भाभा परमाणु अनुसंधान केंद्र
BHABHA ATOMIC RESEARCH CENTRE

Engineering design of Quadrupole magnets for LBNE (3Q120 & 3Q60)

Vikas Teotia
Prashant Kumar
Elina Mishra
Sanjay Malhotra

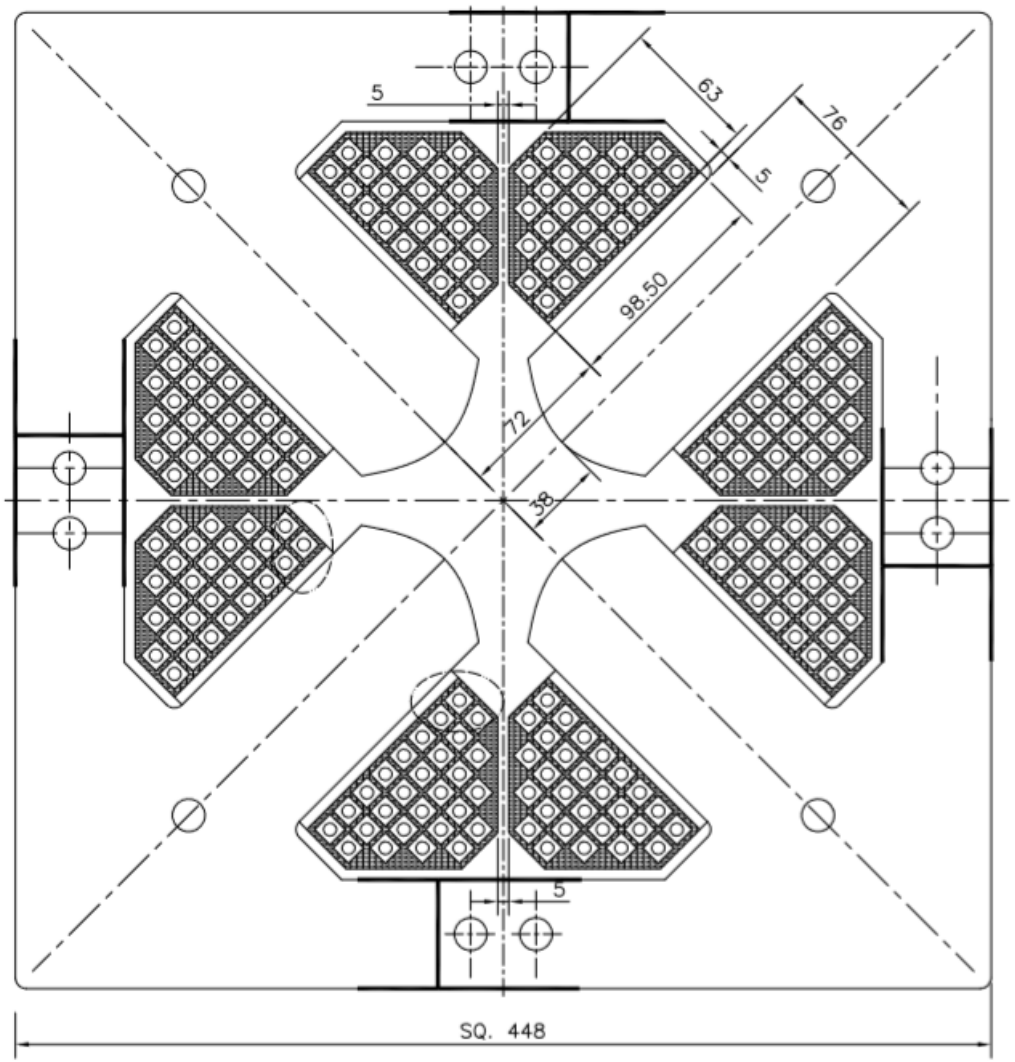
Electromagnetic Application & Instrumentation Division
Bhabha Atomic Research Centre, Trombay

Continuing from Physics design

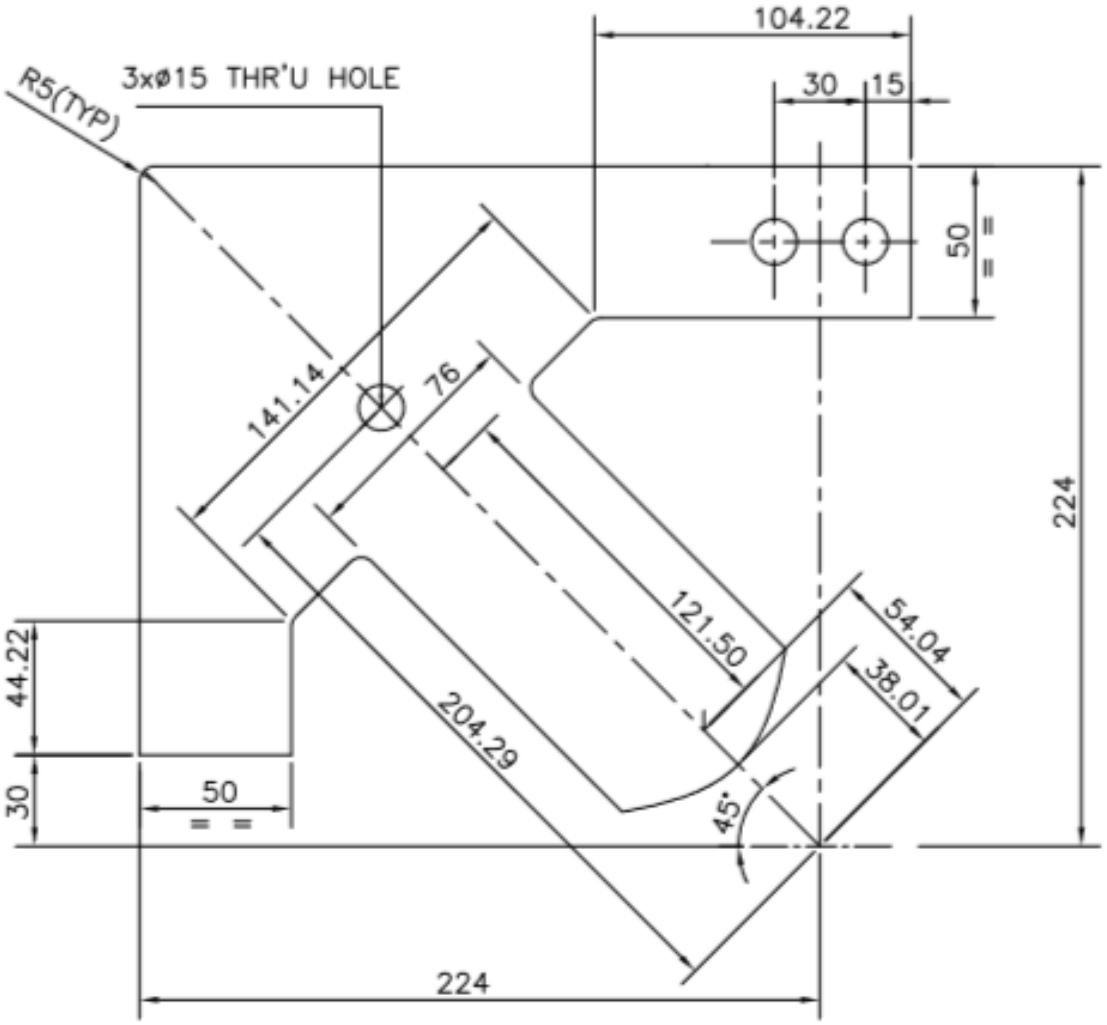
1. On March 19, 2020, BARC presented the magnetic design of 3Q120 and 3Q60 Quadrupole magnets, satisfying the Functional Requirements of the Quadrupoles.

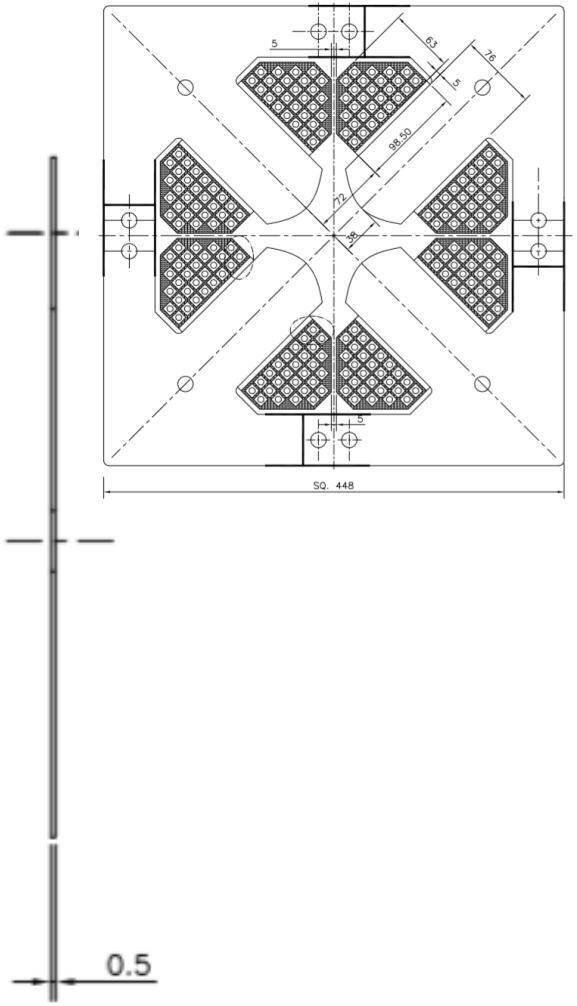
2. This presentation addresses the engineering design of the quadrupoles satisfying the technical requirements of the magnets.

