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Design Report

PERMANENT MAGNET DIPOLE FOR DIRAC

Abstract

Two dipole magnets including one spare unit are needed for the for the DIRAC experiment. The proposed design is a permanent magnet dipole. The design based on Sm_2Co_{17} blocks assembled together with soft ferromagnetic pole tips. The magnet provides integrated field strength of 24.6 10^{-3} T×m inside the aperture of 60 mm. This Design Report summarizes the main magnetic and mechanic design parameters of the permanent dipole magnets.

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1. INTRODUCTION

Two dipole magnets including one spare unit are needed for the for the DIRAC experiment. The proposed design is a permanent magnet dipole. Sm_2Co_{17} was used as a material for the permanent magnet blocks. This report describes the magnetic design of the permanent dipole magnet.

2. REQUIREMENTS AND CONSTRAINTS

The magnet parameters, such as aperture, integrated magnetic field and required field quality are determined by the beam optics considerations. The full magnet aperture should be 60 mm. The magnet should provide the integrated field strength of 0.02 T×m, defined as an integral of horizontal field component B_x at transverse position X=Y=0, where the magnet centre is taken as z=0 mm. The integrated field homogeneity $\Delta\int B_x dz/\int B_x(0,0,z)dz$ has to be better than ± 2% inside the Good Field Region (GFR) of 20 mm × 30 mm. The overall length of the magnet is restricted and has to be less than 66 mm and the overall magnet width and height should not exceed 130 mm and 170 mm respectively. Table 1 summarizes the magnet requirements. Figure 1 shows the sketch of required magnet.

Table 1: Requirements for the dipole magnet

Parameter	Units	
Overall length	mm	< 66
Overall width × height	mm × mm	170 × 130
Yoke length	mm	< 60
Horizontal full aperture	mm	60
Integrated field strength $\int B_{x(0,0,z)}dz$	T×m	0.02
Good Field Region(GFR) X × Y	mm × mm	20 × 30
Integrated field quality $\Delta\int B_x dz/\int B_{x(0,0,z)}dz$ inside GFR	%	< ± 2

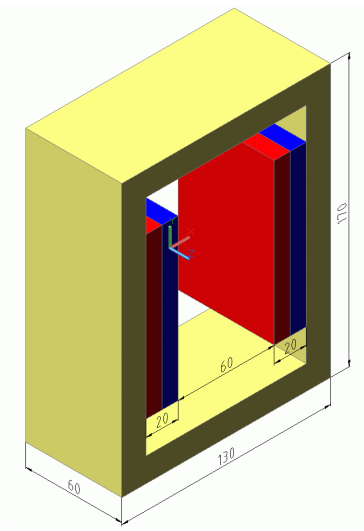


Figure 1: The sketch of the required Permanent magnet dipole for DIRAC.

3. MAGNET DESIGN

The proposed design is a permanent magnet dipole with a mechanical aperture of 60 mm. The overall dimensions of the magnet are 130 mm (width) × 170 mm (height) × 66 mm (length). The total magnet mass is 8.6 kg. The support is not included in the above mentioned dimensions. The main magnet parameters are summarized in the Annex (Table 2). The required integrated field of 0.02 T×m is provided by two permanent magnet assemblies, as flux generators. Each magnet assembly consists of three permanent magnet blocks as shown Figure 2. The Sm_2Co_{17} was chosen as a material for the permanent magnet blocks due to its radiation hardness and weaker temperature dependence. The recommended grade of the permanent magnet blocks in Sm_2Co_{17} is the "RECOMA 30S" from ARNOLD Magnetic Technologies or equivalent. The material properties needs to be consistent with the one listed in the ARNOLD MAGNETIC Technical Documentation, (see Annex).

The field quality inside the magnet aperture is controlled by the soft ferromagnetic poles of suitable size. In addition, the soft ferromagnetic poles will smooth the effects of possible p.m. inequalities.

The return yoke consists of four pieces made of soft ferromagnetic steel. The recommended type of the soft ferromagnetic steel for the poles, return yoke pieces is AISI 1010. The B(H) curve of proposed material is given in the Annex.

