Indian Institutions and Fermilab Collaboration
DAE-DOE Discovery Science Collaboration

DUNE

Sanjib Mishra, USC
Independent Technical Design Review
DUNE-ND
May 28-29, 2015

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DUNE-ND Magnet

Internal Technical Design Review
DUNE-ND
May 28-29, 2015

Electromagnetic Applications Section
Control Instrumentation Division
Bhabha Atomic Research Centre, Trombay, Mumbai

Dipole Magnet- Requirements

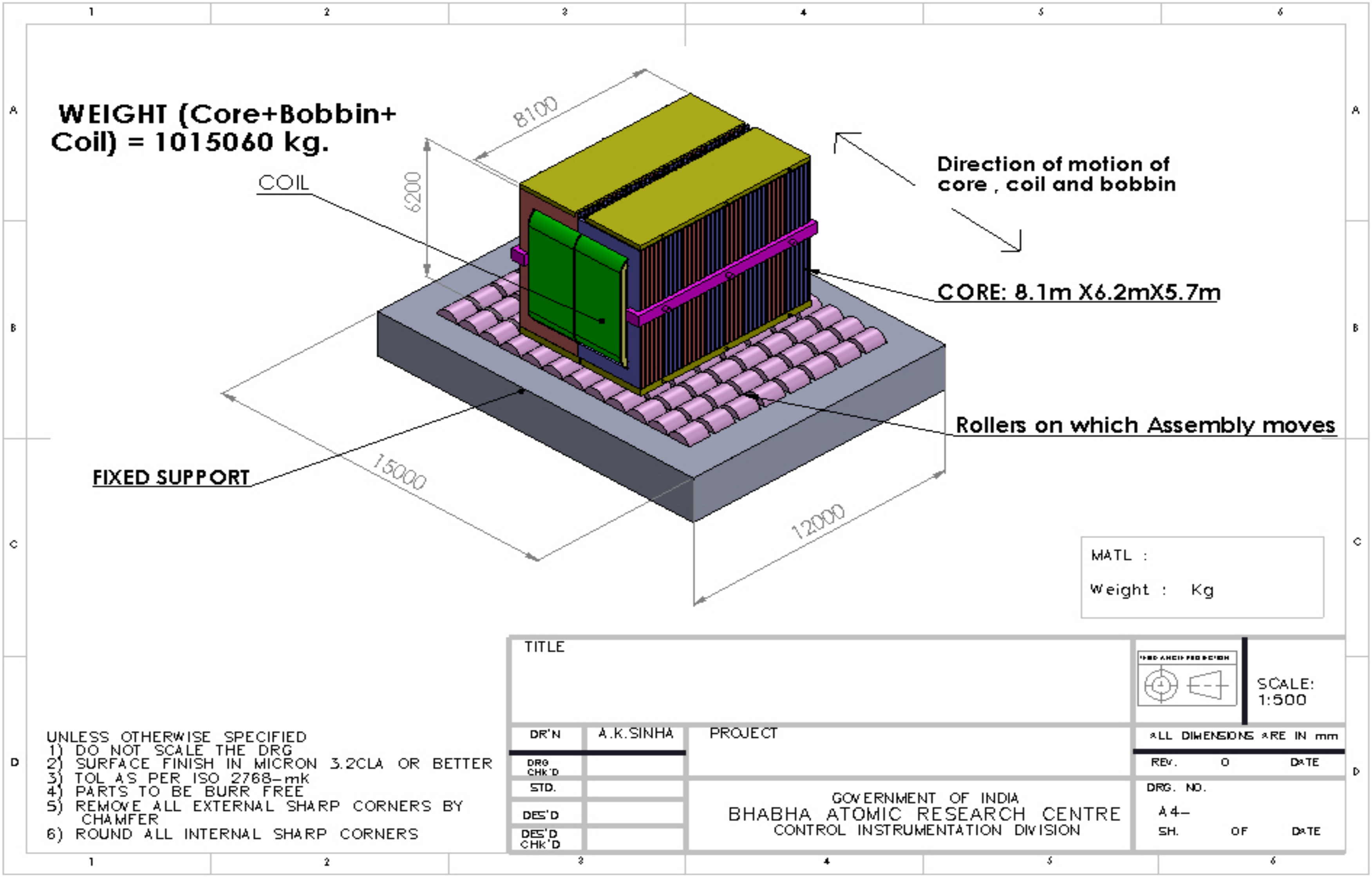
- Tracking detectors and ECAL Modules will reside in 0.4T dipole magnetic field volume with inner dimensions 4.5m*4.5m*8.1m.The magnet needs to support and anchor the detectors
- Dipole magnet should be open–close C-type structure
- Field uniformity in 3.5 m*3.5 m*7 m volume better than 2%
- Field uniformity in 1m*1m*2m better than 1%
- Detector Fiducial volume mass ~8 tonnes

XII Plan layout

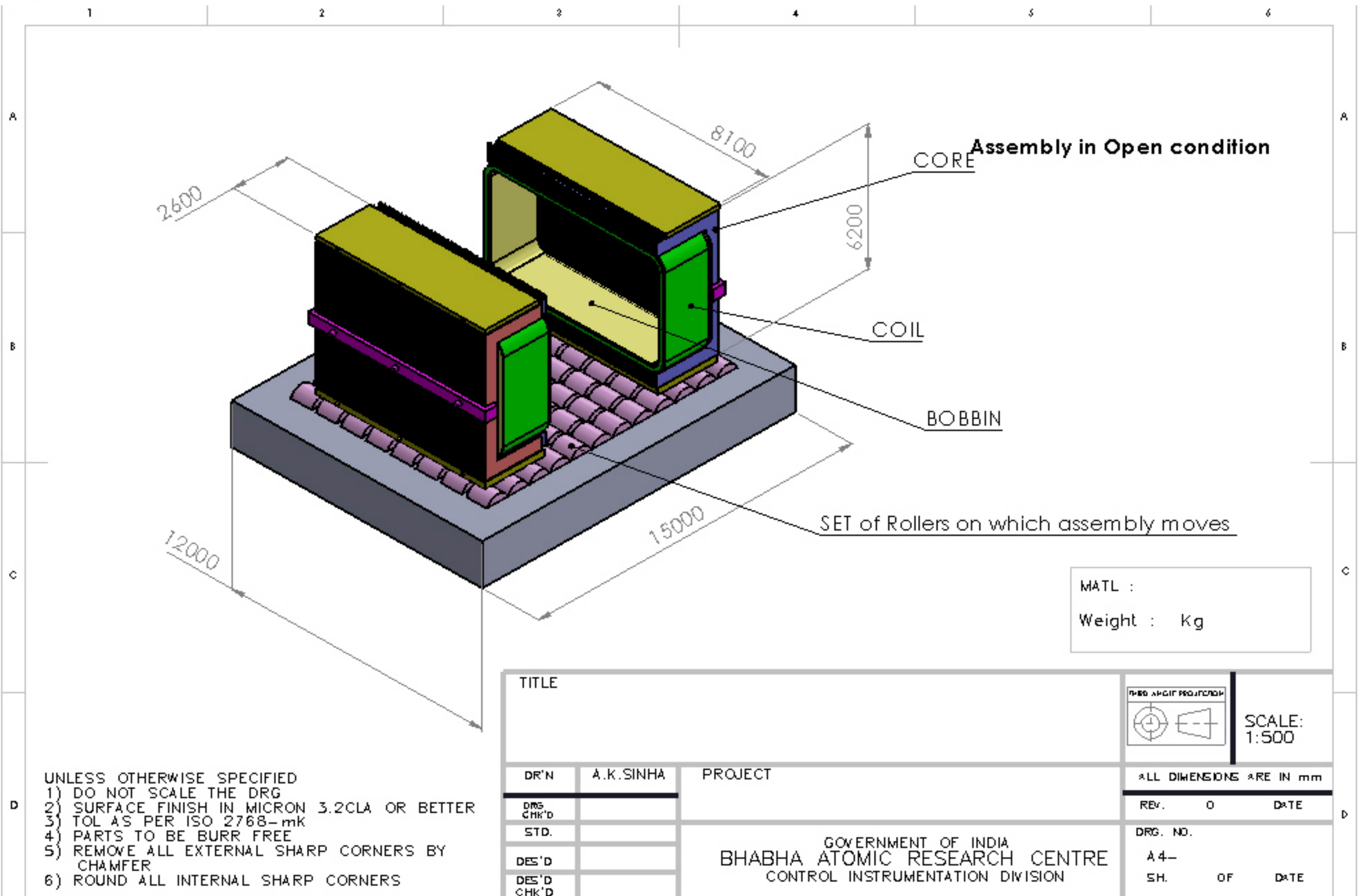
Particulars of work plan	Cost in Millions of INR
LBNE Dipole magnet Design Report Thermal, Electrical, Hydraulic, Structural and Magnetic	11
Prototype magnet and Power supply Development	25
Prototype movable assembly Development	12
Magnetic measurement	5
Magnet Simulations	2
Magnet Design, structural ,thermal design software	25
Infrastructure development	20

