The ALICE Dipole Magnet Calculation

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Introduction

In this note we present the results from the 3-dimentional computation of
the ALICE dipole magnet with the Vector Fields TOSCA code (version 6.6)
[1] on the IBM RISC System 6000 machines combined in the PaRC partition
of the CERNSP UNIX cluster.

We compare several sets of the calculations for two options of the ALICE
wide aperture warm dipole magnet [2,3]. Another part of the ALICE magnet
system – L3 solenoidal magnet – has been described in the same way as in
our previous calculations [4].

Depending on the configuration of the magnet system, the precision of
calculations, and the type of the computer used, one set of the computations
takes 1.6–31.7 hours of the CPU time (25.3 CPU hours in average for both
magnets switched on). For all the calculations we have used the tolerance of
0.5 mT to find a solution in the field convergence procedure.

Magnet system description

General geometry

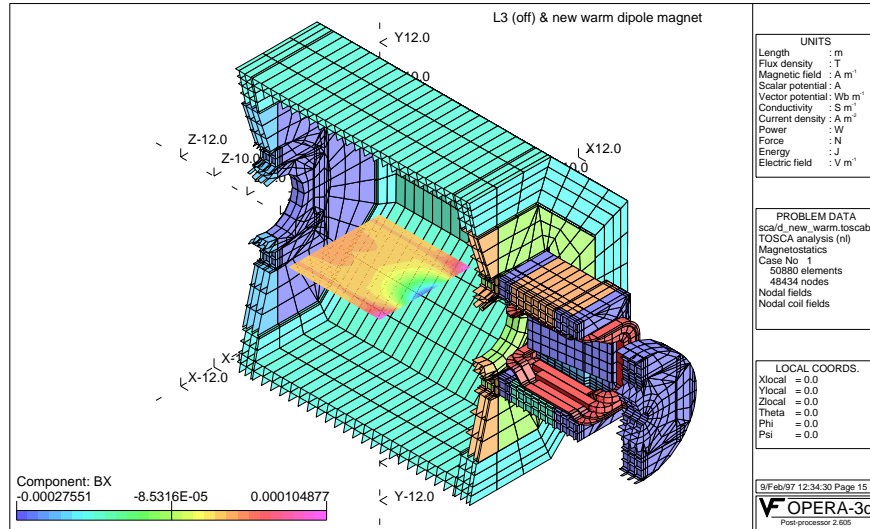The ALICE magnet system models used for the computations are shown in Figs. 1–5.

Figure 1. The model of the ALICE magnetic system with 5.256 m laminated dipole magnet (UA1 model).

To describe the models we use the Cartesian coordinate system with the origin placed in the centre of the L3 solenoid. The z-axis points along the solenoid axis towards the dipole magnet, the y-axis points upward. One model [2], called 'UA1 model', uses iron blocks from the UA1 return yoke, the 2nd design [3], called 'conical coil design', is based on a coil fitted around the required acceptance angle for the dimuon spectrometer.

A brief description of the two options is as follows:

- The L3 solenoidal coil has an octagonal shape in the xy-plane and consists of eight conductor bricks. The brick length along z-axis is 11.764 m, its thickness is 0.89 m. The inscribed radius of the solenoidal coil is 5.93 m. The total current used is adjusted to give a magnetic flux density of 0.5 T (4.916 MA-turns) or 0.2 T (1.987 MA-turns) in the centre of solenoid. The direction of the magnetic flux density vector is along z-axis.

- The L3 flux return yoke consists of three parts: an octogonal yoke body and four doors acting as poles. The length of the yoke is 14.12 m, its
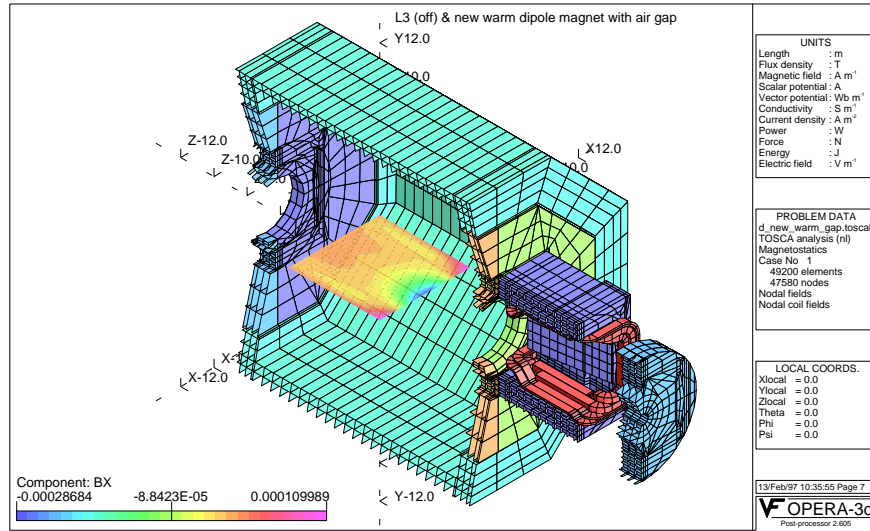
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Figure 2. The model of the ALICE magnetic system with 5.256 m dipole magnet with air gap (UA1 model).
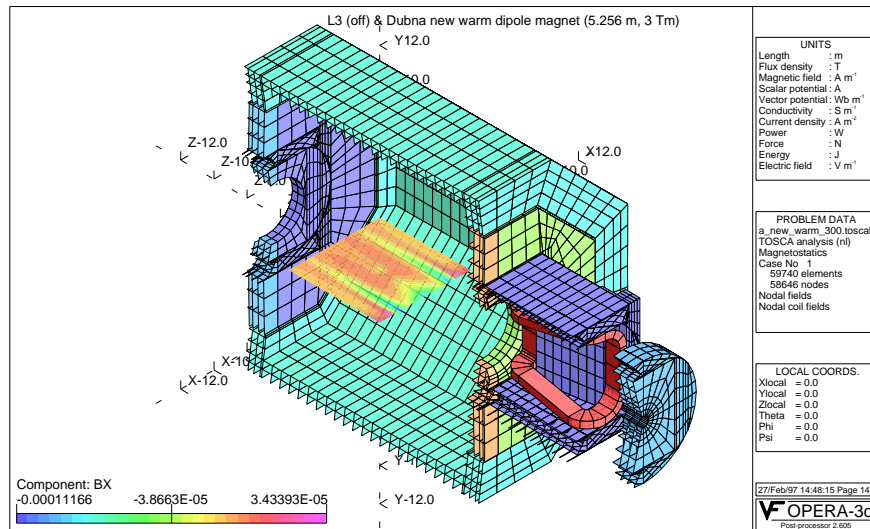