The correct assembly of the magnet is guaranteed by two non-magnetic blocks (central inserts) made of stainless steel. The permanent magnet assemblies, soft ferromagnetic poles and return yoke pieces will be mounted on these blocks and fixed by the bolts. Two aluminum plates of 3 mm thickness are fixed on each side of the magnet, preventing the possible movement of the magnet components in axial direction. Figure 3 shows the mechanical layout of the permanent magnet dipole.

The assembling of the magnet is quite delicate procedure due to the magnetic forces and the brittleness of the permanent magnet blocks. A specific assembling device was designed to guide the magnetic elements of the dipole onto their positions (see Figure 4).

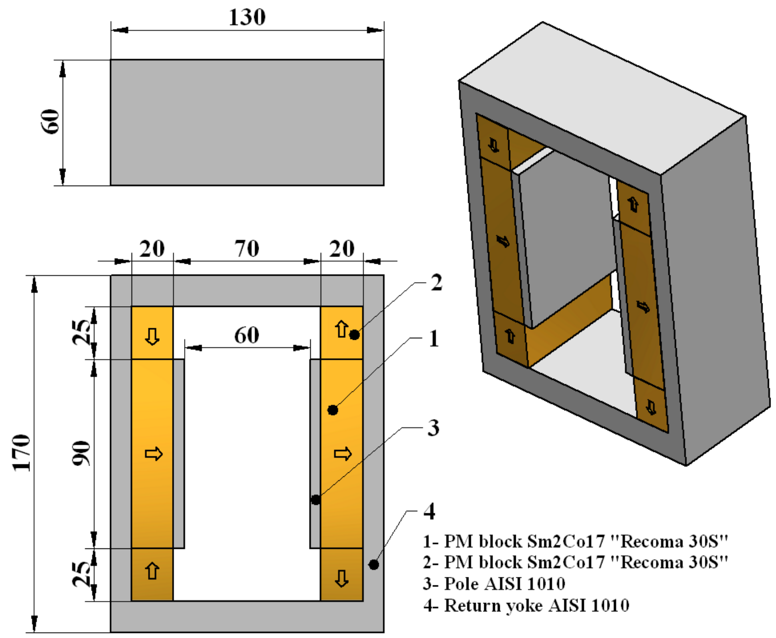


Figure 2: Preliminary layout of the dipole magnet (only magnetic components are shown), arrows indicate the direction of magnetization of the permanent blocks.