Magnet section



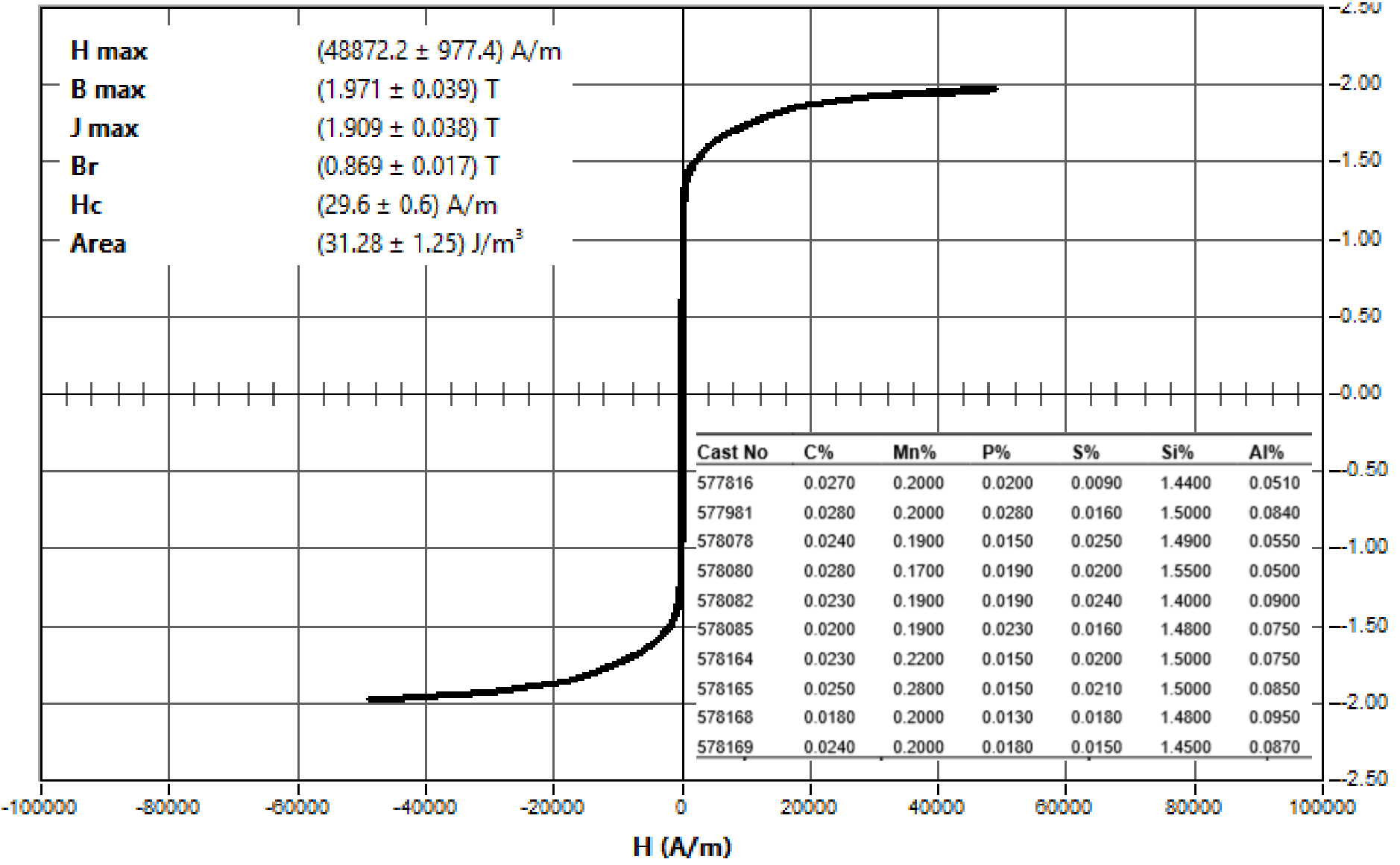
Single Quadrant





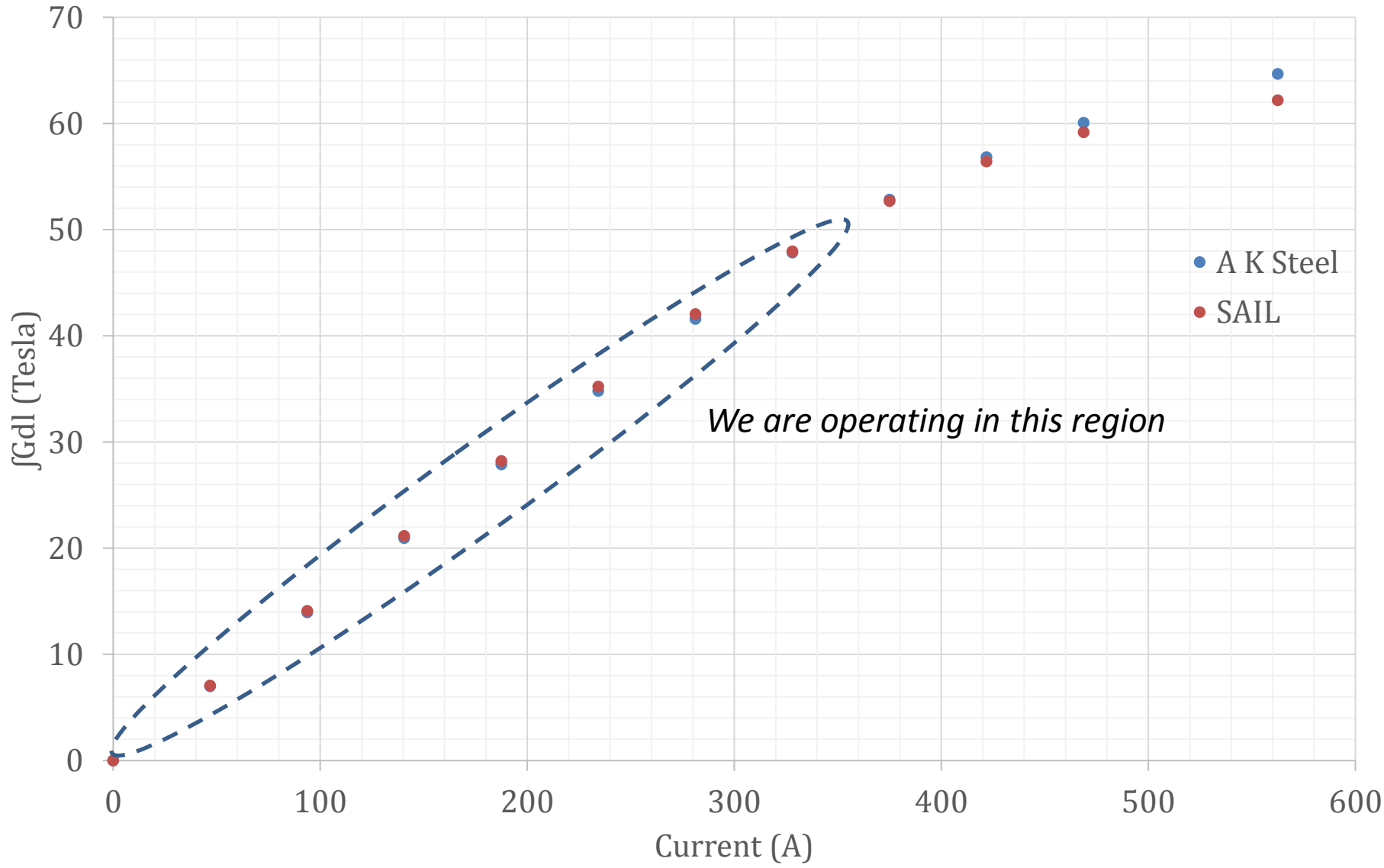
Material : Electrical Steel of SAIL make (50C700 or better)

