



Figure 2.3.3 "Attracting-like" displacement of the magnetic field lines by a ferromagnetic shield: a) closed shield with external source (homogeneous field), b) open shield (three-phase field) and c) closed shield with internal source (single-phase field).

Figure 2.3.14 "Repelling-like" displacement of the magnetic field lines by a pure conductive shield: a) closed shield with external source (homogeneous field), b) open shield (three-phase source)

SHIELDING BENCHMARK Static Shielding and Eddy Current Shielding

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OBJECTIVES

- 2D benchmarks
 - Static shielding
 - Eddy current shielding
- 3D benchmarks
 - Static shielding
 - Eddy current shielding
- Substation example
 - Import of HyperMesh model
 - Thin regions



BENCHMARK CASE

 CIGRE 373-2009 document: MITIGATION TECHNIQUES OF POWER-FREQUENCY MAGNETIC FIELDS ORIGINATED FROM ELECTRIC POWER SYSTEMS



The analysis is developed for simplicity making reference to a two-dimensional source, formed by a lead-and-return conductor. The shield (with thickness Δ and permeability μ) is realized by a planar sheet (having width *L*) or a by a U-shaped sheet, and it is placed at a distance *d* from the source (see Figure 2.3.8).

It must be noted that, in the U-shaped arrangement, each side has the same length L as the planar sheet. Hence, the U-shaped shield involves more shielding material than the planar shield.

The shielding factor depends on the position; the value is plotted along the y-axis (at x = 0) and along the x-axis (at y = d + 0.5, that is at 0.5 m from the shield).

STATIC SHIELDING BENCHMARK



Figure 2.3.9 *SF* of the flat shield of Figure 2.3.8(a) for different values of magnetic permeability: (a) plot along *y* axis at x = 0, (b) plot along *x* axis at y = 0.7 m.

STATIC SHIELDING BENCHMARK FEA MODEL

- Source
 - Lead and return conductor with 4000 A DC
 - Infinite long conductor
- Plate dimensions
 - Length = 1000 mm
 - Thickness = 1 mm
 - Axial length = 1000 mm
 - 2D (infinite long)
 - 3D (actual length)
- Material
 - Linear steel Mur = 1000

- Model
 - 2D
 - 3D
 - 3D extruded
- Boundary conditions
 - Infinite box for 2D and 3D
 - 10000 mm radius for 3D extruded

STATIC SHIELDING BENCHMARK 2D FEA EQUIFLUX LINES



STATIC SHIELDING – 2D FEA POST-PROCESSING

- BX0: Magnitutde of B along Path X (no shield)
- BY0: Magnitude of B along Path Y (no shield)
- BX: Magnitutde of B along Path X
- BY: Magnitude of B along Path Y
- SFX: Shielding factor = BX0/BX
- SFY: Shielding factor = BY0/BY



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STATIC SHIELDING – 2D FEA POST-PROCESSING – BX & BY



STATIC SHIELDING – 2D FEA POST-PROCESSING – SFX



STATIC SHIELDING – 2D FEA POST-PROCESSING – SFY



STATIC SHIELDING – 2D FEA MODEL - COMMENTS

- Good correlation between 2D FEA results with CIGRE data
 - Model of Fig. 238 a
 - Data of Fig. 239 a and b
- 2D FEA model
 - Assumes infinite long conductor
 - Assumes infinite long sheet (axially)
 - Even though the axial length is defined for 1000 mm
 - Uses of infinite box for open field boundaries

STATIC SHIELDING BENCHMARK – 3D MODEL

- Open field boundary conditions with Infinite Box
- Conductors
 - Non meshed coils
 - Infinitely long
- Sheet
 - Volume region with mesh
 - Thin magnetic face region with 1 mm thickness





STATIC SHIELDING BENCHMARK – SHEET

- Sheet with volume region
 - Geometrically represented
 - Volume meshed
 - Magnetic region

C Edit Volume Region[SHIELD]	
Name of the region *	
SHIELD	
Comment	
Magnetostatic 3D \ Appearance \ Mechanical Set \ Evaluated information \	
Type of region	
Magnetic non conducting region	
General \ Material orientation \	
Material of the region *	
STEEL	
	1
OK Apply Orient Cancel Image: Concel Image: Con	

- Sheet with thin faceregion
 - Geometrically represented by a face
 - Magnetic thin face region
 - Thickness of 1 mm

