Status of Magnet Design Studies

2019/2/12

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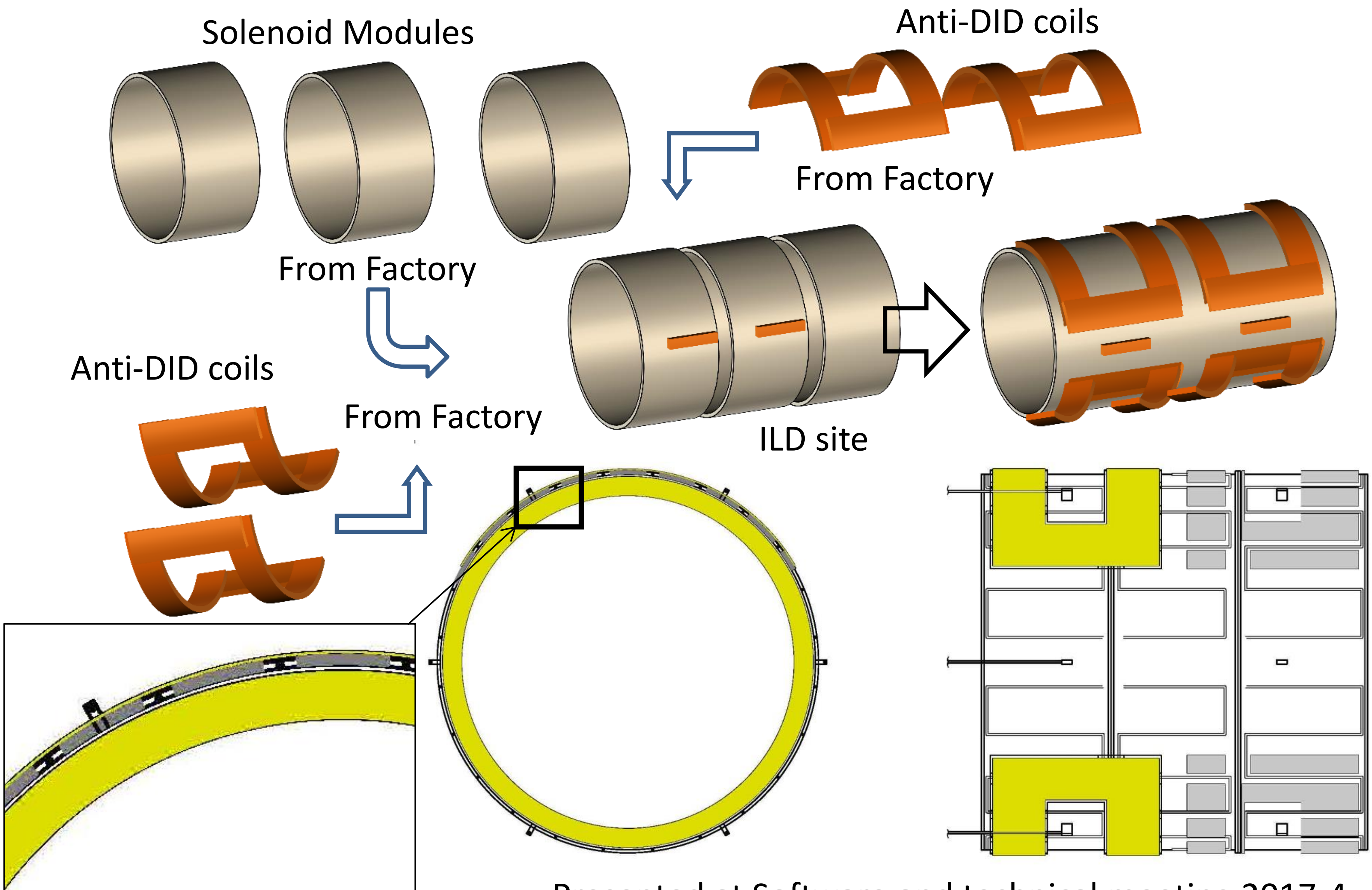
- Design study about ILD solenoid has been carried out with the cooperation of Hitach and Toshiba.
- Recently, a stress analysis due to solenoid coil EMF has been in progress to fix the thickness of an outer shell.
- Stress analysis by Hitach shows that stress in the coil with50 mm thick shell is 105 MPa.
- Toshiba is analyzing stress in the solenoid, which has smaller dimensions, because of realistic transportation.

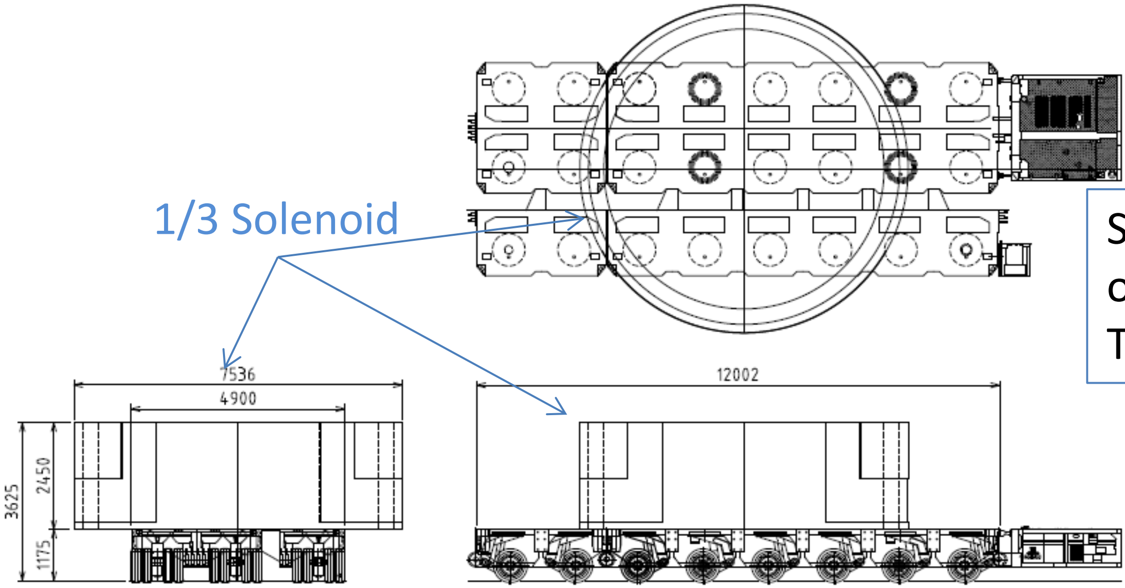
Outline of ILD magnet manufacturing process



Presented at Software and technical meeting 2017-4

Transportation Proposal by Toshiba

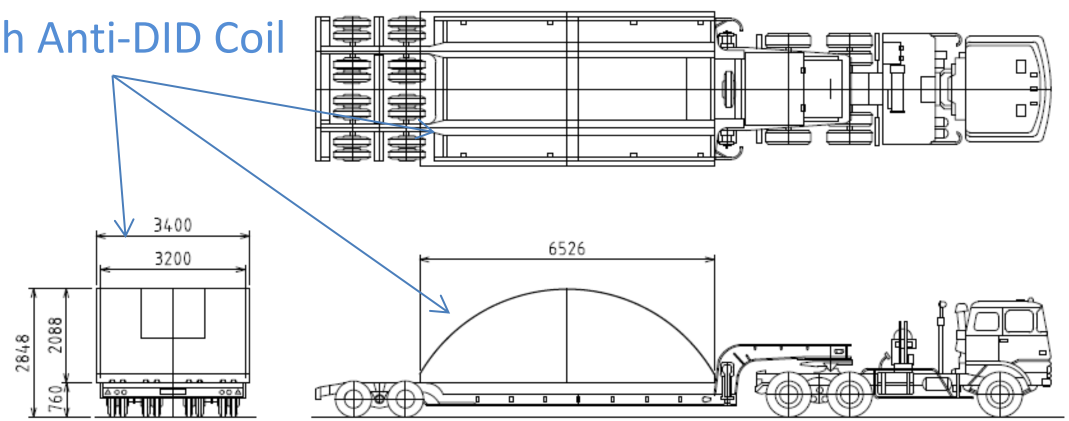
1/3 Solenoid



Solenoid Transportation by “**JUMBO CARRIER**”

Special permission on public roads .
Too slow ?

