Princeton Plasma Physics Laboratory

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Electromagnetic Analysis of ITER Diagnostic Port Plugs and Diagnostic Systems during Plasma Events

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Y. Zhai[1], A. Brooks[1], R. Roccella[2], J. Guirao[2], M. Smith[1], G. D. Loesser[1], S. Pak[3], V. Udintsev[2], R. Feder[1], D. Johnson[1]

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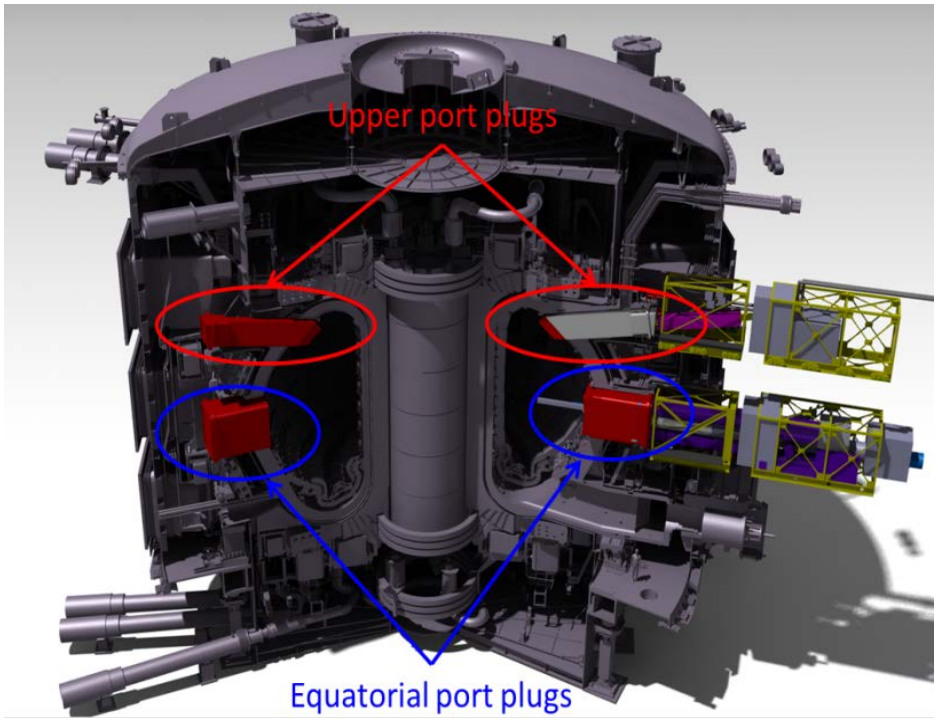
Outline

- Introduction
- EM Global Models
  - VV sector and Port Plug assembly
  - Diagnostic First Wall, Diagnostic Shield Module and PP structure
  - ECE, TIP & Vis/IR systems
  - EM Benchmarks
- Transient Analysis
  - Worst disruption scenarios
  - Eddy current & disruption loads
  - Load reduction/variation
  - Static and transient field maps
- Response Implication
  - DFW, DSM & EPP structure
  - Dynamic impact to diagnostics
- Conclusions

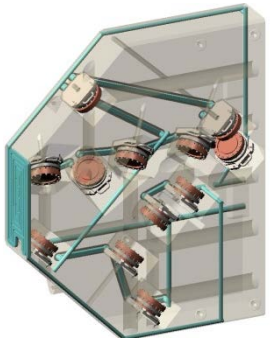


Introduction

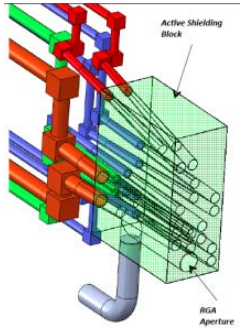
- Diagnostic Port Plugs
  - Provide nuclear shielding & structural support of diagnostic systems while allowing diagnostic access to plasma
  - Design largely driven by EM loads and associate structural responses of PP assembly
- Analysis Models
  - Model description (ANSYS, OPERA and MAXWELL)
  - DINA-Opera interface and EM benchmarks
- Disruption Loads
  - Eddy current and loads on PP structure components
  - DFW-DSM current transfer and loads on in-port diagnostics
- Worst DINA cases
  - 2D DINA scan and 3D analysis validation for in-port diagnostics
- EM Load Response
  - Deflection and dynamic response of PP structure assembly meet requirement but
  - Dynamic impact to in-port diagnostic components can be significant

PP Assembly and In-port Diagnostics

- Structure Components
  - DFWs, DSMs & PP structure
  - Diagnostic components
- Attachment Schemes
  - DSMs: rails, pins and bolts
  - DFWs: pads, keys and bolts
  - Diagnostics: cartridge inserts



TIP



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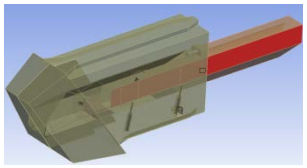
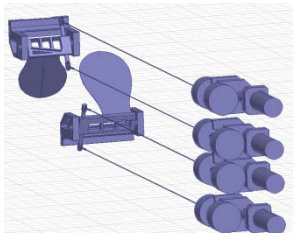
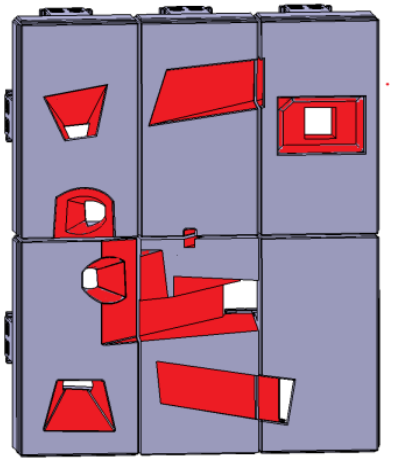


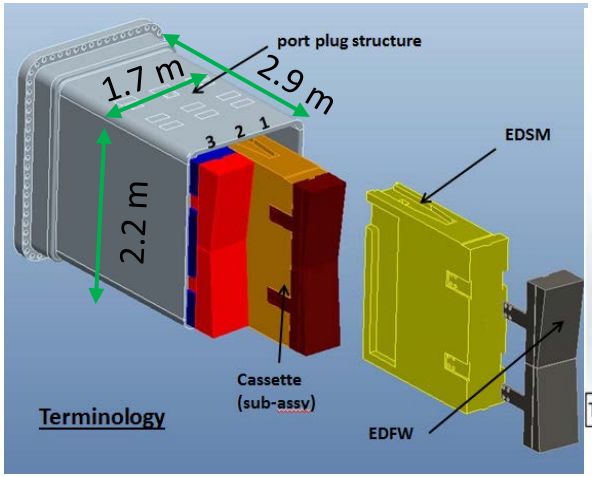
Vis/IR



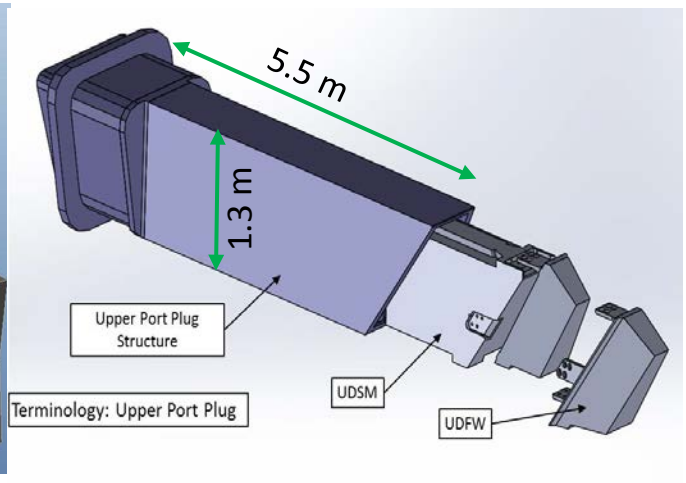
ECE



EPP3 DFW



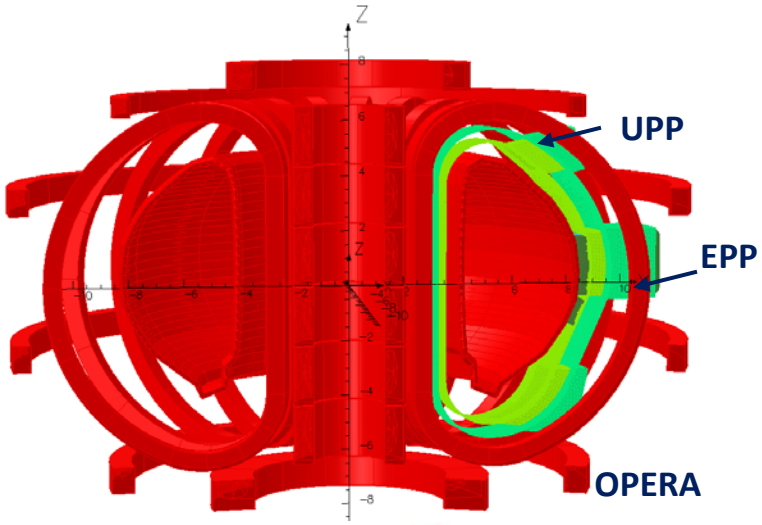
Generic Equatorial Port

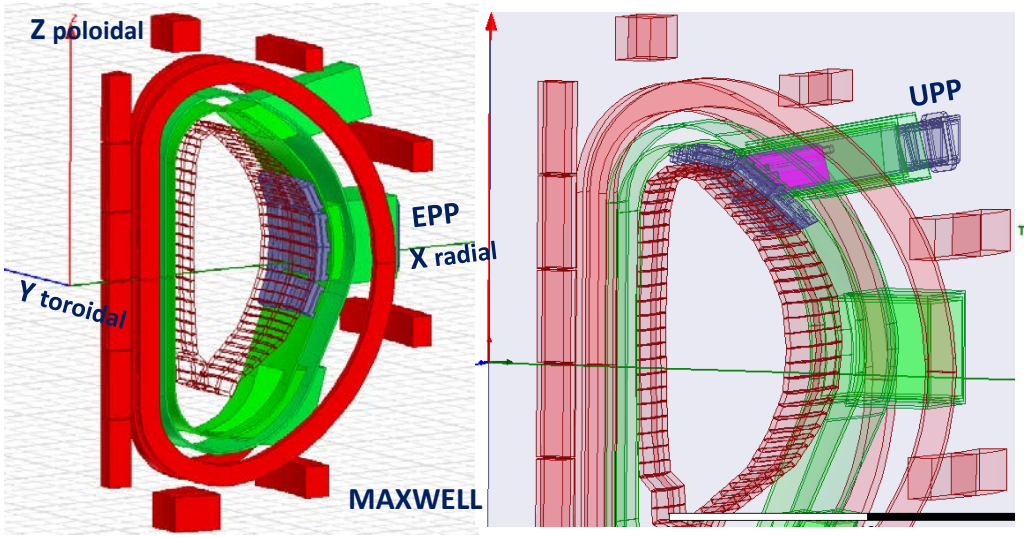


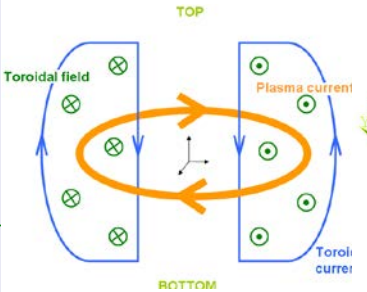
Generic Upper Port

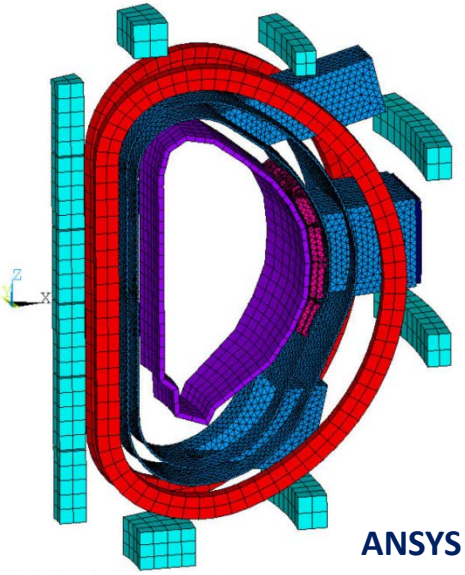
GLOBAL MODELS - DINA-OPERA Interface

- Current drivers
  - Plasma secondary excitation
  - DINA 2010 or 2012 data
- ITER sign and direction convention
  - Plasma current and TF are clockwise (-)
  - Most CS coils are counterclockwise (+)