Figure 3. The model of the ALICE magnetic system with 5.256 m dipole magnet (conical coil design).
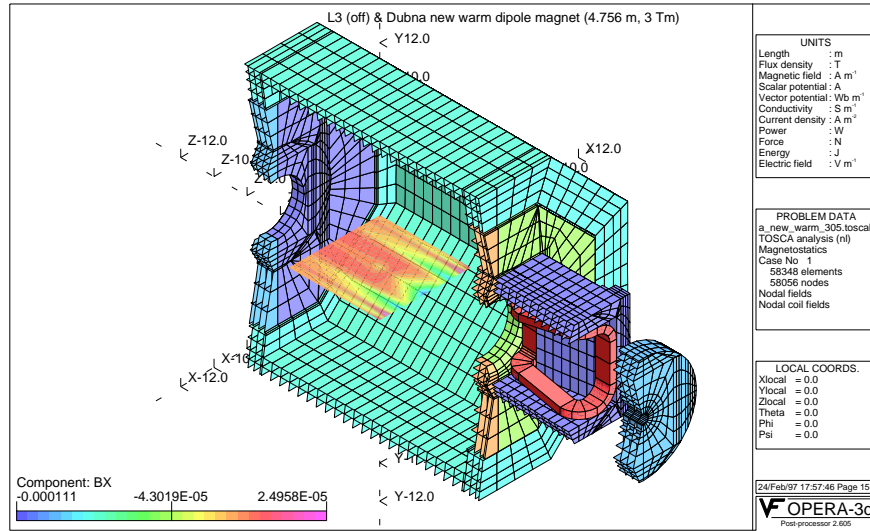
Figure 4. The model of the ALICE magnetic system with
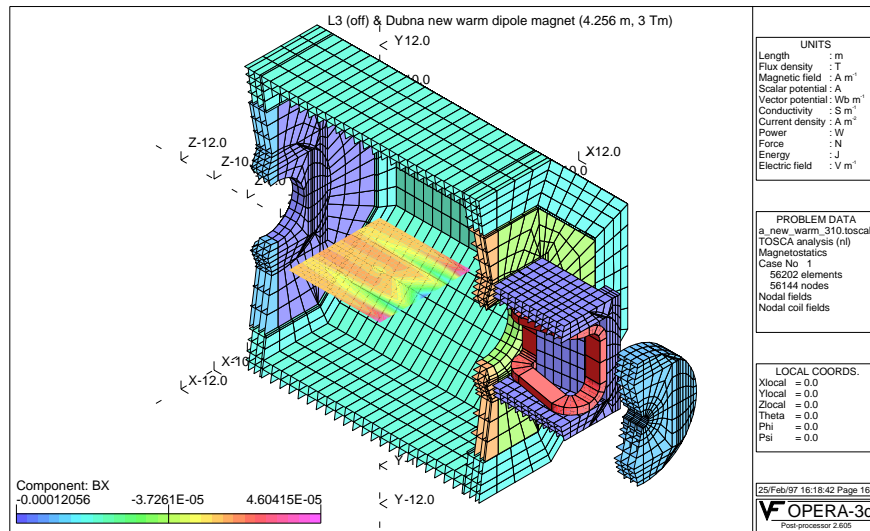4.756 m dipole magnet (conical coil design).

Figure 5. The model of the ALICE magnetic system with
4.256 m dipole magnet (conical coil design).

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inscribed radius is 7.035 m, the thickness in radial direction is 0.87 m. The shape of the yoke follows the shape of the solenoidal coil. The doors cover the inner part of the coil at each coil end. The outer door radius is 5.84 m, the thickness along the z-axis is 0.84 m. The distance between coil and yoke is 0.198 m. The doors have circular holes of 1.6 m radius.

- With respect to the L3 coil, the centre of the dipole magnet is placed at $z = 9.378-9.878$ m on the LHC beam axis which is 0.23 m above the L3 axis. The dipole has vertical poles. Consequently the coils are located symmetrically to the z-y symmetry plane. The shapes of the coils used for the calculations are shown in Figures 6–7. The coil length in z-direction is 5.256 m in the UA1 model and 5.256, 4.756, and 4.256 m in the conical coil design. To reach the specified bending strength of 3 Tm along z the total current needed is between 1.75–2.06 MA-turns in the UA1 model coil and between 1.646–2.006 MA-turns in the conical coil. The direction of the magnetic flux density vector is parallel to the x-axis.

- The flux return yoke for the dipole has in both models a rectangular cross-section. The total height is 6.15 m (UA1) and 6.0 to 6.4 m depending on coil length in the case of the conical coils. The width at the upstream side is 4.815 m (UA1) and 5.1 m (conical coils). The downstream end is respectively 6.15 m (UA1) and 6.4 m (conical coils) wide. The yoke length for the UA1 type is 4.804 m and varies for the conical coils, depending on coil length between 4.256 and 5.256 m. The vertical poles of the dipole yoke open with an angle of 9 degrees with respect to the length axis. The dipole magnet and the L3 magnet are separated by 0.105 m.

- The front of the cylindrical muon filter is located at 14.71m. The filter is 1.2 m thick and has an inner bore of 0.6 m and an outer radius of 3.2 m centered around the LHC beam axis.

To describe the magnetic properties of the steel parts of the models we use the B–H dependence table from [5].

Boundary conditions

To calculate the magnetic system with the TOSCA code we need to determine the conditions for the magnetic potential at the boundaries of the model. We assume the magnetic flux density to be tangential to the cylinder surface with a radius of 10 m and $z = -9/+18$ m. The number of nodes required to describe the models of the ALICE magnet system lies between $47\,580$ and $58\,646$.

Dipole field calculations

The dipole field has been calculated for the case when the L3 solenoid is switched off. The fringe field from the dipole magnet decreases very rapidly inside the L3 volume. At $z = 2.75$ m the magnetic flux density becomes less than 0.1–0.3 mT in the horizontal plane.

The behaviour of the B_x component versus z is shown for all the models in Figs. 8–22. In these plots the values of B_x integrated over $0 \leq z \leq 14.6$ m at different angles with respect to the ALICE interaction point and at azimuthal angles of 0, 45, and 90 degrees with respect to the x-axis are shown in T·m.

In Tables 1 and 2 the absolute values of these integrals are shown for different options of the UA1 and conical coil designs:

UA1 type

- *laminated iron:* The laminated return yoke is modelled with anisotropic steel with packing factor of 0.7583;

- *isotropic iron with air gap:* The laminated return yoke is modelled with isotropic steel with included air gap of 0.255 m;

- *isotropic iron:* The same geometrical dimensions as above and isotropic steel but without airgap;

- *reduced current:* Isotropic steel as above but with the current density reduced by 15%.