Magnet Layout

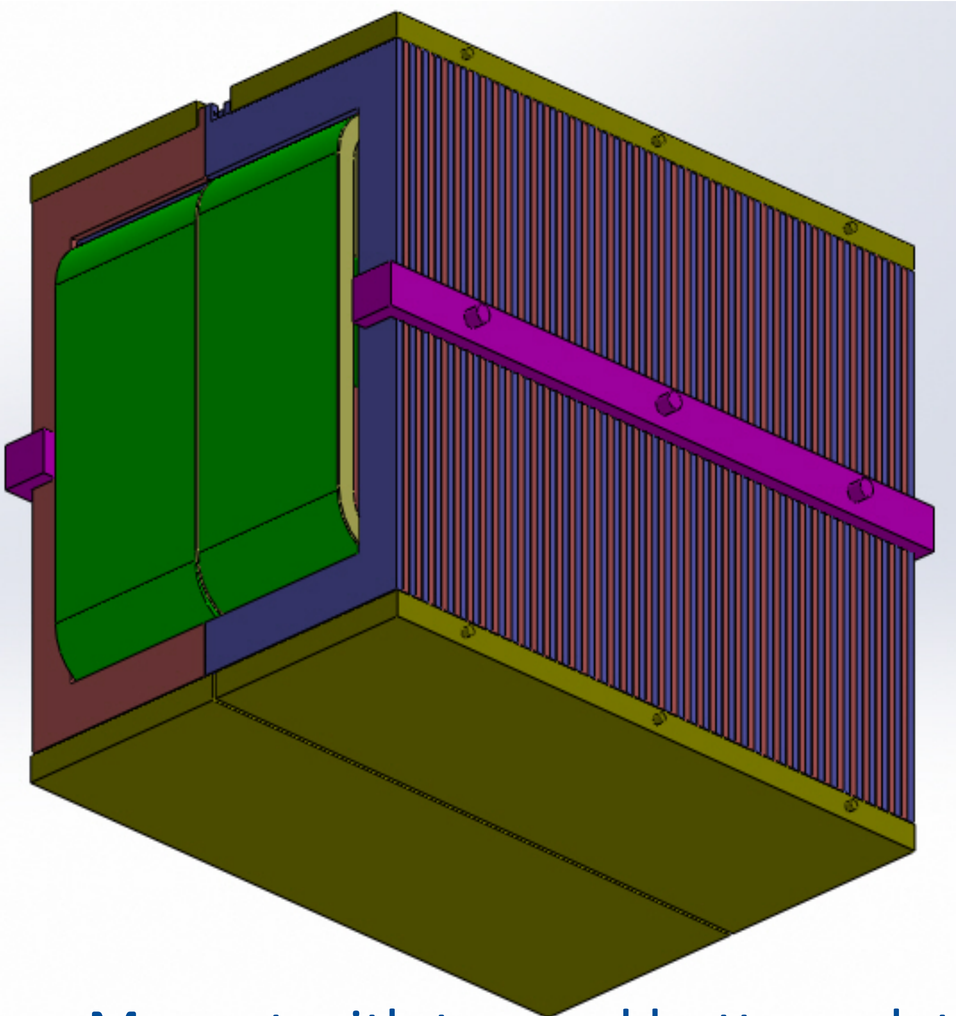
Magnet Assembly in closed condition



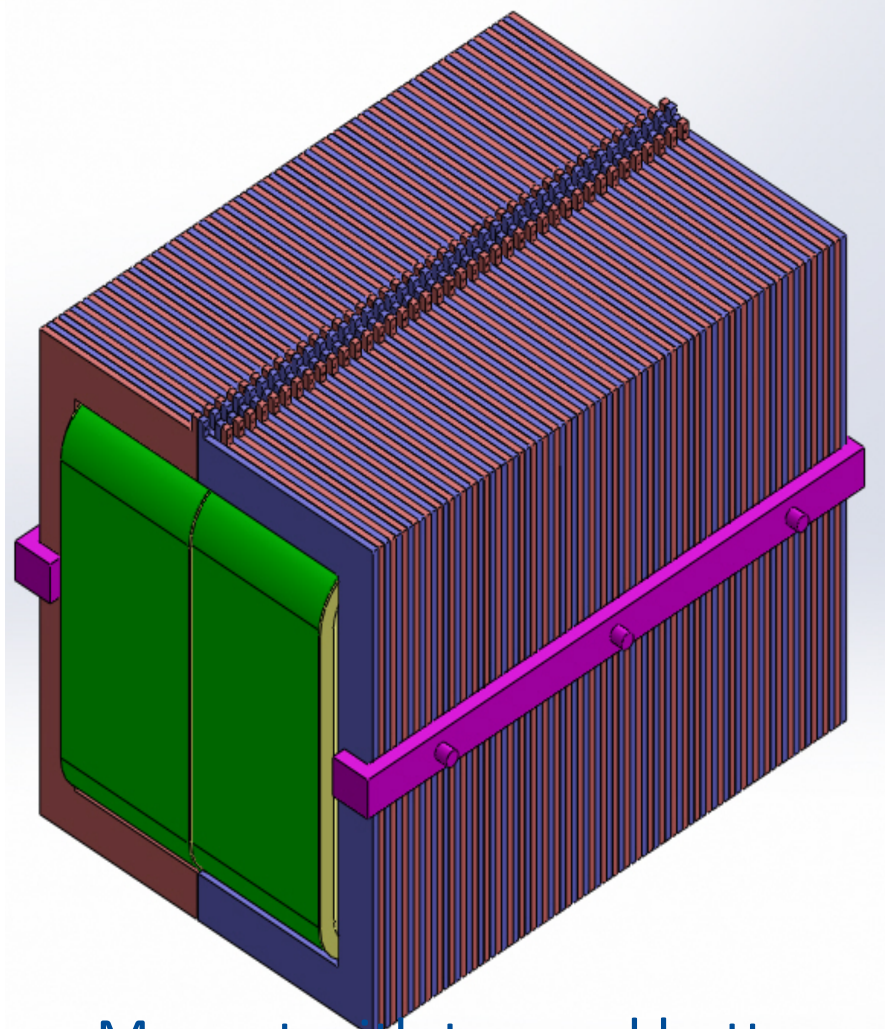
Magnet assembly in open condition



Perspective views of the Magnet

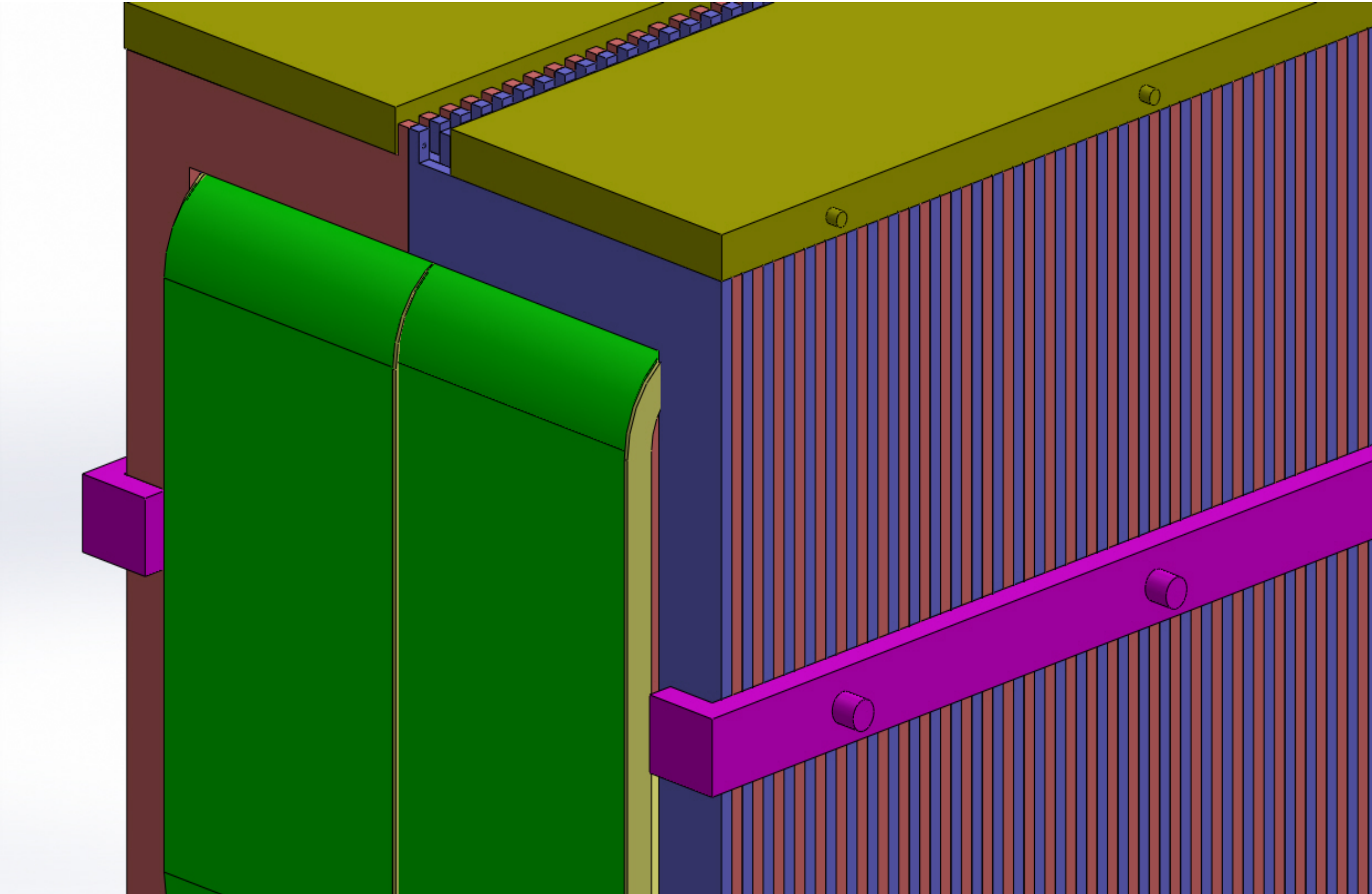


Magnet with top and bottom plates



Magnet with top and bottom plates hidden

Zoomed view of ‘C’ core assembly, coil and supporting plates

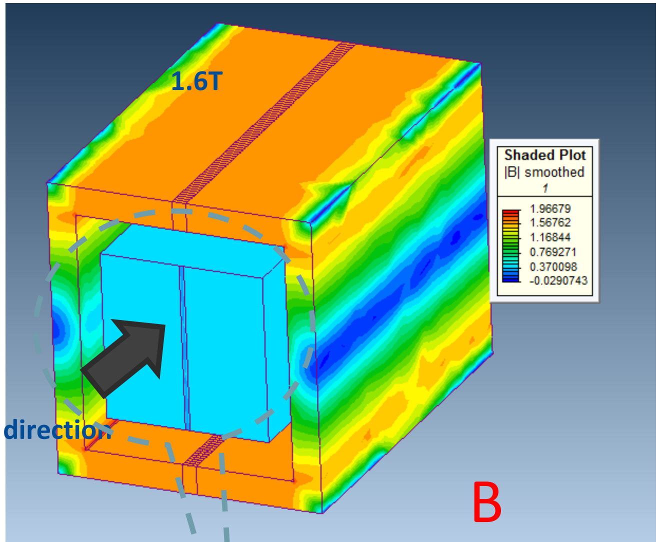


Magnetic Design

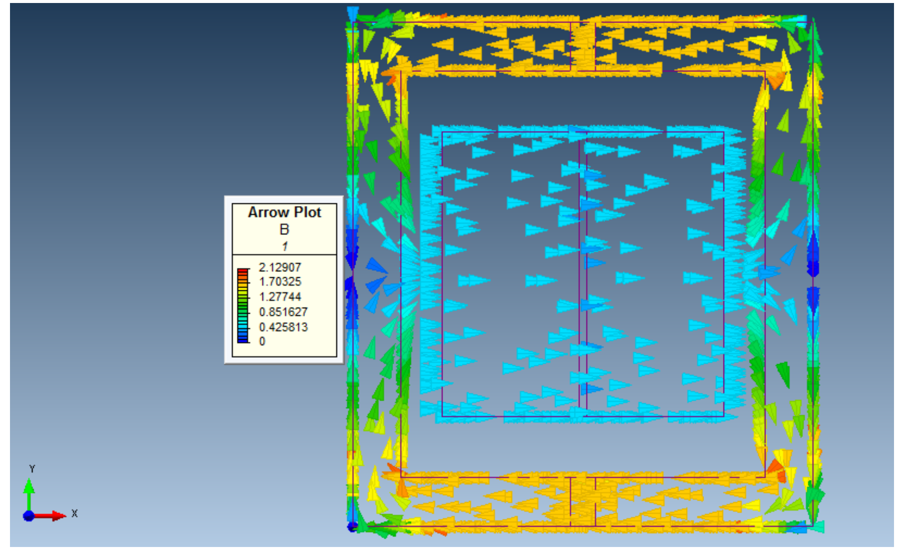
Coil-Bobbin Design: salient features

- 100 mm gap between the two bobbins
- The half cores will move with the coils
- The detectors will be accommodated in the space inside the two bobbins
- Water-cooled hollow copper conductors have been used
- Detachable type cooling tube attachments to chiller
- The Design can support upto 10 Tonnes of detector weight

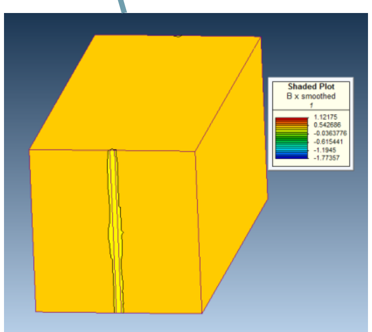
Magnetic simulation Results



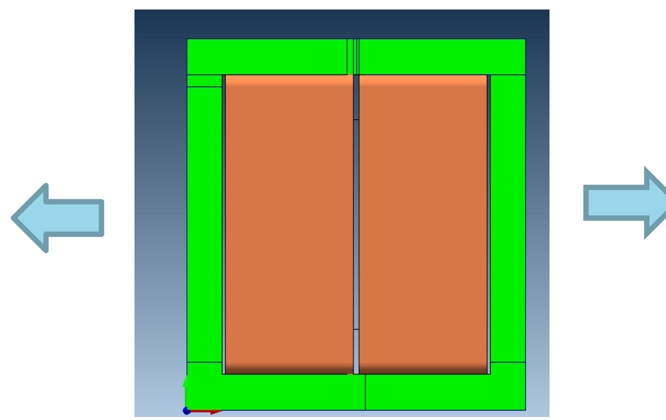
Volumetric Magnet field plot



Arrow plot of Magnetic field (x direction)