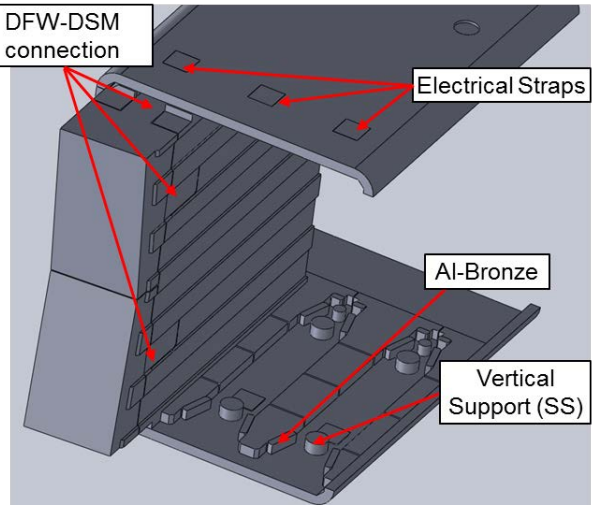


20 degree sector ITER VV, magnet coils, EPP & UPP structures

Material Properties and Electrical Contacts

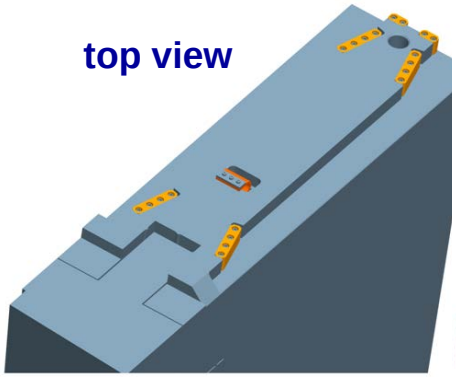
- DINA plasma disruption scenarios (PP assembly)

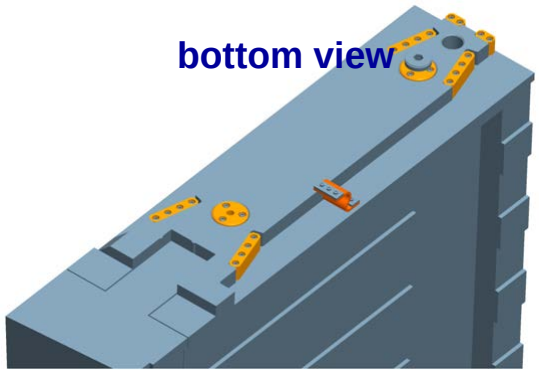
MD_UP_LIN36 – Major upward disruption with 36ms Linear Decay
MD_DW_LIN36 – Major downward disruption with 36ms Linear Decay
VDE_UP_LIN36 – Upward VDE with 36ms Linear Decay (UPP)
VDE_DW_LIN36 – Downward VDE with 36ms Linear Decay
VDE_UP_SF II – Slow fast upward VDE
VDE_DW_SF II – Slow fast downward VDE
MD_DW_EXP16 – MD downward with 16ms exponential decay (EPP)



Electrical conductivity (S/m)

DFWs/DSMs	1.35×10^6 (SS)
Bolts and Pads	1.35×10^6 (SS)
Rails and EPP structure	1.35×10^6 (SS)
VVs	1.35×10^6 (SS)
Inserts	4.065×10^6 (Al. Bronze)
TIP mirrors	6×10^7 (Copper)





Electric straps are defined as flex spring structure for the generic equatorial & upper ports

Electrical contacts:
1. Rectangular inserts (Al. Bronze)
2. electrical straps (CuCrZr)
3. Vertical support bolts (SS)

Disruption Cases – Port Plug Assembly

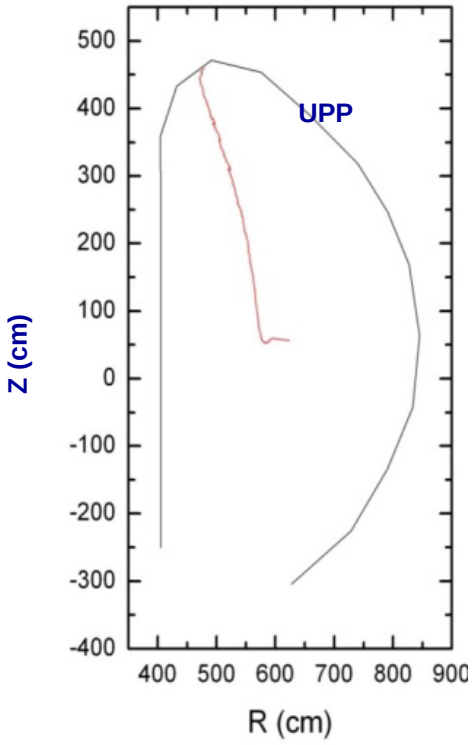
- Plasma disruption scenarios studied for PP assembly

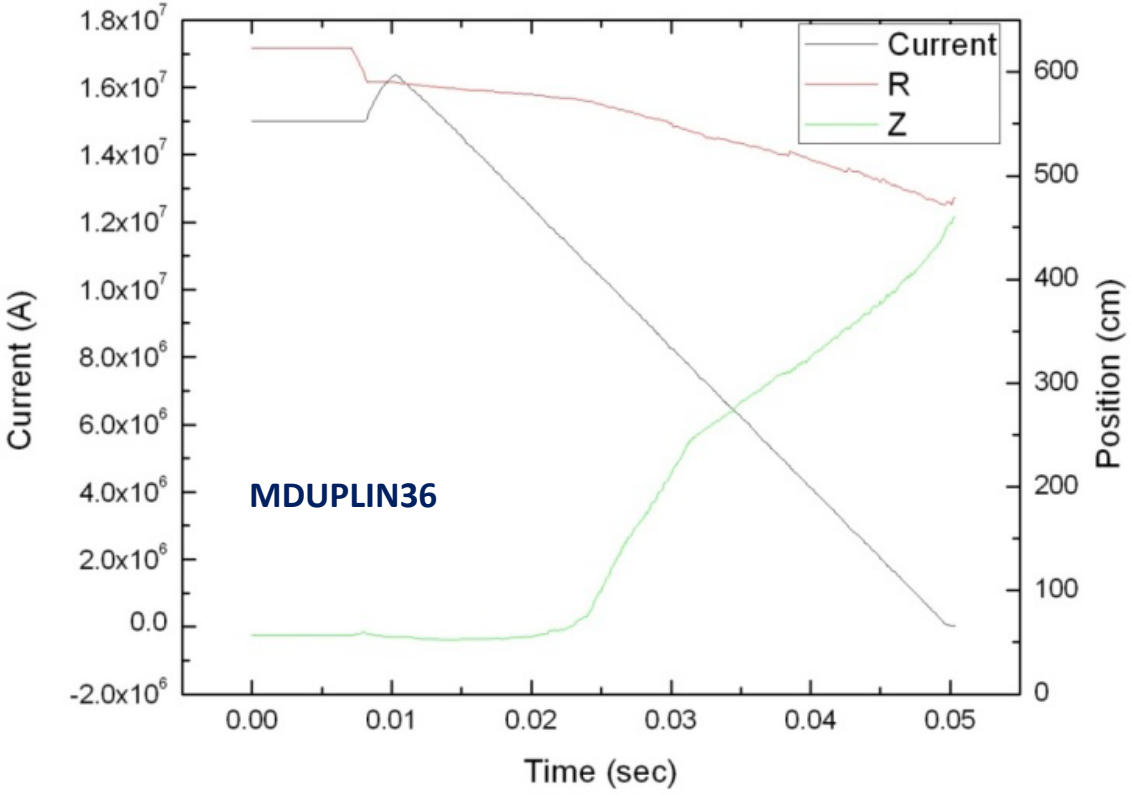
VDE_UP_LIN36 – Upward VDE with 36ms Linear Decay (UPP)

MD_DW_EXP16 – MD downward with 16ms exponential decay (EPP)

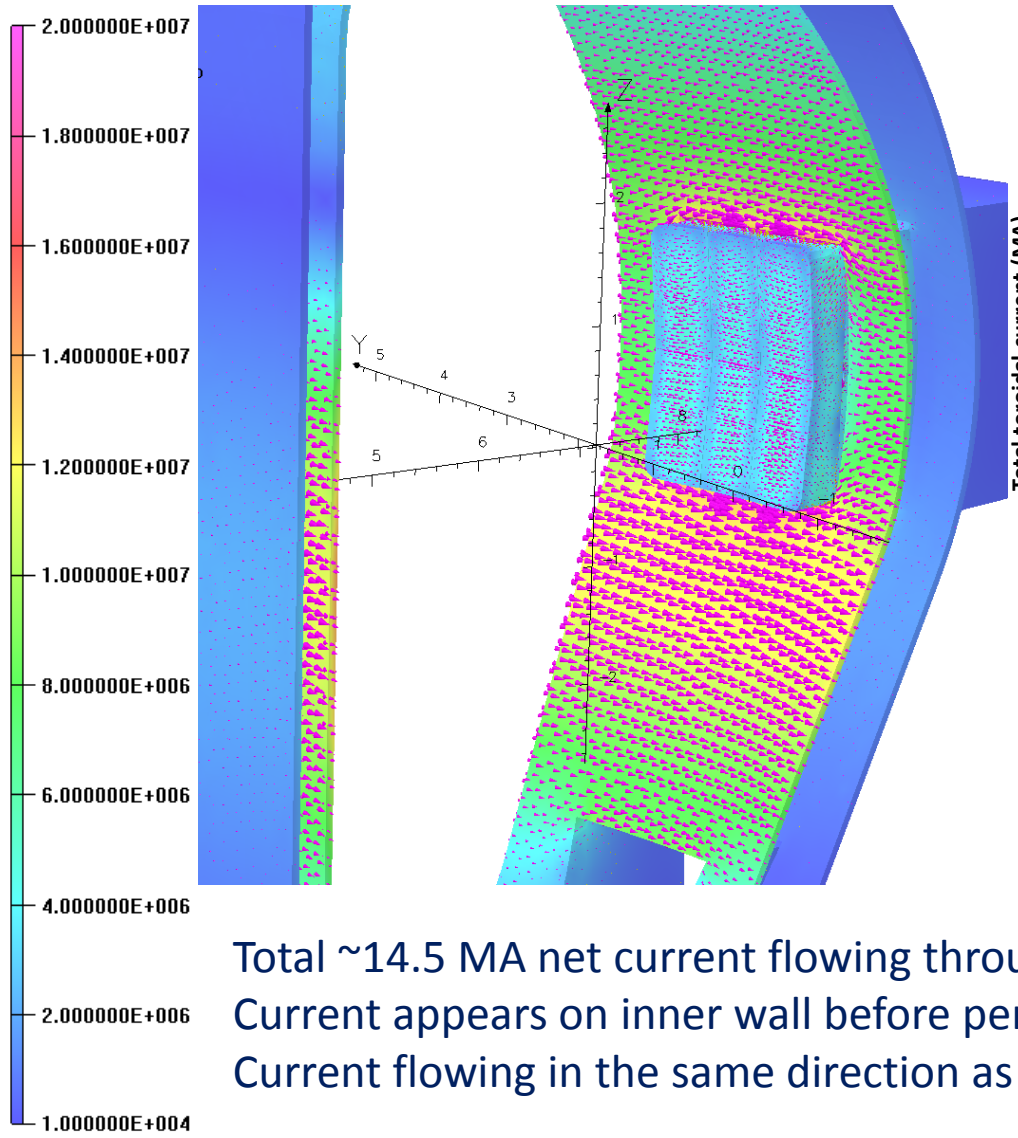
- Plasma currents vary in both magnitude and location during disruption events

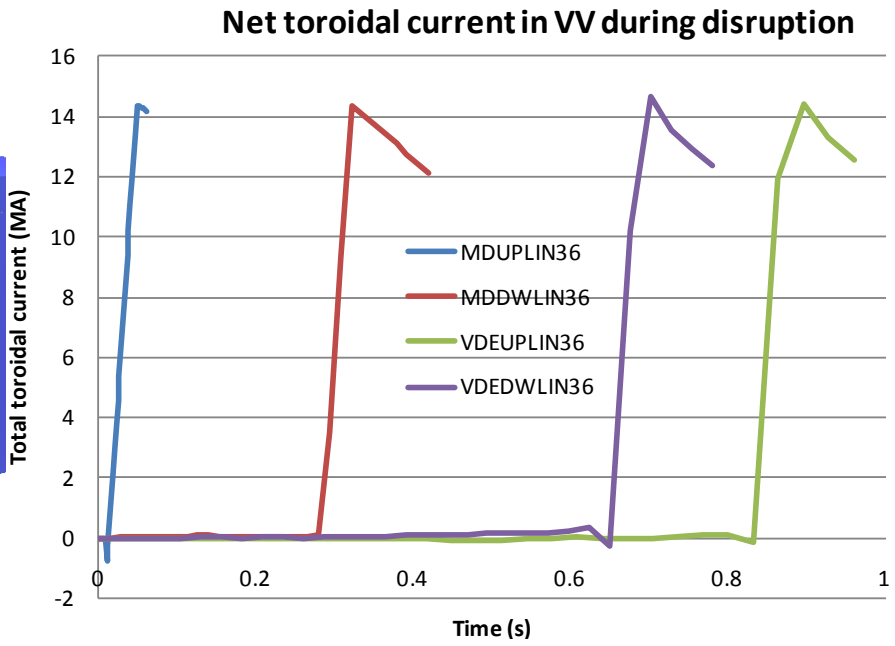
MD_UP_LIN36	MD II	Level A
MD_DW_LIN36	MD II	Level A
MD_DW_EXP16	MD II	Level A
VDE_UP_LIN36	VDE III	Level C
VDE_DW_LIN36	VDE III	Level C
VDEUP slow fast	VDE IV	Level D
VDEDW slow fast	VDE IV	Level D





