





Electromagnetic and Mechanical Design of a 16 T Cos-Theta Dipole for the Collider Ring of Muon Collider





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Introduct	ector	IP 1 IP 1 Muon Collider >10TeV CoM ~10km circumference	Goal: Feasibility Muon ac Accelerator Ring Main Ch	y study and celerator of ¹ 10 TeV. allenges:	l new teo a 10-km-l	chnological solution long collider ring w	ns for an vith a cen	innovative iter-of-mass	 Main Mag HTS technol T_{OP} = 20 K 	plogy • $\Delta T_{MARGIN} = 2.5 \text{ K}$ • $B_1 = 16 \text{ T}$ • $\Phi = 140 \text{ mm}$ • $B_n < 1 \text{ unit}$
4 GeV Target, π Decay μ Cooling Proton & μ Bunching Channel Source Channel	Low Energy µ Acceleration	• Shielding for much decay • Production and cooling processes • High B_1 with large aperture • Short lifetime of muons (2.2 μs at rest) • Quench protection							Cable Ass	umptions $R_{Cu/SC} = \frac{A_{Cu}}{A_{SC}} = 16.15$ $f_f = \frac{A_{SC}}{A_{tot}} = 0.018$
Magnet Co Cost Assumpt	ost tion (C)		Density Assu	mption (ρ)		¹ Value Cost Results	ue referred to the 2 <	e entire cross-section 400 k€/m (cost limit)		 Metal Copper Substrate F 2 PEPCO tapes so wounded
Material	Value	U.M.	Material	Value	U.M.	Material	Value	U.M.		SC layer is with SS laver ¹ (x2)
REBCO tape	2500	€/kg	REBCO tape	8000	kg/m ³	REBCO tape	217 ¹	k€/m		• Maximum allowable stresses
Stainless Steel	10	€/kg	Stainless Steel	7800	kg/m ³	Stainless Steel	1/1	k€/m		intra = 0.11 mm $intra = 0.11 mm$
Iron	8	€/kg	Iron	7800	kg/m ³	Iron	43 ⁻	K€/m		0.11 mm \succ y - direction: $\sigma_{max} = -400 MPa$
Cost Estimatio	on: <i>C</i> = ($\sum A_n \cdot C_n$	$\cdot \rho_n) + C_{LABOR}$	(€/1	n)	Total Cost	297 ^{1,2}	k€/m	$' \downarrow \\ x 12 mn_{1}$	m ¹ SS layer stabilizer thickness based on quench protection study performed by T.Salmi, doi:10.1109/TASC.2025.3540791.
 Electrom Analytical magnetization Use of CO 	agneti harmonio tion effe MSOL sof	c Opti cs calculat cts (curre ftware wit	mization tion considering nt redistribution) th T-A formulatio	B [T] 18 16 14	Esti • 21	mation of th osses estimations EJ Losses : $P_{EJ}\left(\frac{W}{m}\right)$	e Hyst by T-A for $\vec{F} = \vec{E} \cdot \vec{J}$	Example 1 Example 1 Exa	SSES COMSOL): = $\int_0^{t_r^1} P_{EJ} dt$	 Preliminary Mechanical Calculation Non uniform current distribution due to magnetization Homogenized coils surrounded by an infinitely rigid structure
Parameter V	/alue	U.M.		Iron 12		Hysteretic Losses	• M	lagnetization		Standard type contacts frictionless between coils and
I _{OP} 3	3700	A	Staiplaga					\vec{B} (A) \vec{B}	Inon unif [—] ^B I unif	structure (layers are bonded together)
J _{ENG}	571	A/mm^2	Steel	- 8		Losses Value		$M\left(\frac{-}{m}\right) = -$	μ_0	 Use of FEM software COMSOL
B	161	A/mm² T	collar	- 6		(kJ/m)	— • Ну	ysteretic loss	es	• $E_{coils} = 174^1 GPa$ and $v_{coils} = 0.3$
B _{DEAK}	18.2					Q_{EJ} 167 ²	- >	$P_{hyst}\left(\frac{W}{M}\right) =$	$\vec{M} \cdot \vec{B}_{Inon unif}$	$\sigma_{r}[MPa]$ $\sigma_{h}[MPa]$
T _{OP}	20	к				Q_{hyst} 22.5 ²			j non_anti	
ΔT_{MARGIN} 2.	5±1%	K	HTS coils		J/Jc	• •	• IN	tegrated nys (I)	teretic losses	-40
E _{STORED} 39	948 ^{2,3}	kJ/m	Harmonic Valu	e	1	without iron		$Q_{hyst}\left(\frac{1}{m}\right) =$	$= J_0^{\dagger} P_{hyst} dt$	-80 -100
E _{STORED} /V ().29 ²	J/mm ³	b3 4							
	3 <u>4</u> 2,3	mH/m								



Brandt Model in MATLAB for fast simulations

Brandt Model:

Analytical model implemented in MATLAB and evaluating the sheet current density J[A/m] in each REBCO tape by the assumption of **uniform perpendicular magnetic field** B_{\perp} along its width.



Brandt Model (MATLAB) vs T-A formulation (COMSOL):

- Computational time reduced of factor ~ 28 (140 min \rightarrow 5 min) Only linear p
- Good compatibility for <u>field quality</u> and <u>hysteretic losses</u>
- Only quasi-static simulations (no time dependency)
- Only linear phenomenon (no iron)
- Limited by **uniform** *B***_⊥ assumption**



Harmonic ¹	COMSOL	MATLAB	
b3	3	4	
b5	-7	-0.2	
b7	-3	-0.05	
Losses (kJ/m)	COMSOL	MATLAB	
Q _{hyst}	22.5 ²	22 ²	

¹ Field quality without iron yoke and considering current redistribution ² Value referred to the entire cross-section

Conclusions

The study shows that the **EM** and **cost** requirements have been satisfied **Next steps:**

- Reduce the maximum radial stress by an opportune mechanical design
- Upgrade MATLAB code to enhance

the compatibility with COMSOL and to allow time dependent and non-linear studies

• Laboratory test with small coils to validate

MATLAB hysteretic current model



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