Each Anti-DID Coil



Anti-DID Transportation by low-floor trailer

- From view point of transportation from factory to ILC site, solenoid and anti-DID size are considered.
- Anti-DID is smaller and simpler, which meet the field requirement.
- Anti-DID coils are wound in a factory and are set on solenoid in an assembly build on-site.

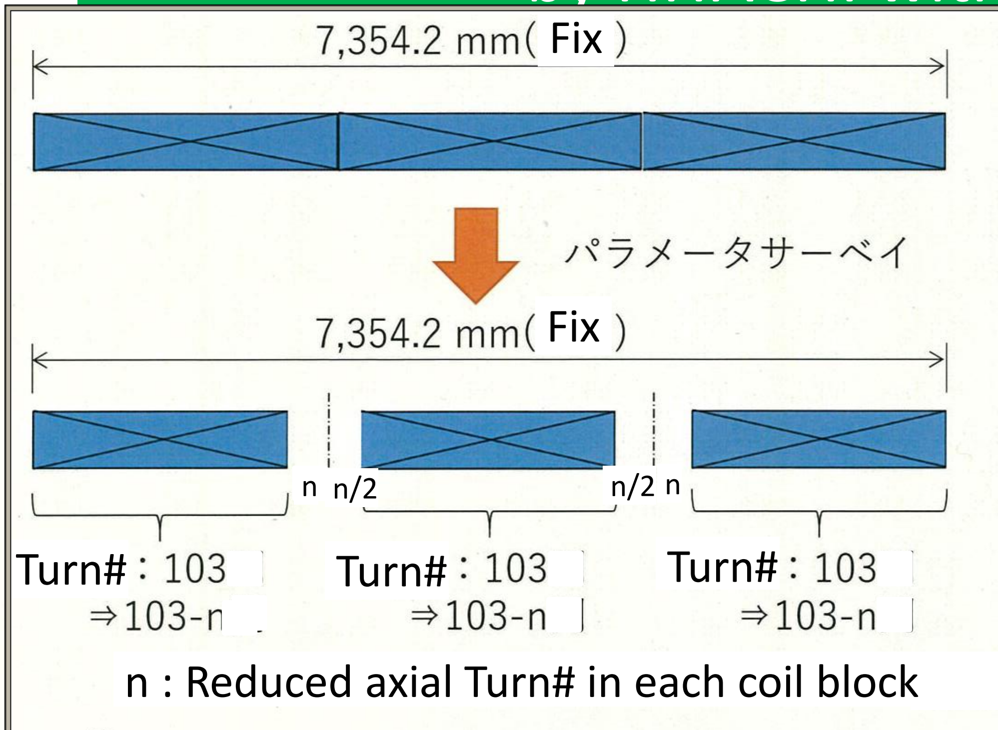
Coil Dimensions and Solenoid Field

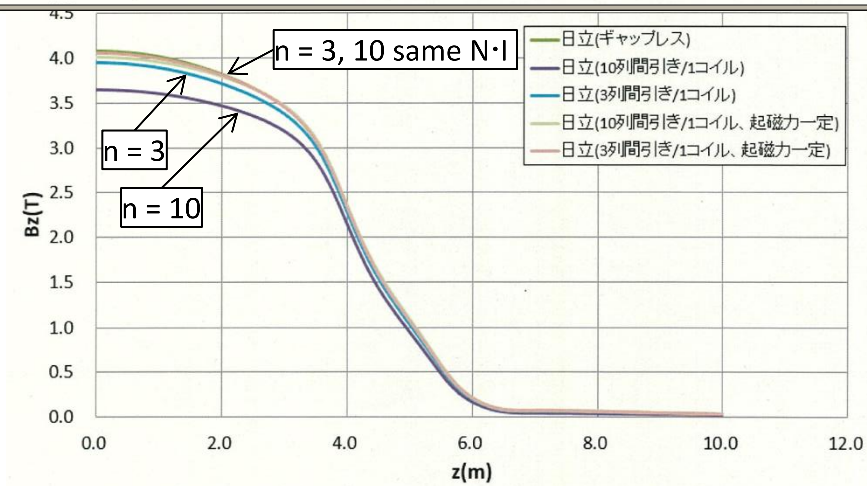
	TDR & HITACHI	TOSHIBA	ILD-Small
Coil Inner Radius (mm)	3615	3215	
Coil Outer Radius (mm)	3970	3570	
Length (mm) Each Block Length (mm)	7350 2450	7350 2450	
Turn × Layer	309 X 4 300 × 4 (for gap b/w module)	330 × 5	
Nominal Current (A)	22400 23072 (in case 300 turn)	15339	
Current Density (A/mm^2)	10.6	9.7	
Central Field (T)	4.0	4.0	
Maximum Field (T)	4.6	4.5	
Support Shell Thickness (mm)	50	10 – 100	
"Coil (Cryostat)" I. R. (mm)			3075.33
"Coil (Cryostat)" O. R. (mm)			**3825.33**
Yoke I.R. (mm)			4125