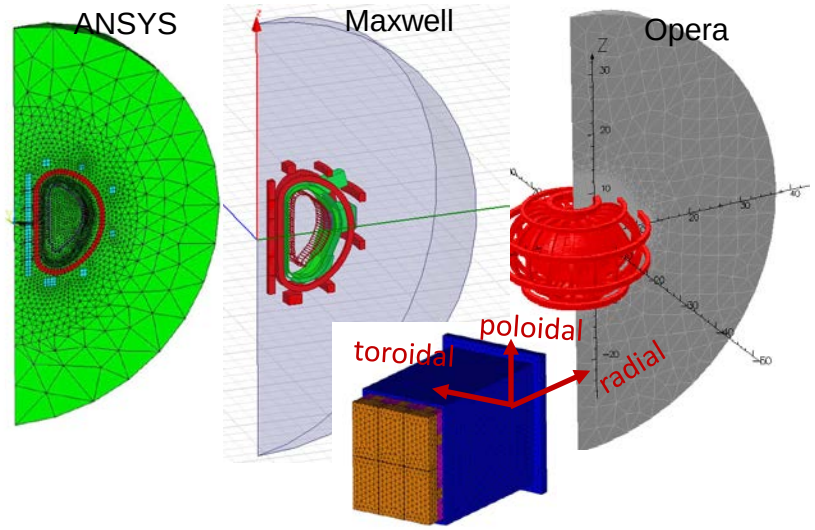
Eddy Current in VV during MDUPLIN36





Total ~14.5 MA net current flowing through VV from 15 MA plasma current quench
Current appears on inner wall before penetrating to outer wall
Current flowing in the same direction as the plasma current

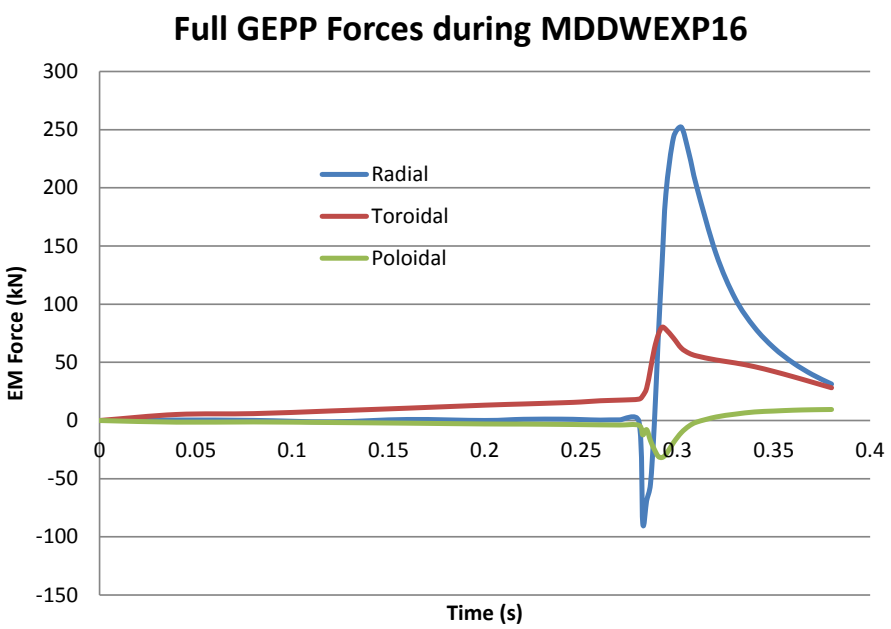
EM Benchmarks

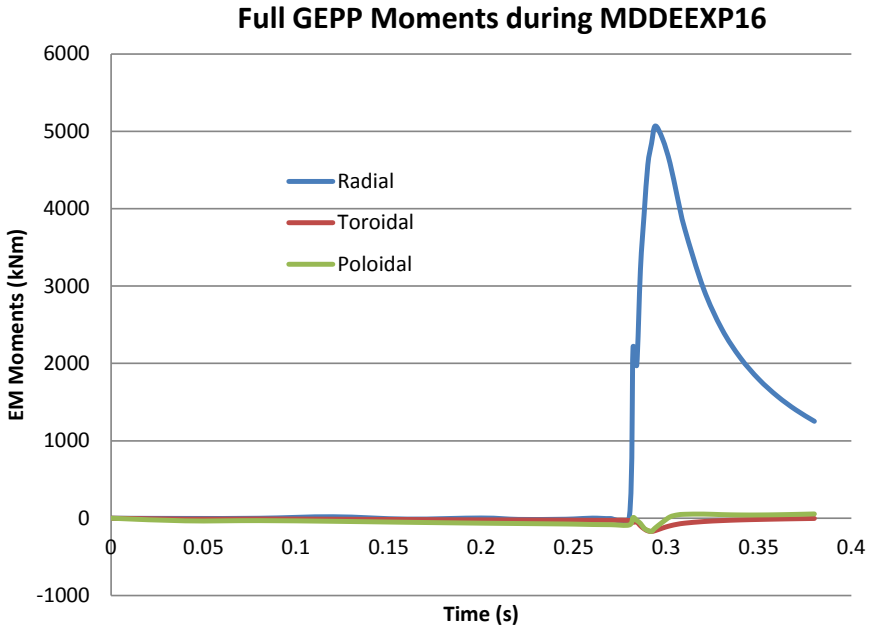


5% difference between OPERA and ANSYS but 5-10% difference in the dominant moments with MAXWELL

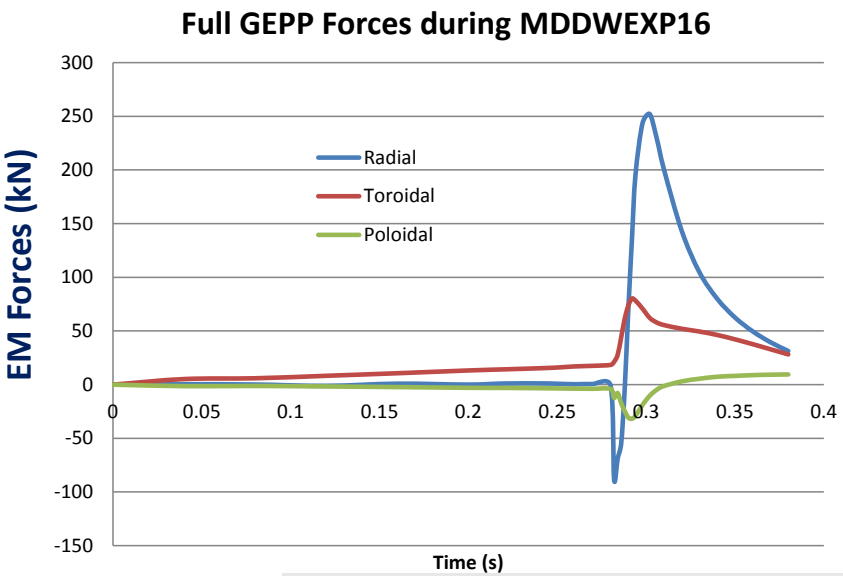
Better agreement (<10%) found when summations of absolute force magnitude over parts are plotted

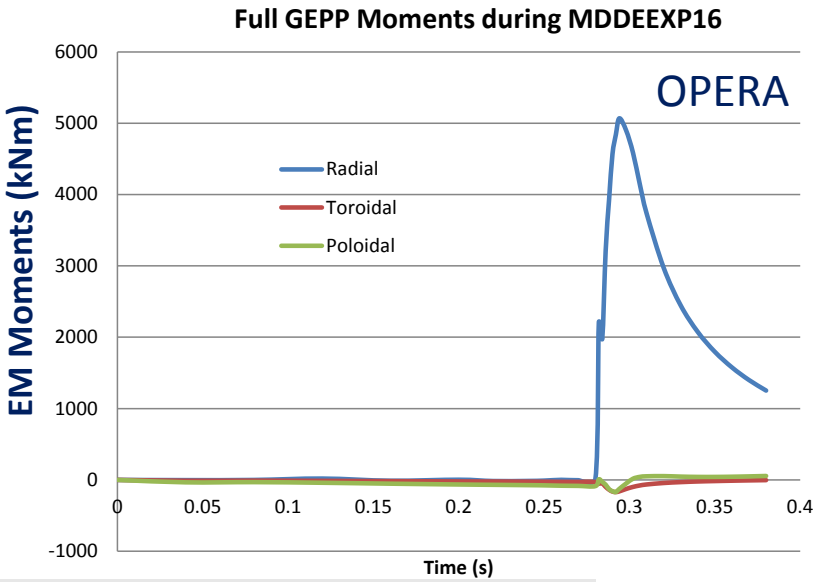
All three models use 25 m outer air boundary, 5 & 10 cm mesh sizes and 1.35e6 S/m steel conductivity