C Edit Face region[SHEET] ×
Name of the region *
SHEET
Comment
Magnetostatic 3D Appearance Mechanical Set Evaluated information
Type of region
Magnetic non conducting region
Conoral Material arientation
Almost tangential magnetic flux
Material of the region *
STEEL
Thickness of the region (in m) *
1E-3 f0
DK Apply Orient Cancel

STATIC SHIELDING – 3D FEA POST-PROCESSING

- BX0: Magnitutde of B along Path X (no shield)
- BY0: Magnitude of B along Path Y (no shield)
- BX: Magnitutde of B along Path X
- BY: Magnitude of B along Path Y
- SFX: Shielding factor = BX0/BX
- SFY: Shielding factor = BY0/BY



STATIC SHIELDING BENCHMARK 3D FEA – FLUX DENSITY B ON X-Y PLANE – 3D VOLUME REGION





STATIC SHIELDING – 3D FEA POST-PROCESSING – BX & BY – VOLUME REGION SHIELD







ΒY

STATIC SHIELDING BENCHMARK 3D FEA – FLUX DENSITY B ON X-Y PLANE – SHEET THIN MAGNETIC FACE REGION



STATIC SHIELDING – 3D FEA POST-PROCESSING – BX & BY – THIN MAGNETIC REGION SHEET





STATIC SHIELDING – 3D FEA POST-PROCESSING – SFX



STATIC SHIELDING – 3D FEA POST-PROCESSING – SFY



STATIC SHIELDING – 3D FEA MODEL – Z DIRECTION EDGE EFFECTS





STATIC SHIELDING – 3D FEA MODEL - COMMENTS

- 3D FEA model
 - Use infinite long conductor
 - Assumes finite axial length sheet (1000 mm)
 - · Uses of infinite box for open field boundaries
 - Shield represented by 3D volume and thin magnetic face region of 1 mm thick show good agreement for SFX and SFY
- Small delta in SFX and SFY between 2D and 3D model (less)
 - 3D edge effect in the axial direction Z
 - · Longer 3D model will reduce delta on SFX and SFY

CONDUCTIVE SHIELDING – EDDY CURRENTS

- Conductive sheet with 10 mm thickness
 - Non magnetic: Mur = 1
 - Conductivity = 50 MS/m

- Model
 - 2D
 - 3D

- Current conductors at 4000 A rms and 50 Hz
- Plate dimensions
 - Length = 1000 mm
 - Thickness = 1 mm
 - Axial length = 1000 mm
 - 2D (infinite long)
 - 3D (actual length)
- Boundary conditions
 - Infinite box for 2D and 3D
 - 10000 mm radius for 3D extruded



CONDUCTIVE SHIELDING – EDDY CURRENTS



Figure 2.3.16 *SF* for different electrical conductivities of the shield of Figure 2.3.8(a): (a) plot along *y* axis at x = 0, (b) plot along *x* axis at y = 0.7 m.

CONDUCTIVE SHIELDING – 2D MODEL – ISOFLUX



CONDUCTIVE SHIELDING – 2D MODEL – EDDY CURRENTS IN SHIELD



CONDUCTIVE SHIELDING – 2D FEA POST-PROCESSING

- BX0: Magnitutde of B along Path X (no shield)
- BY0: Magnitude of B along Path Y (no shield)
- BX: Magnitutde of B along Path X
- BY: Magnitude of B along Path Y
- SFX: Shielding factor = BX0/BX
- SFY: Shielding factor = BY0/BY



CONDUCTIVE SHIELDING – 2D FEA POST-PROCESSING – BX & BY



CONDUCTIVE SHIELDING – 2D FEA POST-PROCESSING – SFX



CONDUCTIVE SHIELDING – 2D FEA POST-PROCESSING – SFY



CONDUCTIVE SHIELDING – 2D FEA MODEL - COMMENTS

- Good correlation between 2D FEA results with CIGRE data
 - Model of Fig. 238 a
 - Data of Fig. 23.16 a and b
- 2D FEA model
 - Non magnetic conductive material
 - Assumes infinite long conductor
 - Assumes infinite long sheet (axially)
 - Uses of infinite box for open field boundaries

CONDUCTIVE SHIELDING BENCHMARK – 3D MODEL

- Open field boundary conditions with Infinite Box
- Conductors
 - Non meshed coils
 - Infinitely long
- Sheet
 - Volume region with mesh
 - Thin conductive face region with 10 mm thickness