Electrical Steel from SAIL

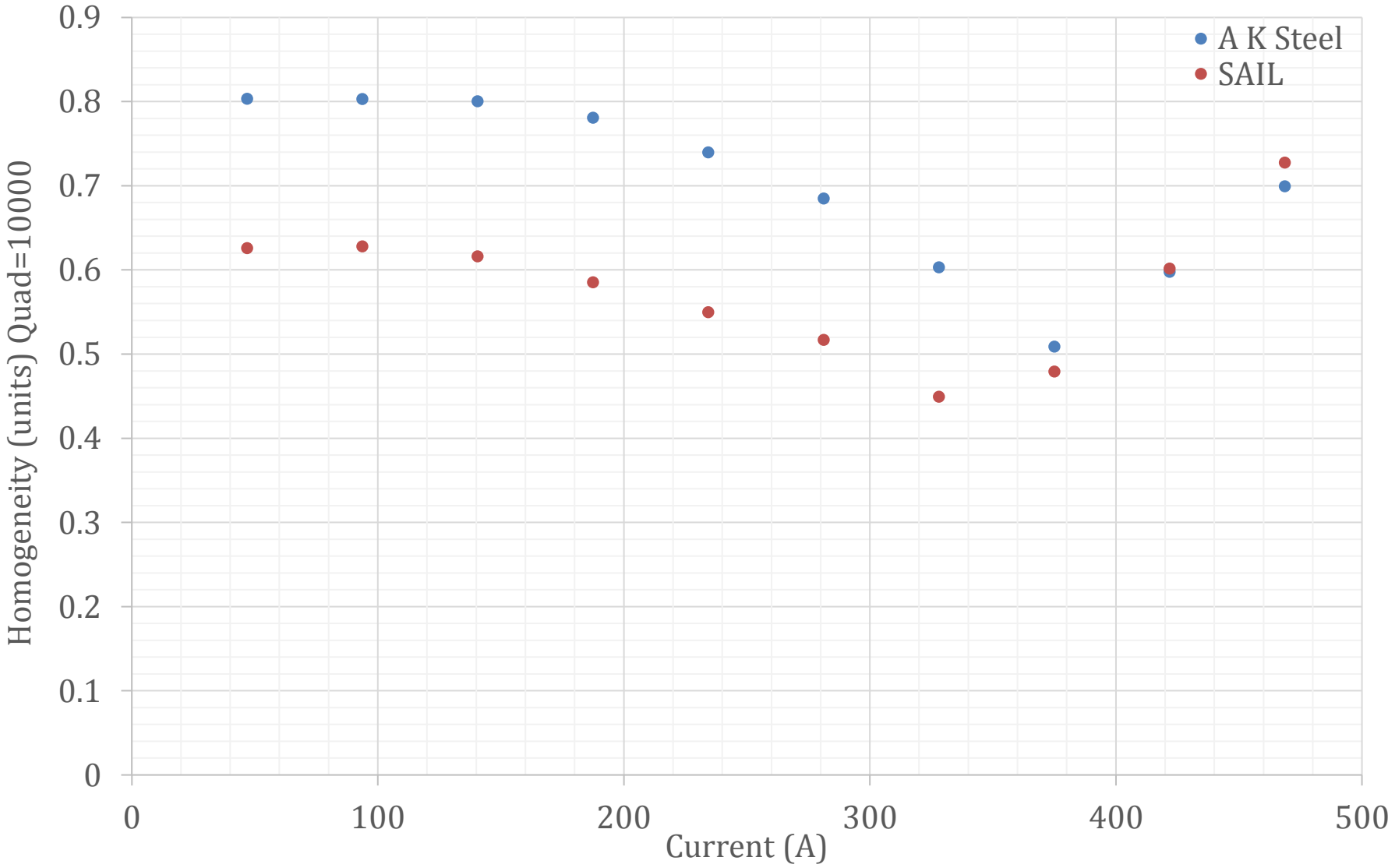


Cast No	C%	Mn%	P%	S%	Si%	Al%
577816	0.0270	0.2000	0.0200	0.0090	1.4400	0.0510
577981	0.0280	0.2000	0.0280	0.0160	1.5000	0.0840
578078	0.0240	0.1900	0.0150	0.0250	1.4900	0.0550
578080	0.0280	0.1700	0.0190	0.0200	1.5500	0.0500
578082	0.0230	0.1900	0.0190	0.0240	1.4000	0.0900
578085	0.0200	0.1900	0.0230	0.0160	1.4800	0.0750
578164	0.0230	0.2200	0.0150	0.0200	1.5000	0.0750
578165	0.0250	0.2800	0.0150	0.0210	1.5000	0.0850
578168	0.0180	0.2000	0.0130	0.0180	1.4800	0.0950
578169	0.0240	0.2000	0.0180	0.0150	1.4500	0.0870

Transfer Function : SAIL and AK Steel



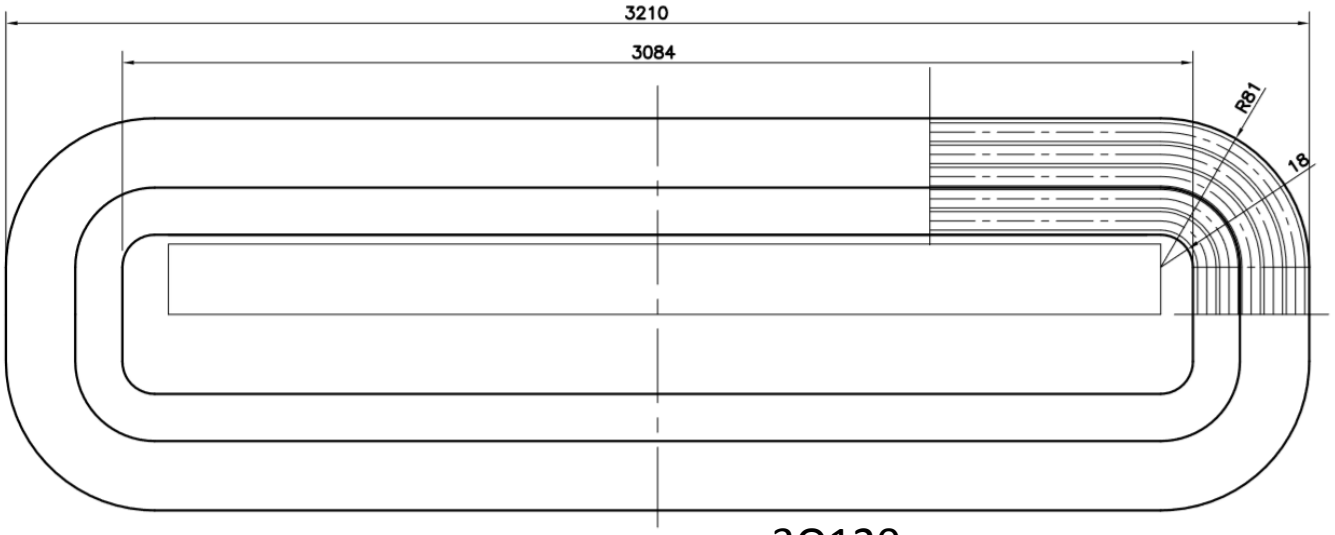
Field Homogeneity: SAIL and AK Steel



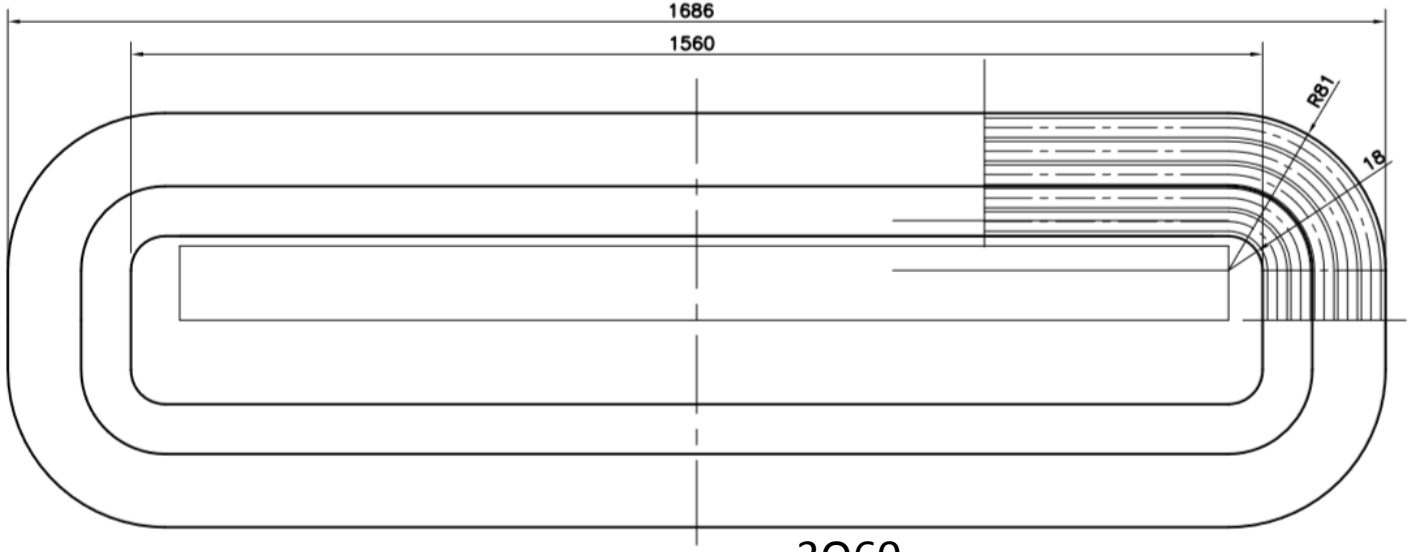
Advantages of Electrical Steel over Soft Iron

1. Available off the shelf in India
2. Manufactured by Indian Steel giant : ***Steel Authority of India Limited (SAIL)***
3. Since it is produced in large quantity, quality control is good.
4. It is supplied with electrical insulation with controlled thickness (
5. Comparable to Soft Iron with respect to magnetic performance of the magnets.
6. Better transient performance of the magnet
7. Less delivery lead time