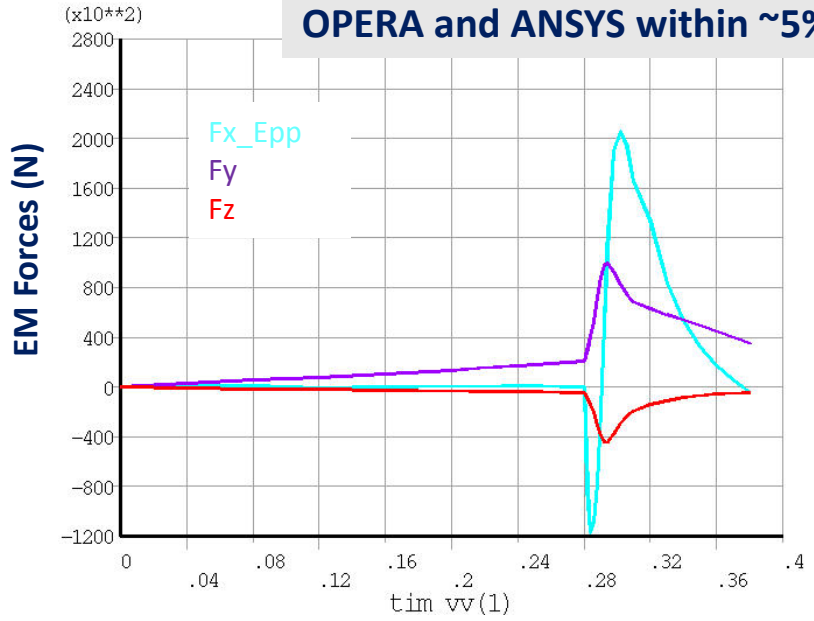


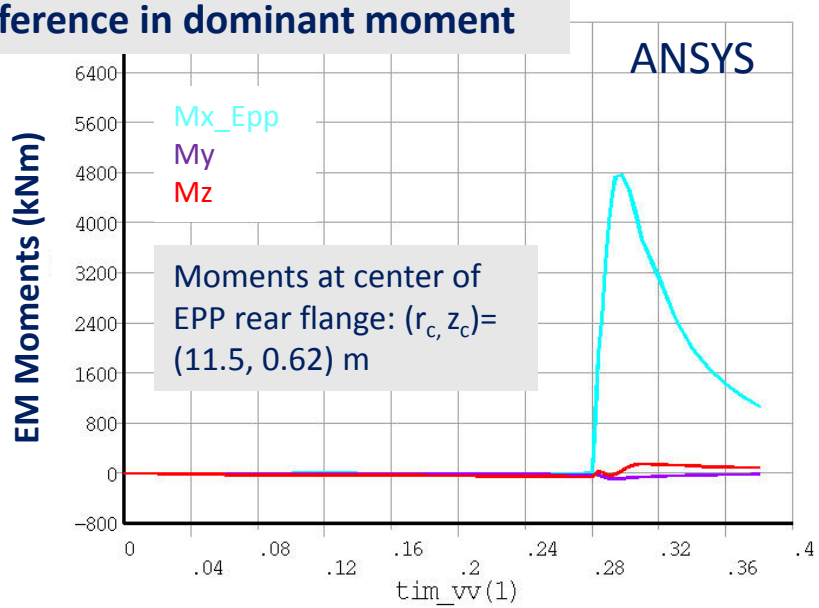
EM Benchmarks



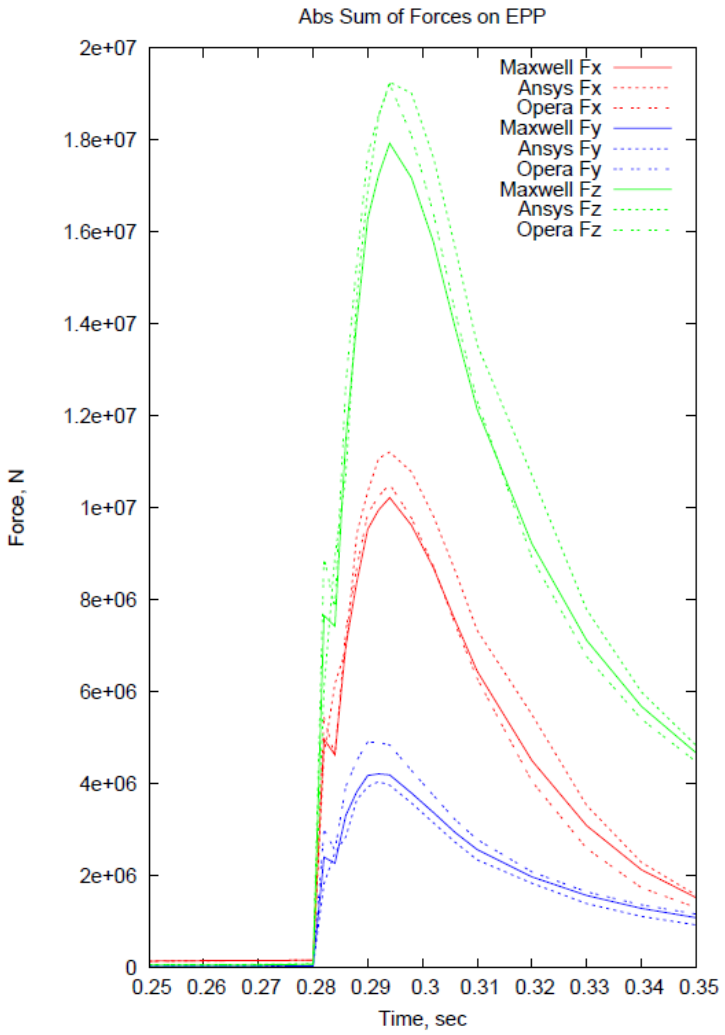


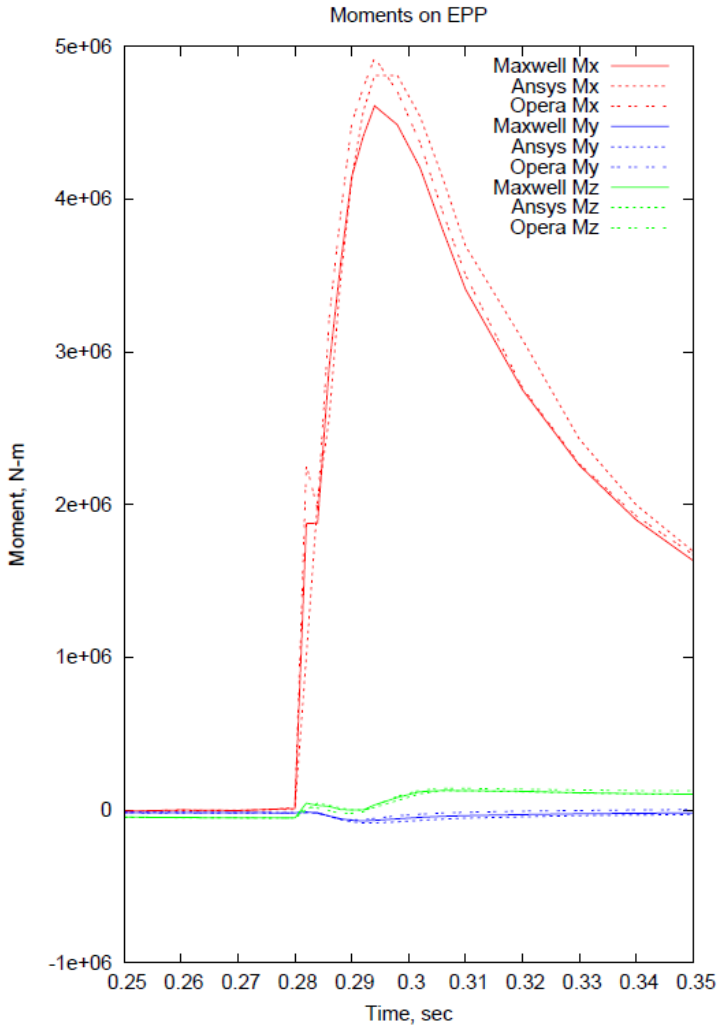
OPERA and ANSYS within ~5% difference in dominant moment





EM Benchmarks



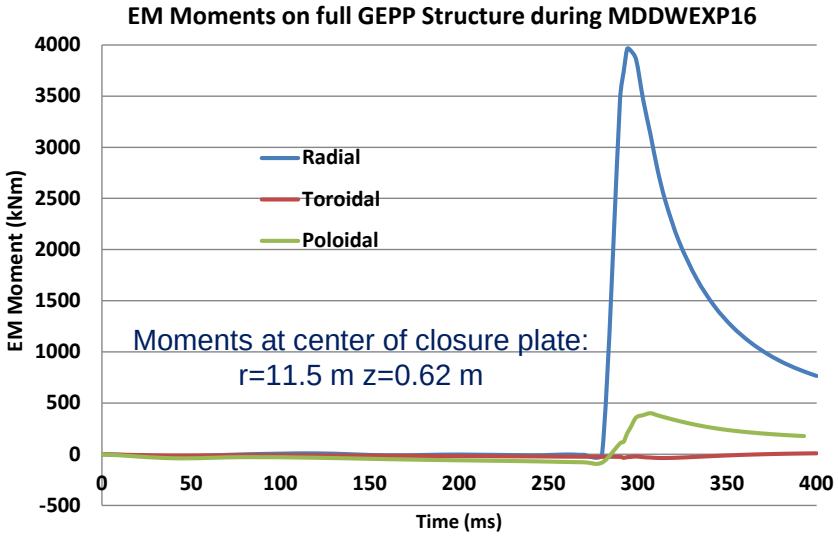


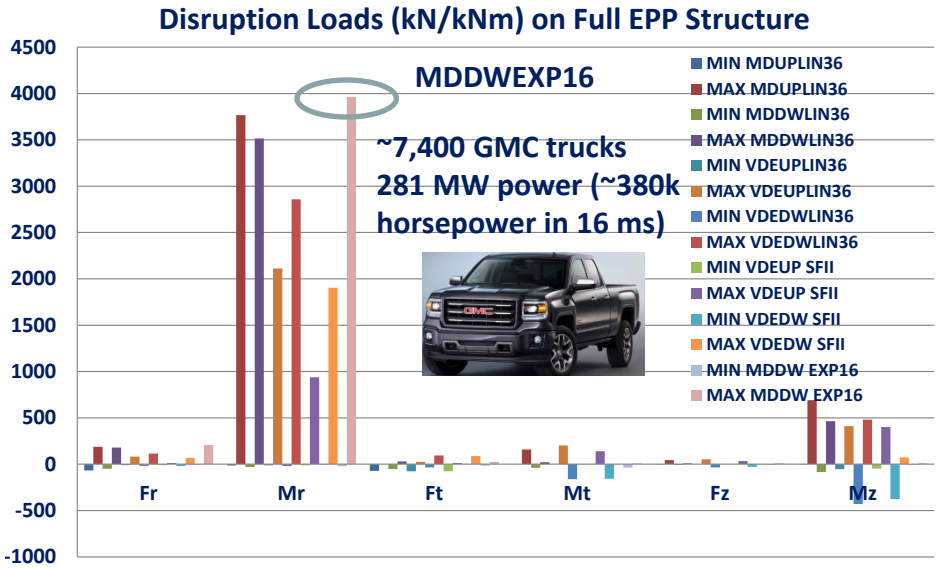
OPERA and ANSYS ~5% difference in dominant moment, OPERA & ANSYS <10% difference with MAXWELL

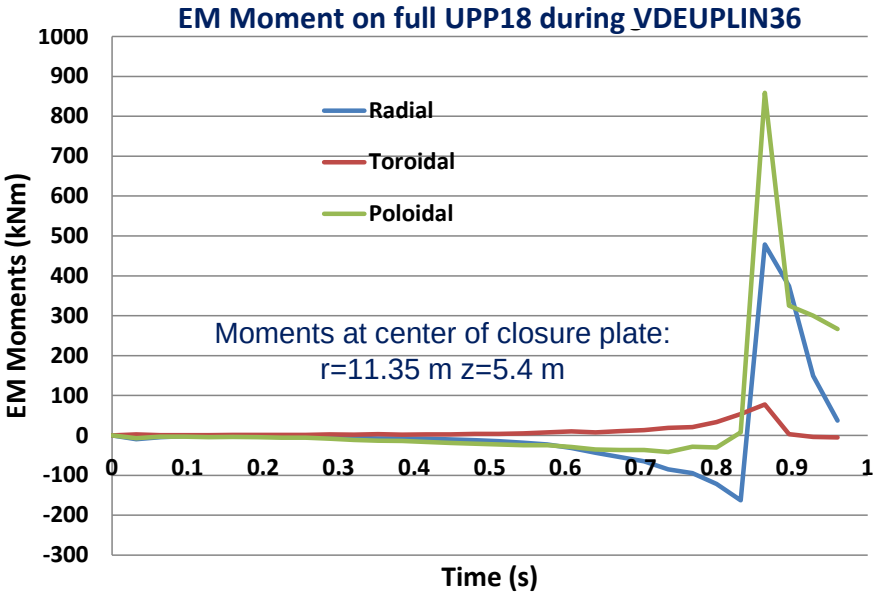
Better agreement (<10%) found when summations of absolute force magnitude over parts are plotted

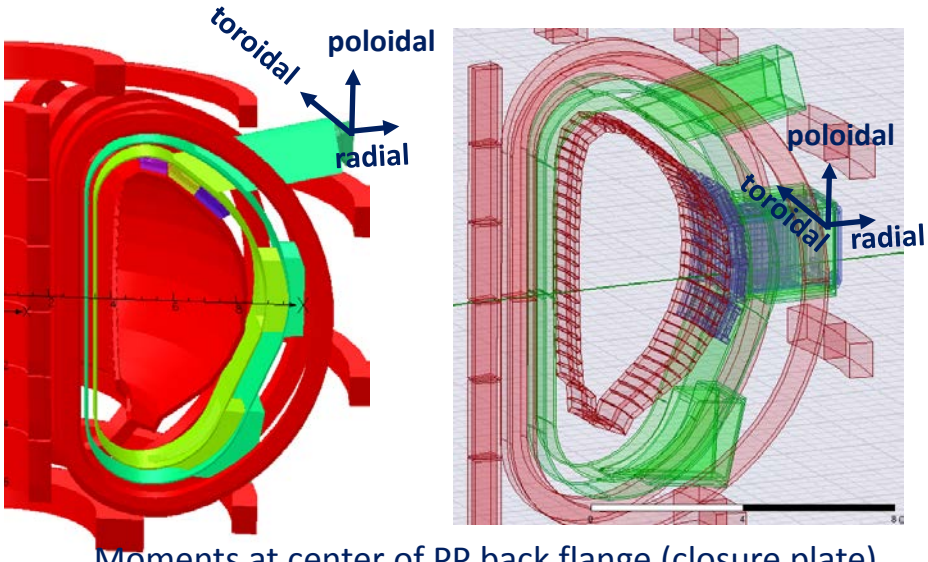
Moment at center of rear flange of EPP structure: (r_c, z_c)= (11.5, 0.62) m

EM Loads on EPP & UPP Assembly



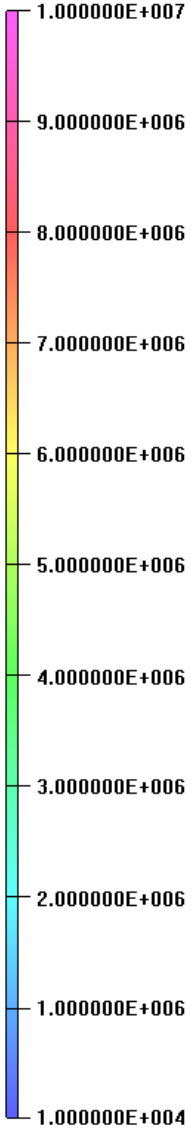




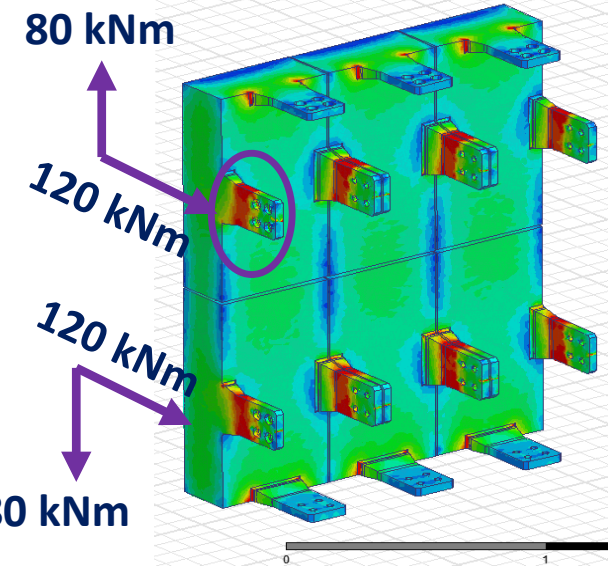


Moments at center of PP back flange (closure plate)