CONDUCTIVE SHIELDING BENCHMARK – SHEET

- · Shield with volume region
 - Geometrically represented
 - Volume meshed

LARGE IN IS INCOMPANY

Solid conductor region

anno or a	he region *
SHIELD	
Commen	t in the second s
Steady	State AC Magnetic 3D \ Appearance \ Mechanical Se
Type of	region
Solid co	nductor region
Solid co Gene	nductor region ral \ Material orientation \
Solid co Gene Materia	onductor region ral \ Material orientation \ al of the region *

- Shield with thin face region: Sheet
 - · Geometrically represented by a face
 - Conductive thin face region
 - Thickness of 10 mm

⇐ Edit Face region[SHEET]
Name of the region *
SHEET
Comment
Evaluated information
Steady State AC Magnetic 3D Appearance Mechanical Set
Type of region
Thin conducting region (hyperbolic current density through the thickness)
Material of the region *
COND
Thickness of the region (in m) *
10E-3 f0
OK Apply Orient Cancel Image: Concel Image: Con

CONDUCTIVE SHIELDING – 3D FEA POST-PROCESSING

- BX0: Magnitutde of B along Path X (no shield)
- BY0: Magnitude of B along Path Y (no shield)
- BX: Magnitutde of B along Path X
- BY: Magnitude of B along Path Y
- SFX: Shielding factor = BX0/BX
- SFY: Shielding factor = BY0/BY



CONDUCTIVE SHIELDING BENCHMARK 3D FEA – CURRENT DENSITY J ON X-Y PLANE – 3D VOLUME REGION SHIELD



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CONDUCTIVE SHIELDING BENCHMARK 3D FEA – FLUX DENSITY B – 3D VOLUME REGION SHIELD


CONDUCTIVE SHIELDING BENCHMARK 3D FEA – FLUX DENSITY B ON X-Y PLANE – 3D CONDUCTIVE VOLUME REGION SHIELD



CONDUCTIVE SHIELDING – 3D FEA POST-PROCESSING – BX & BY – VOLUME REGION SHIELD





CONDUCTIVE SHIELDING BENCHMARK 3D FEA – FLUX DENSITY B ON X-Y PLANE – SHEET THIN CONDUCTOR FACE REGION



CONDUCTIVE SHIELDING – 3D FEA POST-PROCESSING – BX & BY – THIN CONDUCTOR REGION SHEET





STATIC SHIELDING – 3D FEA POST-PROCESSING – SFX



STATIC SHIELDING – 3D FEA POST-PROCESSING – SFY



STATIC SHIELDING – 3D FEA MODEL - COMMENTS

- 3D FEA model
 - Use infinite long conductor
 - Finite axial length shield (1000 mm)
 - · Uses of infinite box for open field boundaries
 - Shield represented by 3D volume and thin conductor face region of 10 mm thick show good agreement for SFX and SFY
- Discrepancies in SFX and SFY between 2D and 3D model
 - 3D edge effect in the axial direction Z
 - Eddy current patterns
 - Flux density edge effects

CONDUCTIVE SHIELDING – 3D FEA MODEL – Z DIRECTION EDGE EFFECTS – CURRENT DENSITY J



CONDUCTIVE SHIELDING – 3D FEA MODEL – Z DIRECTION EDGE EFFECTS – FLUX DENSITY B



CONDUCTIVE SHIELDING – 3D FEA MODEL EXTRUDED

- 3D geometry extruded from 2D
- Tangential boundary conditions
- Outer diameter = 10 m to replicate infinite box





CONDUCTIVE SHIELDING – 3D EXTRUDED FEA MODEL – CURRENT DENSITY J





CONDUCTIVE SHIELDING – 3D EXTRUDED FEA MODEL – FLUX DENSITY B



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CONDUCTIVE SHIELDING – 3D FEA POST-PROCESSING – SFX



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CONDUCTIVE SHIELDING – 3D FEA POST-PROCESSING – SFY



STATIC SHIELDING – 3D EXTRUDED FEA MODEL - COMMENTS

- 3D Extruded FEA model
 - Use infinite long conductor
 - Infinite long axially with tangential boundary conditions
 - 10 m radius for boundary conditions
 - Shield represented by 3D volume and thin conductor face region of 10 mm thick show good agreement for SFX and SFY
- Good agreement in SFX and SFY between 2D and 3D model
 - True representation of 2D is 3D "extruded" albeit Infinite Box is not available with 3D extruded and can be replaced with large radius boundary condition.