Conical coils

All options are described in Table 2.

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Force calculations

For the ALICE magnetic system with the reduced L3 current we have calculated the forces and torques acting on the two wings of the L3 doors, dipole yoke, muon filter, and on the coils. The results are presented in Tables 3 and 4. The doors 3 and 4 are near the dipole magnet and the $x-$component is positive for the door 3 and negative for the door 4.

In comparison with the weights of the iron parts, the forces are small. The forces acting on the coils do equally not need particular attention.

Conclusions

The results of the calculations can be summarized as follows:

- Inside the TPC region the dipole field does not cause any noticeable perturbation to the L3 magnetic fields.

- The resulting magnetic forces in the ALICE system are not negligible but can be compensated with normal engineering precautions.

References

[1] Vector Fields Limited. 24 Bankside, Kidlington, Oxford OX5 1JE, England.

[2] Z.V. Borisovskaya et al., *A Warm Magnet for the ALICE Muon Arm.* ALICE/96-24 Internal Note/MAG, 4 October 1996.

[3] P.G. Akishin et al., *Conceptual design of the warm dipole magnet for the ALICE forward muon spectrometer.* Addendum to ALICE/96-26 Internal Note/MAG, 12 December 1996.

[4] V.I. Klyukhin, W. Klempt, L. Leistam, D. Swoboda. *The ALICE Magnetic System Computation* ALICE/95-46 Internal Note/MAG, 6 December 1995.

[5] M. Nessi et at., *Computer Models for the TILECAL Magnetic Field Distributions.* ATLAS Internal Note TILECAL-NO-012, 9 May, 1994.

Table 1: Comparison of the field integrals for the UA1 model
(total current is 2.06 (1.75) MA-turns for nominal (reduced) current density)

	Laminated iron	Isotropic iron with air gap	Isotropic iron	Isotropic iron, reduced current
ϕ	Field integrals, $T \cdot m$, for $\theta = 0°$			
0°	3.247	3.388	3.637	3.270
ϕ	Field integrals, $T \cdot m$, for $\theta = 2°$			
0°	3.279	3.425	3.680	3.310
45°	3.236	3.375	3.623	3.256
90°	3.242	3.381	3.629	2.262
135°	3.235	3.374	3.622	3.255
180°	3.279	3.424	3.680	3.310
−135°	3.242	3.382	3.630	3.262
−90°	3.241	3.382	3.628	2.260
−45°	3.241	3.382	3.629	3.262
ϕ	Field integrals, $T \cdot m$, for $\theta = 5°$			
0°	3.433	3.601	3.884	3.500
45°	3.253	3.380	3.639	3.269
90°	3.099	3.207	3.443	2.085
135°	3.244	3.387	3.627	3.257
180°	3.432	3.599	3.883	3.499
−135°	3.257	3.395	3.642	3.272
−90°	3.083	3.215	3.422	2.065
−45°	3.247	3.393	3.630	3.260
ϕ	Field integrals, $T \cdot m$, for $\theta = 8.5°$			
0°	3.635	3.834	4.153	3.748
45°	3.392	3.348	3.811	3.432
90°	2.458	2.485	2.617	2.312
135°	3.251	3.384	3.643	3.272
180°	3.634	3.831	4.152	3.747
−135°	3.403	3.558	3.823	3.443
−90°	2.484	2.486	2.660	2.352
−45°	3.263	3.410	3.659	3.289

Table 2: Comparison of the field integrals for the conical coil design

Magnet/coil length, m	5.256/39.3	4.756/36.63	4.256/33.91
Al coil vol,$m^3/weight, tons$	10.23/27.6	9.53/25.7	8.83/23.8
Iron vol, $m^3/weight, tons$	91.30/718.5	79.13/622.8	69.70/548.5
Operating current, MA	0.823	0.892	1.003
Consumed energy, MW	3.07	3.36	3.93
ϕ	Field integrals, $T \cdot m$, for $\theta = 0°$		
$0°$	3.007	3.008	3.006
ϕ	Field integrals, $T \cdot m$, for $\theta = 2°$		
$0°$	2.987	2.986	2.982
$45°$	2.998	2.998	2.995
$90°$	3.039	3.039	3.037
$135°$	2.999	2.998	2.995
$180°$	2.987	2.985	2.982
$-135°$	3.002	3.001	2.999
$-90°$	3.038	3.038	3.036
$-45°$	3.002	3.001	2.999
ϕ	Field integrals, $T \cdot m$, for $\theta = 5°$		
$0°$	2.938	2.926	2.916
$45°$	2.974	2.968	2.962
$90°$	3.164	3.159	3.152
$135°$	2.974	2.968	2.962
$180°$	2.938	2.925	2.915
$-135°$	2.975	2.969	2.964
$-90°$	3.164	3.158	3.152
$-45°$	2.975	2.969	2.964
ϕ	Field integrals, $T \cdot m$, for $\theta = 8.5°$		
$0°$	2.865	2.838	2.806
$45°$	2.545	2.551	2.564
$90°$	3.186	3.192	3.187
$135°$	2.545	2.551	2.563
$180°$	2.865	2.838	2.806
$-135°$	2.552	2.558	2.569
$-90°$	3.185	3.190	3.186
$-45°$	2.552	2.558	2.570

Table 3: Forces

Unit	Magnet type	B_{max}, T	F_x, t	F_y, t	F_z, t
Door 3	Laminated	3.57	-74.2	4.91	213.7
(positive x)	With air gap	3.65	-65.3	3.29	258.4
	5.256 m	1.55	2.27	0.33	-57.0
	4.756 m	1.53	5.02	0.30	-53.9
	4.256 m	1.57	6.76	0.19	-50.9
Door 4	Laminated	3.60	72.3	-2.01	191.2
(negative x)	With air gap	3.75	66.8	-6.76	224.2
	5.256 m	1.34	-6.03	0.15	-60.7
	4.756 m	1.43	-8.04	-0.012	-59.6
	4.256 m	1.51	-9.74	0.014	-60.4
Dipole yoke	Laminated	3.08	4.68	-9.74	-478.1
	With air gap	3.04	4.07	6.43	-558.7
	5.256 m	2.18	-4.40	-0.16	89.4
	4.756 m	2.26	-4.53	-0.26	94.1
	4.256 m	2.43	-4.28	0.38	97.0
Muon filter	Laminated	0.71	0.023	-0.0032	-7.49
	With air gap	0.59	0.032	0.0082	-7.52
	5.256 m	0.33	0.28	0.12	-1.40
	4.756 m	0.35	-0.084	0.0017	-0.71
	4.256 m	0.28	-0.073	0.0017	-0.42
L3 coil	Laminated		-0.083	-0.026	-0.24
	With air gap		-0.10	0.014	-0.53
	5.256 m		-0.097	-0.043	0.22
	4.756 m		-0.049	-0.016	-0.013
	4.256 m		-0.037	0.0029	-0.21
Dipole coil	Laminated		-13.0	4.36	95.57
	With air gap		-15.9	-1.50	99.17
	5.256 m		-5.51	0.32	-192.8
	4.756 m		-5.96	0.82	-212.4
	4.256 m		-6.86	1.21	-222.7