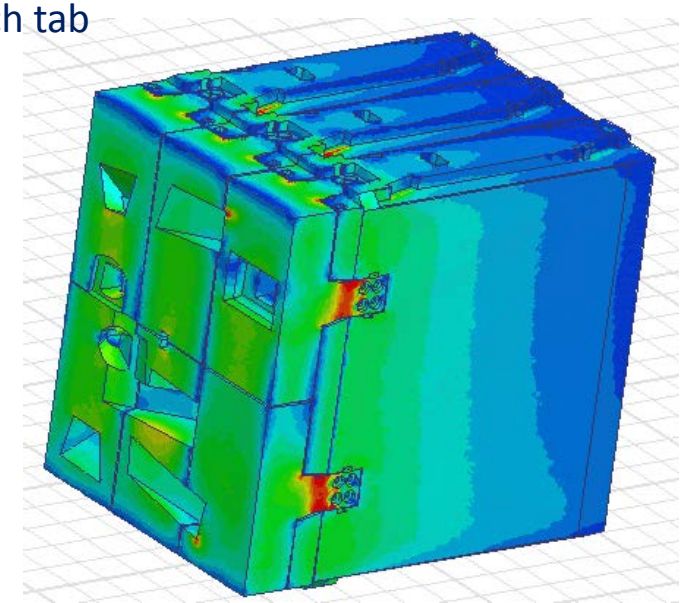
Eddy Current and Loads on DFW-DSM



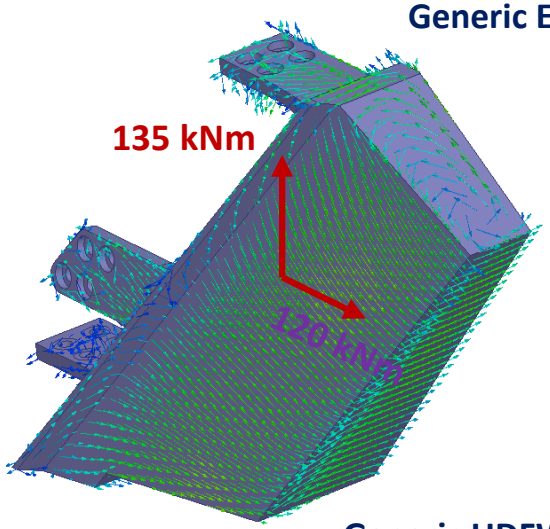
~60 kA net current flow through each tab