3Q120/3Q60 EM Coils



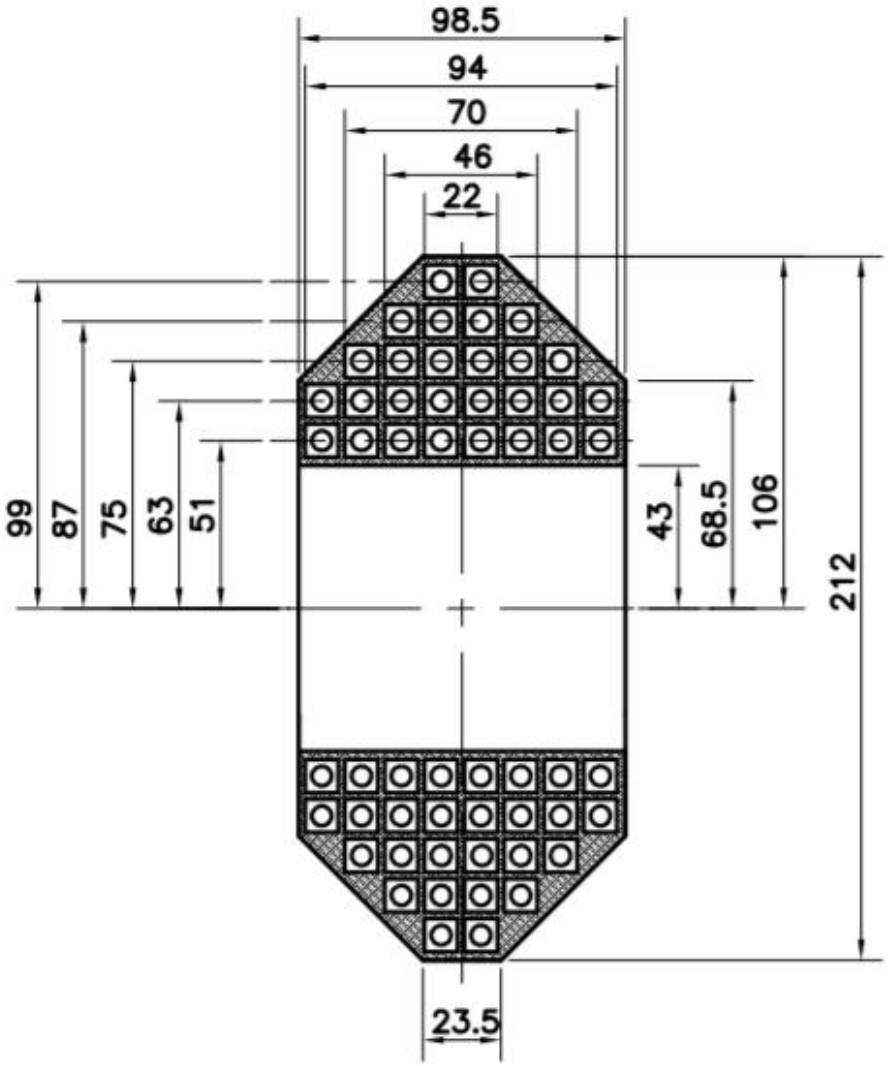
3Q120

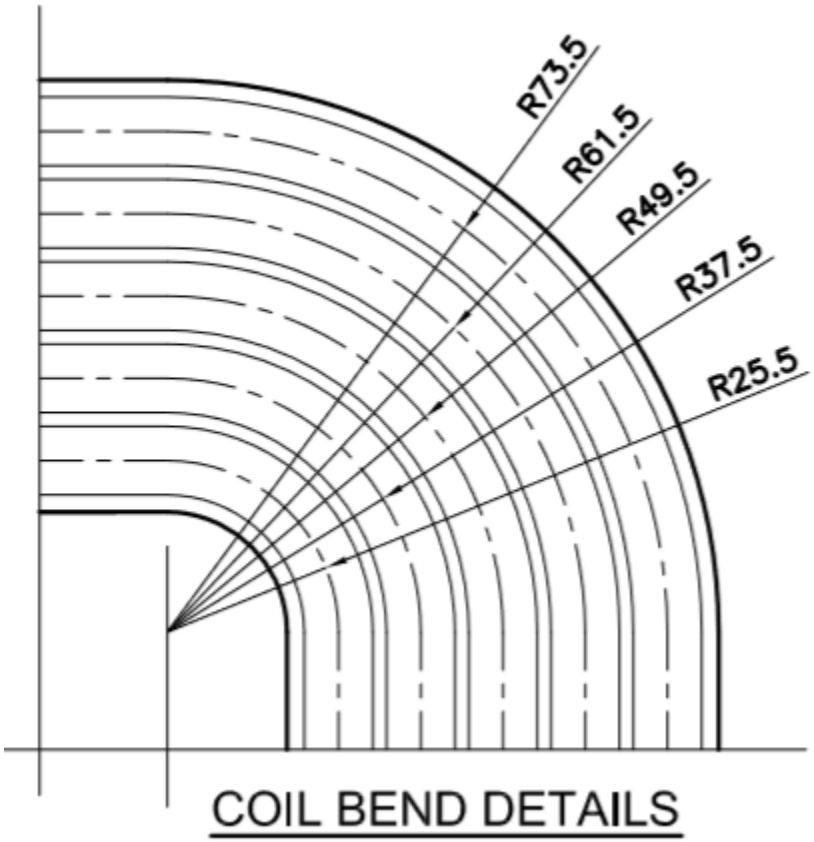


3Q60

Coils will be epoxy potted with minimum 3 mm epoxy between conductor and outer surface