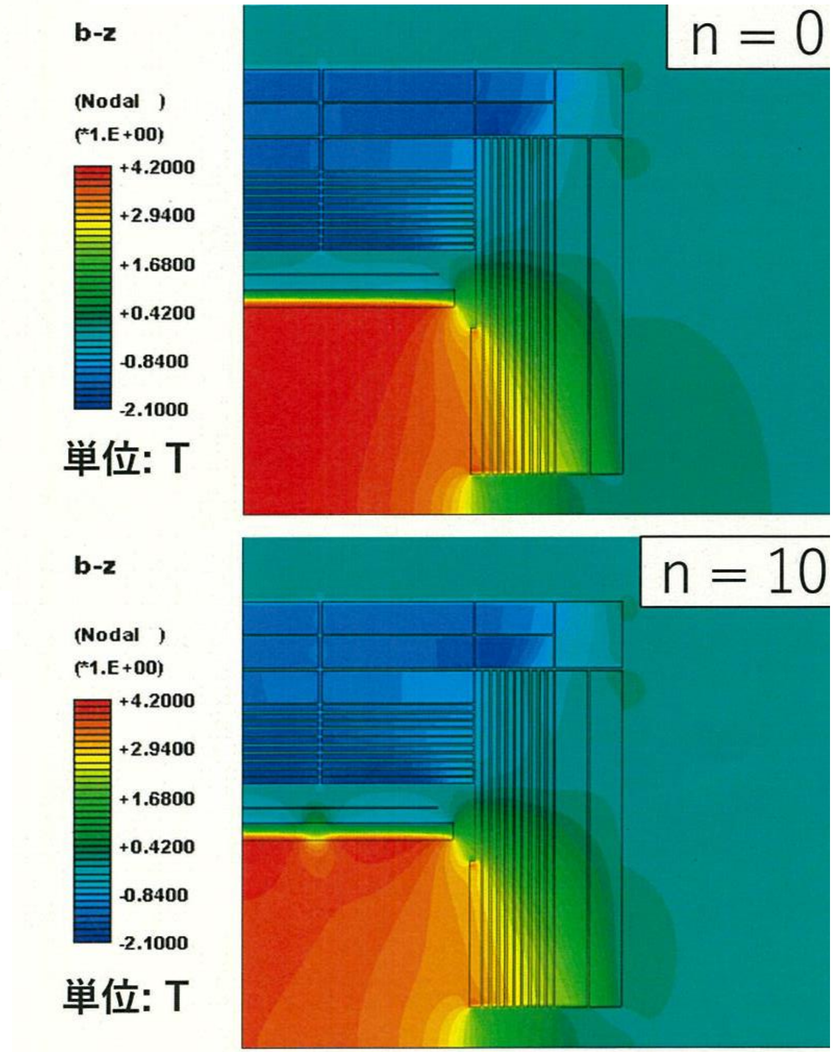
Stress Analysis by HITACHI

Field Check with Gap b/w Coil Block

by HITACHI with EMSolution

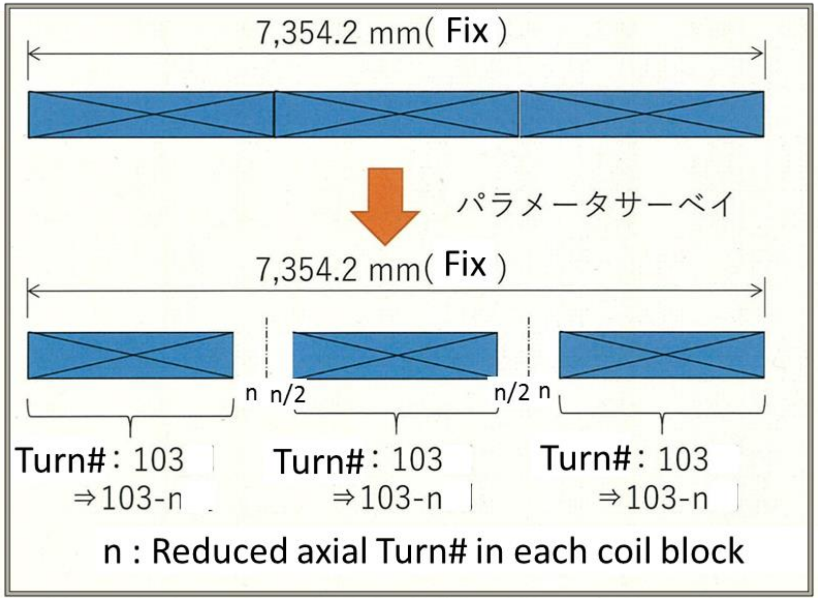


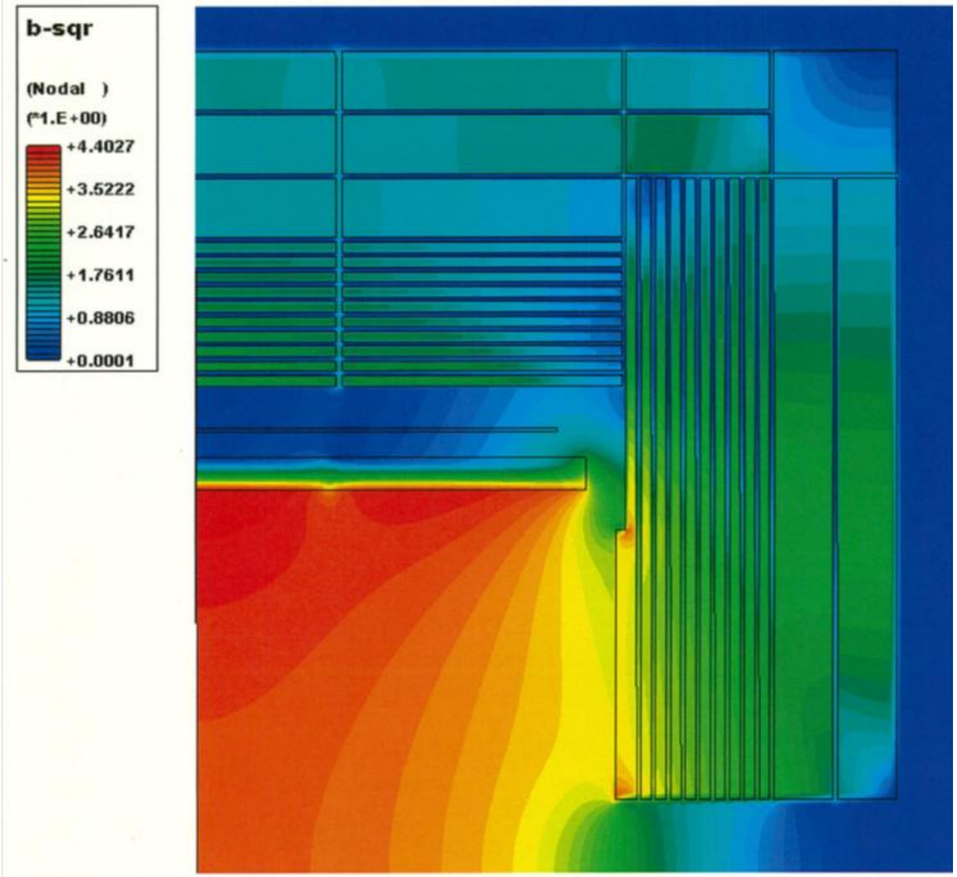


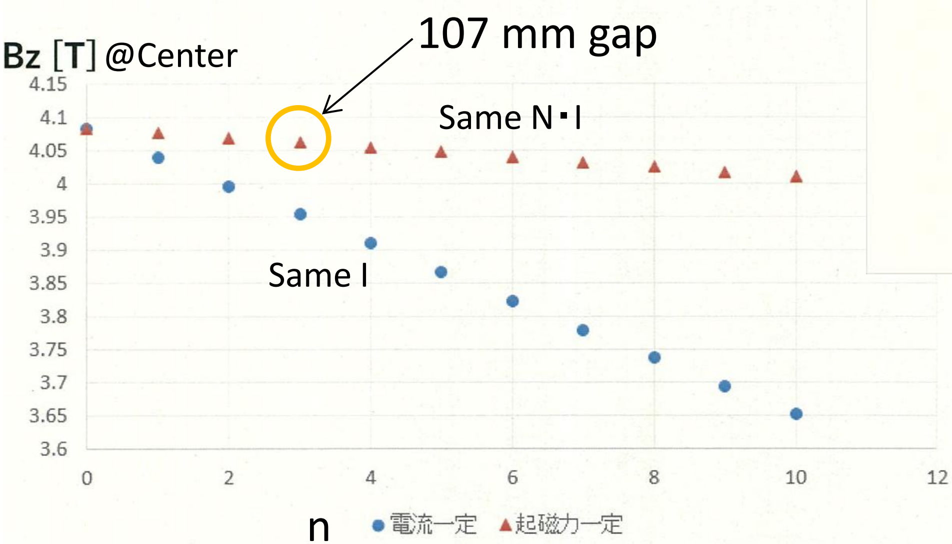


Field Check with Gap b/w Coil Block

by HITACHI with EMSolution

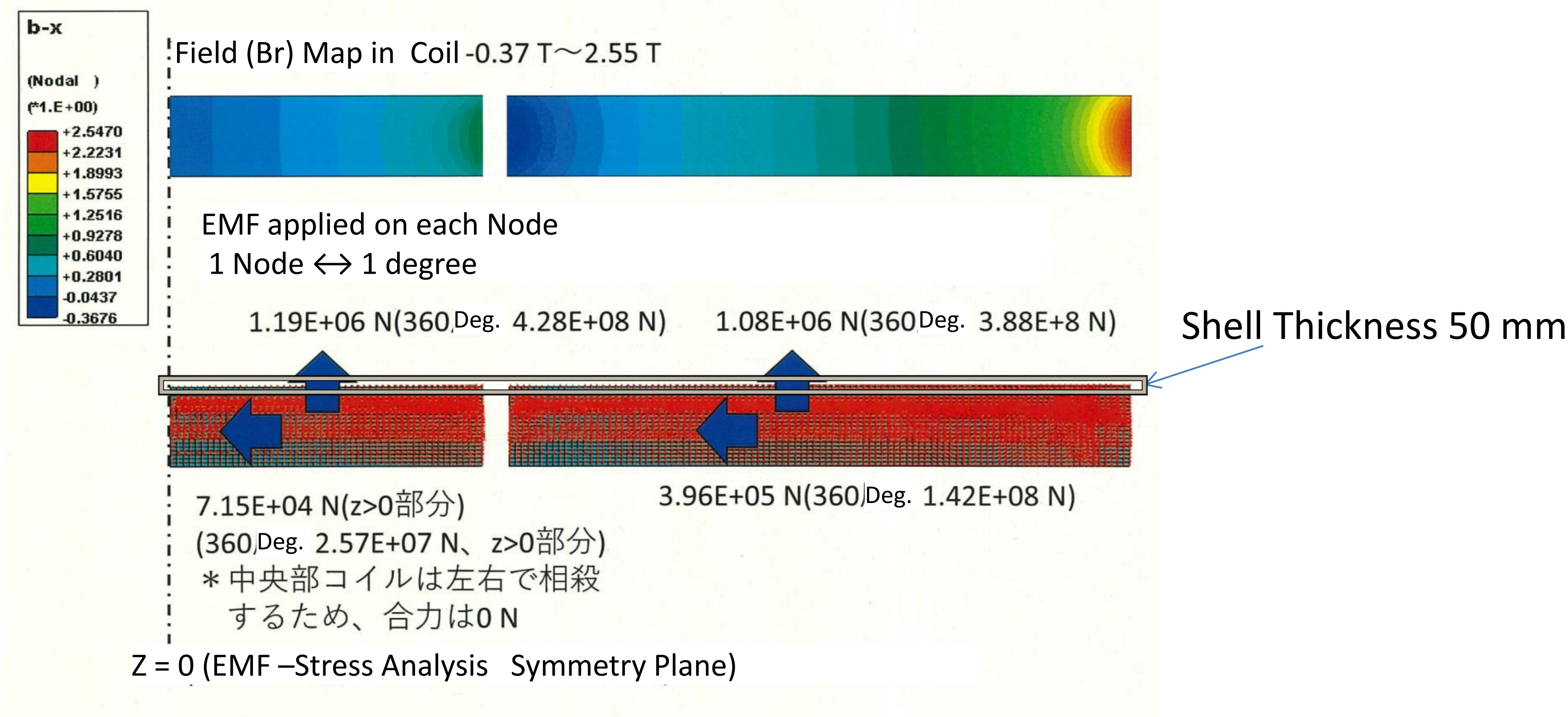






Stress Analysis – Applied Load

by HITACHI with EMSolution & ANSYS

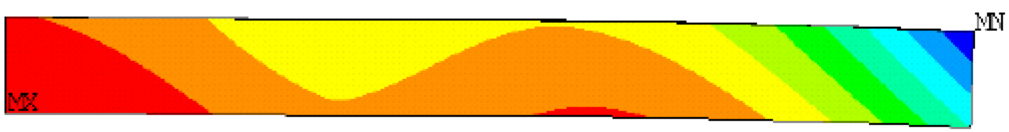


Coil Winding	Radial	Circumferential	Axial
Young Modulus (GPa)	66.8	74.2	62.6

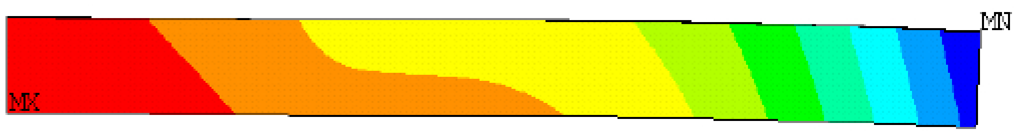
Stress Analysis – Displacement
by HITACHI with EMSolution & ANSYS