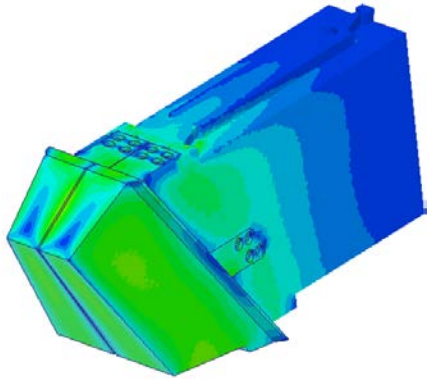
Generic EDFW



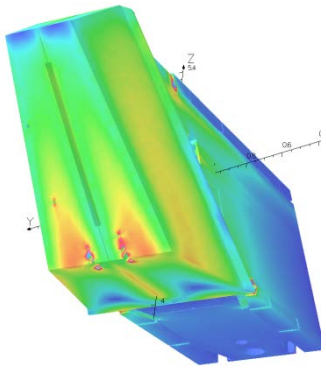
EPP03 DFW & DSM during MDDWEXP16



Generic UDFW



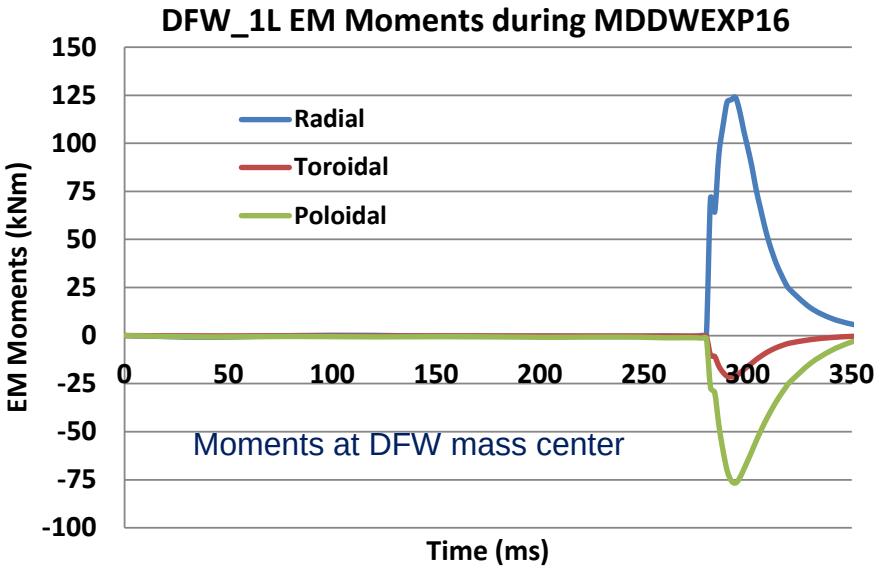
UPP during VDEUPLIN36

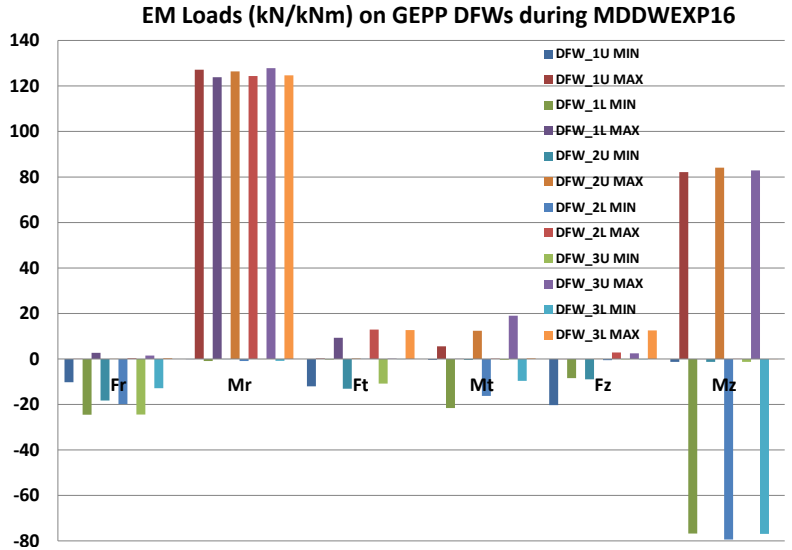


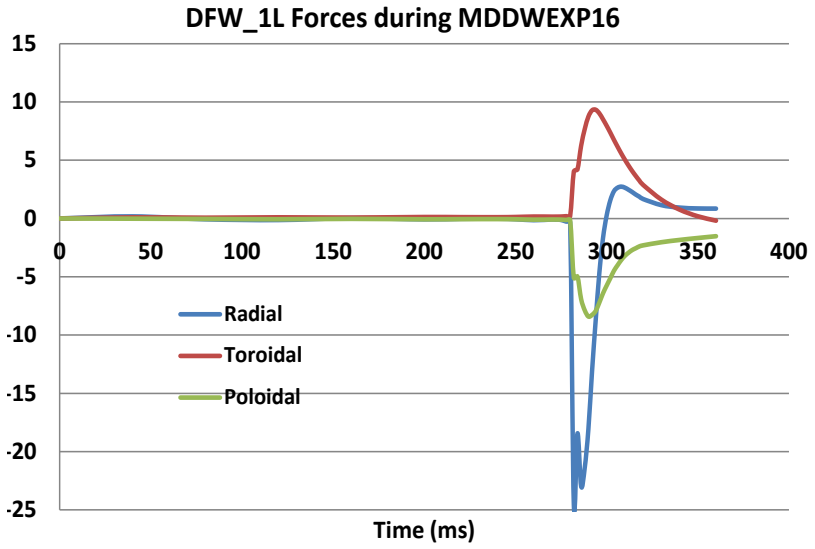
UPP18

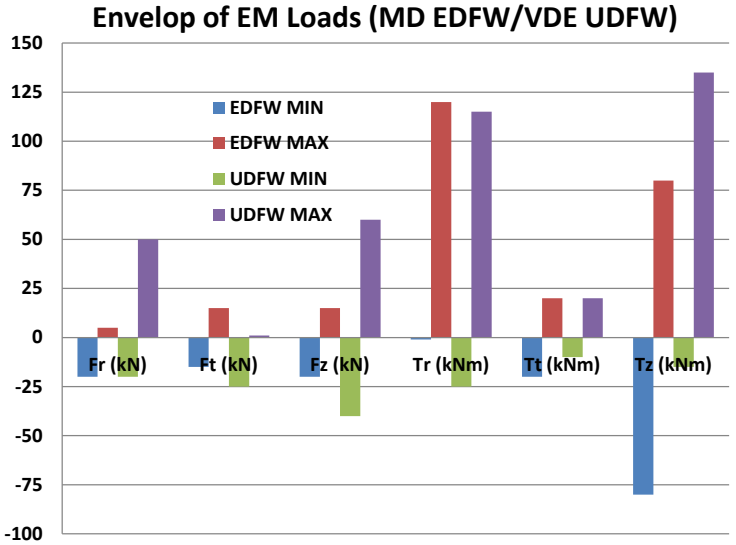
EM Loads on DFWs

Radial/poloidal moments dominant: 125/80 kNm for EDFW; 120/135 kNm for UDFW

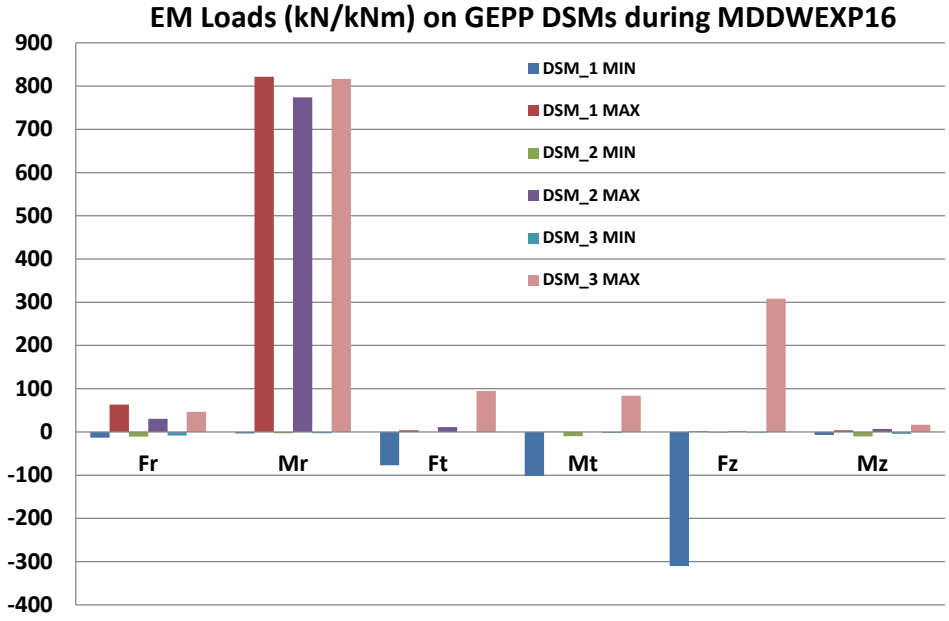


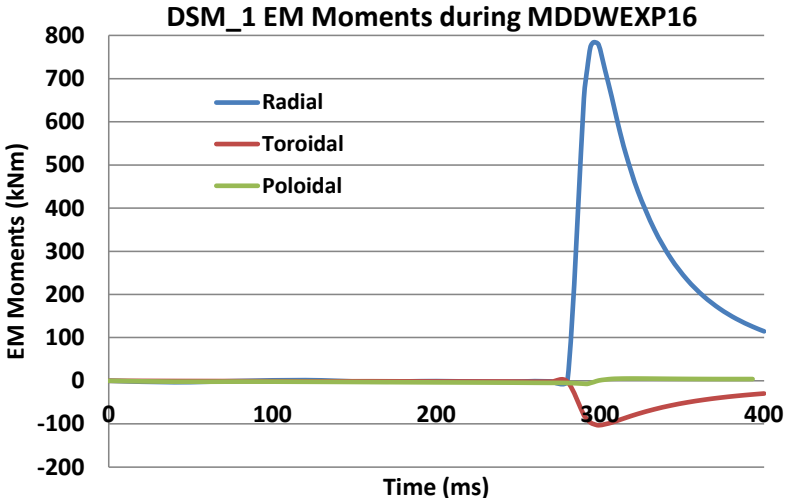


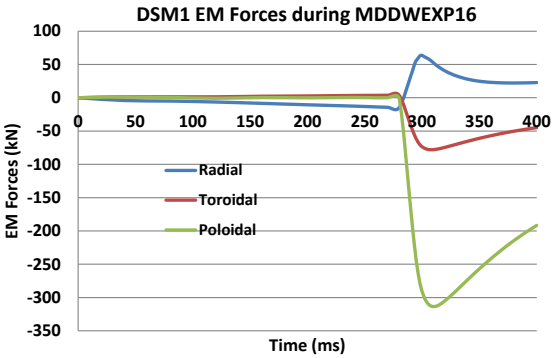


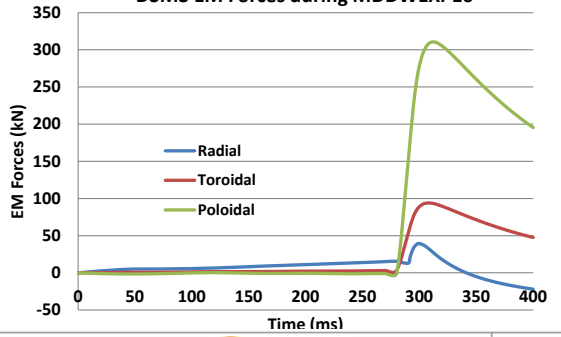


EM Loads on DSMs – MDDWEXP16



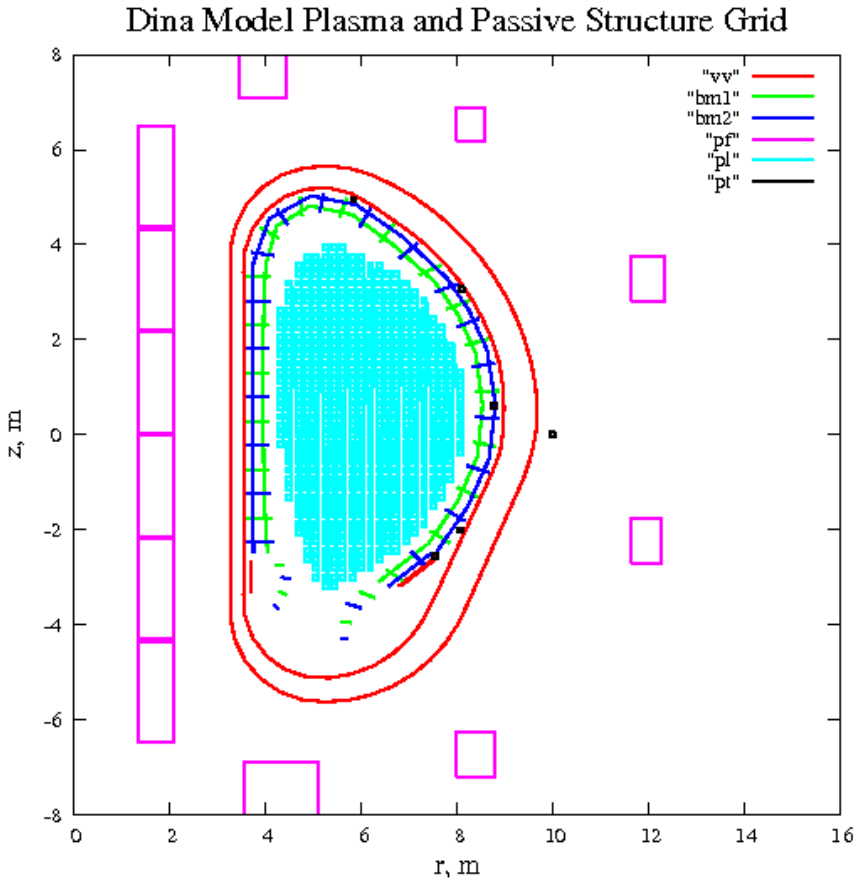


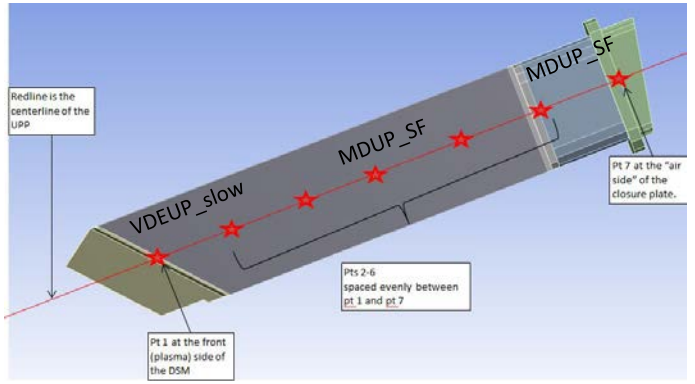




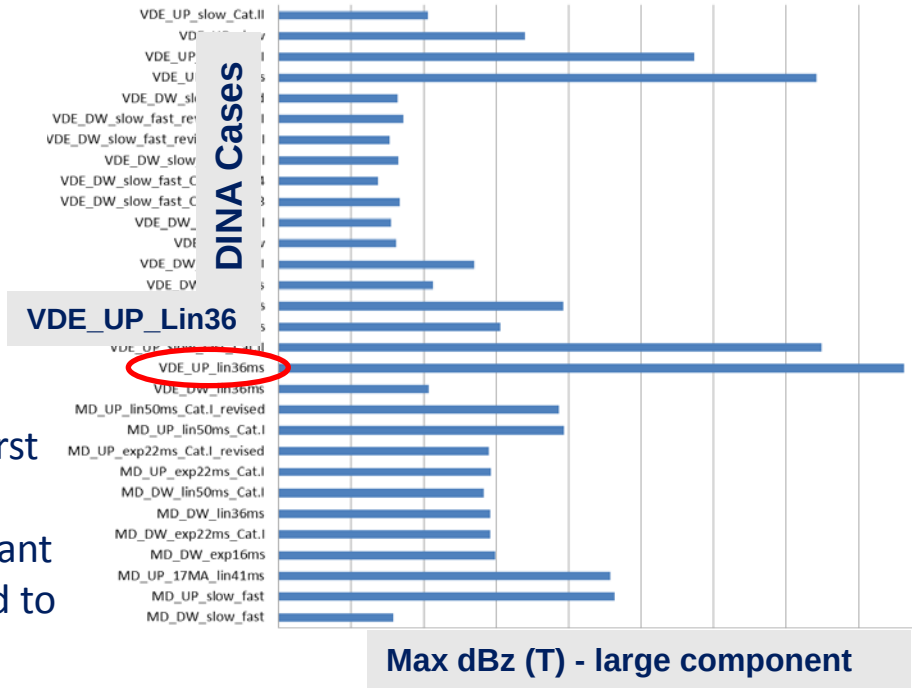
- 800 kNm moment for DSMs; 300 kN poloidal force on left and right DSM but opposite polarity
  - ~500 kJ net energy loss on full EPP (90% on DFW-DSM)
  - ~60 kJ energy loss on EPP structure
  - ~5-6 kJ loss on top and bottom rails
- ~135 kA current flows in the eddy loop at front top and bottom of EPP structure

DINA Scan – Worst Disruption for Diagnostics





Points along UPP centerline for DINA scan



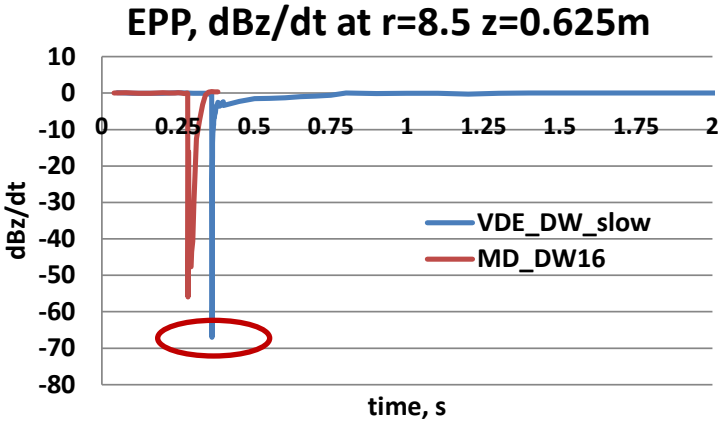
Small components with short time constant (little inductive coupling, L/R<1 ms), max dB/dt to select worst disruption

Large components with longer time constants (significant inductive coupling), max dB during plasma events used to select worst disruption

DINA Scan – Worst Case for Diagnostics

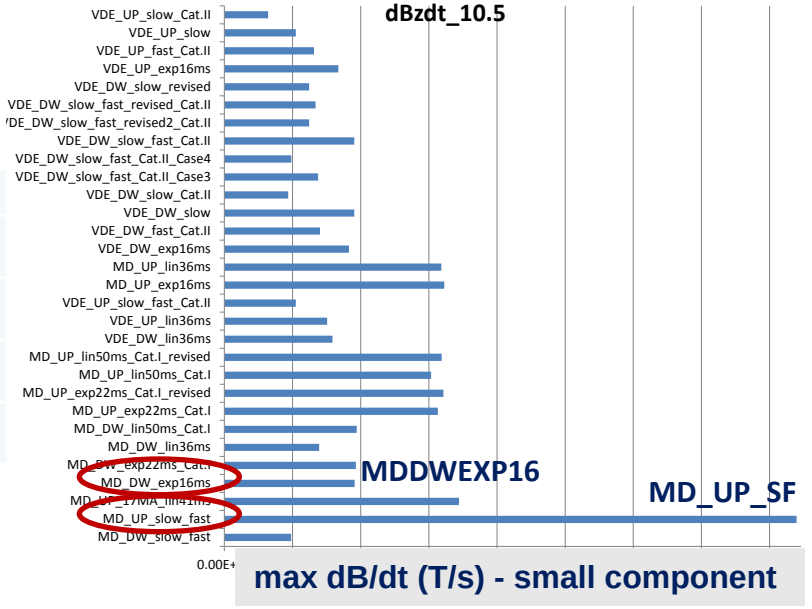
Worst Disruptions for EPP in-port components

Component	Front End	Middle	Back End
Small - dBr/dt	VDE_DW_slow	MD_UP_slow_fast	
Small - dBz/dt			
Large - dBr	VDE_UP_slow		
Large - dBz	**MD_DW_Exp16**	VDE_UP_slow	



Worst Disruptions for UPP in-port components

Component	Front End	Middle	Back End
Small - dBr/dt	MD_UP_slow_fast		
Small - dBz/dt	VDE_UP_slow	MD_UP_slow_fast	
Large - dBr	VDE_UP_slow		
Large - dBz	**VDE_UP_Lin36**	VDE_UP_slow	

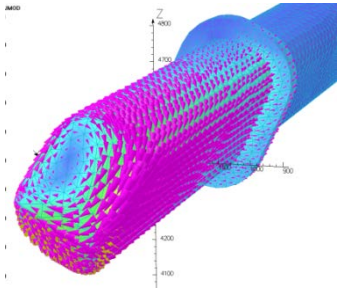


Worst case for full EPP structure (MDDWEXP16) not worst for in-port components (TIP mirror)

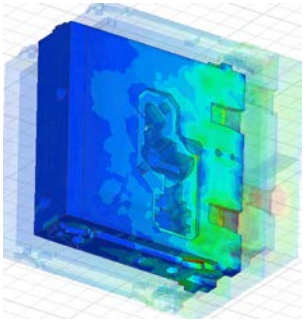
3D analysis to be performed to extract EM loads & validate the worst case from 2D DINA scan

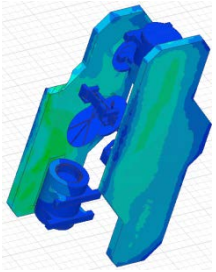
EM Loads – Significant Variations

Components	EM Moments (kNm)	
	Equatorial port	Upper port
Full PP structure	4000-4500	2000
DSM	900	650
DFW	125	135
LFSR front	3	n/a
VisIR front	n/a	1-3
TIP mirrors (Cu)	1	n/a
ECE mirrors	0.01	n/a
VisIR mirrors	0.01	<0.1



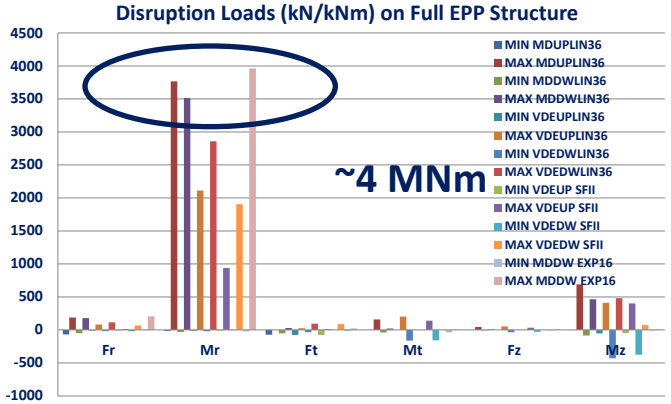
UPP14 Vis/IR front end
Electrical contacts significantly impact loads on VIR tube