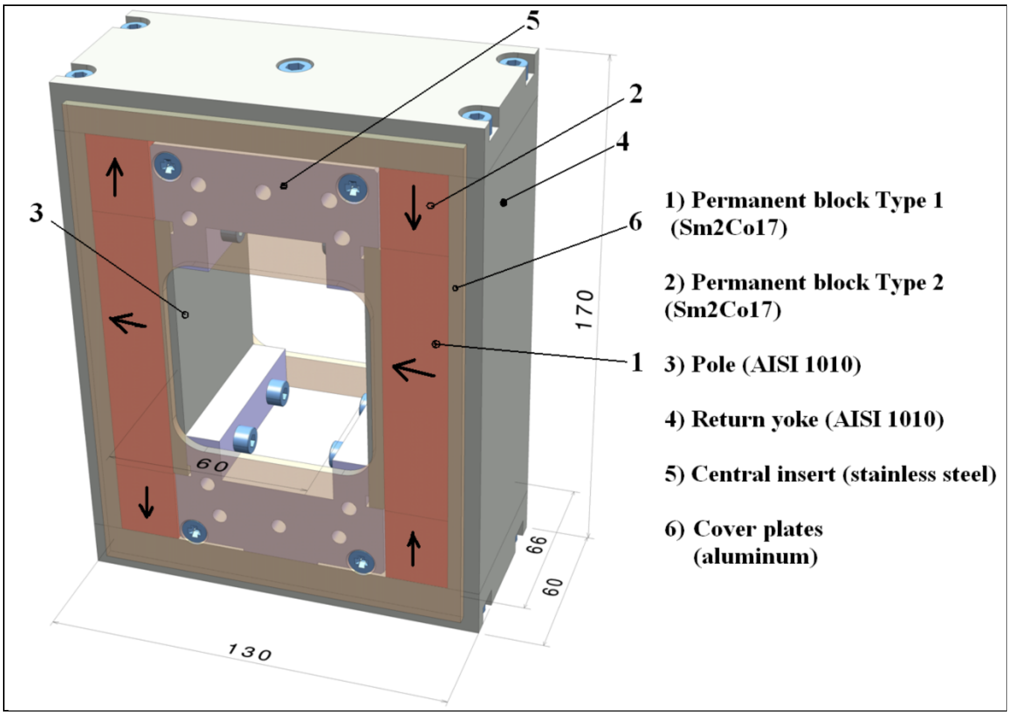


Figure 3: Assembly drawing of the magnet

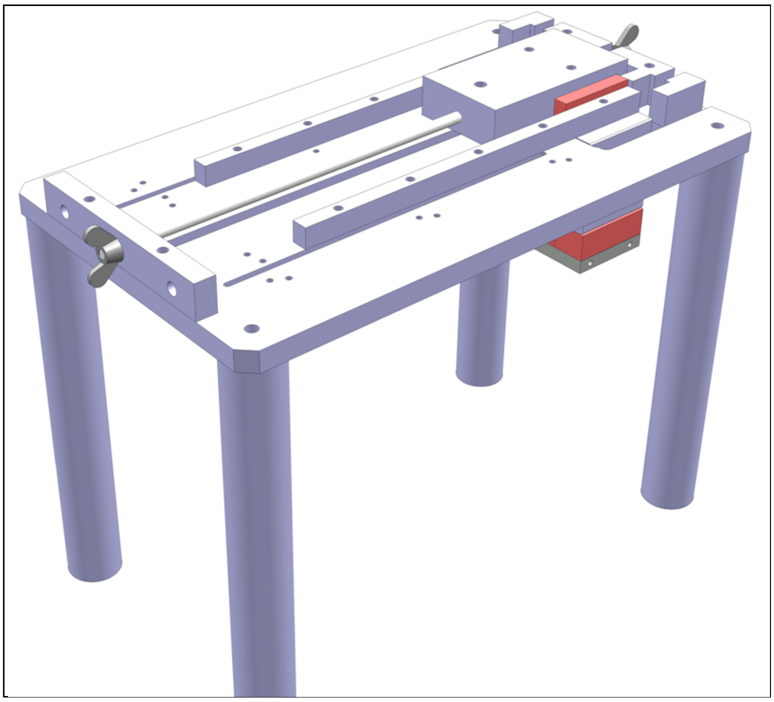


Figure 4: Assembling device.

4. MAGNETIC FIELD CALCULATIONS

Since the magnets are short and have a large aperture, the fringe field in the direction of the beam axis (z-axis) is significant. In this case, the 2D field calculations give only the preliminary results and need to be verified by the 3D modelling. Thus, 3D model of the magnet was constructed and used for analysis of the integrated field characteristics. The B(H) curves of the proposed materials, mentioned above, was used for the simulations.

4.1 3D CALCULATIONS

The calculation was done by Opera-3D/TOSCA program. Due to symmetry only 1/4 of the magnet geometry was modeled. The boundary conditions were chosen in a way that the flux lines were perpendicular to the vertical middle plane and parallel to the symmetry axis and the limiting edge of the model.

The pole width, return yoke cross-section, permanent blocks sizes and position were optimized in order to satisfy the requirements on the integrated field strength and integrated field homogeneity, taking into account the limitations of the magnet overall dimensions.

Figure 5 shows the OPERA-3D model with the field distribution on the magnet surface. For the selected magnet structure the integrated horizontal field of 24.6×10^{-3} T×m was achieved see Figure 6.

The integrated horizontal field error stays below ± 2% inside the GFR defined above as a rectangular region with X= ± 10 mm and Y= ± 15 mm, see Figure 7.