3Q120/3Q60 EM coils

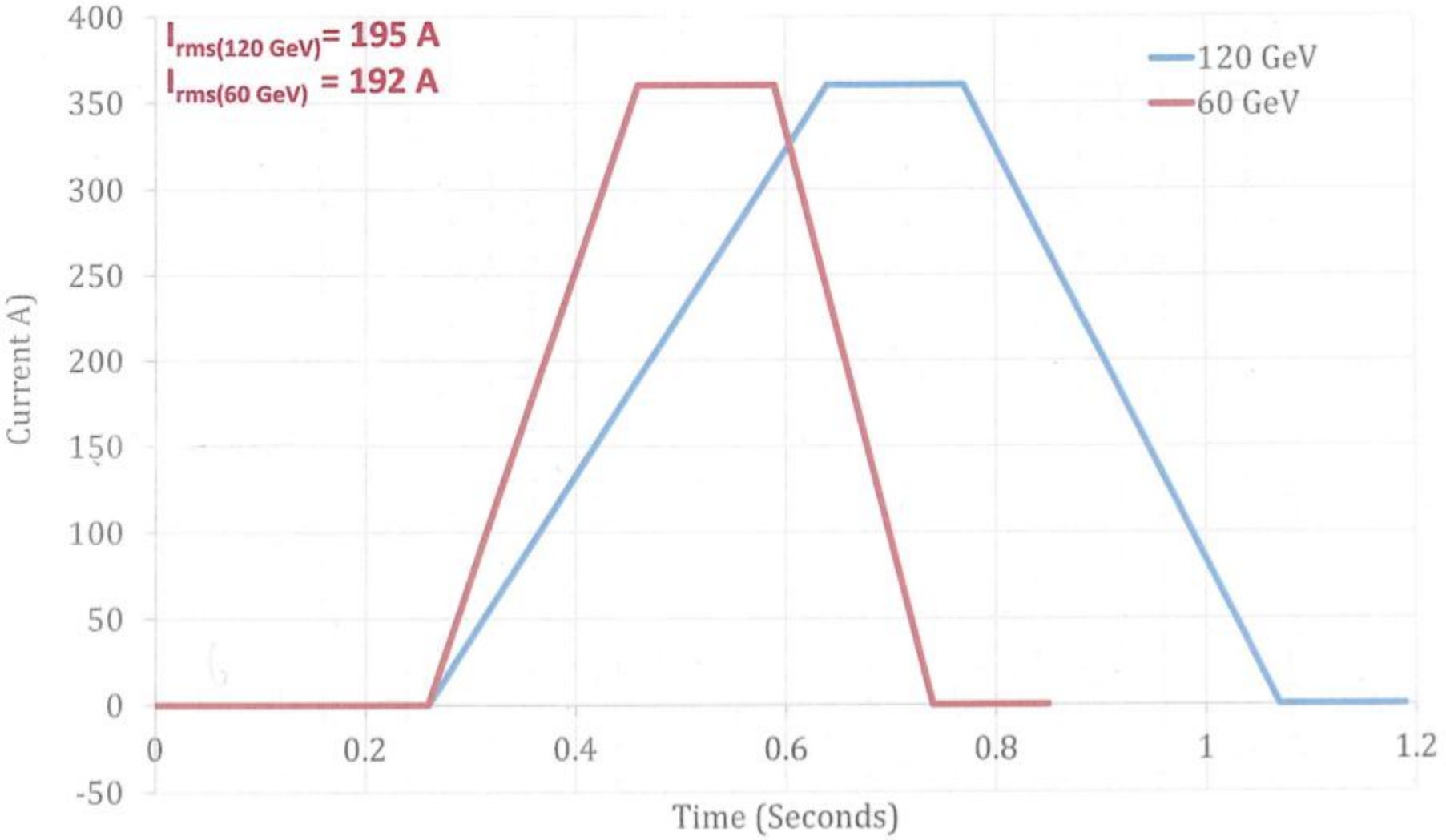




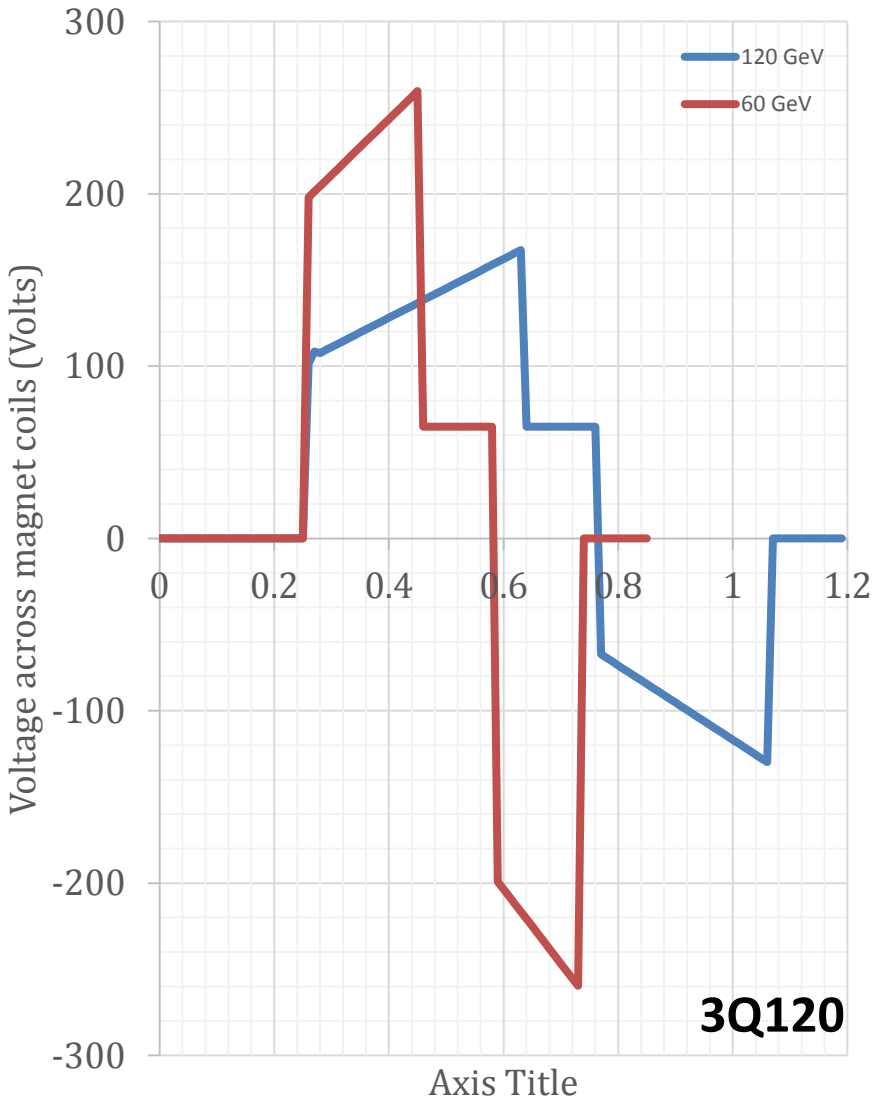
Parameters of electromagnetic coils

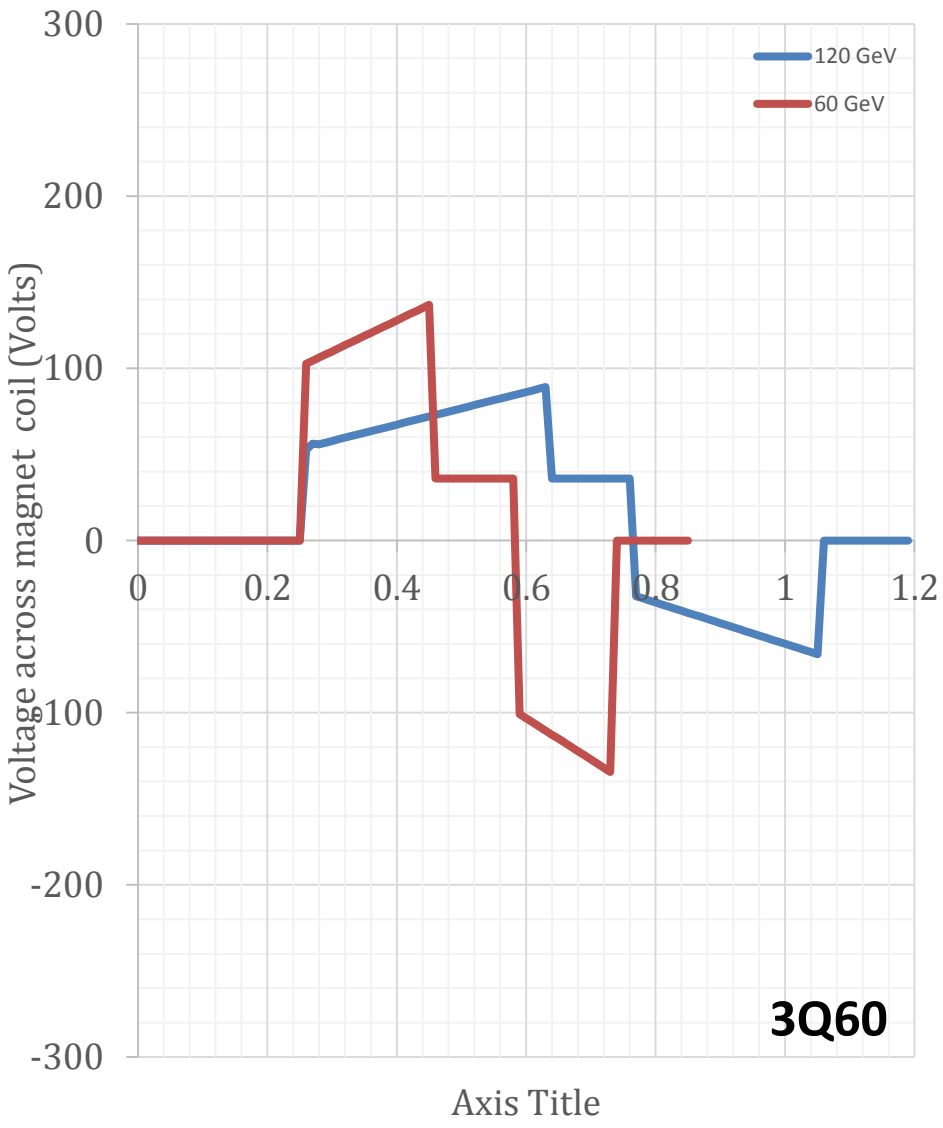
SN	Parameter	Value		Unit
		3Q120	3Q60	
1.	Coil type	Water cooled coils		-
2.	Number of coils per magnet	4	4	-
3.	Turns per coil	28	28	-
4.	Resistance per magnet	0.180	0.100	Ohms
5.	Inductance per magnet	110	57	mH
6.	Nominal Current	360	360	A
7.	RMS Current	195	192	A
8.	Power dissipation per magnet	6.85	3.69	kW
9.	Weight per coil	115	64	Kg

Machine Cycle



Voltage across magnets





Thermal Hydraulic parameters

The coils shall be hydraulically in parallel and electrically in series (quad Configuration)

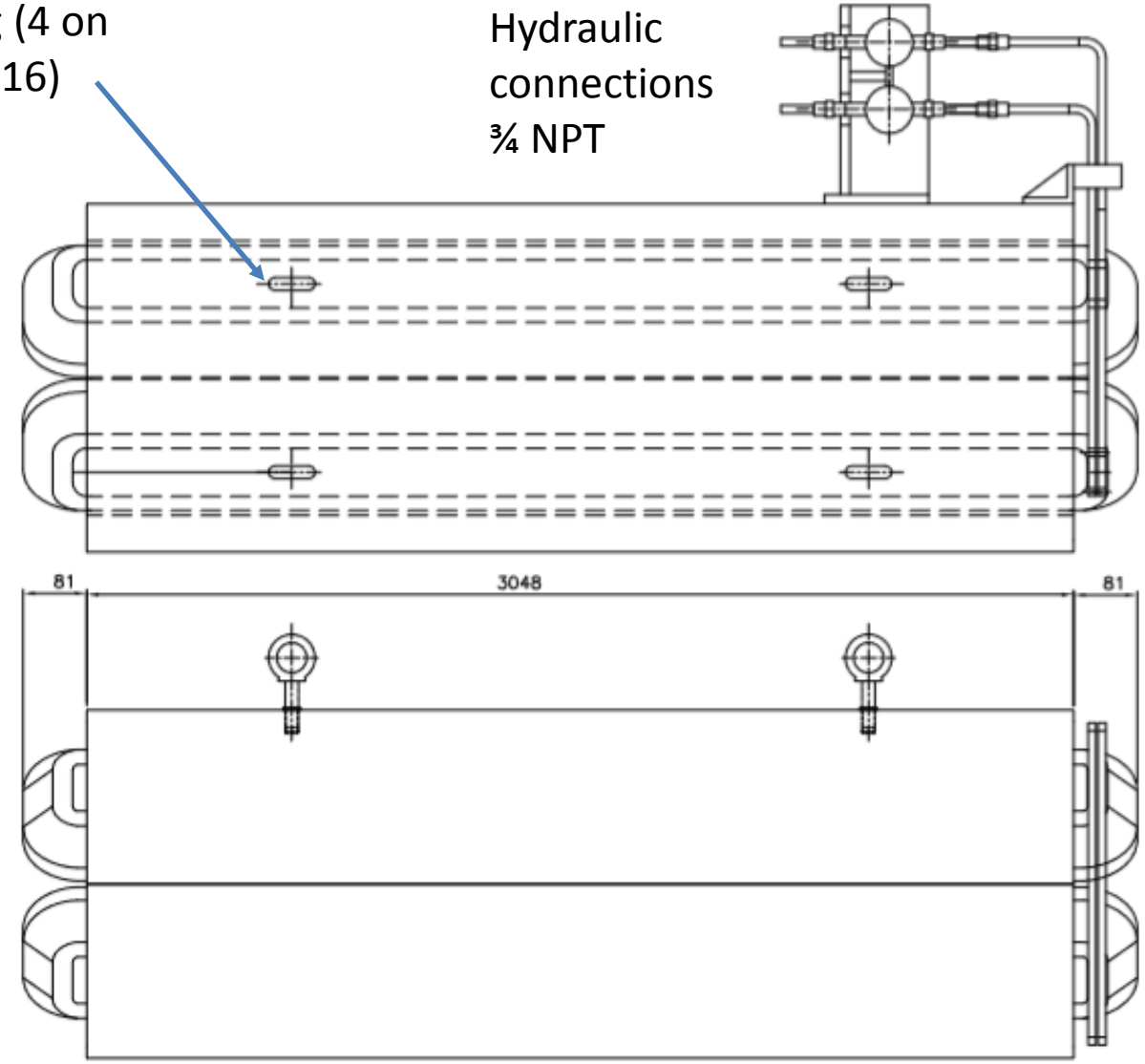
SN	Parameter	Velocity of water @ 1.5 m/s	
		3Q120	3Q60
1.	Volume flow rate (LPM) per magnet	2.5	2.5
2.	Reynolds Number	6994	6994
3.	Nusselt number	71	71
4.	Heat Transfer coefficient (W/m^2K)	6994	6994
5.	Temperature Rise Copper (hot spot)	0.25	0.25
6.	Temperature rise of water (^0C)	9	4.8
7.	Maximum temperature rise of bulk copper (^0C)	0.22	0.22
8.	Total Flow (LPM) per quadrupole	10	10
9.	Pressure drop per coil (bar) per quadrupole	13	8.7

Pressures in inlet and outlet headers will be required

Hydraulic Connections to services

Eye bolt tapping (4 on each face, Total 16)