Table 4: Torques

| Unit	Torque x,y,z	Magnet type	T_x, t·m	T_y, t·m	T_z, t·m
Door 3	0,0.23,6.65	Laminated	19.4	-389.1	-13.5
(positive x)	"	With air gap	29.8	-475.9	-8.53
	"	5.256 m	18.4	140.5	-0.28
	"	4.756 m	18.1	137.8	0.42
	"	4.256 m	16.9	131.6	0.22
Door 4	0,0.23,6.65	Laminated	20.8	344.6	-1.57
(negative x)	"	With air gap	30.4	413.9	-12.3
	"	5.256 m	18.2	-144.4	-2.24
	"	4.756 m	16.7	-146.1	-3.26
	"	4.256 m	17.1	-147.3	-2.46
Dipole yoke	0,0.23,9.878	Laminated	1.51	-22.5	4.03
	"	With air gap	-1.29	-19.3	-9.84
	"	5.256 m	-0.11	4.04	-0.28
	0,0.23,9.628	4.756 m	-1.93	10.8	-0.66
	0,0.23,9.378	4.256 m	-1.56	19.3	-0.0097
Muon filter	0,0.23,15.31	Laminated	0.022	6.82	0.031
	"	With air gap	0.054	6.70	-0.0068
	"	5.256 m	0.20	2.16	-0.38
	"	4.756 m	-0.0054	2.13	0.0053
	"	4.256 m	0.0059	1.47	-0.0014
L3 coil	0,0,9.75	Laminated	0.053	-1.72	-0.001
	"	With air gap	0.12	-2.23	-0.021
	"	5.256 m	-0.57	-1.06	0.013
	"	4.756 m	-0.034	-0.44	-0.020
	"	4.256 m	-0.14	-0.43	-0.012
Dipole coil	0,0.23,9.878	Laminated	0.605	113.2	-13.01
	"	With air gap	-1.22	118.0	-5.37
	"	5.256 m	1.01	8.55	0.047
	0,0.23,9.628	4.756 m	2.26	5.06	-0.017
	0,0.23,9.378	4.256 m	2.59	0.53	-0.16
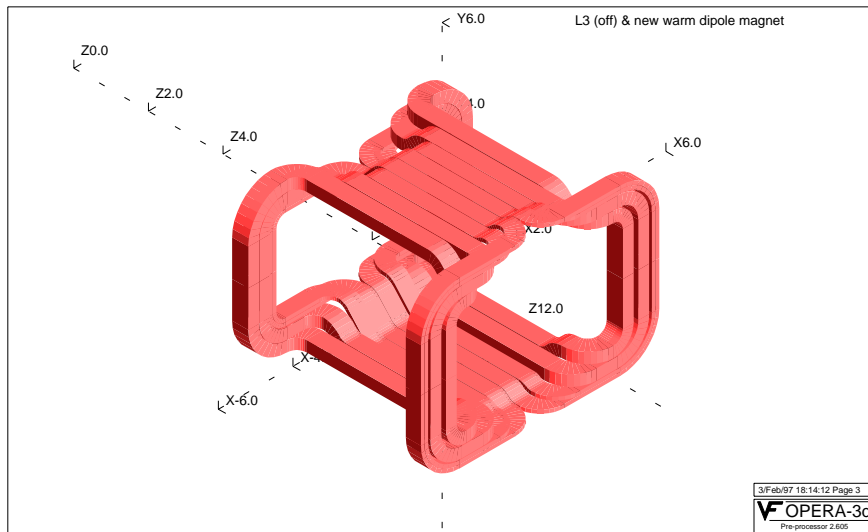
Figure 6. The coil layout in the UA1 model.
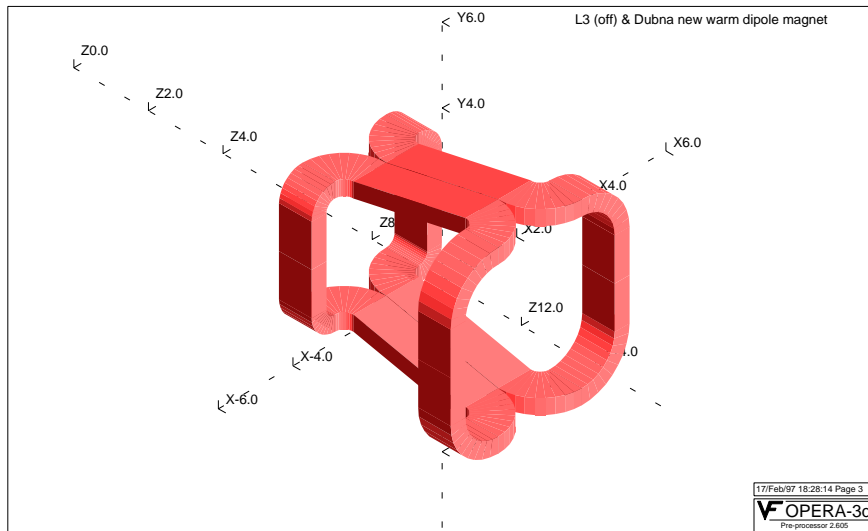
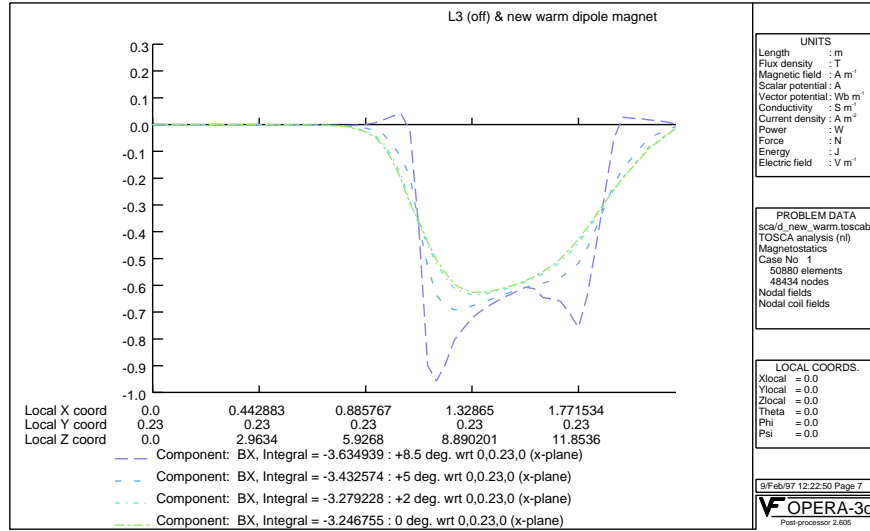Figure 7. The coil layout in conical coil design.