Displacement Contour Map

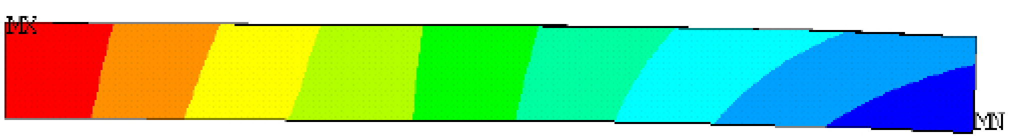
(1)Radial + Axial：3.6～4.4mm



(2)Radial　　　：3.1～4.4mm



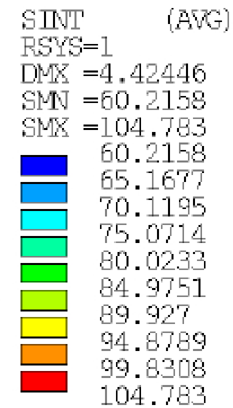
(3)Axial　　　：Max 2.2 mm at end of coil to center



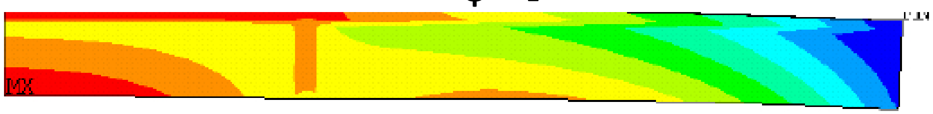
Stress Analysis – Stress

by HITACHI with EMSolution & ANSYS

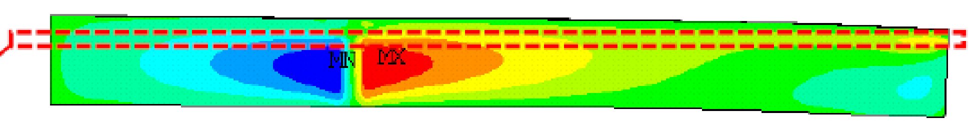
Displacement Contour Map

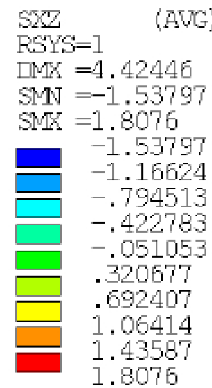


Tresca's yield condition (σ_ϕ-σ_z<Y): 60~105 MPa

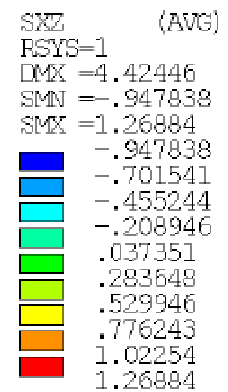


Shearing Stress (ϕz plane) : max 1.3 MPa





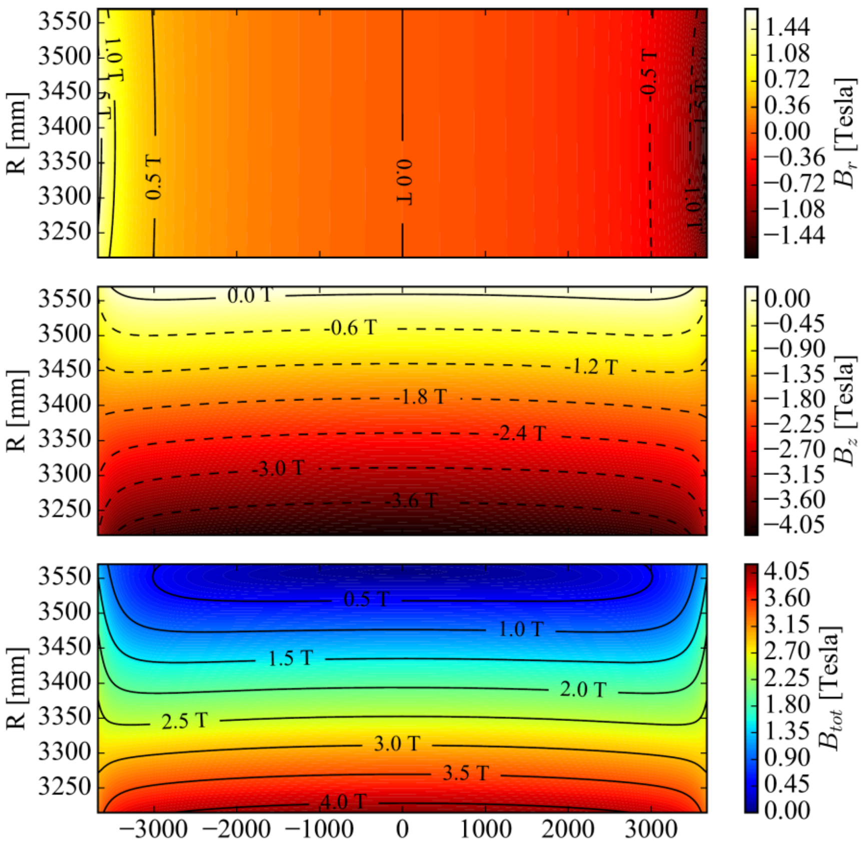
Shearing Stress (ϕz plane , b/w winding & shell)