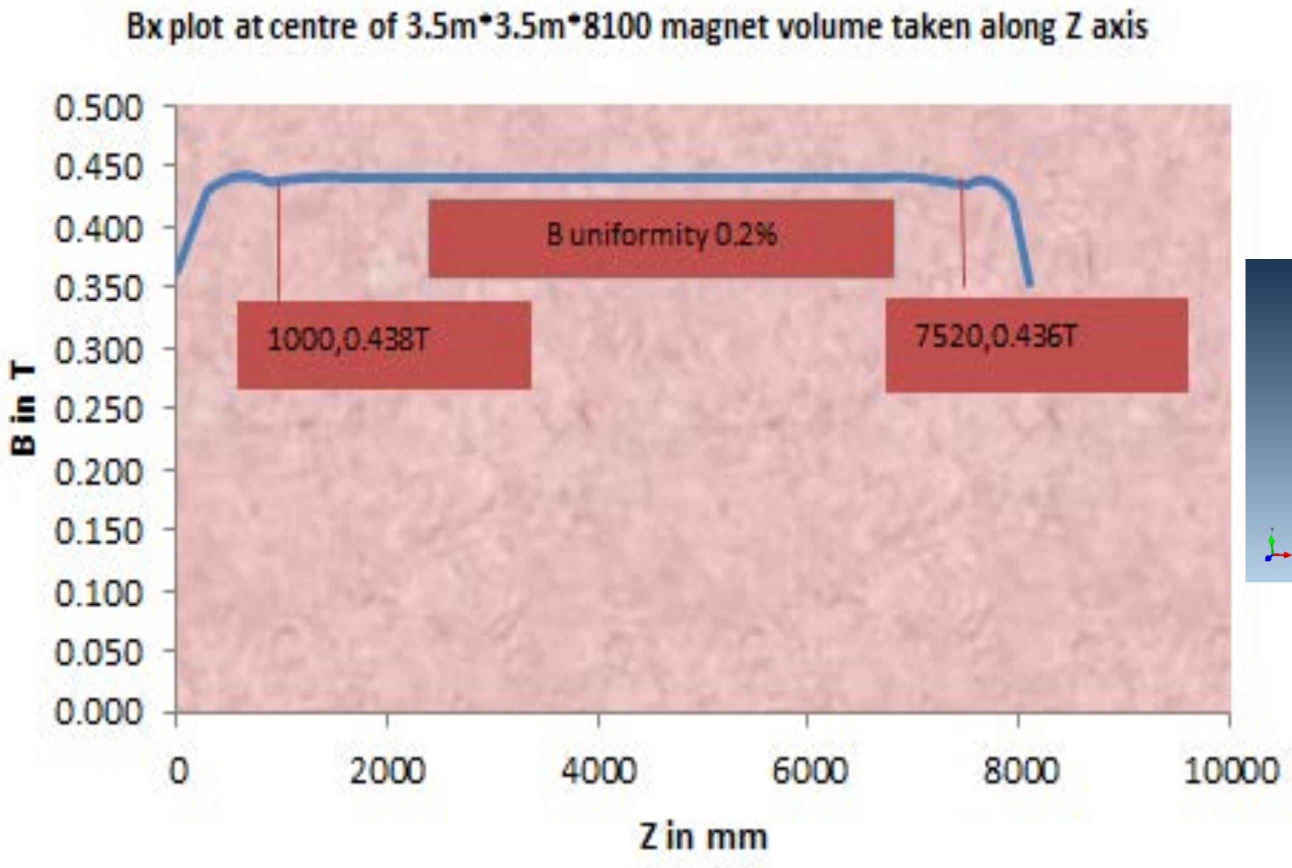


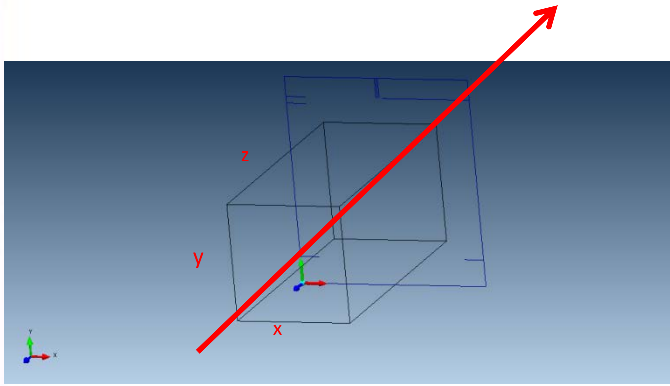
Volumetric Magnet field plot of Good field region (3.5 m X 3.5 m X 7.1 m)



Opening of core and coil bobbin

Bx plot at Centre of 3.5m*3.5m*8.1 magnet volume taken along z axis





Department of Science & Technology

Electrical and Thermal design parameters

Particulars	*Units*	*23/13/2R (Hollow conductor)*
8 layer Double pan cake Coil	*-*	*8+8*
MMF	*Ampere Turns*	*1600000*
Electrical turns	*-*	*1376*
Current in conductor	*Ampere*	*1163*
Current Density	A/mm^2	*2.96*
Copper Cross-sectional Area	mm^2	*393*
Water flow area	mm^2	*133*
Total Resistance	Ω	*1.80*
Total Inductance	*Henry*	*11.7*
Total weight of Copper	*MT(Metric Tonnes)*	*150*
Time to settle of current	*Seconds*	*32*
Total length of Copper conductor in one hydraulic circuit	*m*	*480 (available 520 m)*
Total Power Loss (MW)	*MW*	*2.43*

& Technology

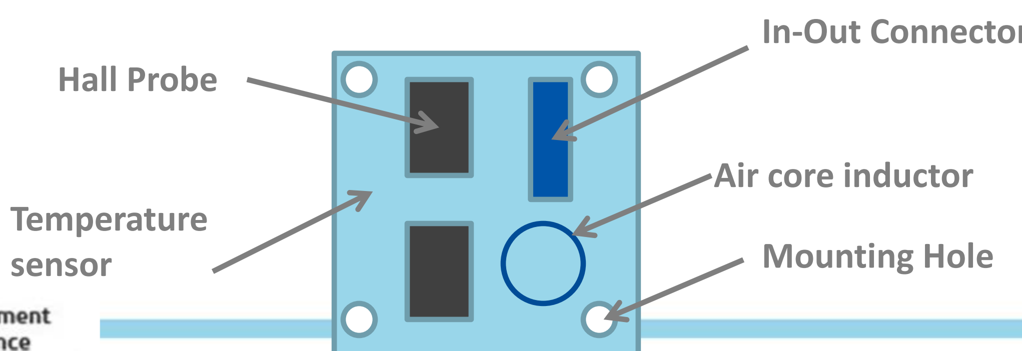
Hydraulic design Parameters

Particulars	Units	Value
Single hydraulic circuit (Turns, length)	meter	16 ,480
Total number of hydraulic circuits in parallel	-	86
Power Loss per hydraulic circuit	kW	28.25
Cooling Flow rate	LPM	8.968
Pressure drop in single hydraulic circuit	bar	8.58
Water velocity	m/s	1.15
Temperature difference between inlet and outlet header for single hydraulic circuit	^oK	45
Cooling Surface area	m^2	19.59
Reynolds Number	-	21900
Prandtl number	-	4.536
Nusselt Number	-	112.93
Heat Flux	kW/m^2	1.44
Temperature difference between Copper surface and Bulk water temperature	^oK	0.26
Bulk water temperature (taken ref inlet water temperature as 20)	^oC	42.5
Heat Transfer Coefficient	$W/m^2/^oK$	5458

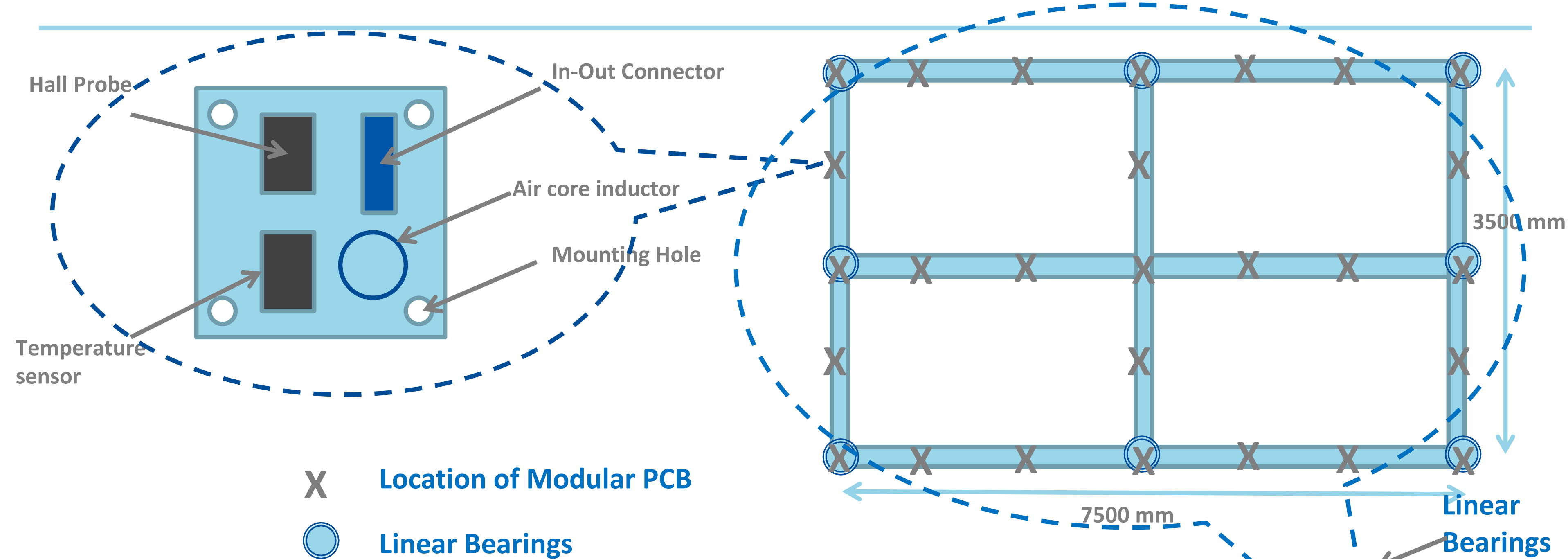
Magnetic Measurements

Magnetic Measurement methods

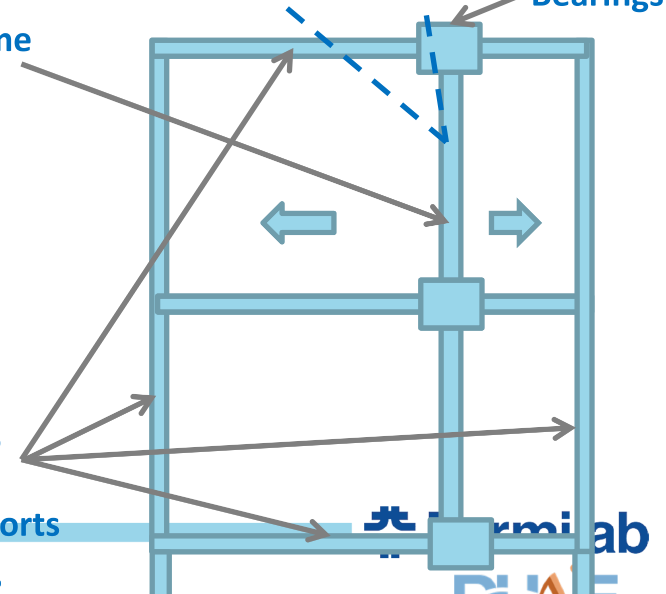
1. Hall probe and search coil based magnetic measurement system has been envisaged for magnetic qualification of LBNE Dipole Magnet.
2. The parameters to be measured are (a) Magnetic field density, and (b) Magnetic field uniformity in the GFR.
3. Modular Magnetometer PCBs housing Hall probes and PCB based search coils/air core inductors shall be fabricated and magnetic field mapped using multichannel Data Acquisition system having Lab VIEW GUI for instant data interpretation.
4. The large Good Field Region poses challenges for Magnetic field measurement, for which moving SS frame movable on linear bearings shall be designed. Modular PCB Magnetometers shall be mounted on this frame and measurements shall be carried out at discrete longitudinal locations in one plane.
5. Possibility of using Magneto-Optical (MO) sensors for Magnetic field measurement using shall be explored.