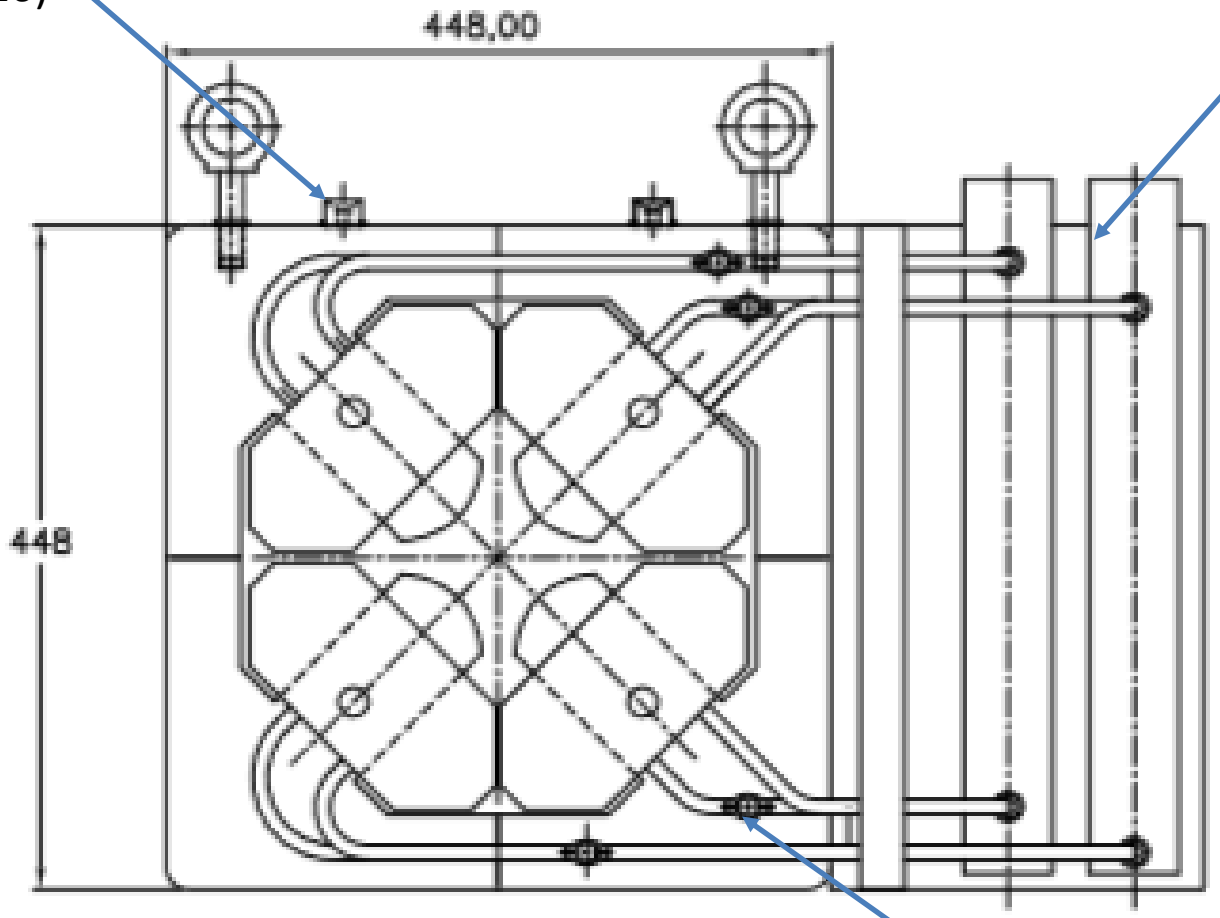
Hydraulic connections ¾ NPT



Front view of the magnet

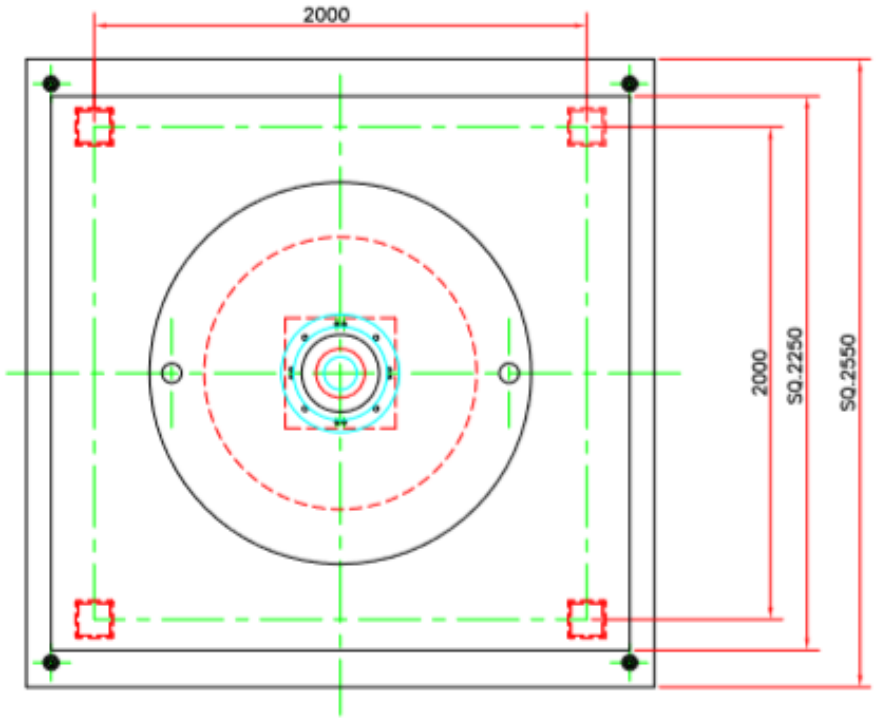
Next ball targets (4 on each face, Total 16)

