		
Overall Length	0.615	m
Core Length	0.45	M
Overall Width	400	mm
Overall Height	375	mm
Coil		
Resistance (at 20^{o}C)	10	mΩ
Inductance	10.5	mH
Excitation		
Nominal Current	3.5	A
Dissipated Power	0.17	kW
Cooling	Natural Convection	
Weight		
Total weight	300	kg

Two SPS type correctors (MDS) are installed in TT40 and TI 8 where the need for high correction strength coincides with the need for a larger aperture than that provided by the MCIA correctors. It has been verified that higher-order multipole correctors are not needed to operate TI 2 and TI 8 correctly.

24.6 SUMMARY AND CONCLUSION

The total quantities of each type of magnet needed for each of the two LHC transfer lines is given in Tab. 24.7. Spares are not included. The magnet system of the LHC injection transfer lines is of considerable volume. A maximum of magnets and power supplies have been recuperated from then closed-down installations. Newly built magnets feature a cost-optimised design. For the bulk of the new magnets construction has been completed.

Magnet Type	**Required Quantities**		**Sum**
	TI 2	**TT 40 + TI 8**	
MBI	112	236	348
MBB	2		2
B280	6	5	11
B340	33	23	56
BHC		3	3
Sum Dipoles	***153***	***267***	***420***
MCIAH	22	22	44
MCIAV	26	21	47
MDS		2	2
Sum Correctors	***48***	***45***	***93***
MQI	95	83	178
QTR		2	2
QTL		1	1
Sum Quadrupoles	***95***	***86***	***181***
Total	**296**	**398**	**694**

REFERENCES

[1] The LHC Study Group, "*The Large Hadron Collider Conceptual Design*", CERN/AC/95-05 (LHC) (1995).

[2] G. Kouba et al., "*The bending magnets for the LHC injection transfer lines*", Proceedings of the 17th Int. Conf. On Magnet Technology, MT17, Geneva, Switzerland, September 2001.

[3] P. Burla, CERN, private communication.

[4] A. Hilaire, V. Mertens & E. Weisse, "*Trajectory Correction of the LHC Injection Transfer Lines TI 2 and TI 8*", LHC Project Report 122 (1997).

[5] K.M. Schirm et al., "*The quadrupole magnets for the LHC injection transfer lines*", Proceedings of the 16th Int. Conf. On Magnet Technology, MT16, Ponte Vedra Beach, Florida, USA, September 1999.

[6] Definitive Technical Specification for the MCIA resistive correction dipole magnets for the TI 2 and TI 8 beam transfer lines, CERN AT-MEL, April 2003.

[7] SPS Conceptual Design Report, "*The 300 GeV Programme*", CERN/1050, 1972.