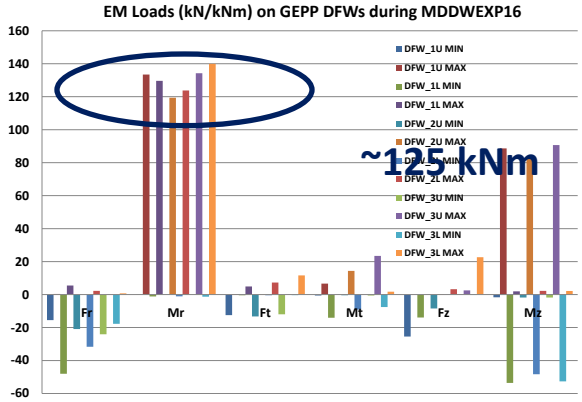


ECE DSM
Electrical contacts significantly impact loads

Significant load reduction from large to small components
Torque density for large components (800-950 kJ/m^3) but an order of magnitude lower torque density in small in-port diagnostic components

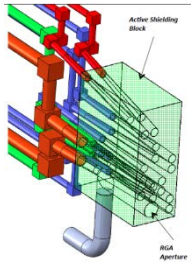


Full EPP structure



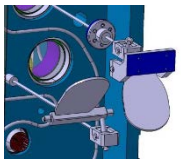
single DFW

LFSR



~500 N/m

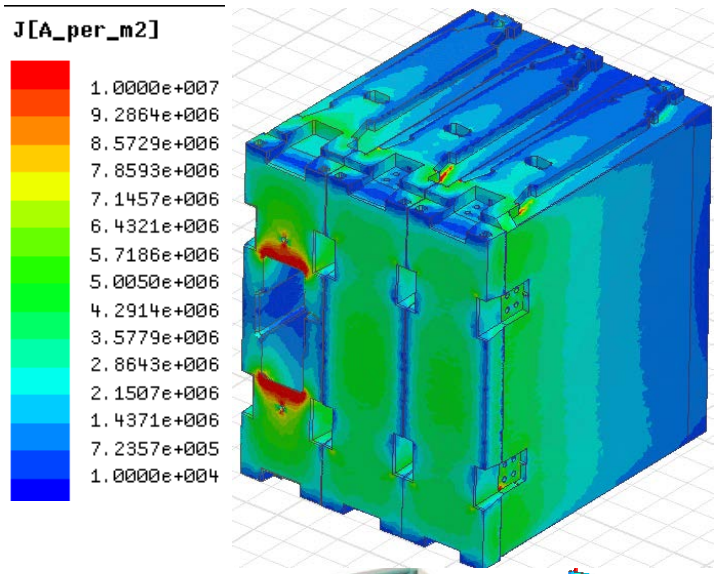
ECE

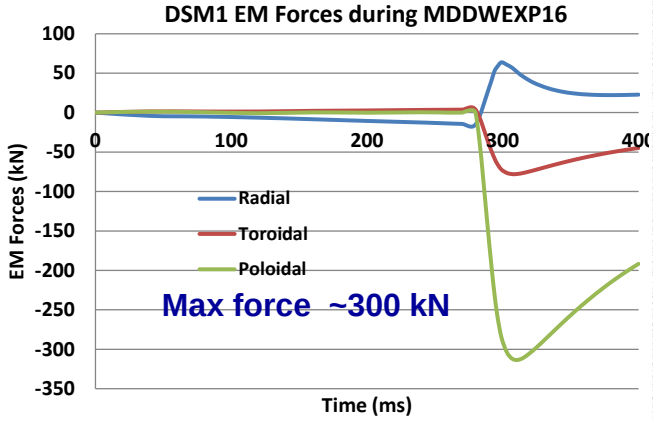


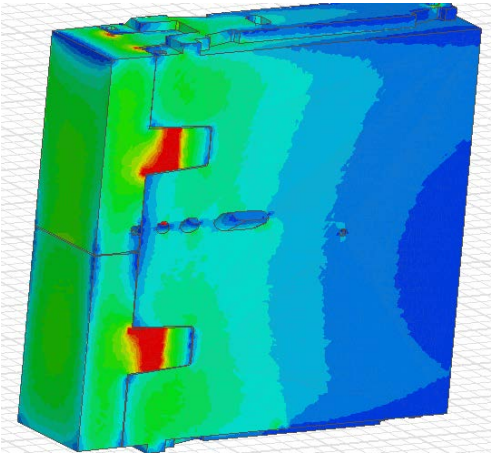
<5 N(m)?

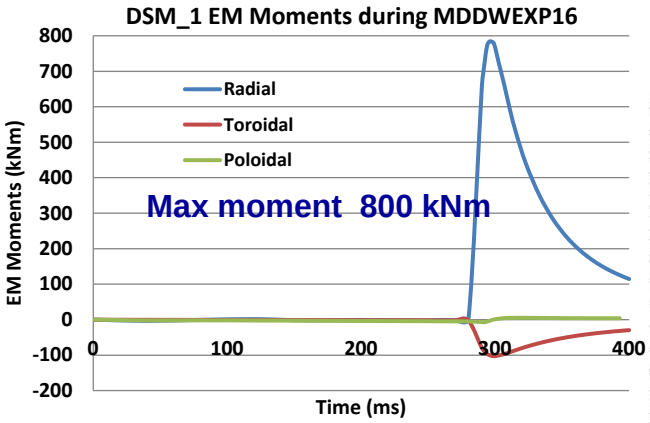
diagnostics

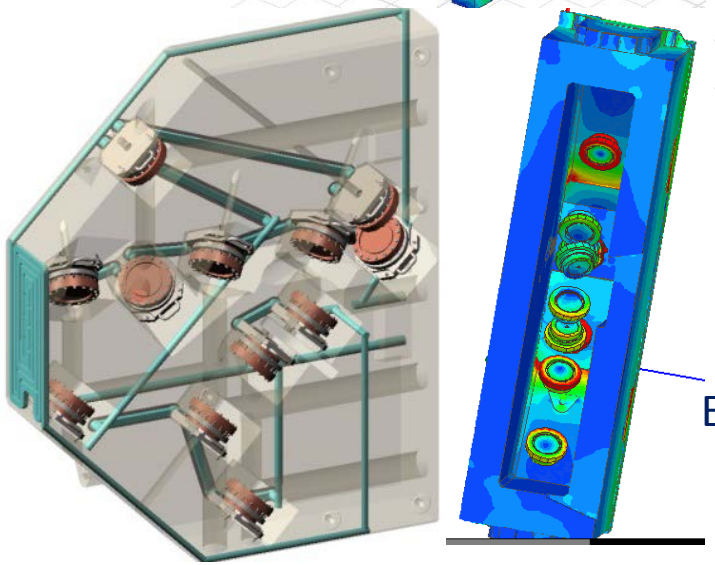
TIP DSM & Diagnostics – Eddy Current & EM Loads



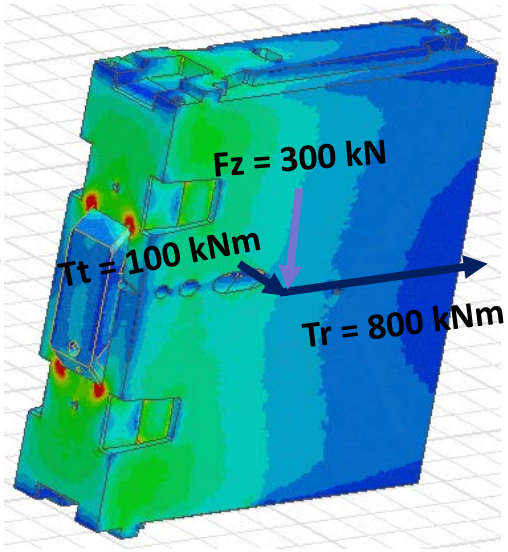








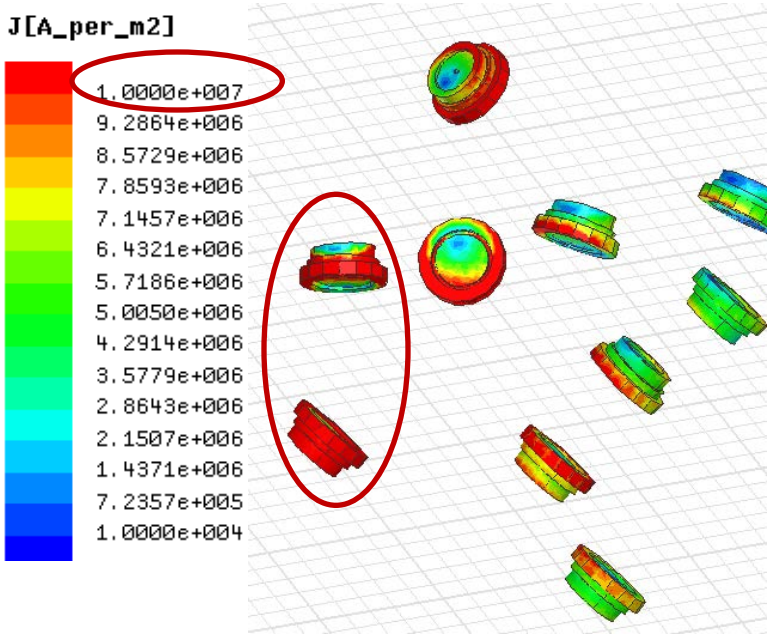
EM loads on TIP DSM and mirrors

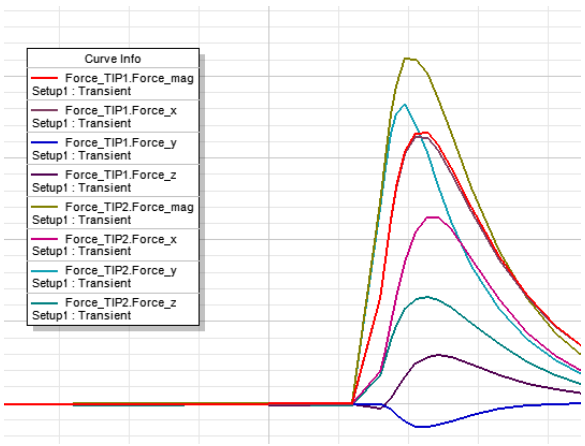


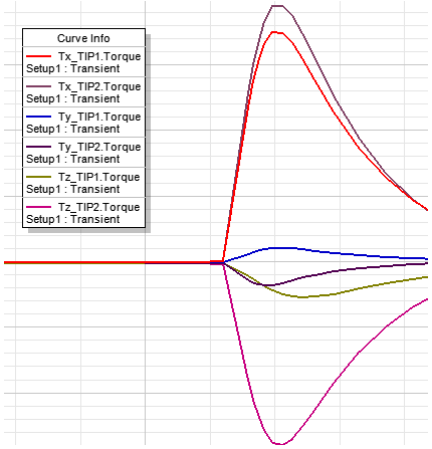
TIP cartridge insert & TIP DSM

Moments at mass center of DSM

Eddy Current and EM Loads on Diagnostics

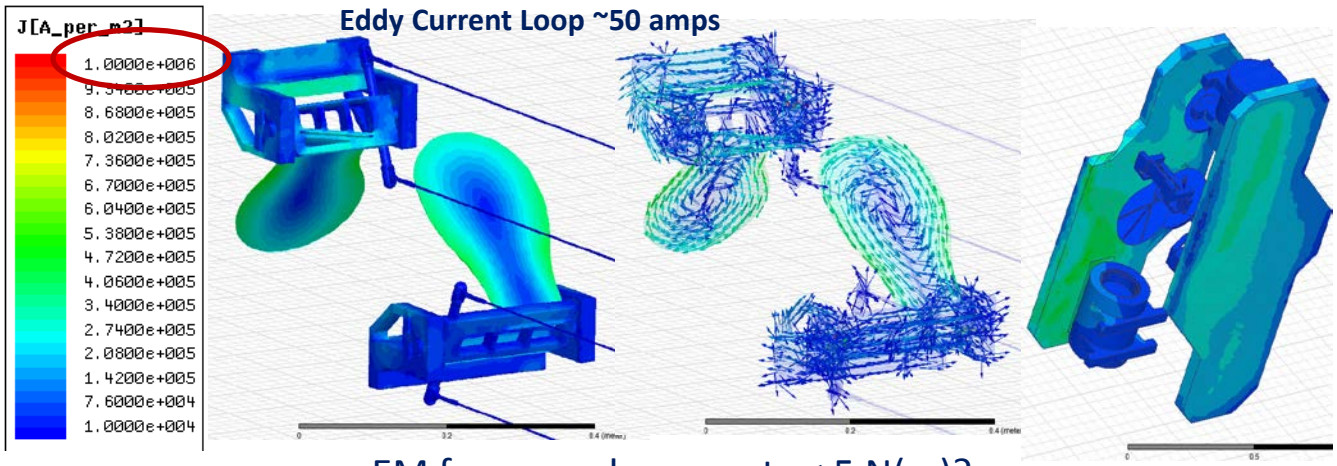






Max Forces ~200-250 N **Max moments ~1 kNm**

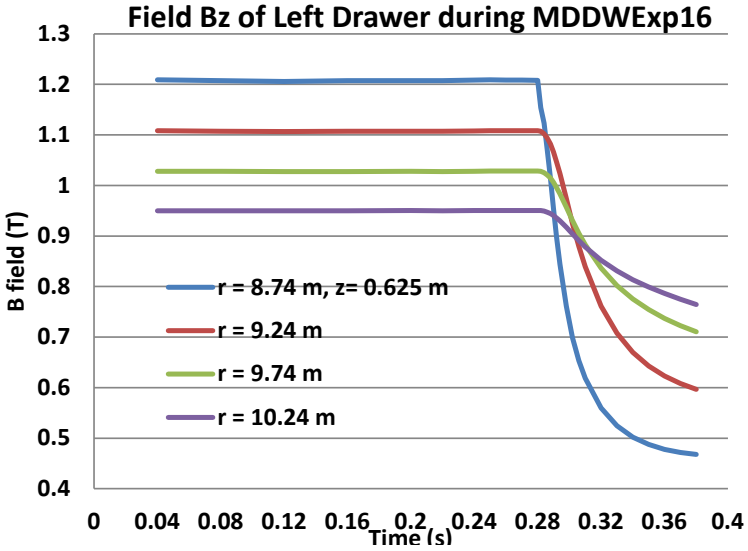
Order of magnitude smaller current density as ECE shutters shielded electromagnetically by DFW/DSM