Stress Analysis by TOSHIBA

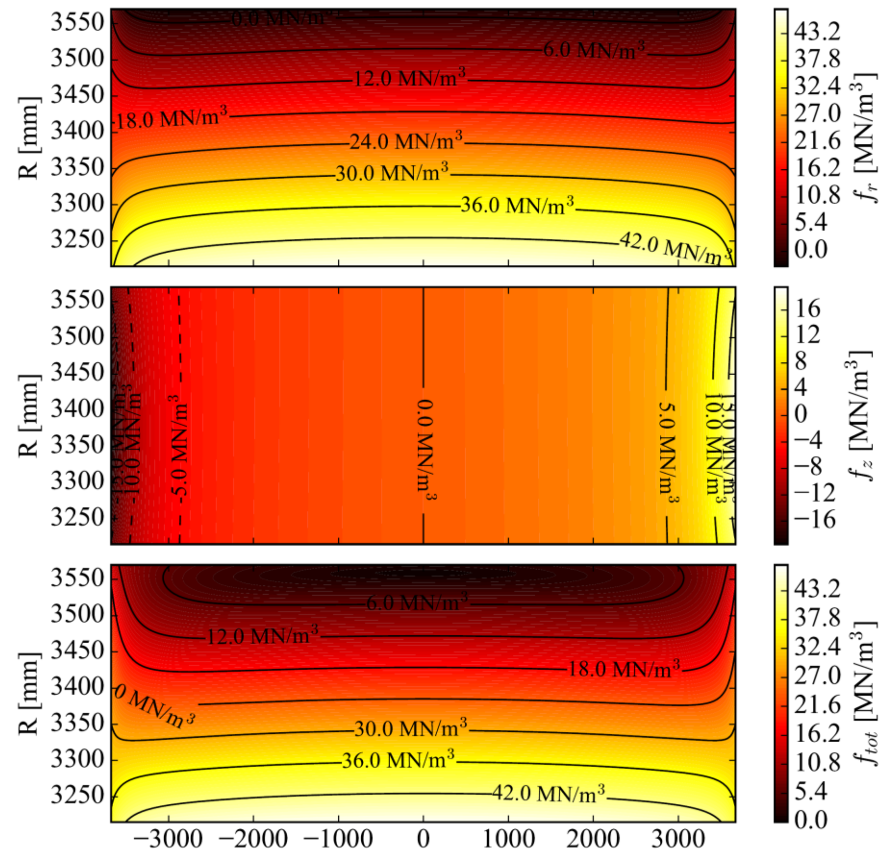
Field and EMF in Coil by TOSHIBA

very preliminary



Bmax：

- Br: 1.7 T, Bz: 4.2 T

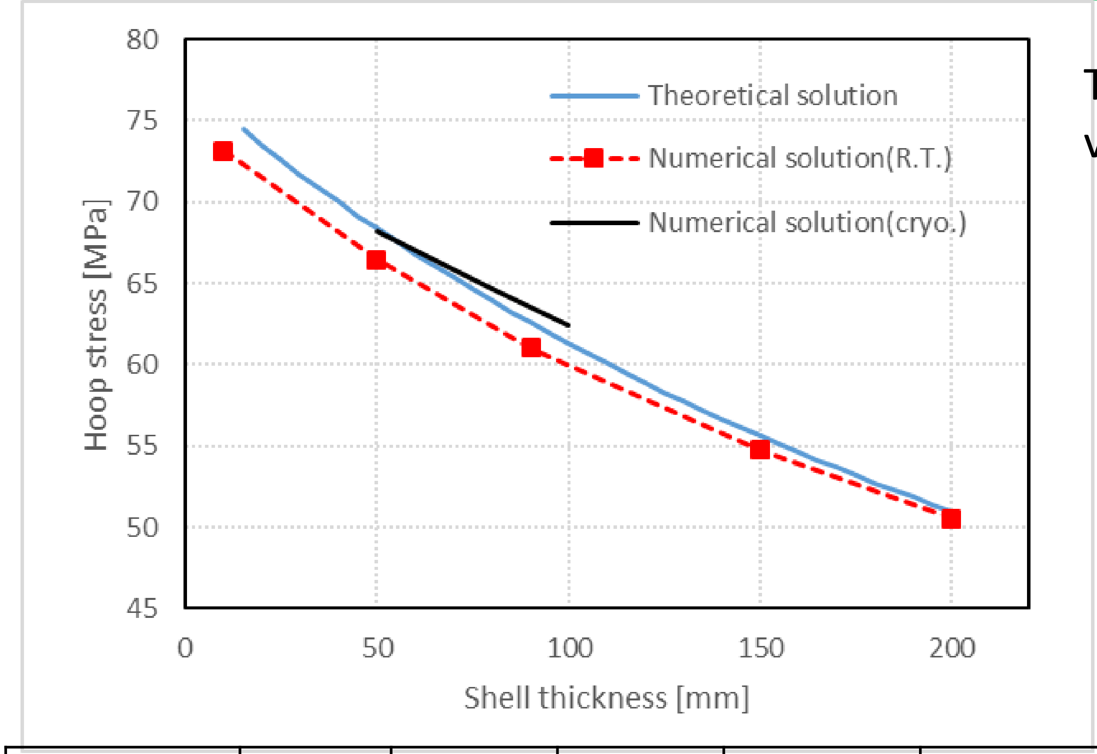


EMF max：

- Fr: 47.5 MN/m^3, Fz: 19.4 MN/m^3

Stress Analysis by TOSHIBA with Nastran

very preliminary



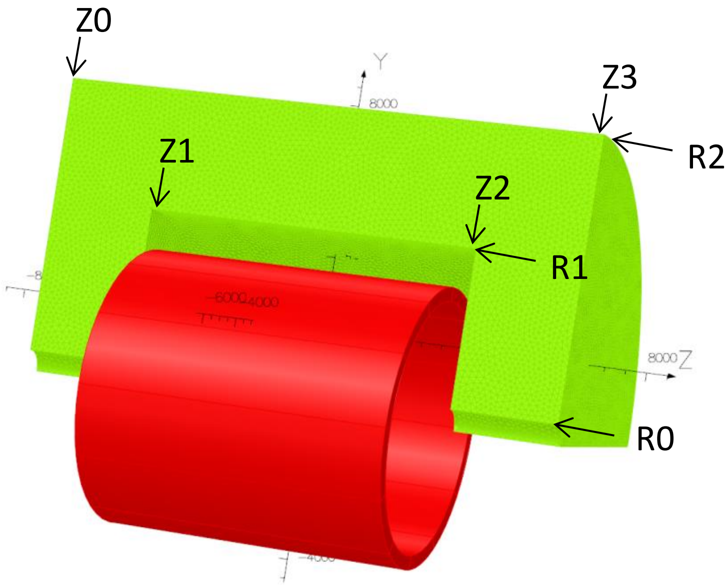
Thickness of 90 mm results in a von Mises stress of M 70 MPa