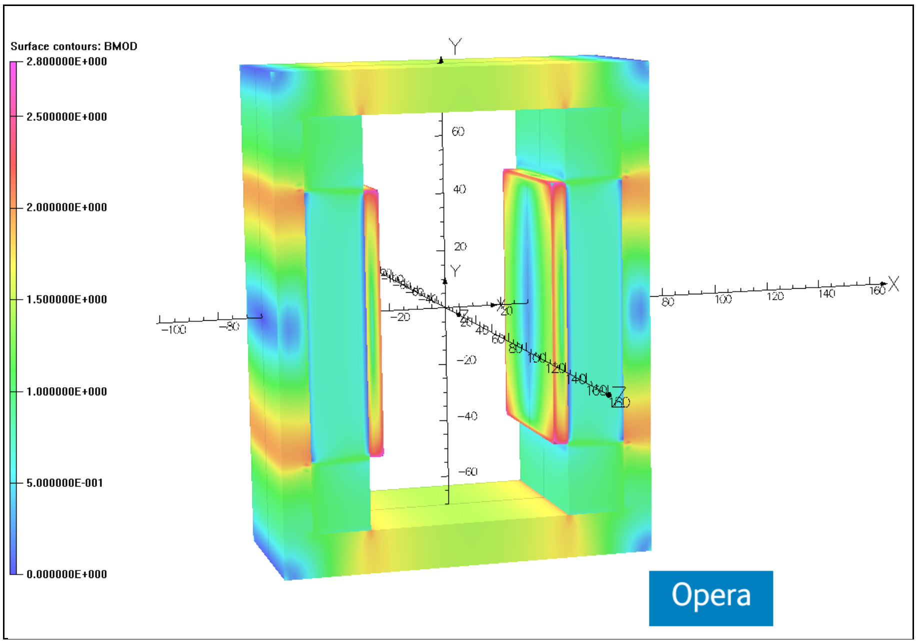


Figure 5: Opera 3D model with surface field distribution.