Magnetic Measurements System

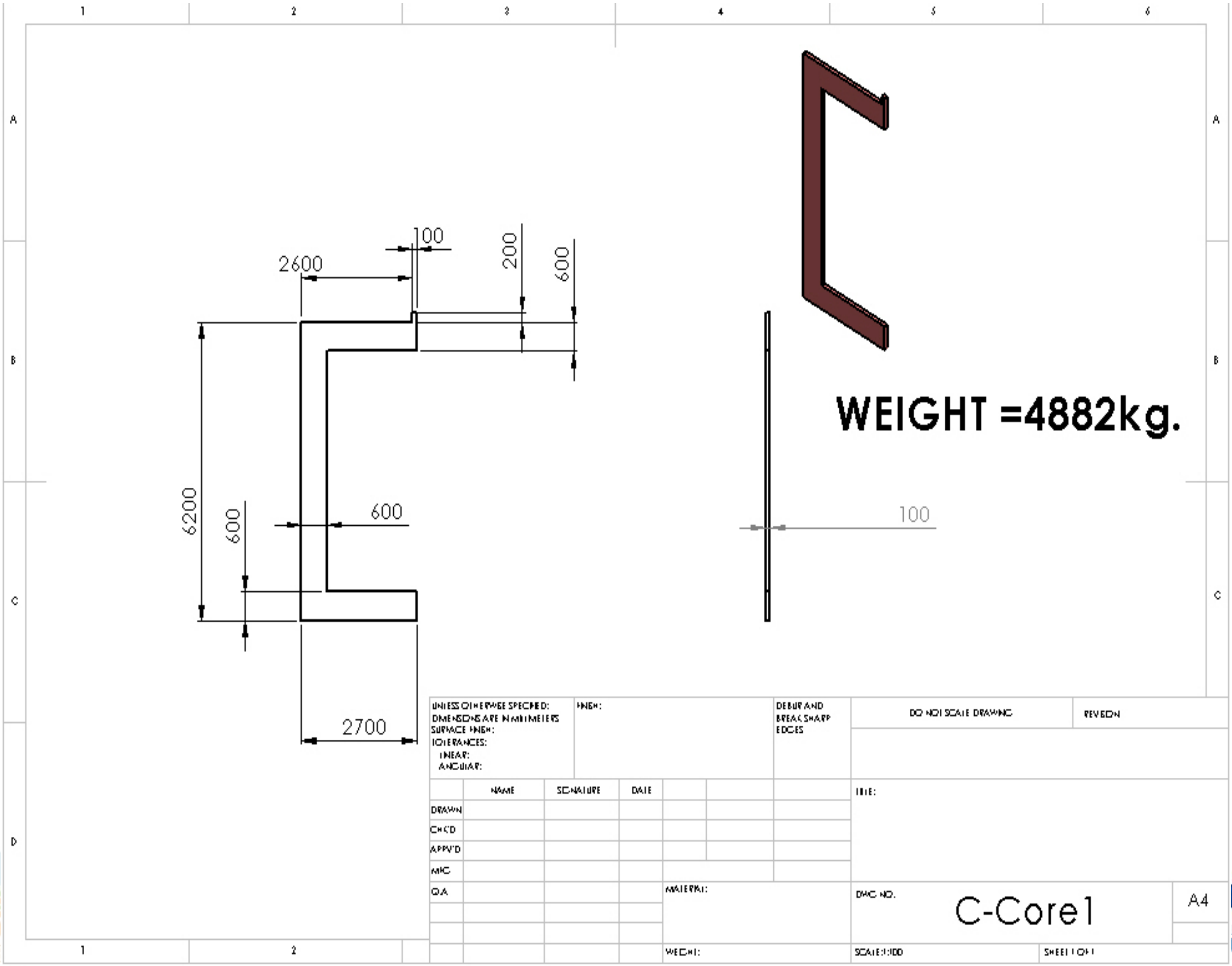


1. The sensor configuration is tentative and more number of sensors can be accommodated; 80 channel DAS is planned for the system.
2. Same system shall be used for Magneto-Optical based measurement systems. The MO sensor shall be placed on moving