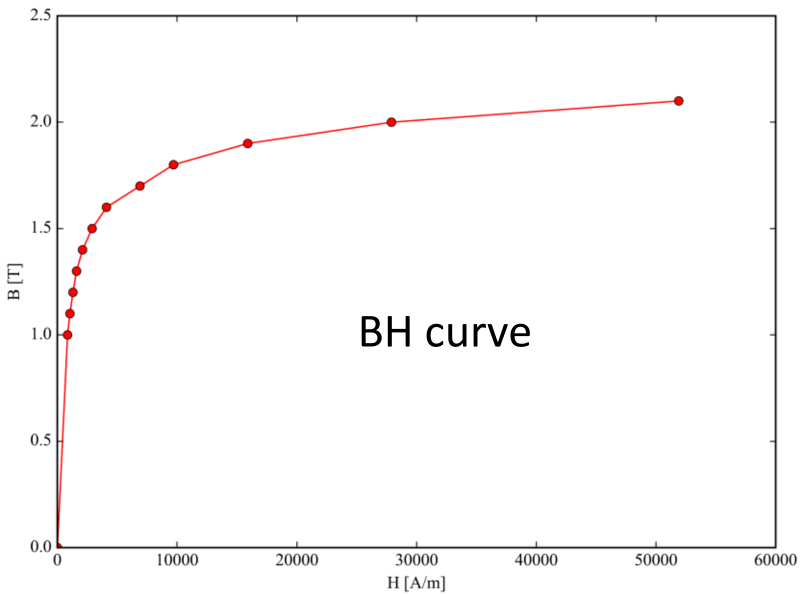
Thickness [mm]	σz [MPa]	σθ [MPa]	τθr [MPa]	τmax [MPa]	von Mises [MPa]	Δz [mm]	Δϕ [mm]	Sum [mm]
10	-22.54	73.12	40.6	44.03	84.84	1.86	3.64	4.01
50	-19.79	66.43	37.26	39.62	76.88	1.7	3.31	3.55
90	-20.2	61.01	34.58	36.72	70.51	1.58	3.04	3.24
150	-20.42	54.73	31.47	33.1	63.36	1.43	2.72	2.88
200	-20.37	50.55	29.36	30.61	58.74	1.32	2.51	2.65

Coil Dimensions and Solenoid Field

	TOSHIBA	ILD-S
Coil Inner Radius (mm)	3215	
Coil Outer Radius (mm)	3570	
Length (mm) Each Block Length (mm)	7350 2450	
Turn × Layer	330 ×5	
Nominal Current (A)	15339 (will be smaller)	
Current Density (A/mm^2)	9.7	
Central Field (T)	4.0	
Maximum Field (T)	4.5	
Support Shell Thickness (mm)	10 – 100 (now analyzing)	
“Coil (Cryostat)” I. R. (mm)		3075.33
“Coil (Cryostat)” O. R. (mm)		3825.33
“Coil (Cryostat)” Length (mm)		7744

Coil Dimensions and Solenoid Field





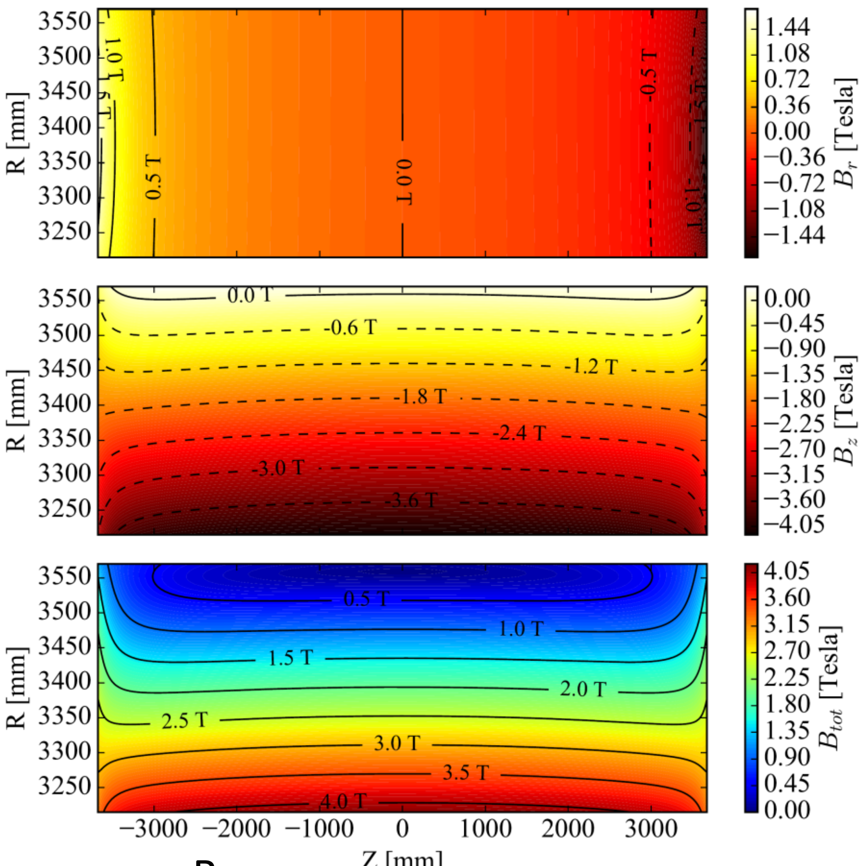
Solenoid dimensions :

R0 [mm]	R1 [mm]	Z0 [mm]	Z1 [mm]	J [A/mm^2]
3215	3570	-3675	3675	9.7

Iron yoke dimensions :

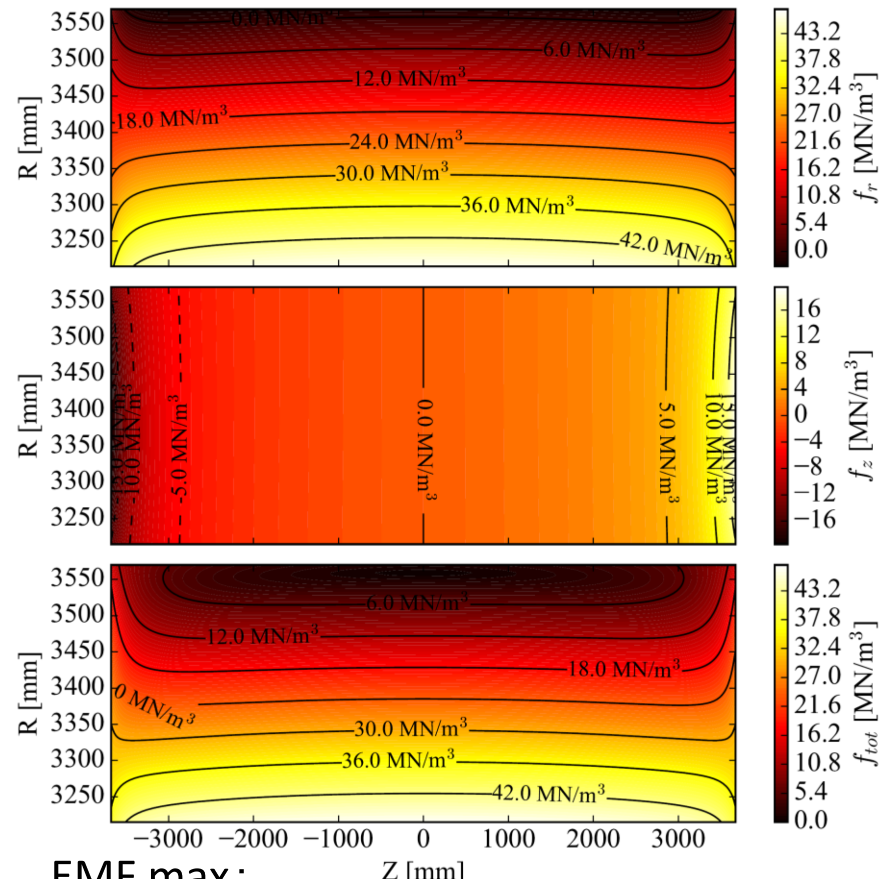
R0 [mm]	R1 [mm]	R2 [mm]	Z0 [mm]	Z1 [mm]	Z2 [mm]	Z3 [mm]
550	4595	7755	-6620	-4060	4060	6620