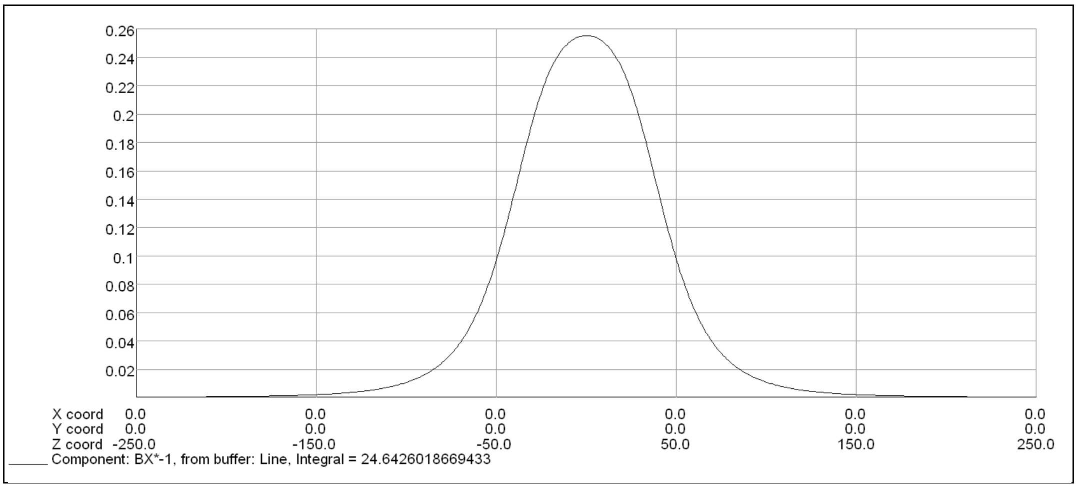


Figure 6: Horizontal field distribution along z-axis

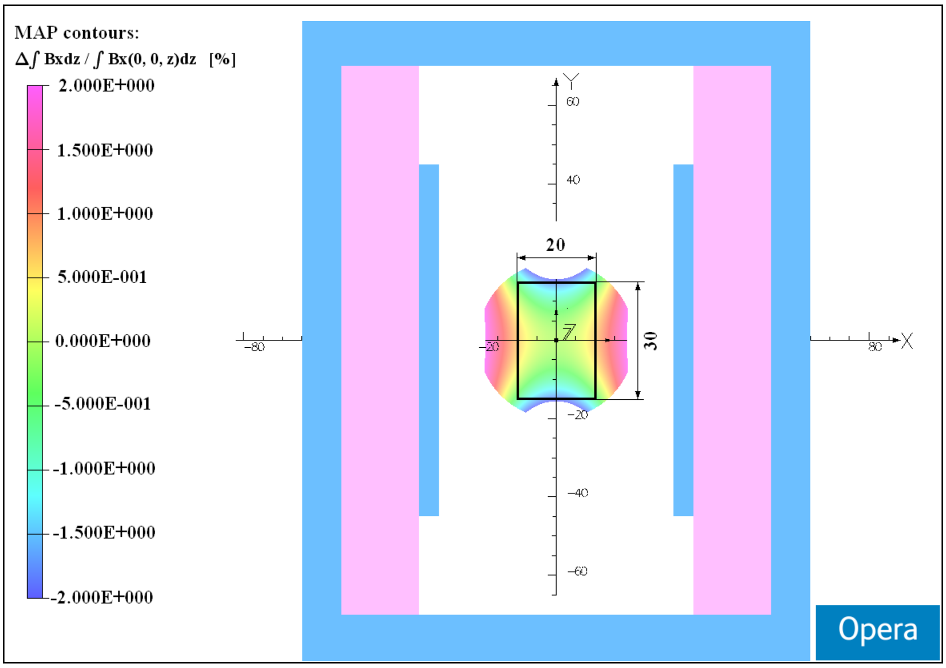


Figure 7: Integrated horizontal field homogeneity [%]

5. ANNEX

5.1 PARAMETER TABLE

Table 2: Main parameters of the PM Dipole for DIRAC (Support structure is not included).

Magnet	
Type	Permanent Magnet Dipole
Quantity	1+1(spare)
Magnet Height × Width × Length	170 mm × 130 mm × 66 mm
Full horizontal aperture	60 mm
Good Field Region(GFR) Horizontal × Vertical	20 mm × 30 mm
Nominal integrated horizontal field $\int B_{x(0,0,Z)}dz$	24.6 10^{-3} T×m
Horizontal field in magnet center $B_{x(0,0,0)}$	0.255 T
Magnetic length $\int B_{x(0,0,Z)}dz$ / $B_{x(0,0,0)}$	96.5 mm
Integrated field homogeneity inside GFR	< ±2%
Components	
Permanent Blocks Type 1	
Material type	Sm2Co17, "Recoma 30S" or equivalent
Height × Width × Length (w.r.t. direction of magnetization)	20 mm × 90 mm × 60 mm
Quantity per magnet	2
Permanent Blocks Type 2	
Material type	Sm2Co17, "Recoma 30S" or equivalent
Height × Width × Length (w.r.t. direction of magnetization)	25 mm × 20 mm × 60 mm
Quantity per magnet	4
Pole tips	
Material type	AISI 1010
Length	60 mm
Height	5 mm
Width	90 mm
Quantity per magnet	2
Return Yoke	
Material type	AISI 1010
Number of pieces	4
Block Type 1	
Quantity per magnet	2
Height × Width × Length	15 mm × 130 mm × 60 mm
Block Type 2	
Quantity per magnet	2
Height × Width × Length	10 mm × 140 mm × 60 mm
Central inserts	
Material type	Stainless steel 316L+N
Quantity per magnet	2
Cover plates	
Material type	Aluminum EN-AW-6082
Thickness	3 mm
Quantity per magnet	2

5.2 RECOMA 30S (SM_2CO_{17}) MAGNETIC PROPERTIES

ARNOLD MAGNETIC TECHNOLOGIES

RECOMA® 30S
Magnets based on Sm_2Co_{17}

Magnetic properties at room temperature

			RECOMA 30S	
			Typ.	Min.
Remanence	Br	(T) (kG)	1.12 11.2	1.09 10.9
Coercive force	HcB	(kA/m) (kOe)	844 10.6	820 10.3
Intrinsic coercive force	HcJ	(kA/m) (kOe)	2150 27	1750 22
Max. specific energy product	(BH)max	(kJ/m3) (MGOe)	235 29.5	225 28