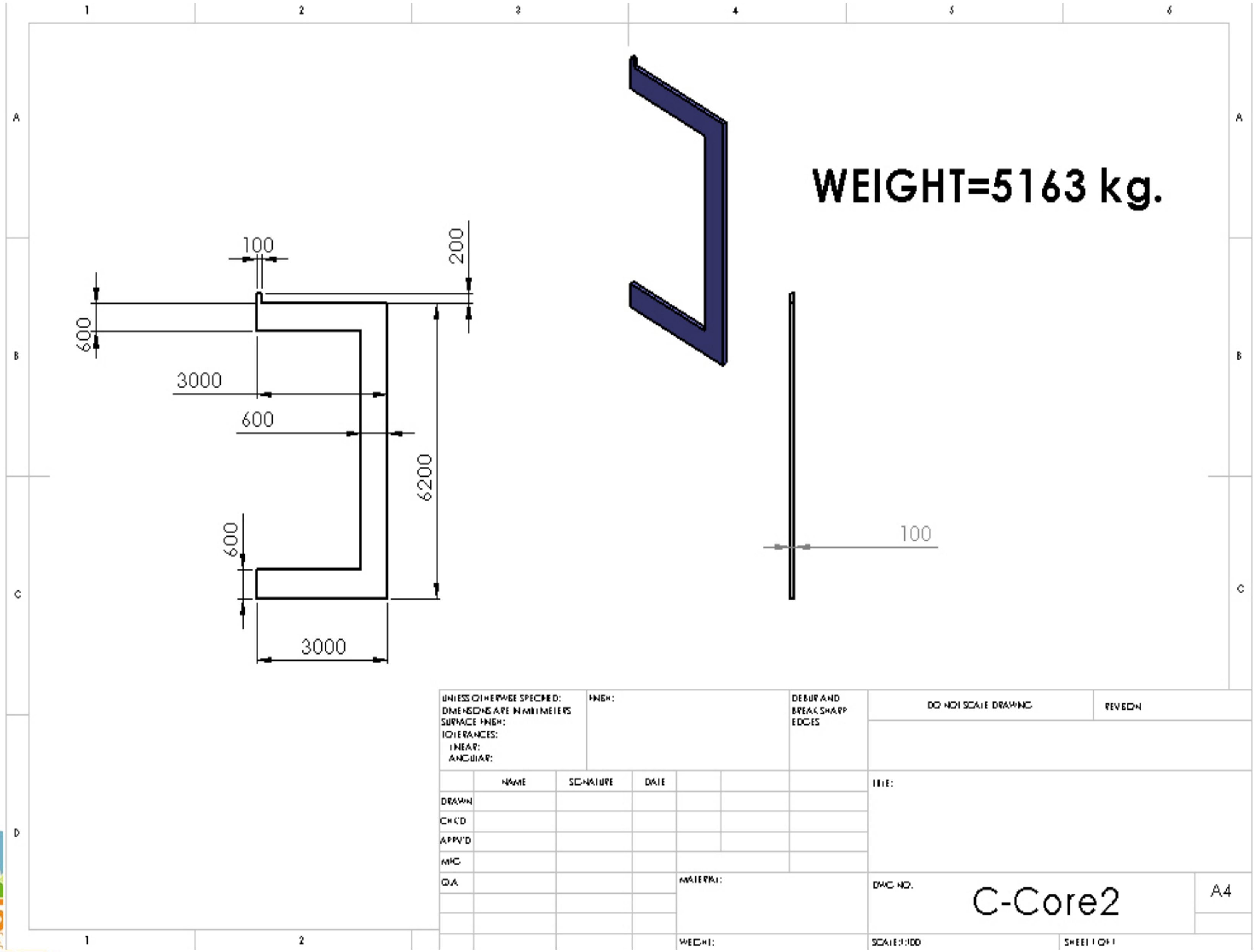


Structural Design

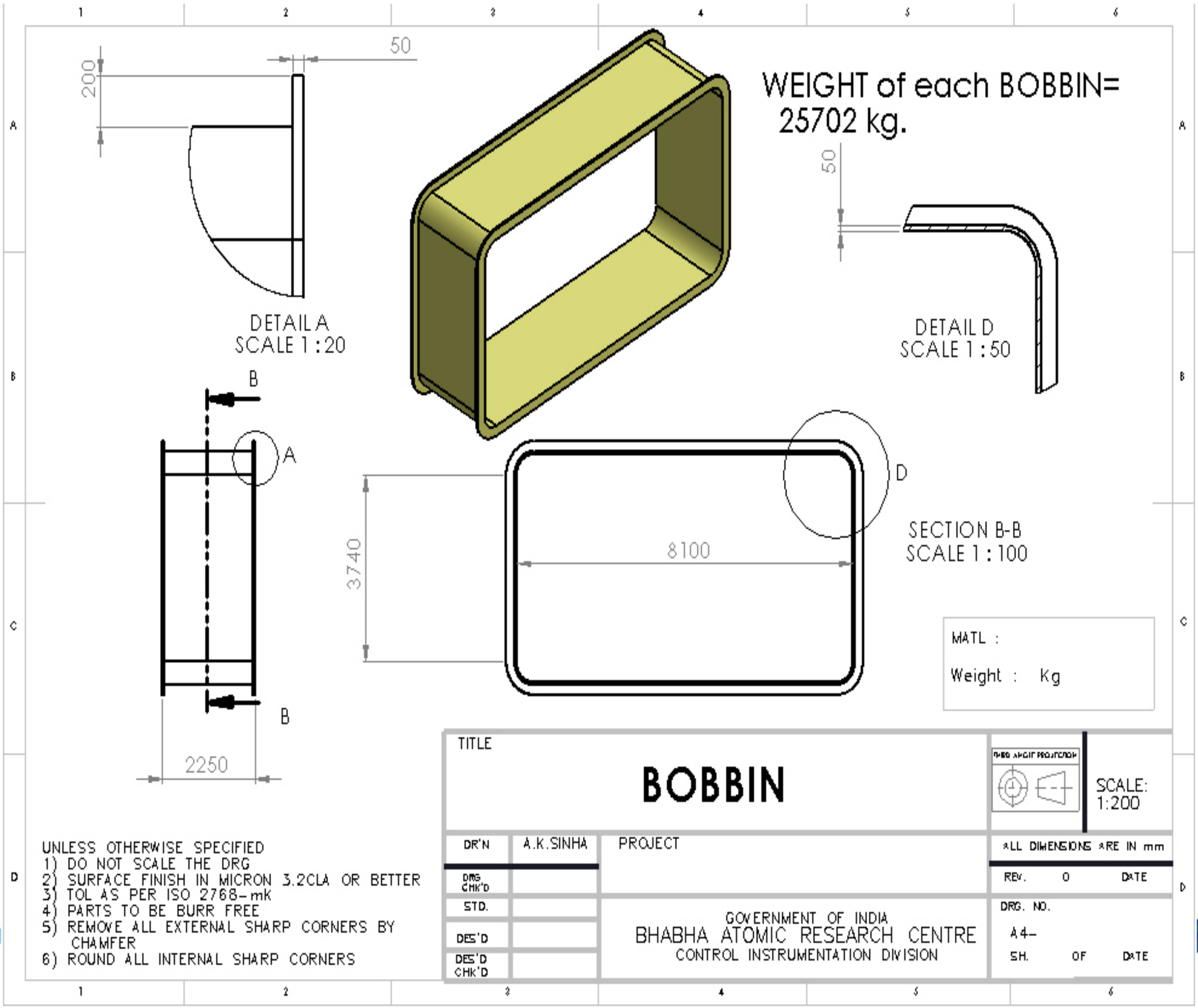
‘C’ Core Type I


2600
100
200
600
6200
600
600
2700
100
WEIGHT =4882kg.
DO NOT SCALE DRAWING
C-Core1
A4

‘C’ Core Type II

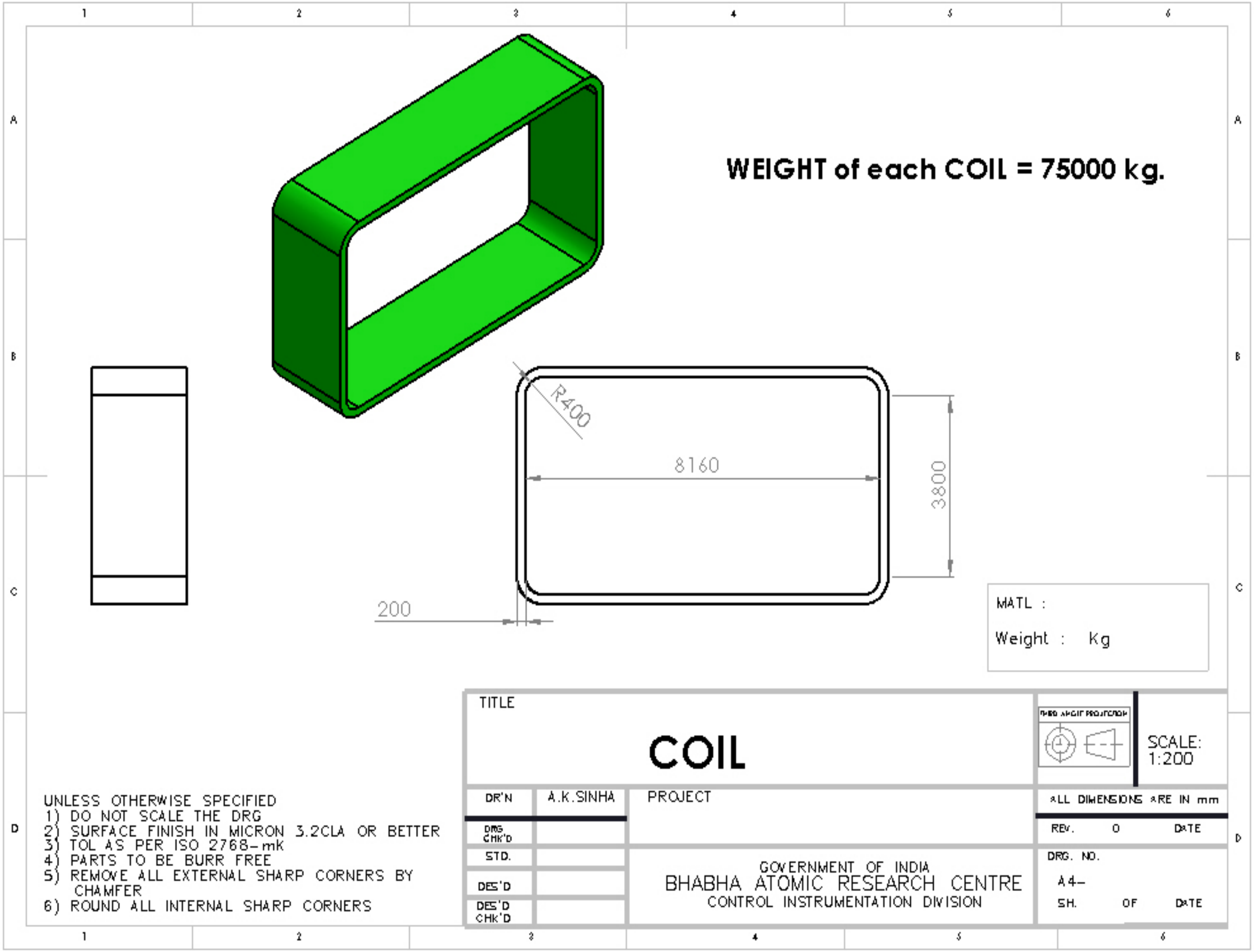


Coil Bobbin



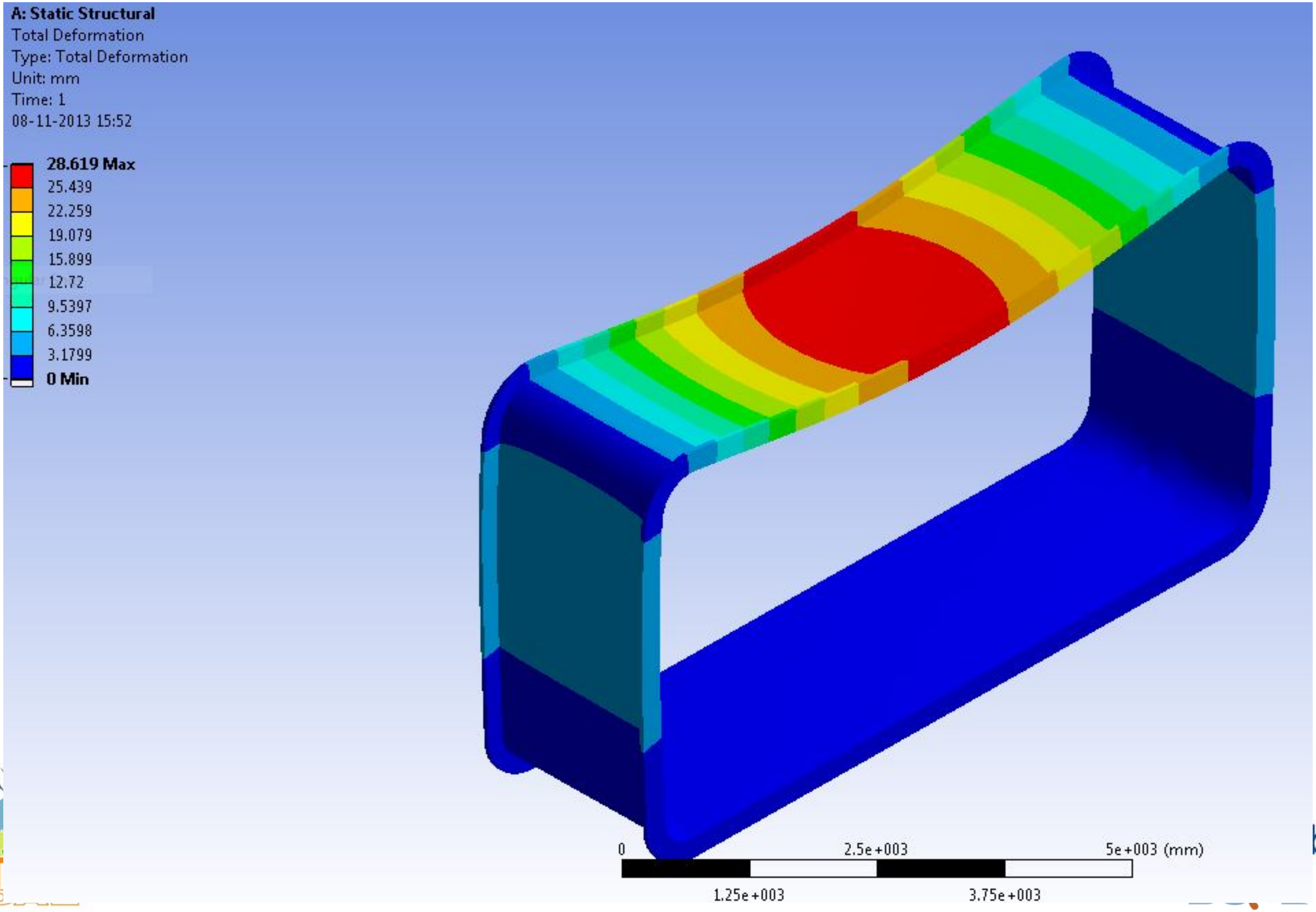
WEIGHT of each BOBBIN=
25702 kg.
DETAIL A
SCALE 1 : 20
DETAIL D
SCALE 1 : 50
SECTION B-B
SCALE 1 : 100
200
50
50
2250
3740
8100
A
B
B
D
MATL :
Weight : Kg
TITLE
BOBBIN
SCALE:
1:200
DR'N
A.K.SINHA
PROJECT
DRG CHK'D
STD.
DES'D
DES'D CHK'D
ALL DIMENSIONS ARE IN mm
REV. 0 DATE
DRG. NO.
A4-
SH. OF DATE
GOVERNMENT OF INDIA
BHABHA ATOMIC RESEARCH CENTRE
CONTROL INSTRUMENTATION DIVISION
UNLESS OTHERWISE SPECIFIED
1) DO NOT SCALE THE DRG
2) SURFACE FINISH IN MICRON 3.2CLA OR BETTER
3) TOL AS PER ISO 2768-mk
4) PARTS TO BE BURR FREE
5) REMOVE ALL EXTERNAL SHARP CORNERS BY CHAMFER
6) ROUND ALL INTERNAL SHARP CORNERS

COIL

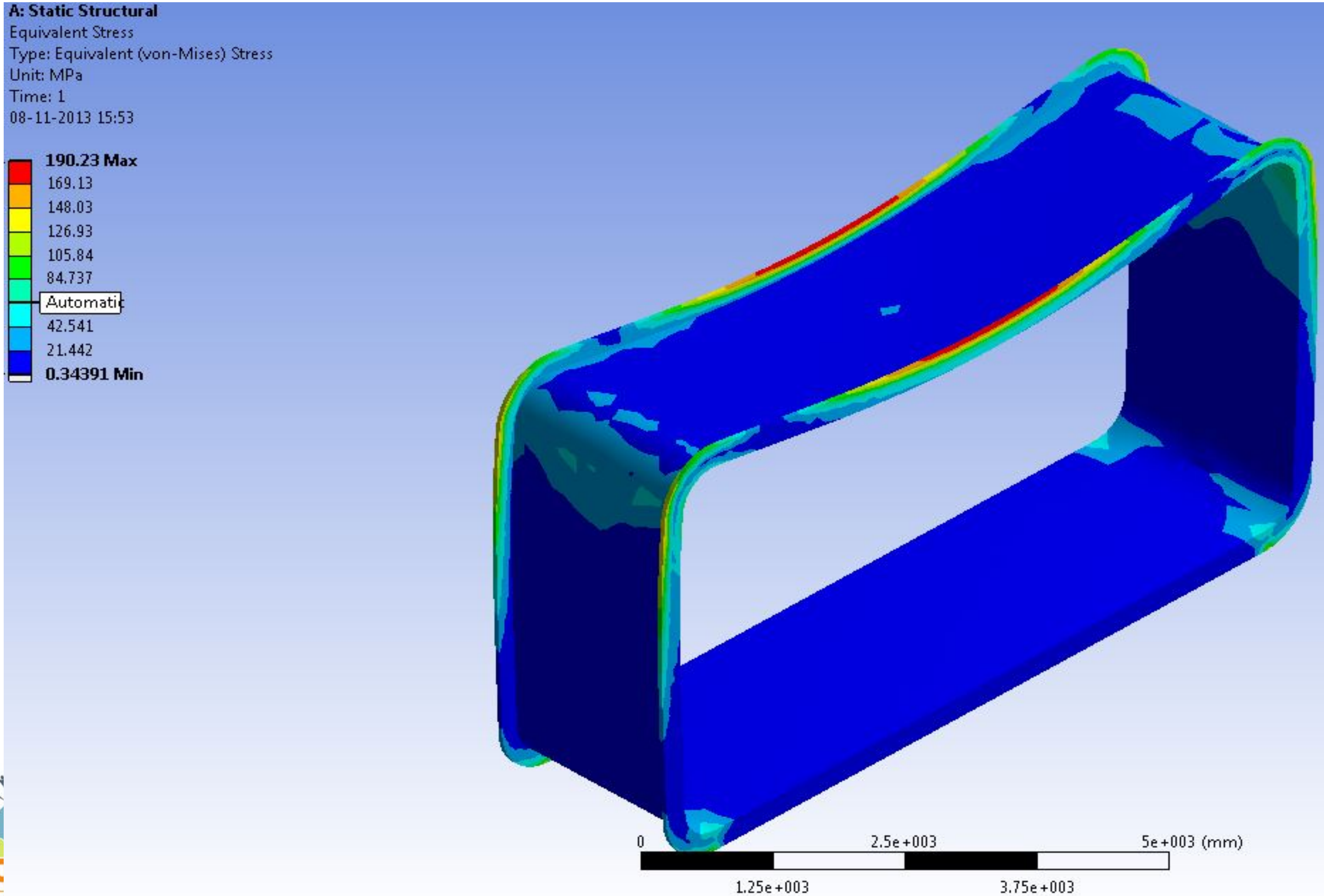


WEIGHT of each COIL = 75000 kg.
R400
8160
3800
200
MATL :
Weight : Kg
TITLE
COIL
SCALE: 1:200
DR'N A.K.SINHA
PROJECT
ALL DIMENSIONS ARE IN mm
DRG CHK'D
REV. 0 DATE
STD.
DRG. NO.
A4-
DES'D
GOVERNMENT OF INDIA
BHABHA ATOMIC RESEARCH CENTRE
CONTROL INSTRUMENTATION DIVISION
DES'D CHK'D
SH. OF DATE
UNLESS OTHERWISE SPECIFIED
1) DO NOT SCALE THE DRG
2) SURFACE FINISH IN MICRON 3.2CLA OR BETTER
3) TOL AS PER ISO 2768-mK
4) PARTS TO BE BURR FREE
5) REMOVE ALL EXTERNAL SHARP CORNERS BY CHAMFER
6) ROUND ALL INTERNAL SHARP CORNERS