Field and EMF in Coil by TOSHIBA



Bmax :

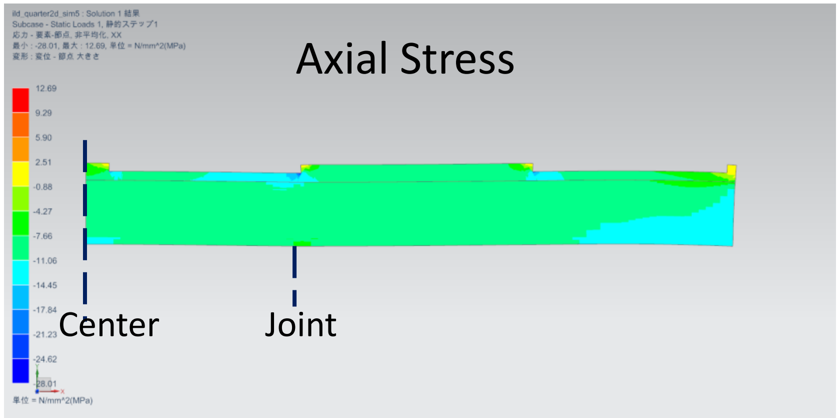
- Br: 1.7 T, Bz: 4.2 T

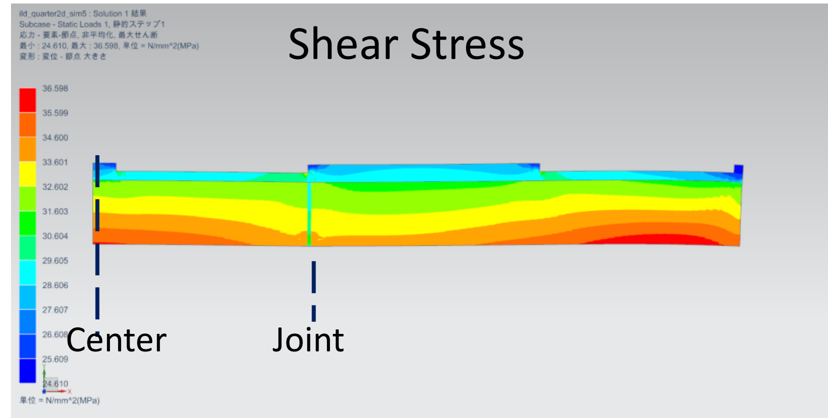


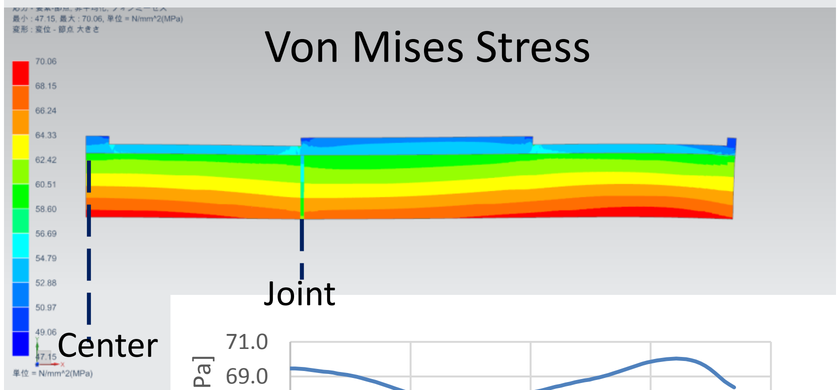
EMF max :