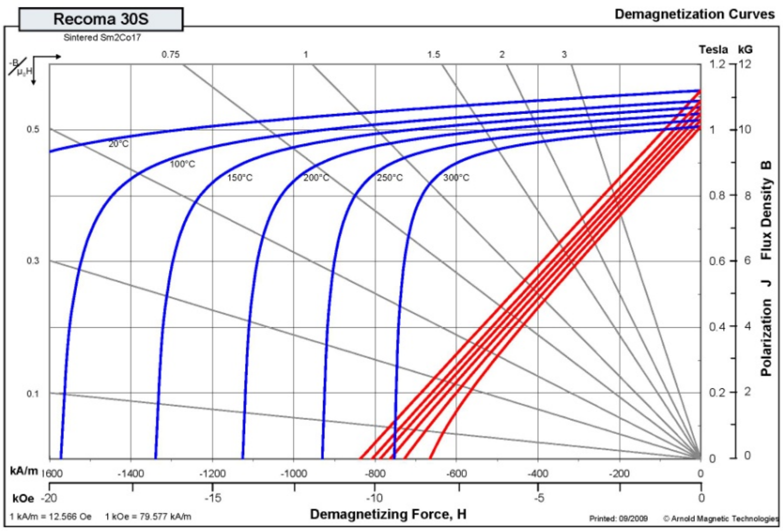
The values given in this table may deviate depending on the size and shape of the magnets.

Saturation field strength (inner field)		(kA/m) (kOe)	4000 50
Rev. temp. coefficient of Br (20 to 150° C)		%/°C	ca. -0.035
Max. operating temperature		°C	350 ¹)
Processing method			Pressed in transverse field or isostatically

¹) In the presence of strong demagnetizing fields, or if the magnets operate on a low load line, the max. temperature may be lower.

Characteristic properties at room temperature (indicative values)

Density	g/cm³	8.3
Compressive strength	N/mm²	800
Flexural strength	N/mm²	120
Young's modulus	kN/mm²	140
Vickers hardness (HV 5)		600
Electric resistivity	10^{-6} Ω•m	0.9
Linear expansion coefficient (20 to 200°C)	10^{-6}/K	II c: 11 ⊥c: 13
Thermal conductivity	W/(m•K)	10
Specific heat	J/(kg•K)	350



5.3 AISI 1010 MAGNETIC PROPERTIES

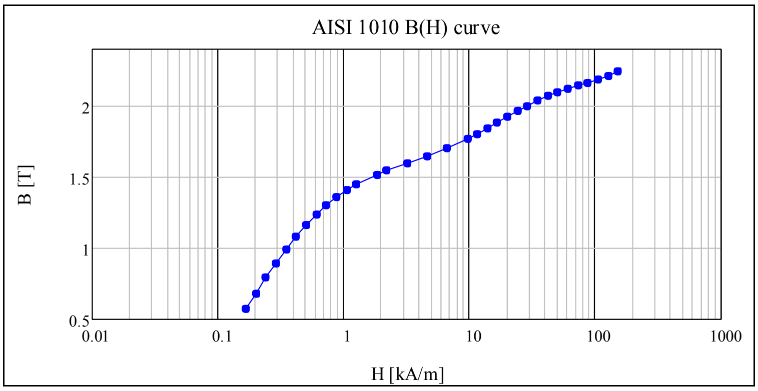


Figure 8: AISI 1010 B(H) curve

Table 3: B(H) data of the proposed steel type AISI 1010

B [T]	H [kA/m]
0	0
0.576	0.166
0.68	0.199
0.792	0.24
0.895	0.289
0.992	0.347
1.082	0.418
1.164	0.502
1.237	0.604
1.302	0.726
1.359	0.872
1.407	1.049
1.449	1.261
1.517	1.823
1.545	2.192
1.595	3.167
1.646	4.579
1.702	6.619
1.768	9.568
1.805	11.499
1.843	13.831
1.883	16.624
1.924	19.99
1.964	24.032
2.002	28.893
2.038	34.736
2.071	41.762
2.1	50.209
2.125	60.375
2.146	72.575
2.165	87.257
2.187	104.907
2.214	126.122
2.246	151.595