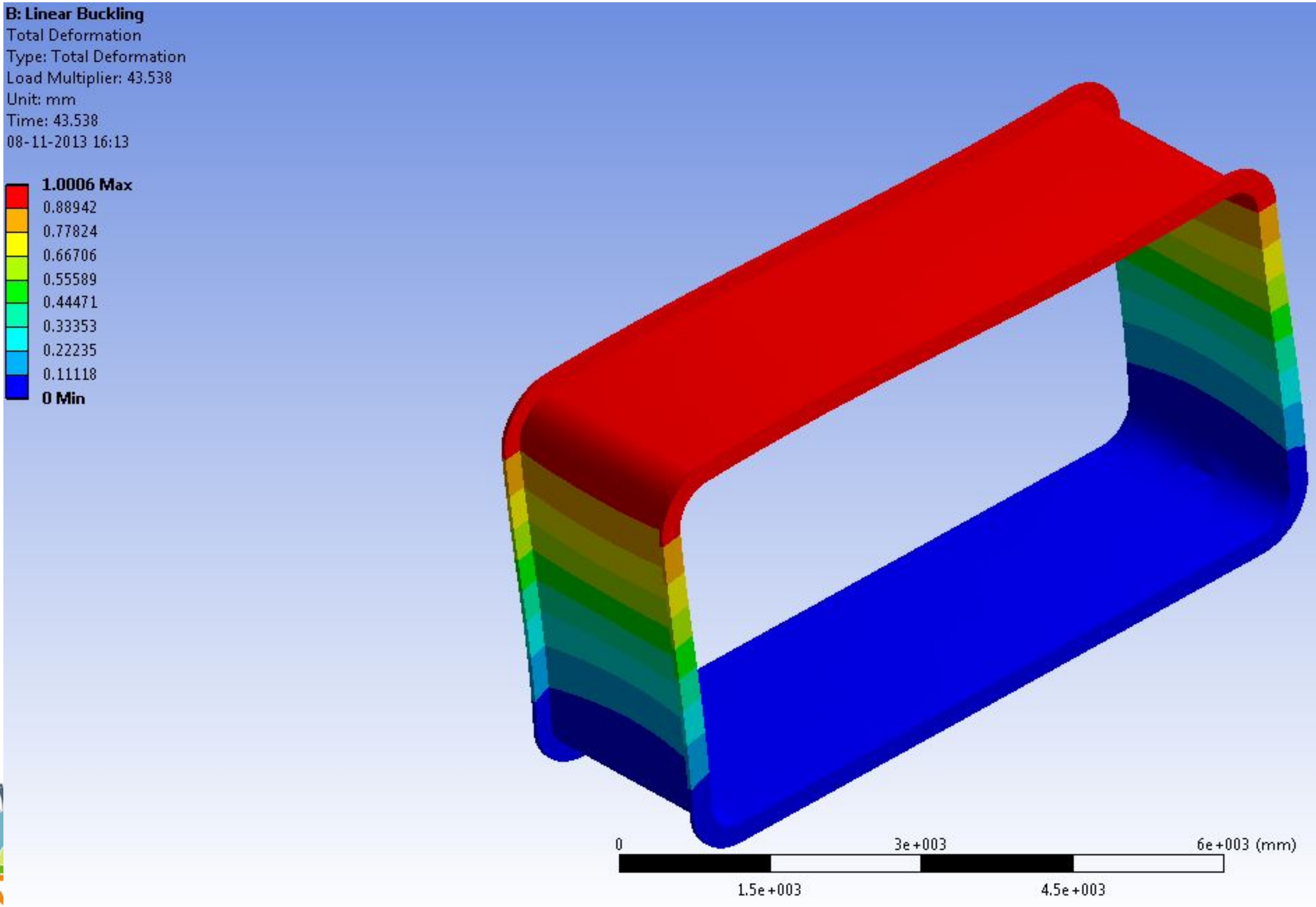
Max. Deformation of bobbin = 28.6 mm



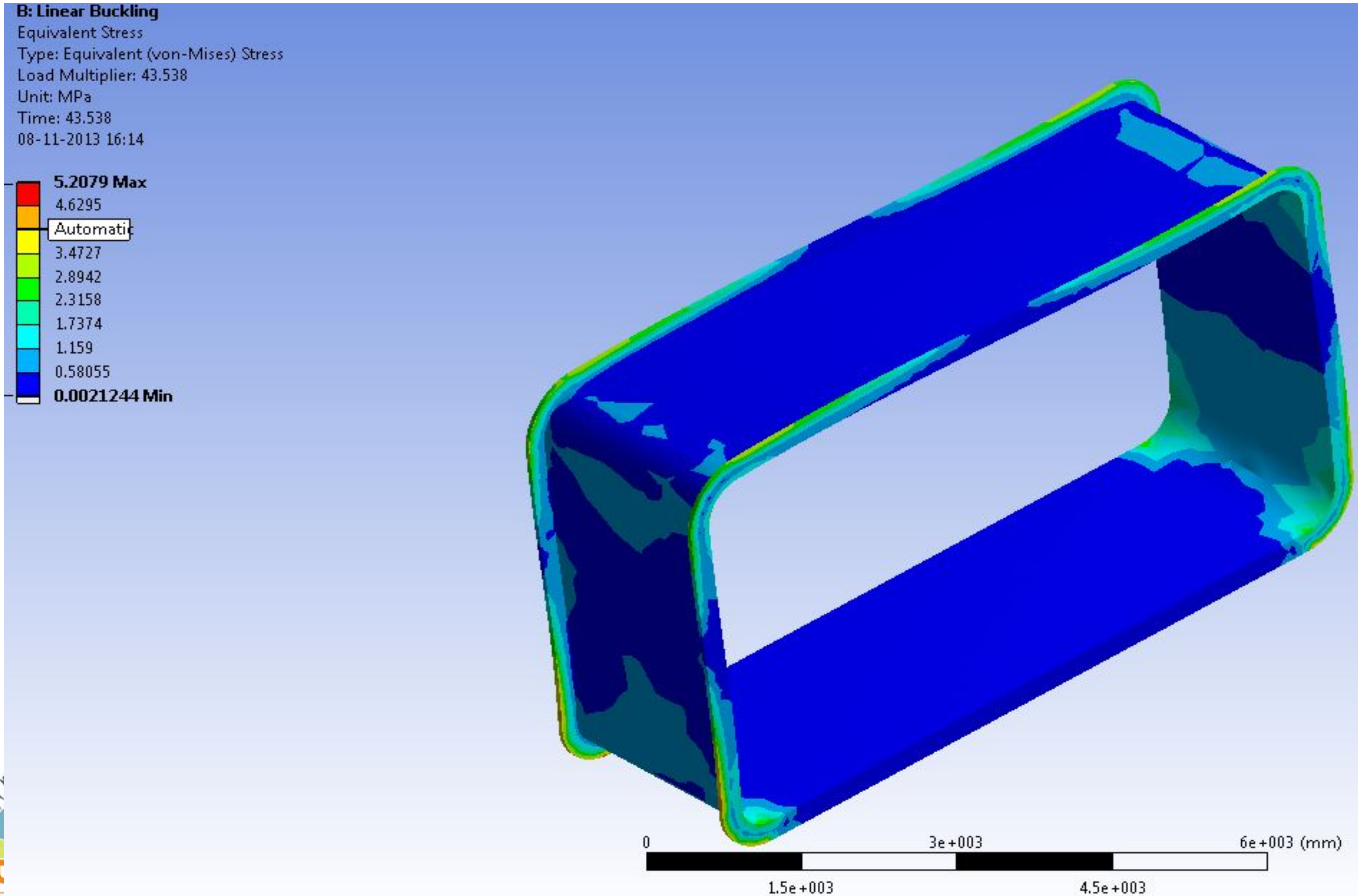
Maximum Von Mises Stress = 190 MPa



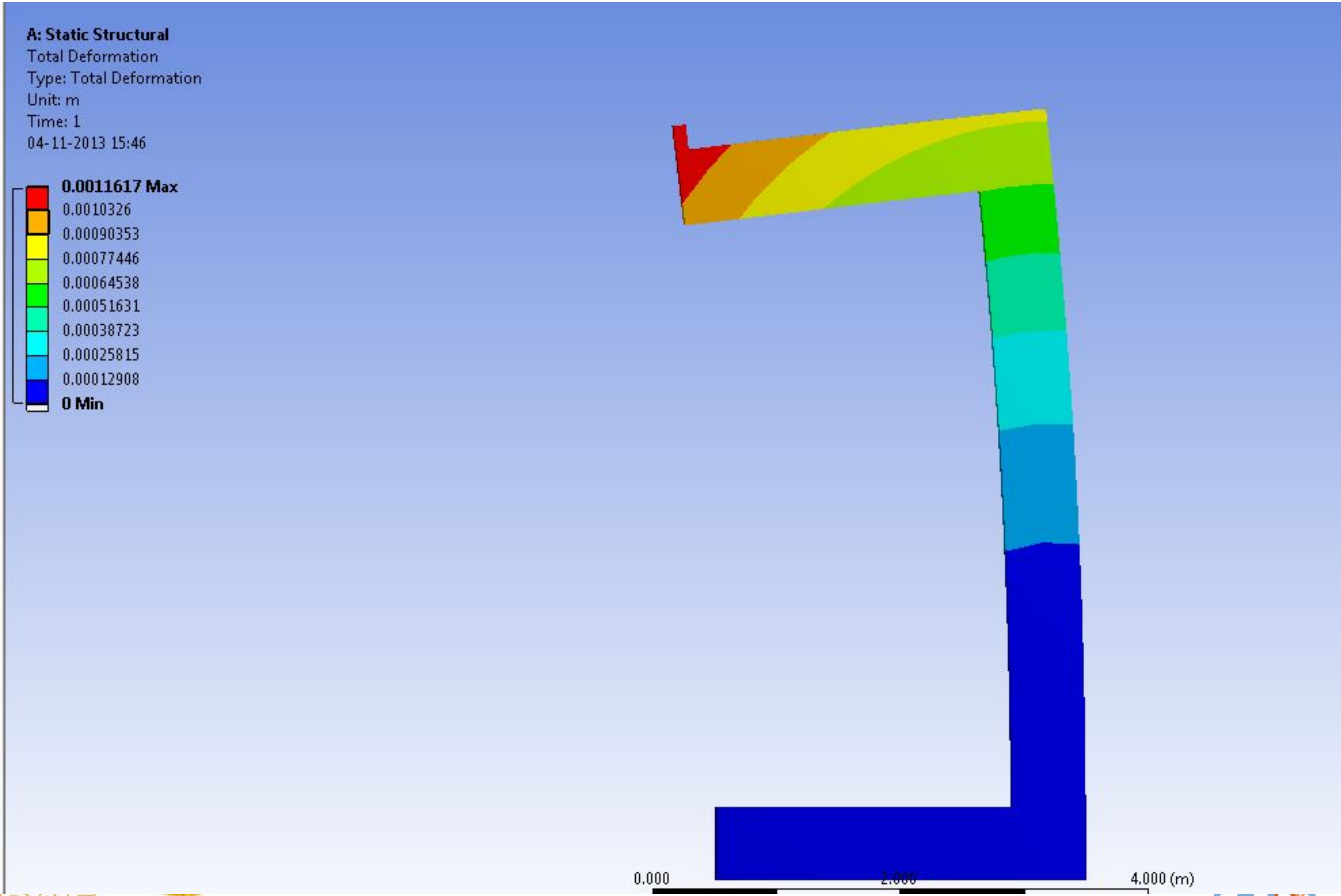
Max. deformation (buckling)=1 mm



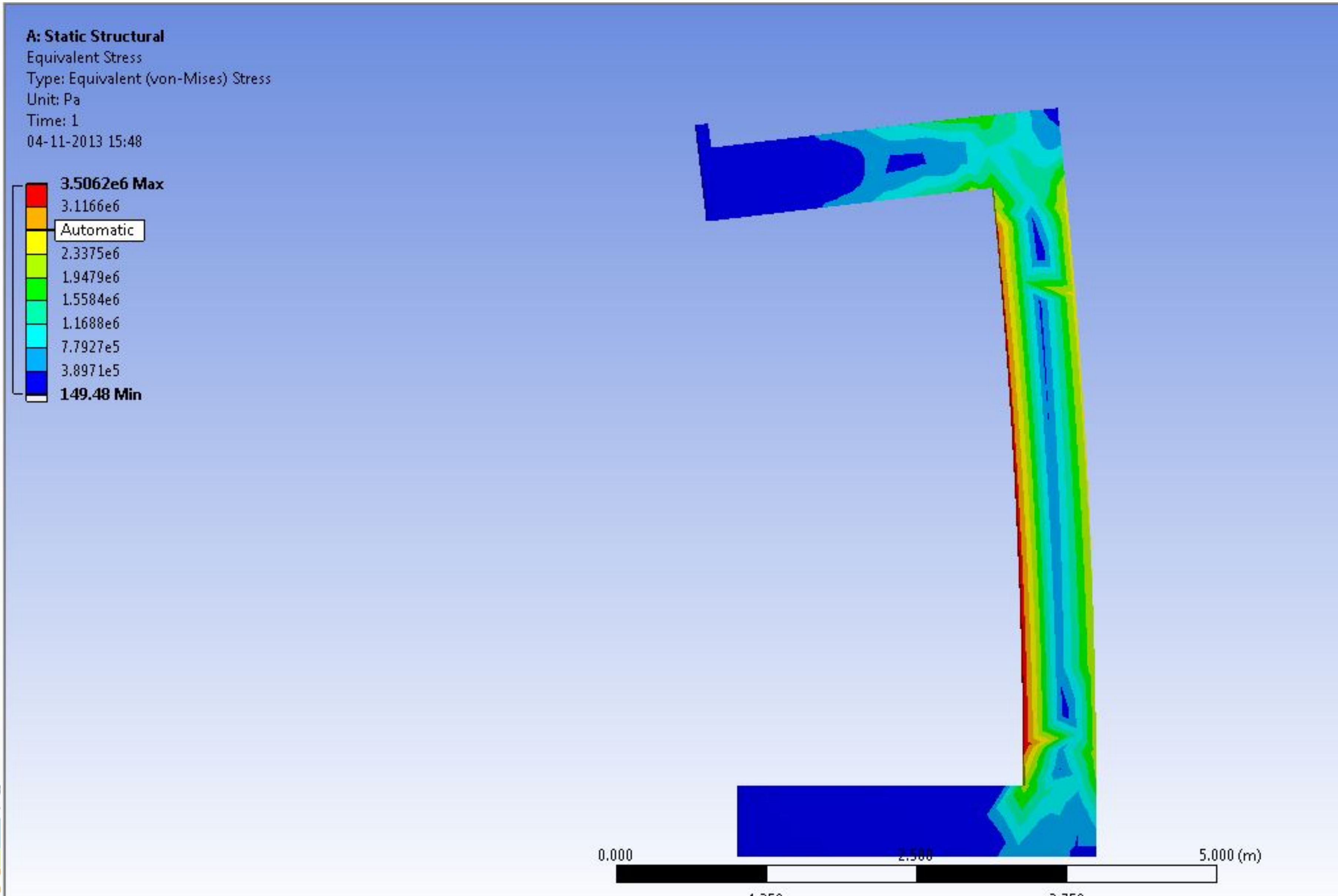
Max. Von Mises Stress (buckling) =5.20 MPa