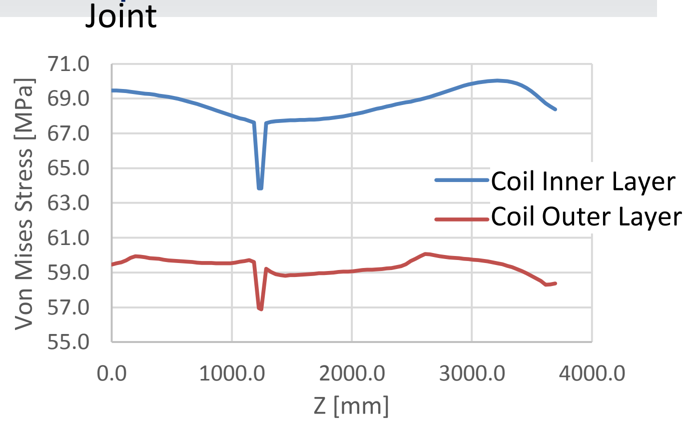
- Fr: 47.5 MN/m^3, Fz: 19.4 MN/m^3

Stress Analysis by TOSHIBA with Nastran
50 mm Thick Support Shell Case



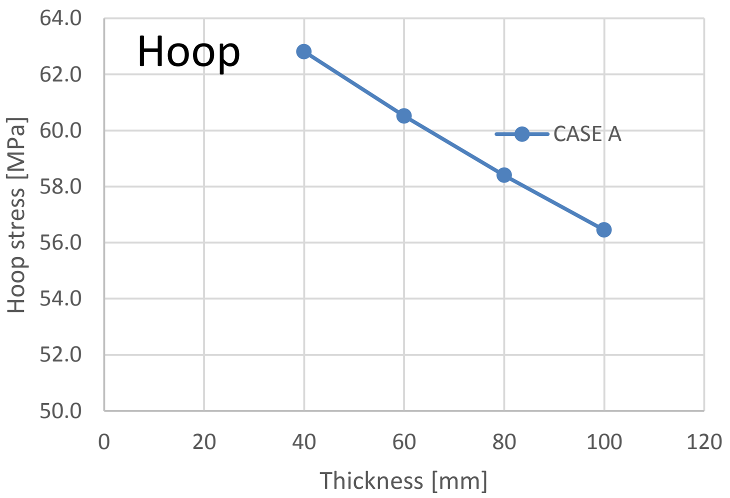


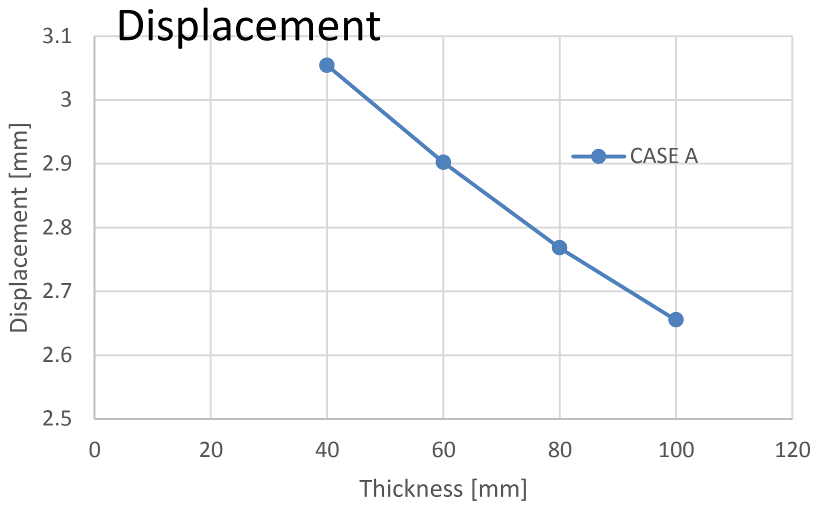


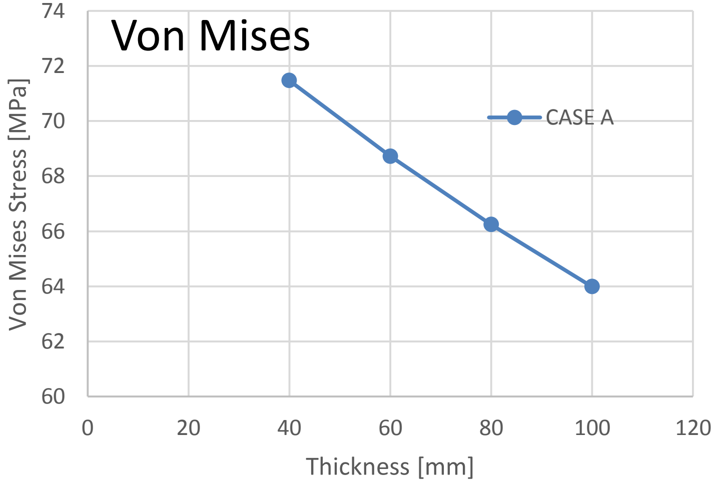


Stress	Unit	Coil	Shell	Joint
Axial	MPa	-13.863	-28.01	-13.056
Hoop	MPa	61.64	53.72	55.51
Shear（Rθ）	MPa	1.837	-9.63	-0.631
Shear Max	MPa	36.598	34.59	30.965
Von mieses	MPa	70.055	60.73	60.688

Stress Analysis by TOSHIBA with Nastran Shell Thickness vs. Von Mises Stress

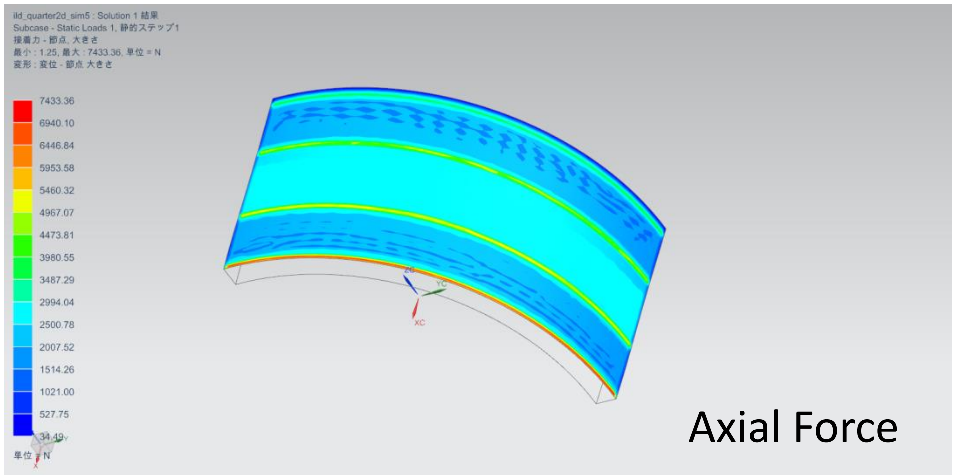




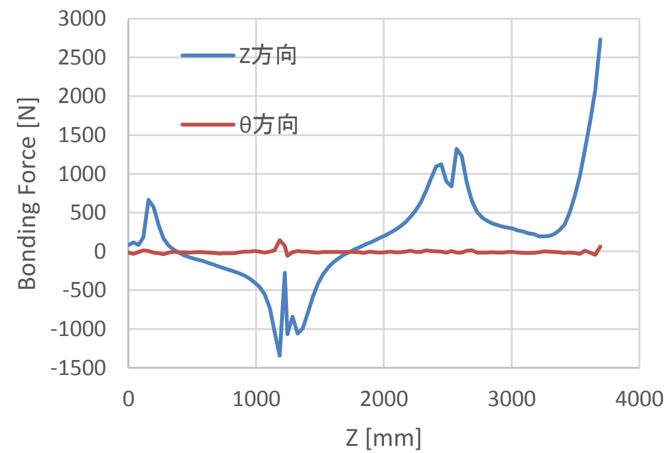


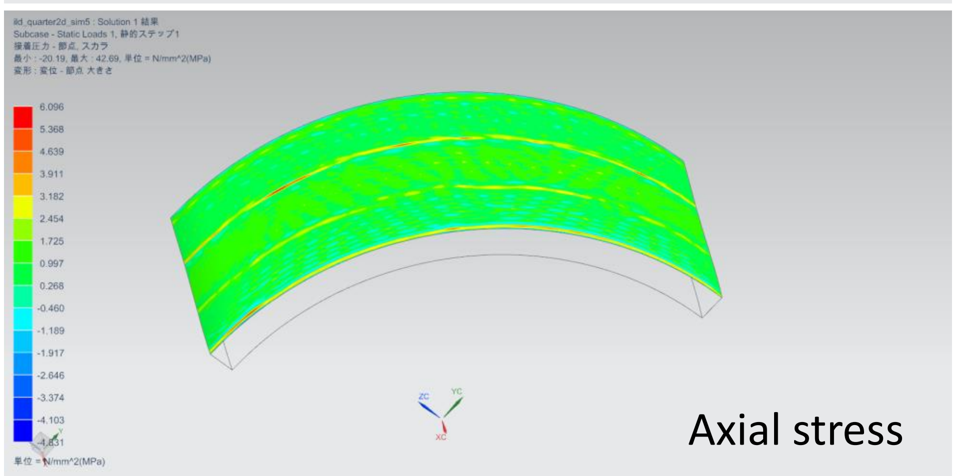
Criteria (Yield Limit) :
Conductor : 76 MPa ($0.85\sigma_{0.2}$)

EMF b/w Coil and Shell
50 mm Thick Support Shell Case

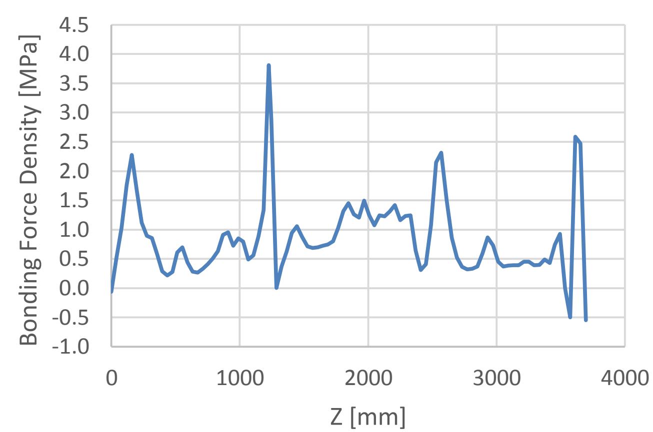


Axial Force





Axial stress



Summary & Study Plans

- HITACH has analyzed the stress in the coil due to EMF of solenoid.
  - Maximum stress in the coil with 50 mm thickness support shell is 105 MPa, which is lower than 150 MPa (CMS criteria).
- TOSHIBA has been analyzing the stress in the coil, which diameter is smaller.
  - 800 mm reduction , IR 3215 and B_{center} = 4.0 T
  - 70 MPa with 50 mm thickness support shell
  - Cryostat Design -> ILD small dimensions.
- Smaller Al stabilized conductor for realistic manufacture.
  - Too large 74.3 X 22.4 mm^2 (TDR) -> CMS size 50 X 22 mm^2
  - 4 layers -> 6 layers, 22.4 kA -> 15.0 kA
  - Radial thermal conductivity, quench characteristic.