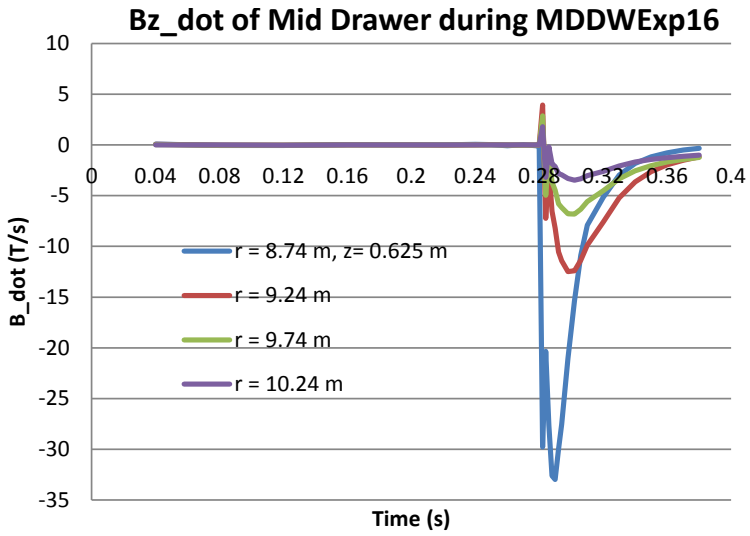


No electrical contact with Cartridge; loads increase significantly when in contact at cartridge attachment

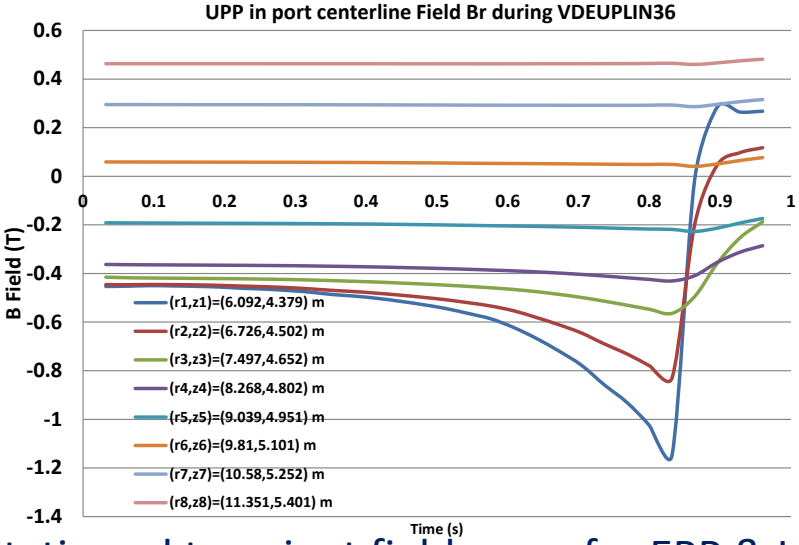
EM forces and moments < 5 N(m)?

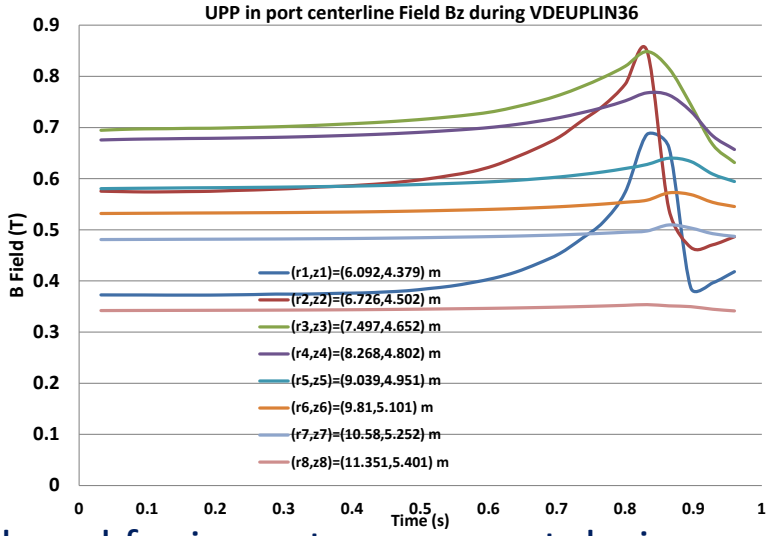
Magnetic Field Maps





Vertical field varies greatly (> 30 T/s at EDFW front) during fast decay of plasma current

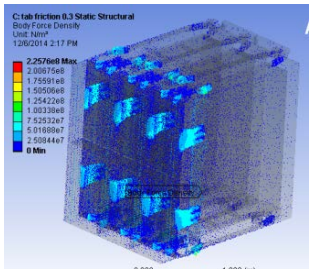


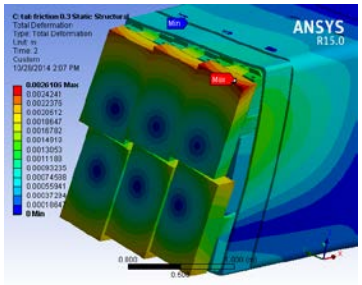


Static and transient field maps for EPP & UPP are developed for in-port component design

Response Implication

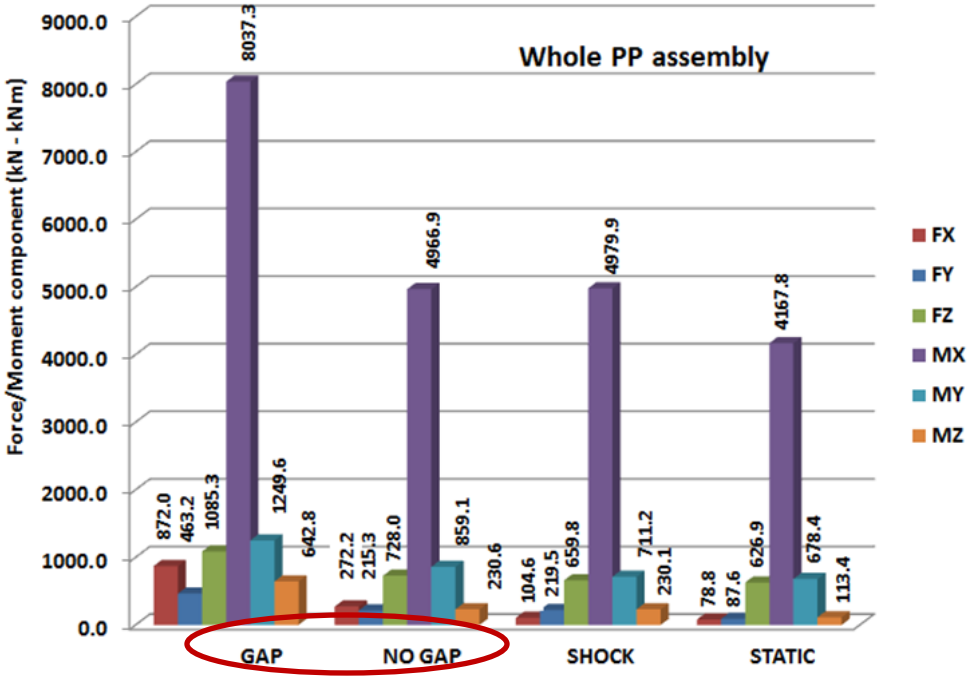
- Transient elemental forces mapped onto structural model for dynamic analysis
- Dynamic response of full PP assembly under transient EM loads
  - May have significant impact to in-port diagnostic components
  - DSM to PP structure attachment shall meet tight tolerance to remove gaps (rattling)





High frequency components may participate in system dynamic response, in addition to inertia effect (mass).

Static equivalent approach (1.5 DAF for low frequency seismic loads) may or may not apply to response under disruption loads.



J. Guirao at IO

Conclusions

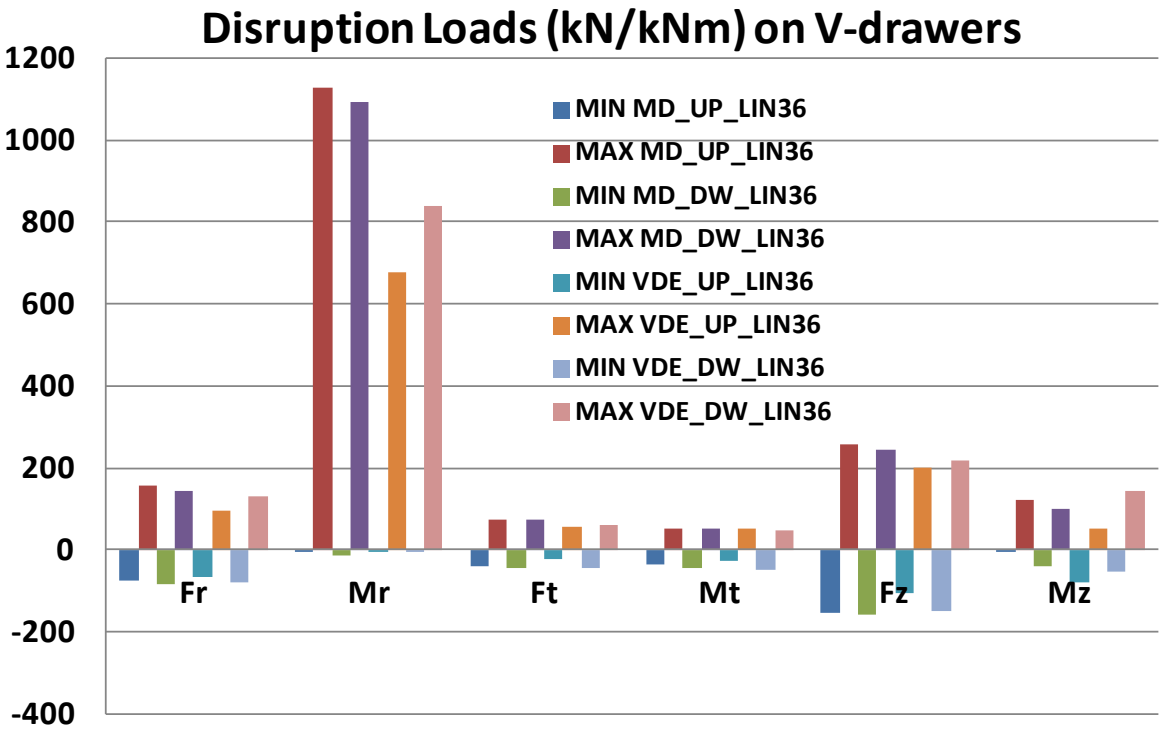
- Global EM models are developed and benchmarked for ITER PP and diagnostics
- EM disruption loads are extracted for full PP assembly and in-port diagnostics
- DINA scan over 30 scenarios performed to identify worst case for diagnostics
- Worst case for full PP assembly may not the worst for in-port diagnostics
- EM Loads
  - Max net moments on EPP and UPP structure are 4.5 MNm and 2 MNm
  - Dominant moments on DFWs are 125/80 kNm (EDFW); 120/135 kNm (UDFW)
  - Significant variation on diagnostics (component location, size & electrical contact)
- Dynamic impact to in-port diagnostics
  - Reduce/remove gap in DSM to PP structure attachment system design
  - Shock isolator for in-port system attached to DSM to avoid large impact loads
- Static and transient field maps developed for in-port component design
- Assessment of uncertainties
  - DINA-OPERA interfaces and model mesh size
  - Critical electrical contact size and location

Backup Slides

EM Load Summary on Vertical Drawers

Observations

- Drawer radial moment always dominant but M_z also important
- Poloidal force is larger than radial force
- Unlike radial moment all other loads tend to change polarity
- MDUP is the worst load case



V-Drawers	Total Force (kN)	Total Moment (MNm)
MD_UP_LIN36	269.6	1.13
MD_DW_LIN36	262.1	1.09
VDE_UP_LIN36	211.9	0.68
VDE_DW_LIN36	231.4	0.85

- For a single vertical drawer
- Max and min of all three drawers
- Peak over 36 ms disruption
- Moment at drawer mass center

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