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Figure 8. B_x versus z calculated for the UA1 5.256 m laminated dipole magnet in the plane at $0°$ w.r.t. x-axis.
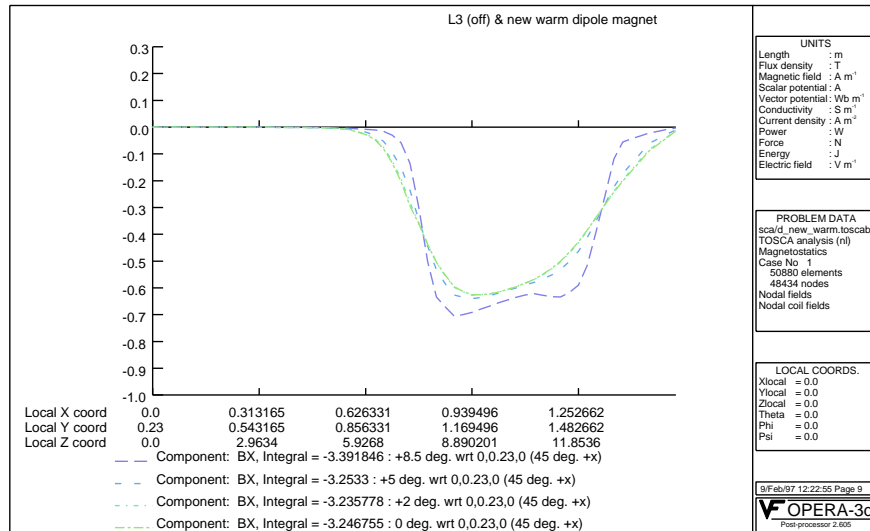

Figure 9. B_x versus z calculated for the UA1 5.256 m laminated dipole magnet in the plane at $45°$ w.r.t. x-axis.
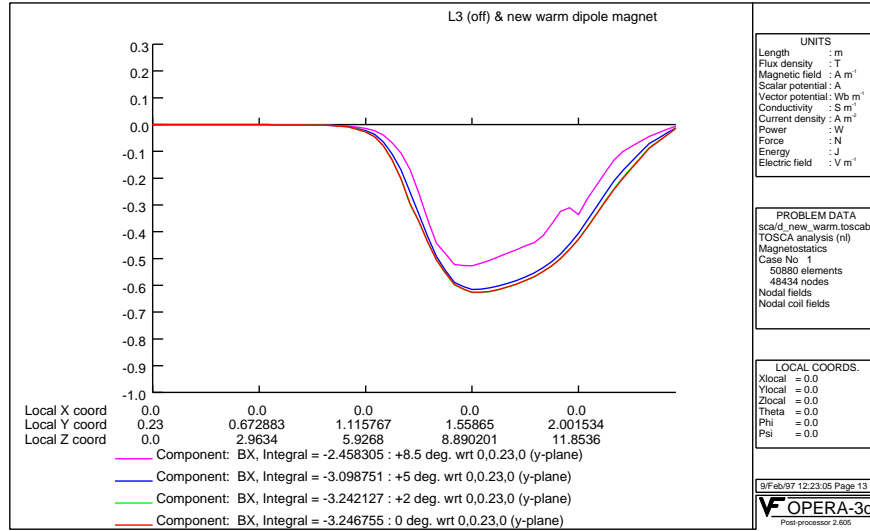
Local X coord	0.0	0.0	0.0	0.0	0.0
Local Y coord	0.23	0.672883	1.115767	1.55865	2.001534
Local Z coord	0.0	2.9634	5.9268	8.890201	11.8536

Component: BX, Integral = -2.458305 : +8.5 deg. wrt 0,0.23,0 (y-plane)
Component: BX, Integral = -3.098751 : +5 deg. wrt 0,0.23,0 (y-plane)
Component: BX, Integral = -3.242127 : +2 deg. wrt 0,0.23,0 (y-plane)
Component: BX, Integral = -3.246755 : 0 deg. wrt 0,0.23,0 (y-plane)

Figure 10. B_x versus z calculated for the UA1 5.256 m laminated dipole magnet in the plane at 90° w.r.t. x-axis.

Local X coord	0.0	0.442883	0.885767	1.32865	1.771534
Local Y coord	0.23	0.23	0.23	0.23	0.23
Local Z coord	0.0	2.9634	5.9268	8.890201	11.8536

Component: BX, Integral = -3.833768 : +8.5 deg. wrt 0,0.23,0 (x-plane, PHI=0 deg.)
Component: BX, Integral = -3.601105 : +5 deg. wrt 0,0.23,0 (x-plane, PHI=0 deg.)
Component: BX, Integral = -3.425164 : +2 deg. wrt 0,0.23,0 (x-plane, PHI=0 deg.)
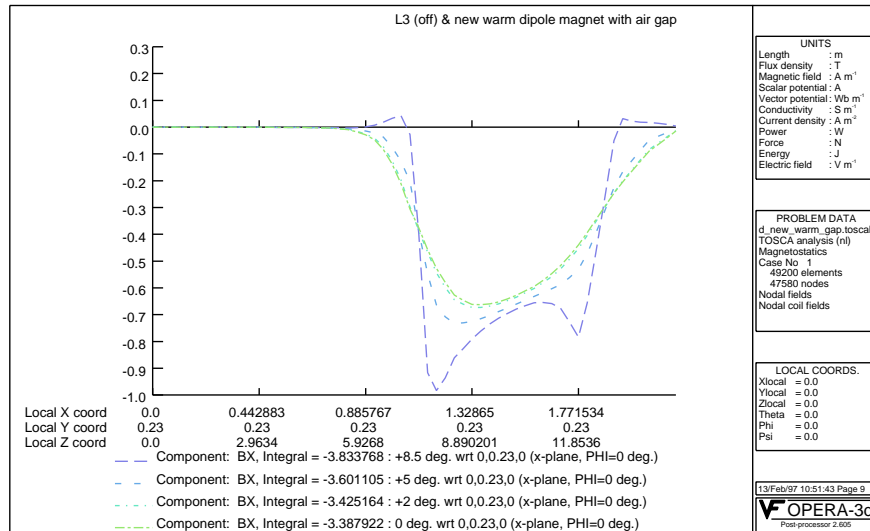Component: BX, Integral = -3.387922 : 0 deg. wrt 0,0.23,0 (x-plane, PHI=0 deg.)