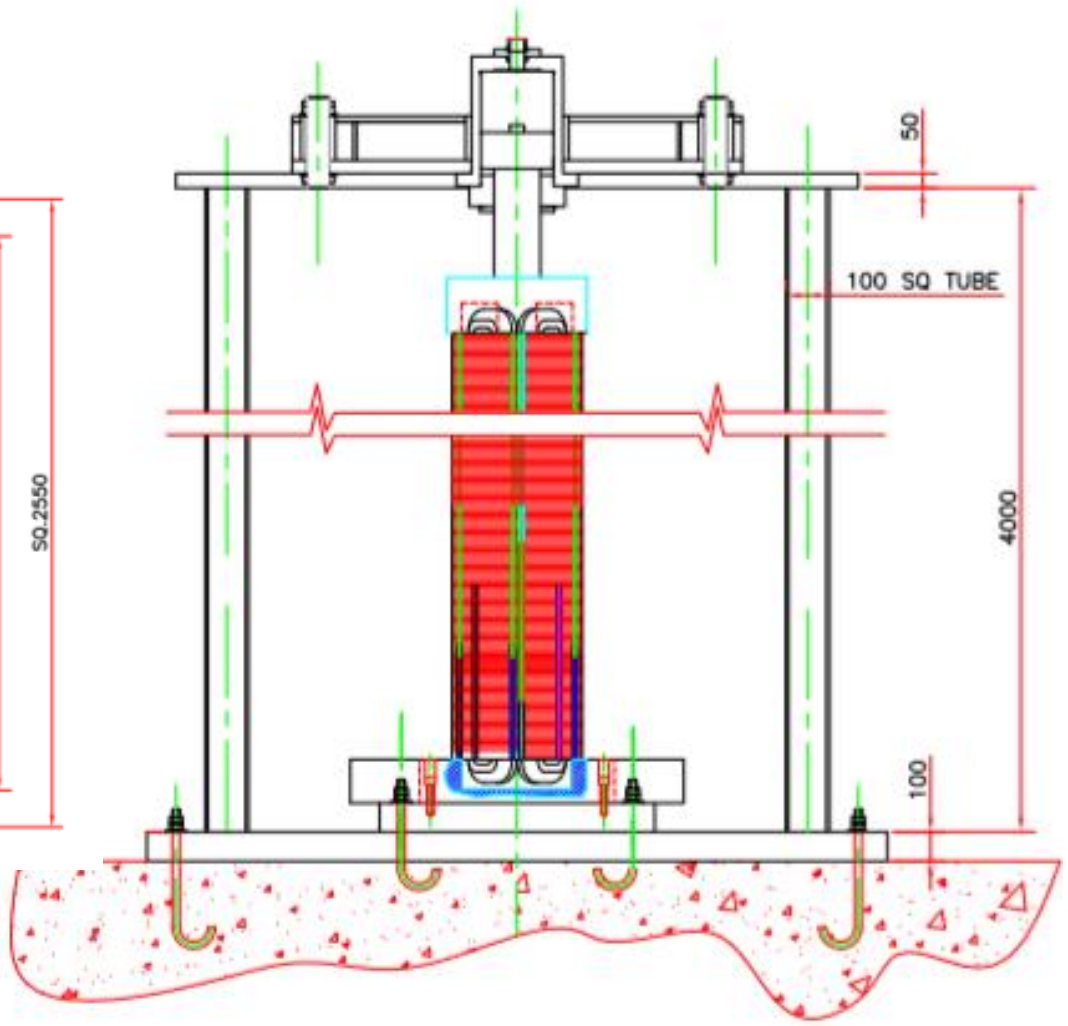
Inlet and Outlet header pair



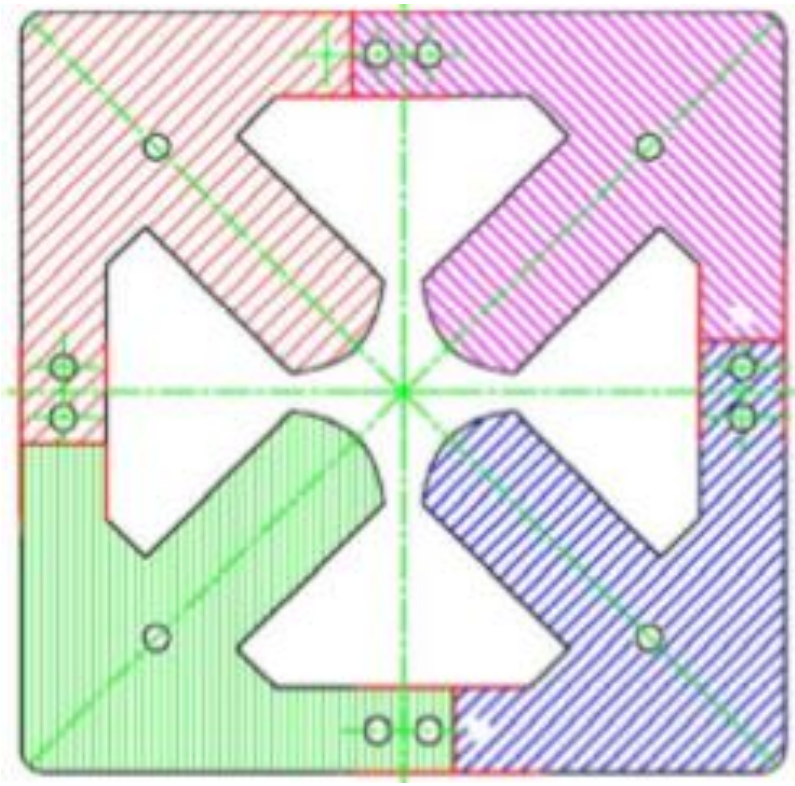
Thermal switch, one on each coil

Assembly facility

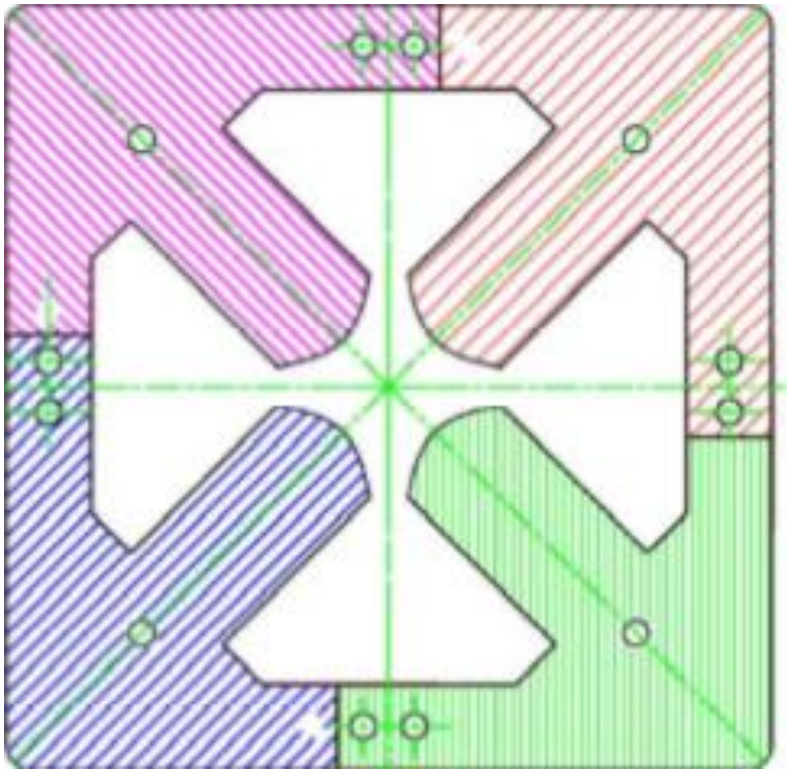




Interleaving of consecutive layers

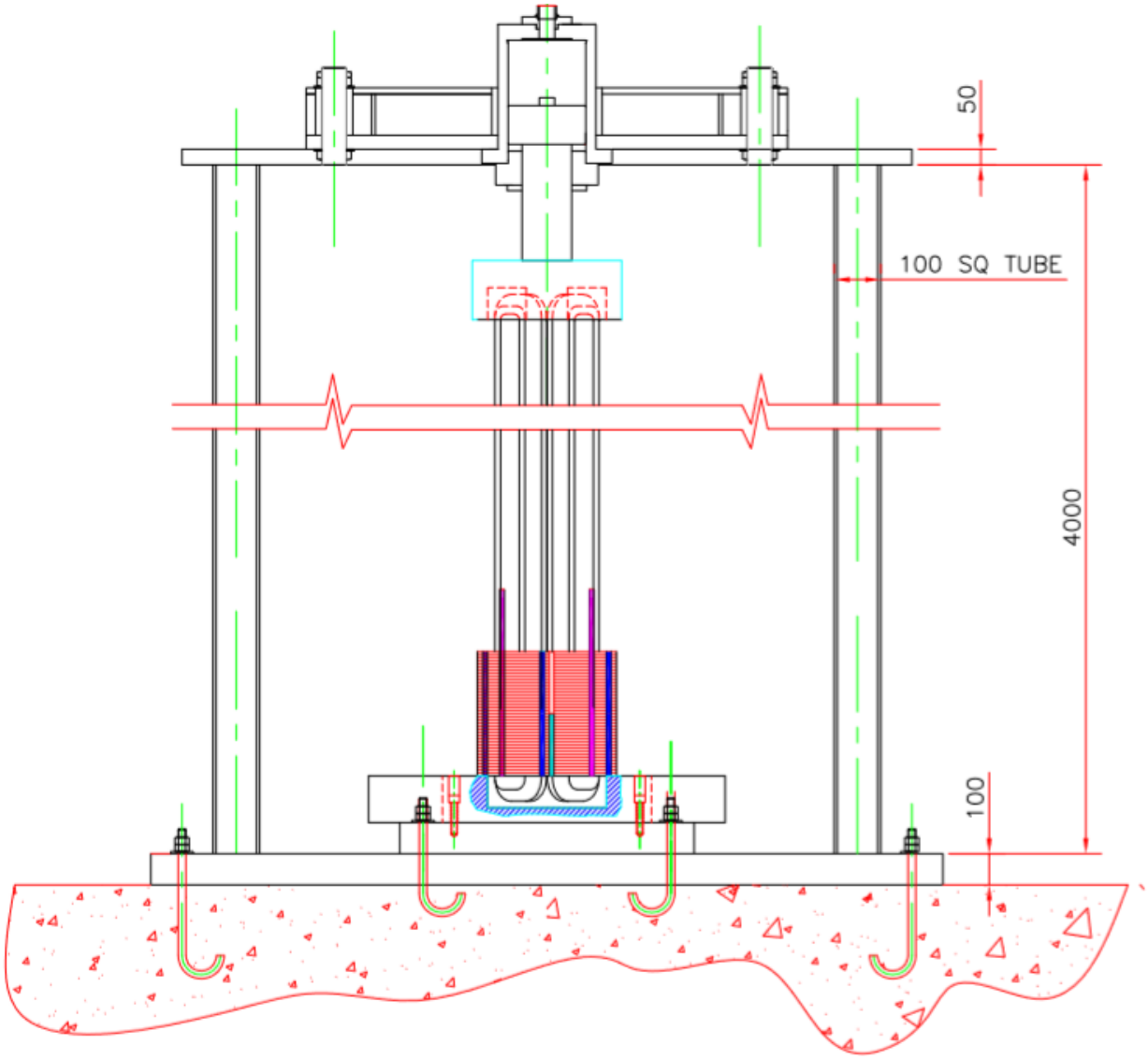


Odd Layer



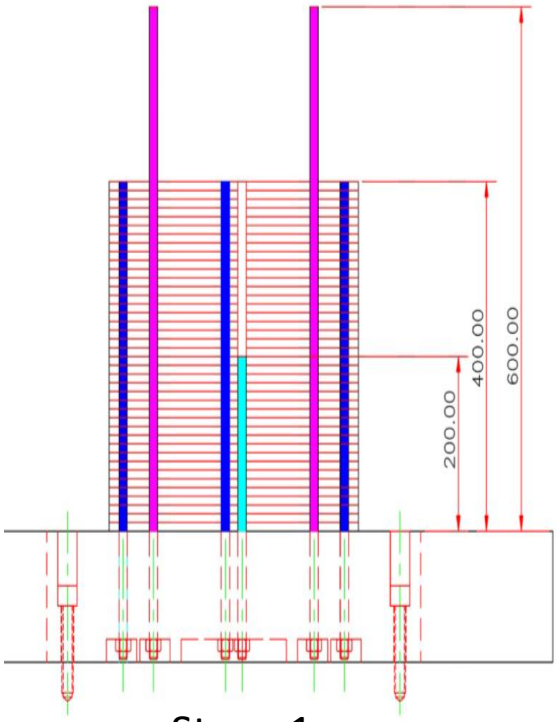
Even Layer

First stage

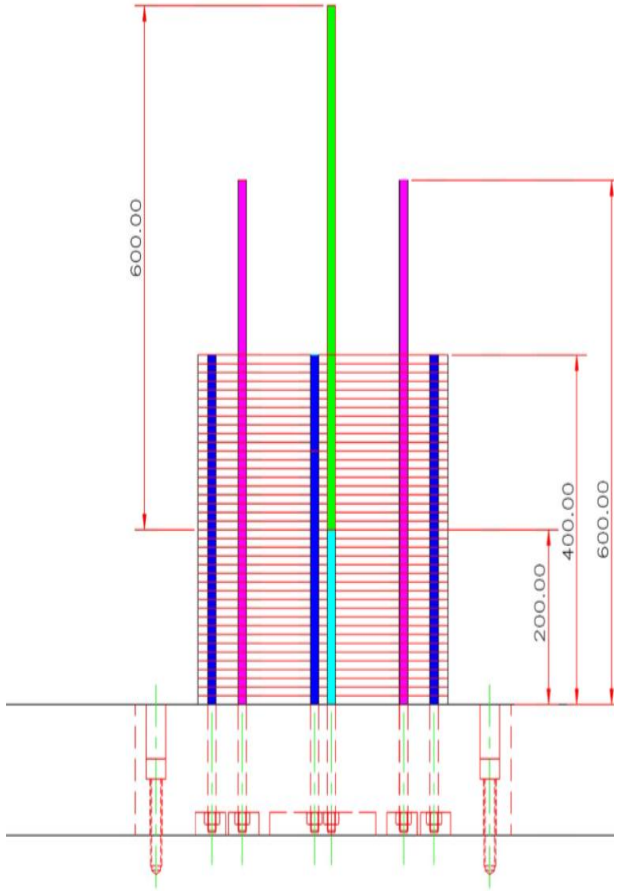


Typical Assembly sequence

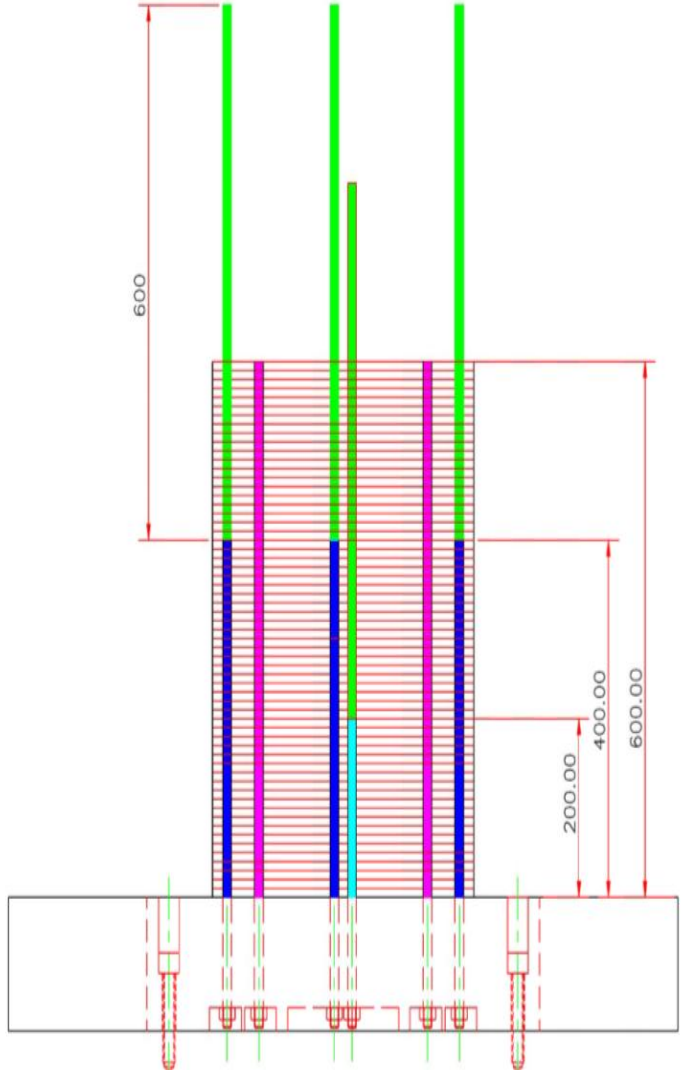
Coils and assembly facility not shown for simplicity



Stage 1

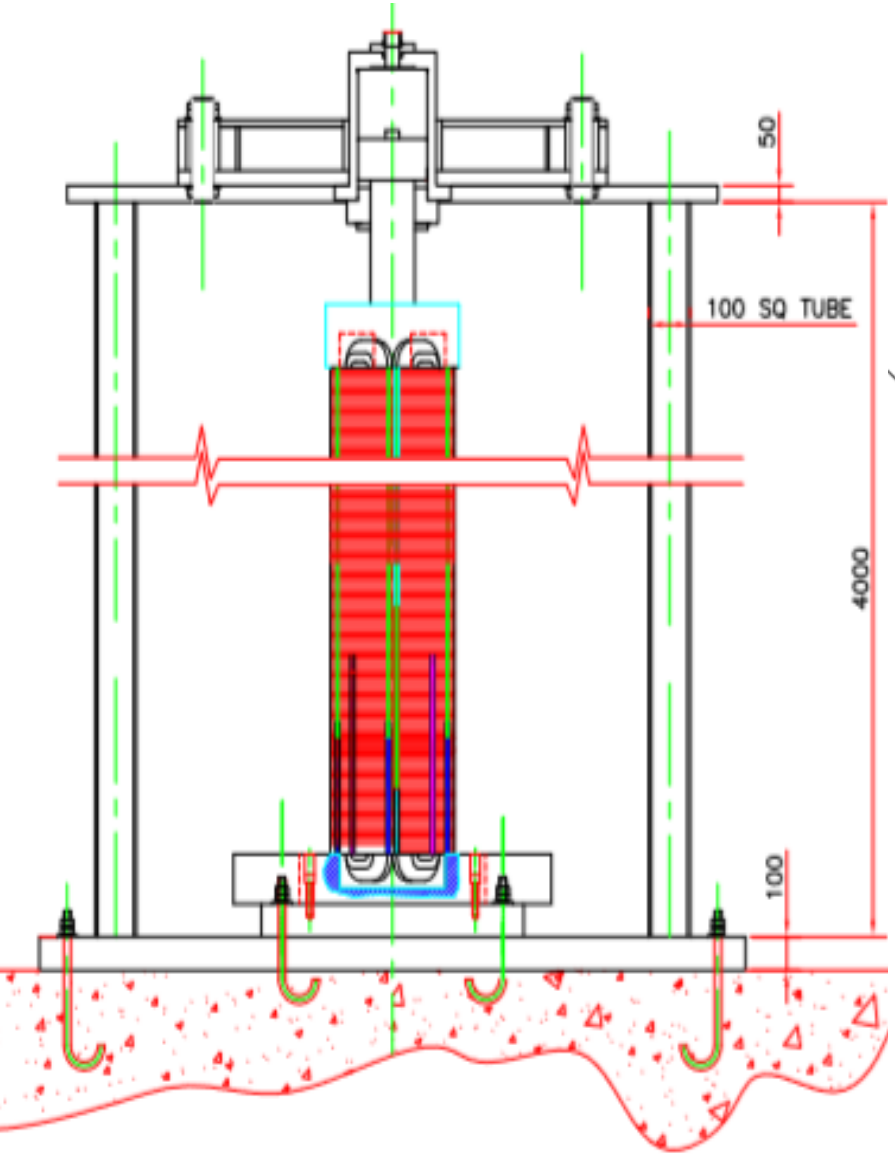


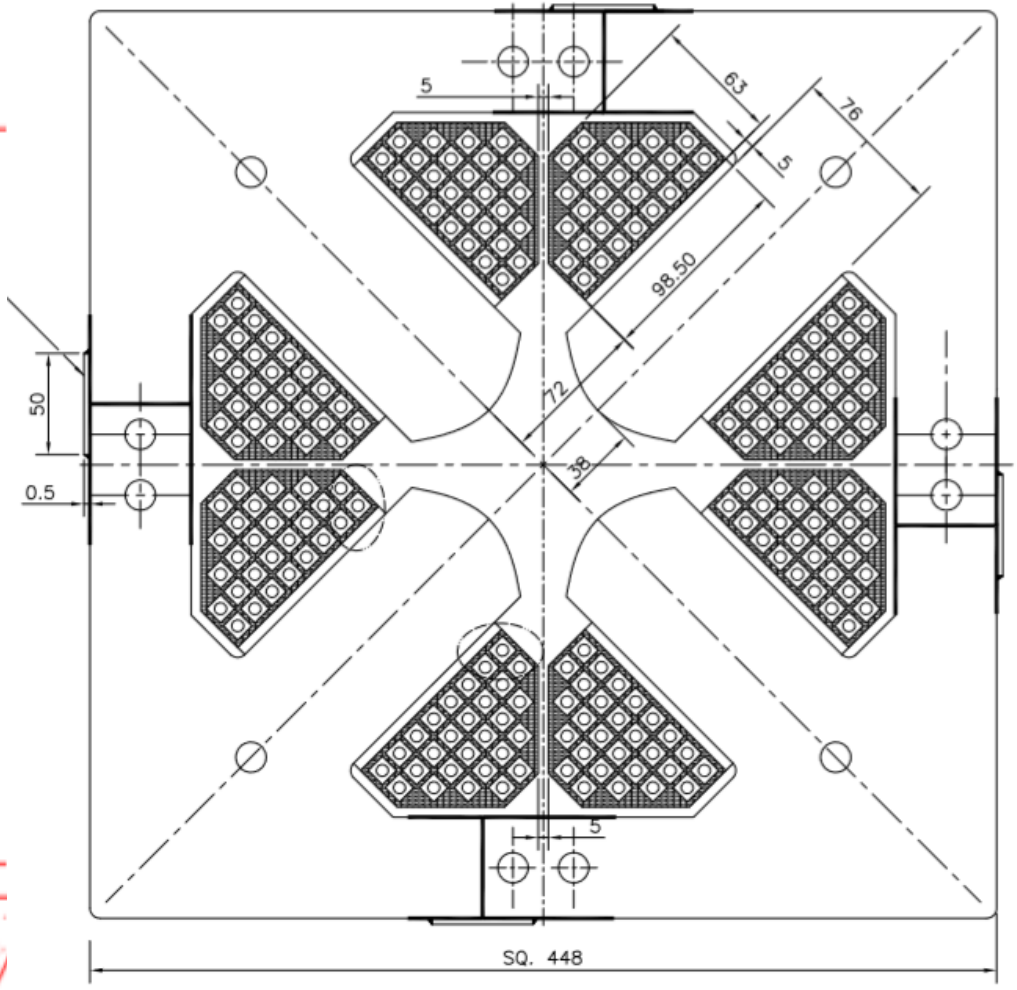
Stage 2



Stage 3

Final assembled magnet





Production and Qualification

Potential Vendors	Method	Remarks
Vendor 1	Fabrication of laminations Assembly of laminations & Coils Hydraulic Qualification Electrical qualification (BARC) Magnetic Qualification (BARC) Packing	Vendor Identified
Vendor 2	Fabrication of coils	Vendor Identified

Thanks !

Measured Insulation thickness on laminations

GRADE	WattLoss at 1.5 Tesla	Coating Type	Coating Th.
	Watt / K		Micron
STD IS648 50C 700	6.34	C6	1.9
STD IS648 50C 700	6.33	C6	1.9
STD IS648 50C 700	6.50	C6	2
STD IS648 50C 700	6.35	C6	2
STD IS648 50C 700	6.54	C6	1.8
STD IS648 50C 700	6.52	C6	1.8
STD IS648 50C 700	6.35	C6	1.9
STD IS648 50C 700	6.31	C6	1.7
STD IS648 50C 700	6.36	C6	2
STD IS648 50C 700	6.36	C6	2
STD IS648 50C 700	6.31	C6	1.8
STD IS648 50C 700	6.33	C6	1.9
STD IS648 50C 700	6.34	C6	1.7
STD IS648 50C 700	6.32	C6	1.8
STD IS648 50C 700	6.31	C6	1.8
STD IS648 50C 700	6.36	C6	2