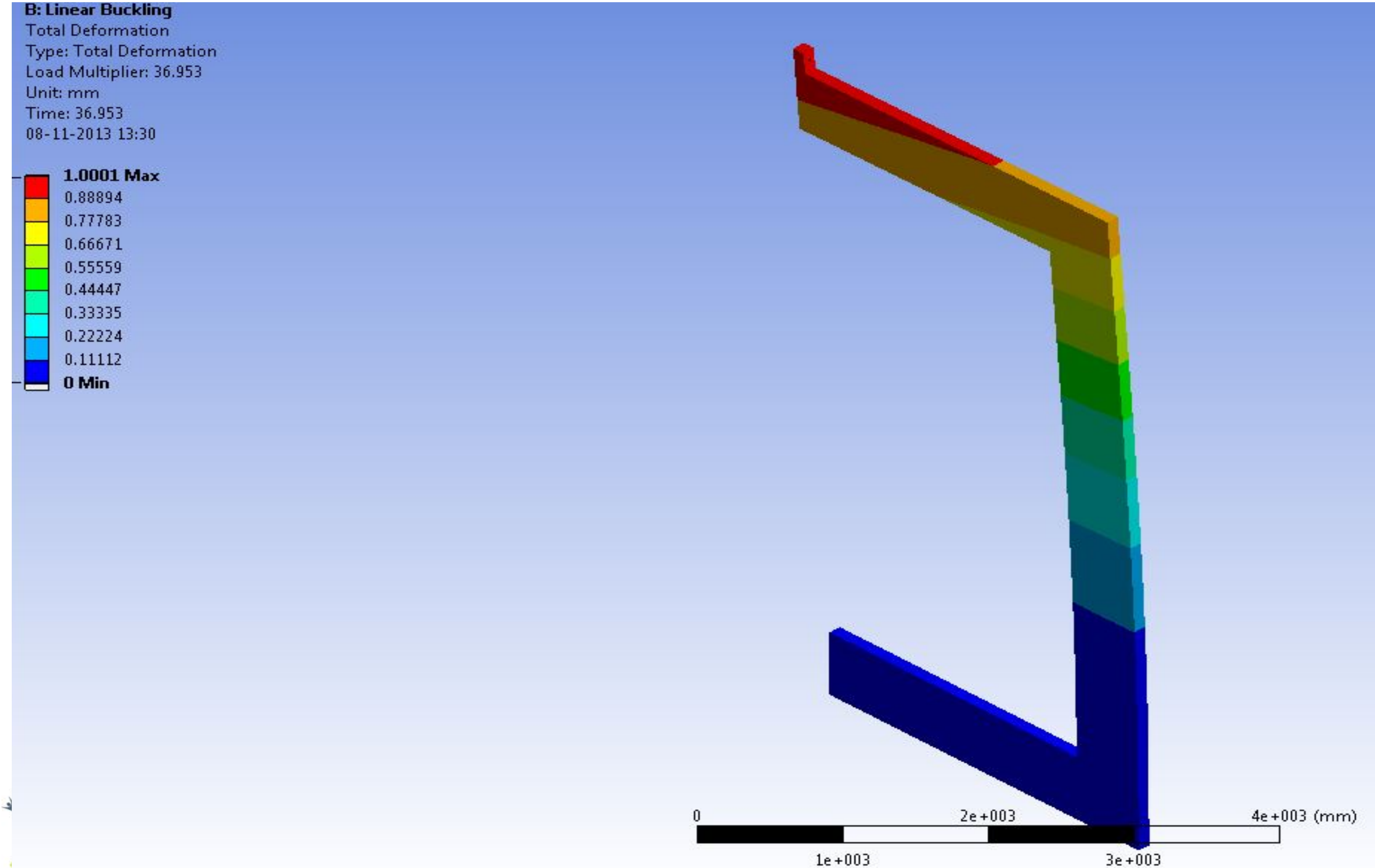
Max. Deformation of C-Segment = 1.16 mm



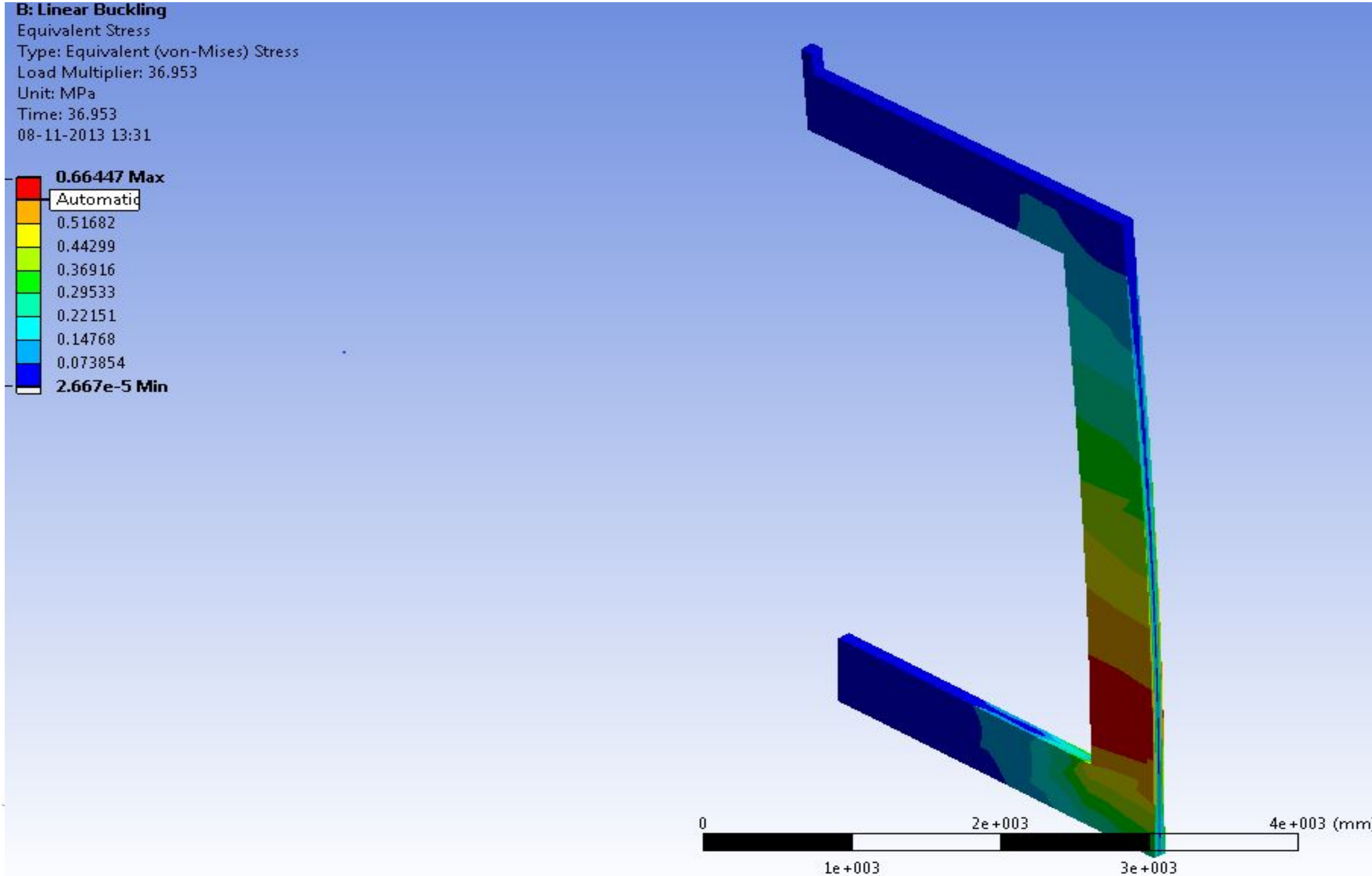
Max. Von Mises Stress =3.5 MPa



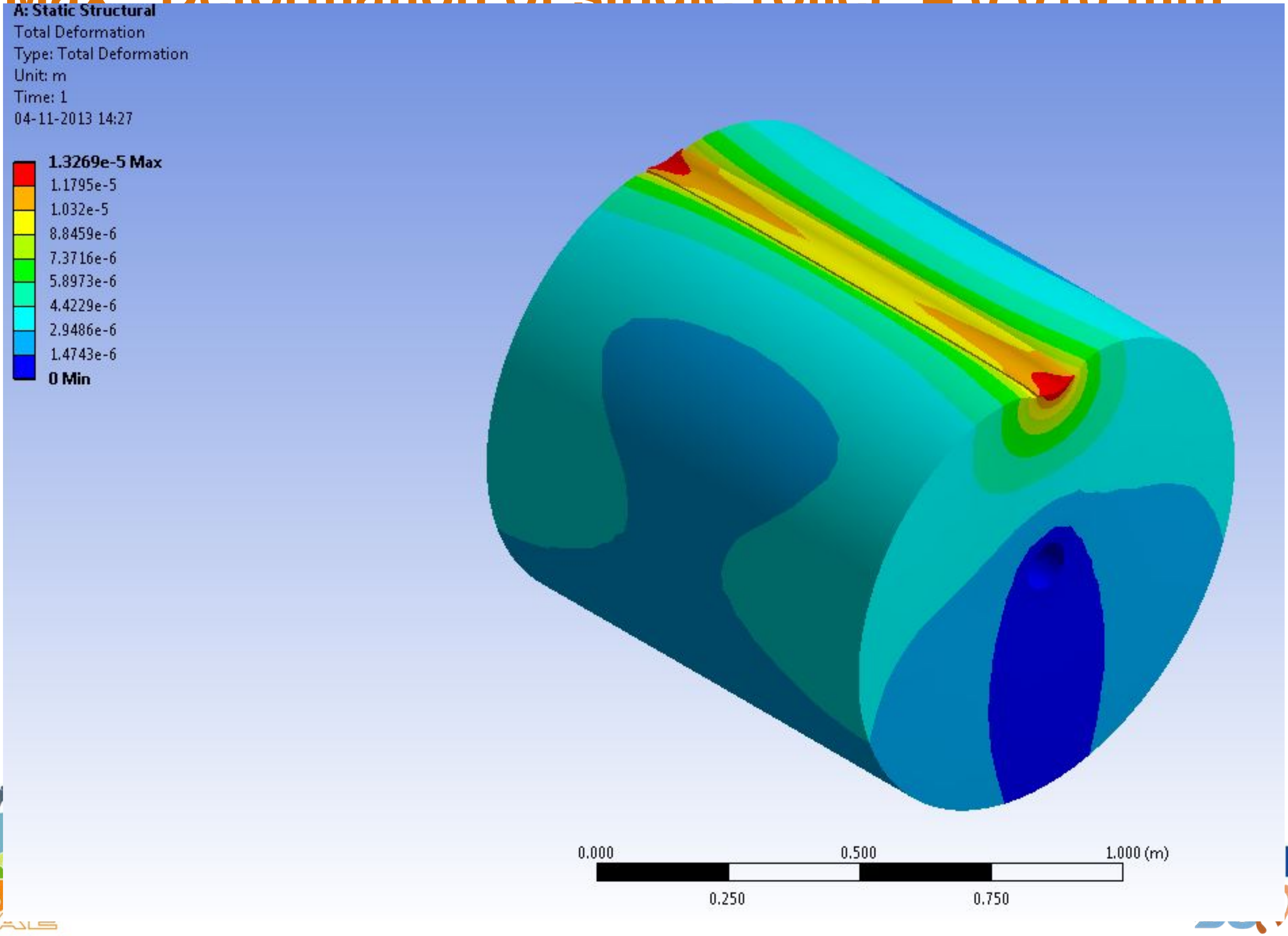
Max. Deformation (buckling)=1.00 mm



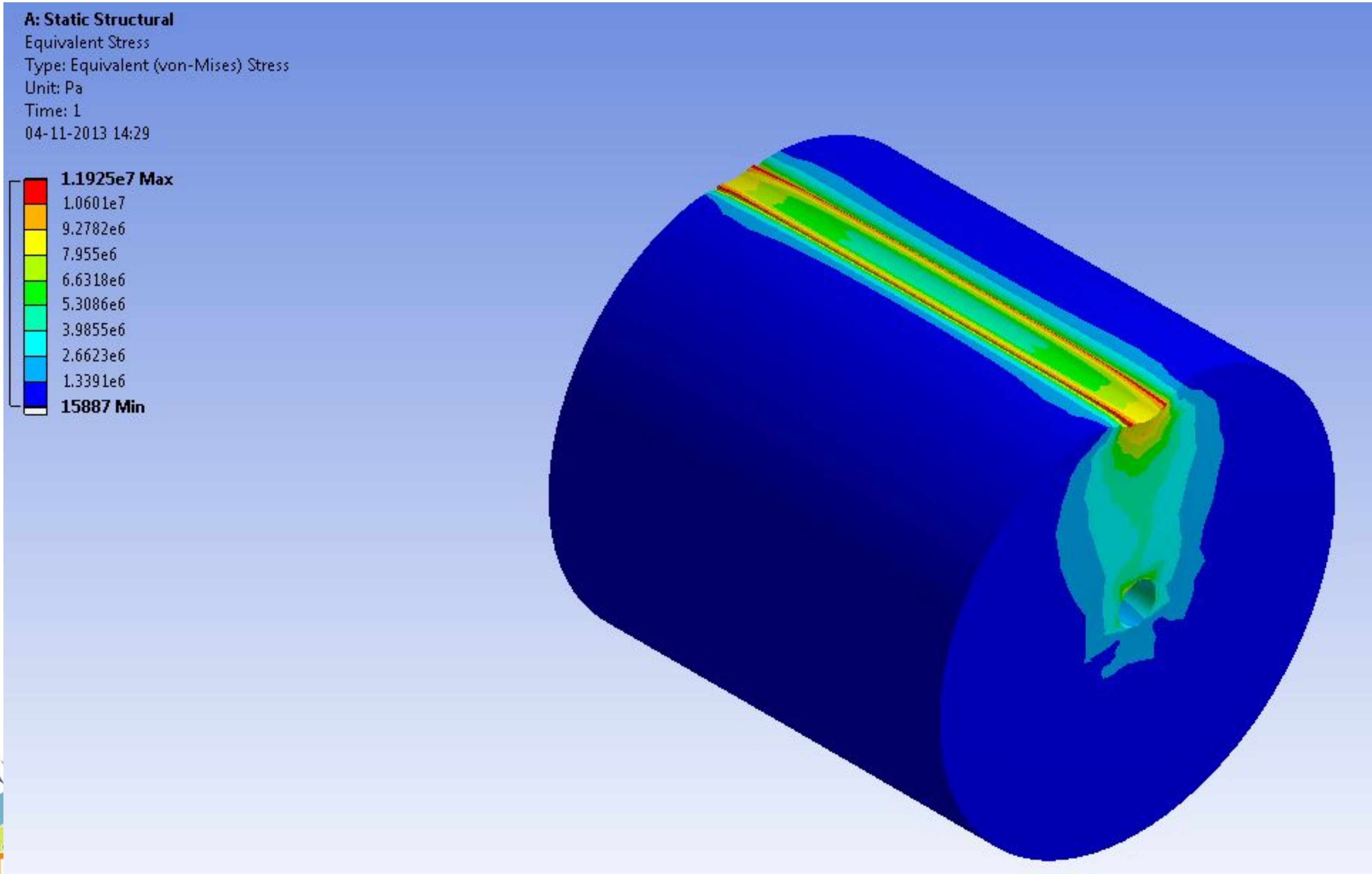
Max . Von Mises Stress(buckling) =0.664 MPa



Max. Deformation of single roller = 0.013 mm



Max. Von- Mises Stress of roller =11.9 MPa



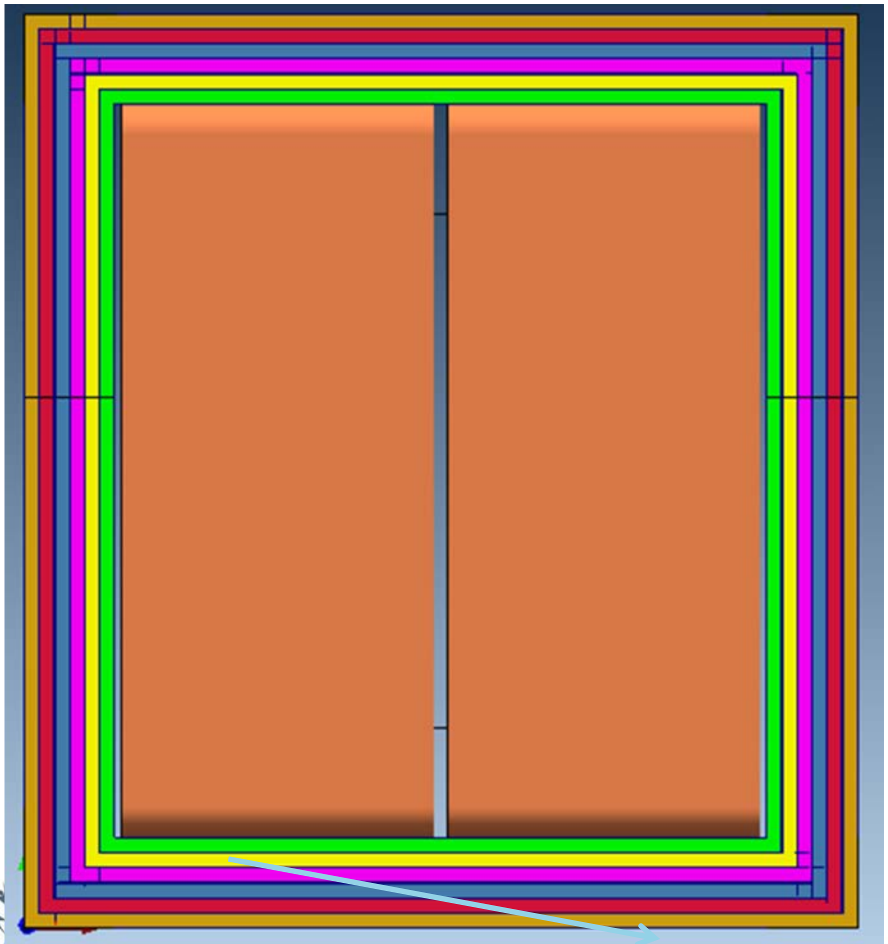
Bill of Material

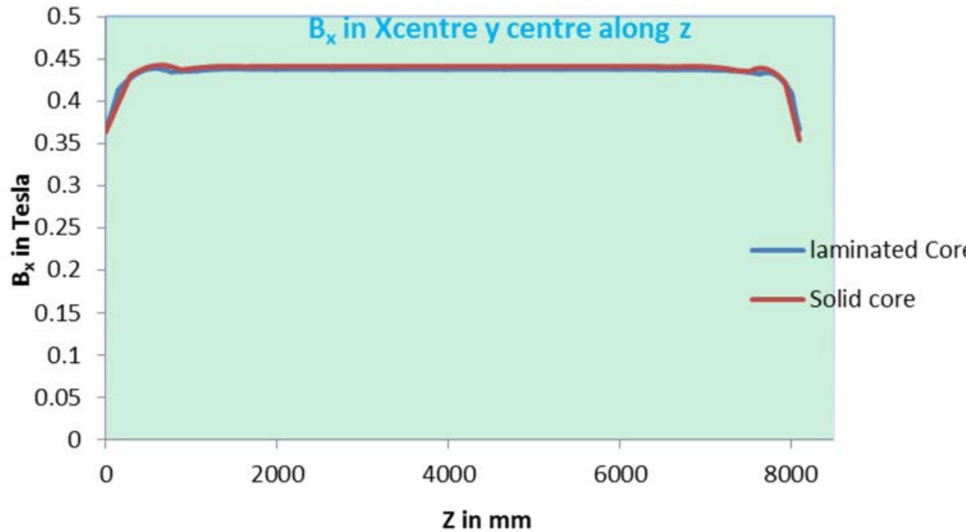
PART	Quantity	Material	Weight per unit (Tonnes)	Total weight (Tonnes)
Bobbin	2	Austenitic SS	25.7	52
C-Segment Type I	81	Soft Magnetic Steel	4.9	396
C-Segment Type II	81	Soft Magnetic Steel	5.2	421
Coil	2	OFE Copper	75	150
Anchor Plates (Top)	2	Austenitic SS	32.5	65
Anchor Plates (Bottom)	2	Austenitic SS	54	108
Total Weight of the assembled magnet (except detectors and fasteners)				**1192**

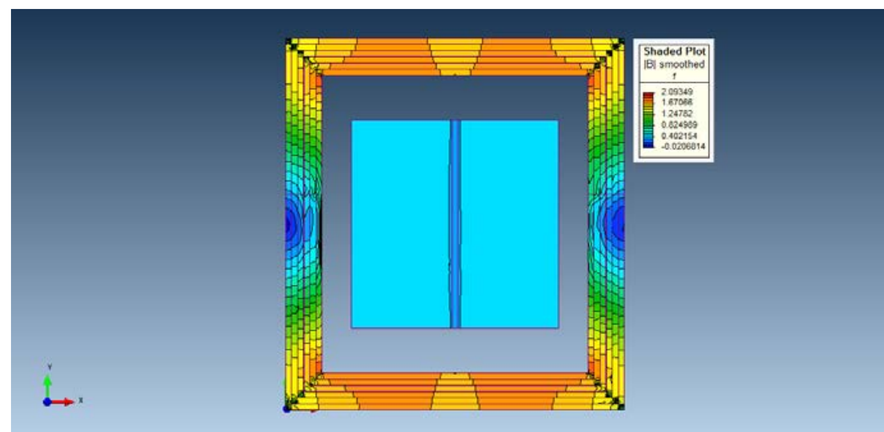
Conclusion: The Max. Von Mises Stress in the critical parts are within acceptable limits (Yield Stress = 230 MPa)

Alternate core design : Laminated Core structure

600mm six laminate core made by each laminate core structure 100mm with 4 mm gap between each core







Magnetic field distribution in the core and Good Field Region

Discussions

- **Field uniformity, magnitude of magnetic field and the desired good field region(GFR) :** ***Present design has magnetic field uniformity better than 2% in a GFR of 3.5m*3.5m*7.0 m.***
- **What is the operational life of Magnet?**
- **Detector lay-out : Weight/Volume, location and drawings of individual detectors**
- **Permissible temperature in detector vicinity and dependence of detector performance on temperature**
- **Permissible pressure of cooling water in magnet facilities (safety issues)**
- **Limitation on LPM (if any)**
- **Dipole magnet inclination**
- **Limitation on longitudinal and transverse size and how to retrofit the magnet on beam line**
- **Drawings of accelerator Lay-out**
- **Are magnetic field measurements required during experiments?**
- **Limitation on power availability (V, I, MW)**
- **Is there any possibility of charged heavy particle interaction with magnet/sub-systems (Concerns of Nuclear irradiations)**

Thanks