Figure 11. B_x versus z calculated for the UA1 5.256 m dipole magnet with air gap in the plane at 0° w.r.t. x-axis.
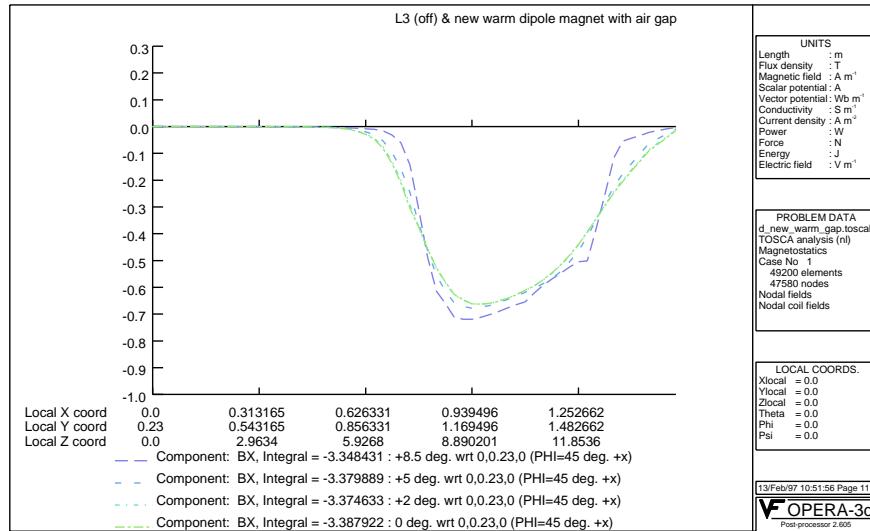
15

Figure 12. B_x versus z calculated for the UA1 5.256 m dipole magnet with air gap in the plane at $45°$ w.r.t. x-axis.
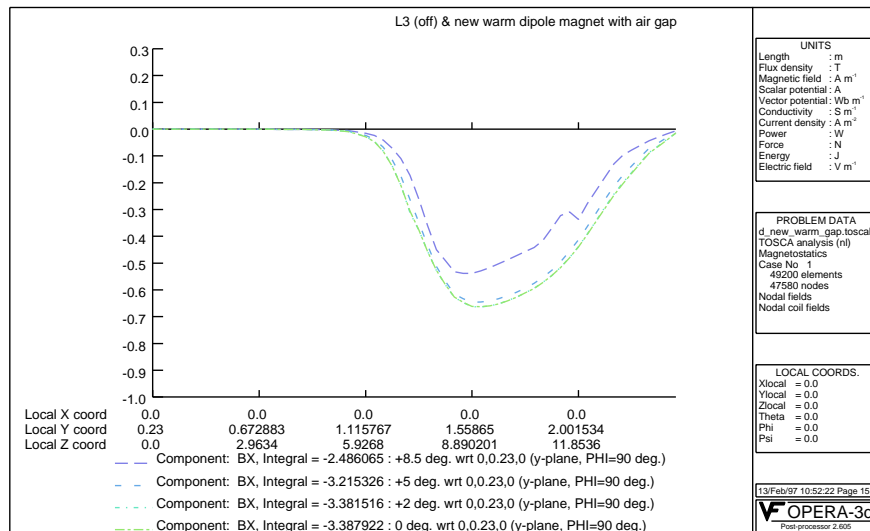

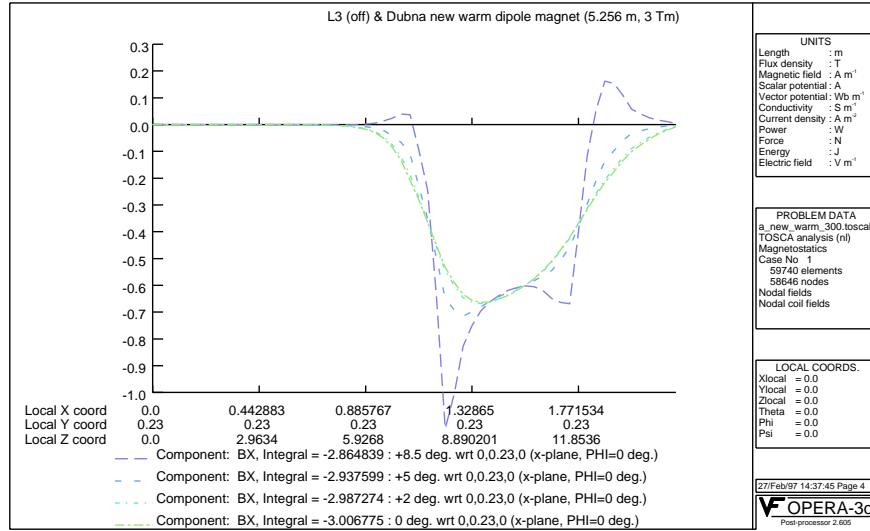Figure 13. B_x versus z calculated for the UA1 5.256 m dipole magnet with air gap in the plane at $90°$ w.r.t. x-axis.

Figure 14. B_x versus z calculated for the 5.256 m conical coil magnet in the plane at $0°$ w.r.t. x-axis.
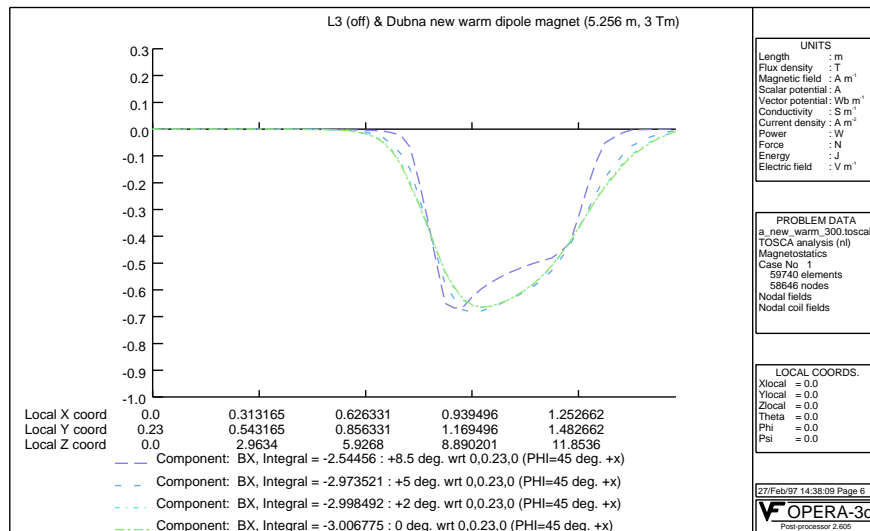