HYPERMESH MODEL OF SUBSTATION

- Substation
 - Wall
 - · Wall thickness represented
 - Volume with volume elements
 - · Metal sheet on both sides of the wall with much small thickness
 - No geometric representation with thickness
 - Face region with shell elements
 - Roof
 - Roof thickness represented
 - · Volume with volume elements
 - · Metal sheet for shielding on surfaces of roof
 - No geometric representation with thickness
 - Face region with shell elements
 - Steel Beam
 - Thin cross section not represented
 - Face region with shell elements
 - Room
 - · Volume with volume elements

HYPERMESH MODEL OF SUBSTATION

- Preparations for Flux import
 - Air box: Volume in parallepiped shape to envelop the whole SubStation
 - Air box volume and elements
 - Shell or face where post-processing paths occurred
 - Uniform shell elements

FLUX IMPORT OF SUBSTATION HYPERMESH MODEL

- Under Flux context
 - Import/Import mesh/Import mesh from HyperMesh-SimLab-OptiStruct (Nastran) file

Flux3D 2018 - ANONYMOUS

Proj	ject A	oplication	Geor	metry	Mesh	Pł	ysics	Disp	lay	View	Se	ect	Tools	Ex	tensio	ons	Help					
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FLUX IMPORT OF SUBSTATION HYPERMESH MODEL

- File to import
- Face split angle: 45 (default)
- Center the geometry: (recommended yes)
- Check the geometry: yes (default)

Import mesh from a HyperMesh/SimLab/Opti X
HyperMesh/SimLab/OptiStruct (Nastran) file to import *
SimpleRoom3.fem
Coordinate system to attach the imported geometry
Lenght unit (by default: millimeter)
- ▶
Face split angle
45.0
Center the geometry yes no
O no
OK Cancel

SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – FACES







SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – VOLUMES



3 volumes



SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – FACE (SHELL) REGIONS



3 shell regions

- Roofbeam (turquoise)
- TransformerFace (red)
- WallSkins (white)

SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – VOLUME REGIONS



1 volume region

• TransformerFace (yellow)

SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – FACE MESH



SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – VOLUME MESH



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SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – FACE (SHELL) REGION MESH



SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – VOLUME REGION MESH



SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – ADDING INFINITE BOX





- Geometry/Infinite Box/New
- Dimensions are in mm (default)

SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – COMPLETE INFINITE BOX

- Geometry/Infinite Box/Complete
- Building options for propagation
 - Add geometry and mesh after mesh import
- · Coordinates system of points creation
 - Nastran_1
- Periodicity
 - · Add link mesh associated

1 Import3 with box geo.FLU Geometry Mesh Physics Display View Select Tools Extensions Help 💐 Modeler Context 🎎 🍋 🏥 🤽 🥙 🦓 Infinite box So New 🕨 🦾 Edit Reriodicity Ctrl-E Edit array Ctrl-F d) Symmetry 🕨 🐜 Delete Oomain options Supprimer 🖉 Geometric parameter 🗻 Set visible Coordinate system 🗻 Set Invisible Complete Infinite box Transformation Point

ኛ Complete Infinite box	×					
Infinite Box *						
InfiniteBoxCube 🗸						
Building options for propagation *						
Add geometry and mesh after mesh import	•					
Coordinates system of points creation *						
NASTRAN 1						
Periodicity => Associated link mesh *						
Add link mesh associated	•					
OK Cancel						

SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – INFINITE BOX MESH

- First order mesh
- Generate second order mesh if needed





SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – MS TEST CASE

- 4000 A DC conductor
- Steel with Mur = 1000
- Roofbeam with 10 mm wide thick xsection
- Transformerface with 1 mm thick sheet
- Wallskins with 1 mm thick sheet
 - Middle wall
 - No sheet
 - 1 sheet
 - Sheets on both side
- Transformercore and wall are non magnetic
- Flux density along the middle wall Bx



SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – MS TEST CASE – SIMULATIONS

- Reference case: NoMag No magnetic materials Just DC source in the air
- Middle wall has no magnetic sheets: NoSheet
- Middle wall has magnetic sheet on 1 side: 1Sheet
- Middle wall has magnetic sheets on both sides: 2Sheets

SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – MS TEST CASE – AIR ONLY (REFERENCE) – BMAP ON YZ XSECTION



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SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – MS TEST CASE – 2 SHEETS MIDDLE WALL – BMAP ON YZ XSECTION



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SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – MS TEST CASE – FLUX DENSITY BX ALONG THE MIDDLE WALL



SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – AC TEST CASE

- Source 3 Phase
 - A (red): 4000 A rms 0 deg.
 - B (green): 4000 A rms 120 deg.
 - C (cyan): 4000 A rms -120 deg.
- Steel with Mur = 1000 and Sigma = 2 MS/m
- Roofbeam with 10 mm wide thick xsection
- Transformerface with 1 mm thick sheet
- Wallskins with 1 mm thick sheet
 - Middle wall
 - No sheet
 - 1 sheet
 - Sheets on both side
- Transformercore and wall are non magnetic
- Flux density along the middle wall Bx


SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – AC TEST CASE – THIN CONDUCTOR REGIONS

- Roofbeam with 10 mm wide thick xsection
 - Thin conductor region

✓ Edit Face region[ROOFBEAM]
Name of the region *
ROOFBEAM
Comment
Evaluated information \
Steady State AC Magnetic 3D Appearance Mechanical Set
Type of region
Thin conducting region (hyperbolic current density through the thickness)
Material of the region *
STEEL V
Thickness of the region (in m) *
1e-2 f()
OK Apply Orient Cancel

Skin depth computation	ı	×
Values		
Resistivity	5e-7	Ohm.Meter
Conductivity : 2.00E006 S	Siemens/Meter	
Relative permeability	1000	
Frequency	60	Hz
$\delta = \sqrt{\frac{\rho}{\pi \mu_0 \mu_r f}}$	-	
Result		
Skin depth 1.45288		mm 🗸
		Quit



SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – AC TEST CASE – THIN CONDUCTOR REGIONS

- Transformerface with 1mm thick sheet
 - Thin conductor region

C Edit Face region[TRANSFORMERFACE] X
Name of the region *
TRANSFORMERFACE
Comment
Evaluated information \
Steady State AC Magnetic 3D Appearance Mechanical Set
Type of region
Thin conducting region (hyperbolic current density through the thickness) 🔻
Material of the region *
STEEL V
Thickness of the region (in m) *
1e-3 f()
OK Apply Orient Cancel

- Wallskins with 1mm thick sheet
 - Thin conductor region

lame of the region "	
WALLSKINS	
comment	
Evaluated information \	
Steady State AC Magnetic 3D	Appearance Mechanical Set
Type of region	
Thin conducting region (hyperbolic	current density through the thickness) $$
Material of the region *	
STEEL	-
Thickness of the region (in m) *	
1e-3	f()

SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – AC TEST CASE – SIMULATIONS

- Reference case: NoMag No magnetic and conductive materials Just 3 phase sources in the air
- Middle wall has no magnetic & conductive sheets: NoSheet
- Middle wall has magnetic and conductive sheet on 1 side: 1Sheet
- Middle wall has magnetic and conductive sheets on both sides: 2Sheets
- Middle wall has magnetic and conductive sheets on both sides and surface impedance method: Surf_Imp

SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – AC TEST CASE – SURFACE IMPEDANCE

- Surface impedance for the magnetic and conductive sheets of the wall
- Apply to outer surface of wall volume region Wall_Core
- Shell region WallSkins inactive

lame of the region *	
WALL_CORE	
comment	
Steady State AC Magnetic Type of region	3D \backslash Appearance \backslash Mechanical Set \backslash Evaluated information \backslash
Solid conductor region de	scribed by surface impedance
General Material orien	itation
Material of the region *	
STEEL	-
Land to the second s	Languist Languist
C Edit Face region[WA	LLSKINS]
Edit Face region[WA lame of the region * WALLSKINS	LLSKINS]
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C Edit Face region[WA Name of the region * WALLSKINS Comment Evaluated information Steady State AC I	ALLSKINS) on \ Magnetic 3D \ Appearance \ Mechanical Set
C Edit Face region[WA Name of the region * WALLSKINS Comment Evaluated informatic Steady State AC I	ALLSKINS) on \ Magnetic 3D \ Appearance \ Mechanical Set



SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – AC TEST CASE – AIR ONLY (REFERENCE) – BMAP ON YZ XSECTION



SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – AC TEST CASE – 2 SHEETS MIDDLE WALL – BMAP ON YZ XSECTION



SUBSTATION HYPERMESH MODEL – SIMPLEROOM3 – MS TEST CASE – FLUX DENSITY BX ALONG THE MIDDLE WALL





SUBSTATION HYPERMESH MODEL – CONCLUSIONS

- 3D substation example Process and requirements developed
 - Import of HyperMesh model
 - Volumes and Shells
 - Mesh
 - Thin regions
 - Magnetic thin region
 - Conductor thin region
 - Thickness > skin depth: hyperbolic
 - Thickness < skin depth: surface impedance
- Test cases Validation of conductive shielding effectiveness with thin conductor regions
 - Static field with 4000 A DC conductor
 - AC field with 3 phase 60 Hz 4000 A rms conductors