Figure 15. B_x versus z calculated for the 5.256 m conical coil magnet in the plane at $45°$ w.r.t. x-axis.
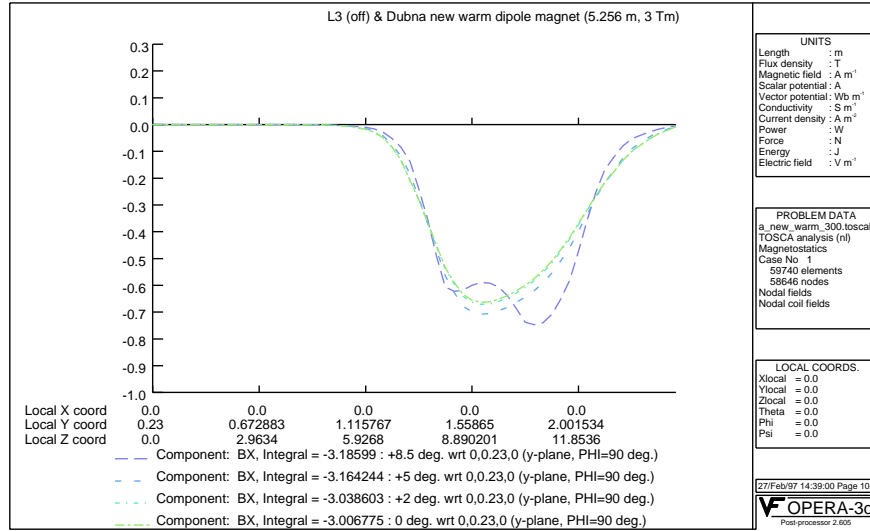
Figure 16. B_x versus z calculated for the 5.256 m conical coil magnet in the plane at $90°$ w.r.t. x-axis.

Figure 17. B_x versus z calculated for the 4.756 m conical coil magnet in the plane at $0°$ w.r.t. x-axis.

Figure 18. B_x versus z calculated for the 4.756 m conical coil magnet in the plane at $45°$ w.r.t. x-axis.

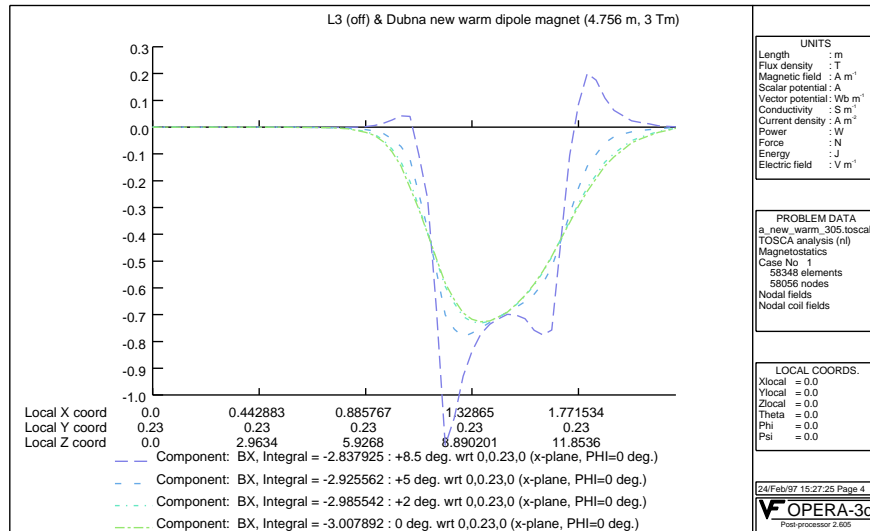Figure 19. B_x versus z calculated for the 4.756 m conical coil magnet in the plane at $90°$ w.r.t. x-axis.

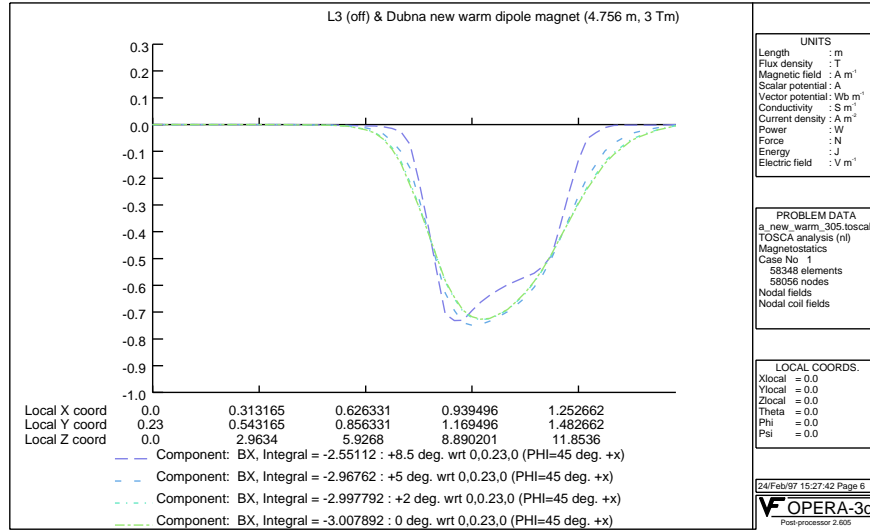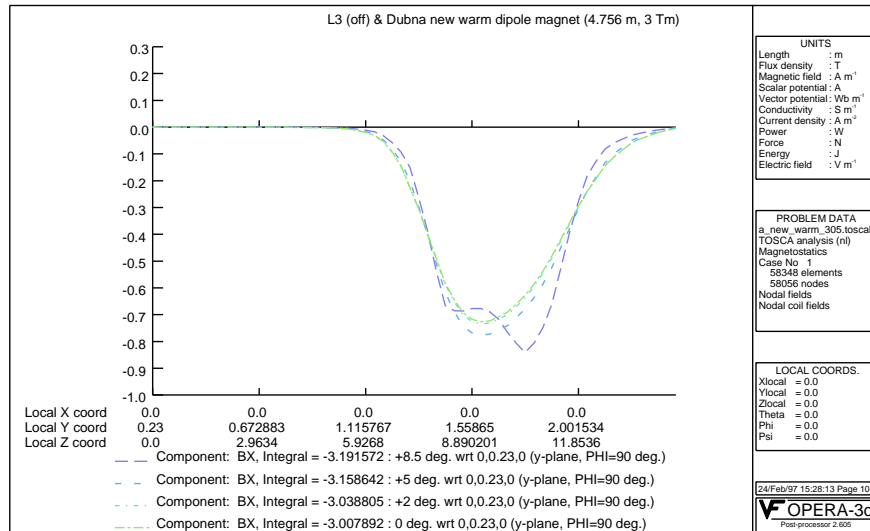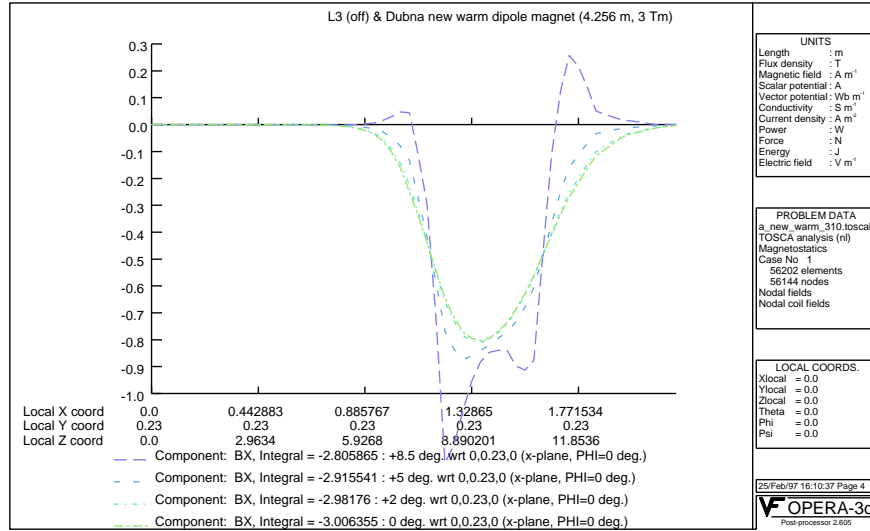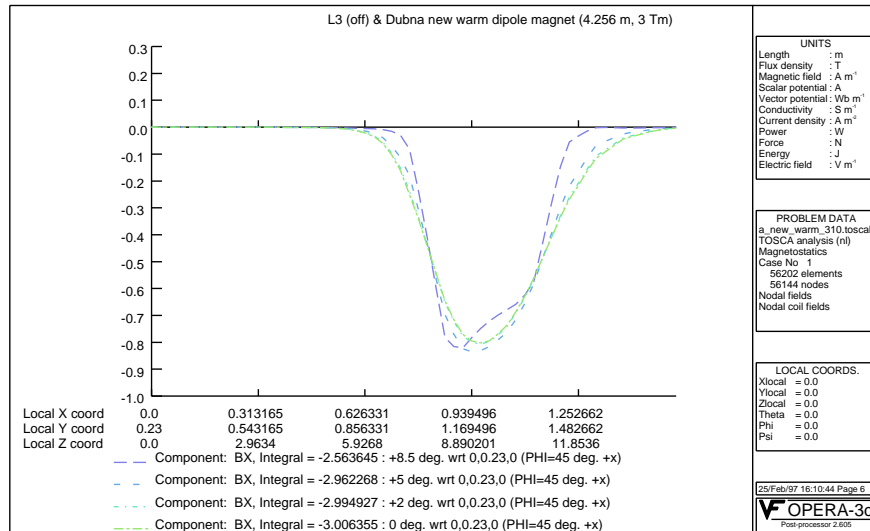Figure 20. B_x versus z calculated for the 4.256 m conical coil magnet in the plane at $0°$ w.r.t. x-axis.

Figure 21. B_x versus z calculated for the 4.256 m conical coil magnet in the plane at $45°$ w.r.t. x-axis.

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L3 (off) & Dubna new warm dipole magnet (4.256 m, 3 Tm)

Local X coord	0.0	0.0	0.0	0.0	0.0
Local Y coord	0.23	0.672883	1.115767	1.55865	2.001534
Local Z coord	0.0	2.9634	5.9268	8.890201	11.8536

Component: BX, Integral = -3.187269 : +8.5 deg. wrt 0,0.23,0 (y-plane, PHI=90 deg.)

Component: BX, Integral = -3.152337 : +5 deg. wrt 0,0.23,0 (y-plane, PHI=90 deg.)

Component: BX, Integral = -3.036646 : +2 deg. wrt 0,0.23,0 (y-plane, PHI=90 deg.)

Component: BX, Integral = -3.006355 : 0 deg. wrt 0,0.23,0 (y-plane, PHI=90 deg.)

UNITS
Length   : m
Flux density   : T
Magnetic field   : A m⁻¹
Scalar potential : A
Vector potential : Wb m⁻¹
Conductivity   : S m⁻¹
Current density : A m⁻²
Power   : W
Force   : N
Energy   : J
Electric field   : V m⁻¹

PROBLEM DATA
a_new_warm_310.toscab
TOSCA analysis (nl)
Magnetostatics
Case No 1
   56202 elements
   56144 nodes
Nodal fields
Nodal coil fields

LOCAL COORDS.
Xlocal   = 0.0
Ylocal   = 0.0
Zlocal   = 0.0
Theta   = 0.0
Phi   = 0.0
Psi   = 0.0

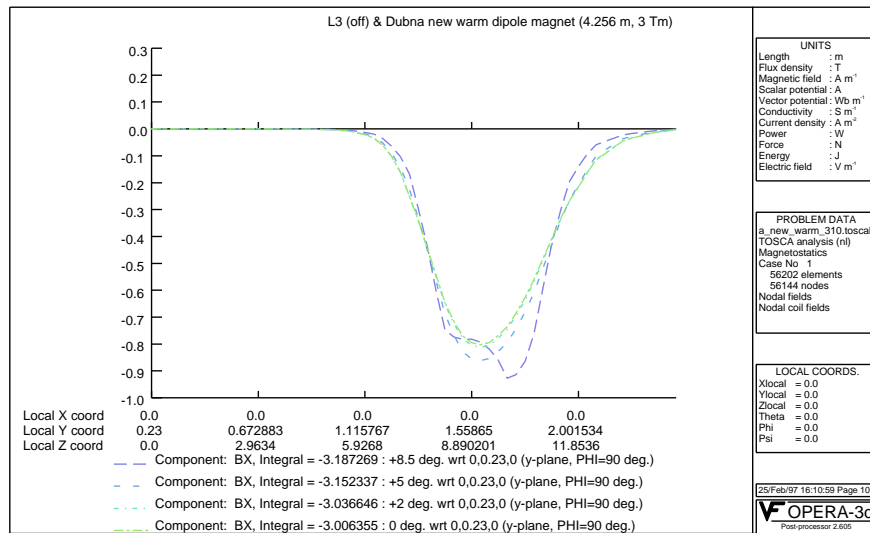25/Feb/97 16:10:59 Page 10

OPERA-3d
Post-processor 2.605

Figure 22. B_x versus z calculated for the 4.256 m conical coil magnet in the plane at $90°$ w.r.t. x-axis.