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LHC Note 311

SR 9509

## Design and Parameters of the Warm Magnets for the LHC Cleaning Insertions

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**Abstract**

A FODO structure consisting of warm quadrupoles has been proposed for the LHC cleaning sections. For effective beam collimation, the two beams will be separated from their normal 180 mm radial distance to 210 mm separation. This is done by two sets of dipoles.

Quadrupoles and dipoles are of the conventional type, with laminated iron cores and copper coils. The design of these magnets is described and their main characteristics are given.

Geneva, Switzerland
15 February, 1995

## 1. INTRODUCTION

A FODO structure consisting of warm quadrupoles has been proposed for the LHC cleaning sections (Reference 1). For effective beam collimation, the two beams will be separated from their normal 180 mm radial distance to 210 mm separation. This is done by two sets of dipoles.

Quadrupoles and dipoles are of the conventional type, with laminated iron cores and copper coils. Basic parameters for the magnets are proposed in Reference 2.

## 2. DIPOLES

The required dipole strength is 11 Tm. A nominal peak field of 1.8 T with a magnetic length of 6.15 m was chosen. The cross section of the dipoles is shown in Fig. 1. Their design is similar to the SPS main dipoles with somewhat larger transverse dimensions resulting from the beam-beam separation of 210 mm.

The steel cores are laminated and will be made from 1.5 mm thick low carbon steel of the same quality as used for the SPS and LEP magnets.

The excitation coils are made of high conductivity copper conductor insulated with a glass-epoxy compound. A reasonable compromise had to be found between a compact coil design and the lowest possible value for the excitation current.

The parameters of the dipoles are given in Table 1, while Table 2 shows a field plot across the aperture and a permeability table of the iron core. It can be seen that the field variation along the beam path is less than $\pm 2 \cdot 10^{-4}$.

## 3. QUADRUPOLES

The FODO structure proposed for the cleaning insertions requires twin aperture quadrupoles with identical magnetic properties in the two apertures (i.e. opposite optical polarities "FD" or "DF" seen by the two beams). The cross section of this twin aperture quadrupole is shown in Fig. 2. The design has a somewhat unconventional appearance with two poles in each quadrant of the magnet.

With an aperture of 44 mm diameter and a beam-beam separation of 210 mm, a gradient of 30 T/m can be obtained. This value is lower than can be expected for a single quadrupole since the iron cross section of the return yoke is reduced and

saturation in the yoke starts for lower values of fields in the aperture. It should be noted that this effect is further amplified if the beam-beam separation is reduced.

The main parameters of the quadrupoles are given in Table 3. A cross-section with flux lines is shown in Fig. 3.

The magnetic field calculations were made with the program "FLUX 2 D". A typical output for the field calculations is given in Table 4. A further increase in field quality will probably be possible by using a mathematical optimisation technique such as "POISOPT" for example.

The quadrupoles are assembled from 8 half-quadrants, each with its pre-assembled excitation coil. As for the dipoles, the yokes are laminated from 1.5 mm thick low carbon steel laminations. The coils are made from copper conductor. Such assemblies have successfully been made before as octupoles with length of about 1 m. In order to avoid serious manufacturing difficulties, it is suggested to limit the length of the twin aperture quadrupoles to about 3.5 m.

## REFERENCES

[1] Thys Risselada, Regular FODO Structures in the LHC Insertions without Ring Crossing, SL/Note 93-83 (AP), September 1993.

[2] J. B. Jeanneret and T. Trenkler, LHC Cleaning Insertion : Some Parameters for the Dog-leg and the Warm Quadrupoles, LHC Note 304, November 1994.

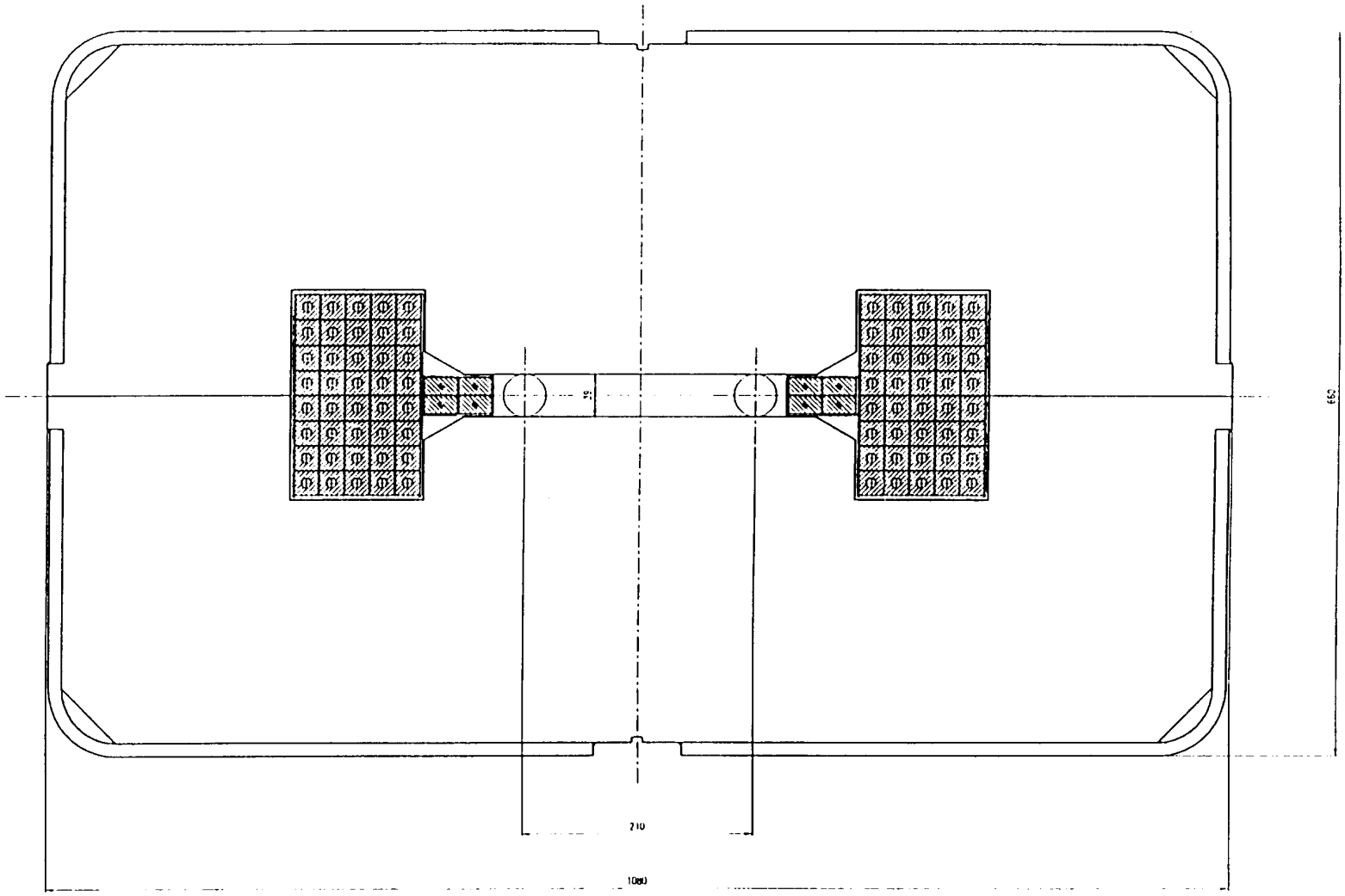


FIG.1 SEPARATION DIPOLE D2 FOR CLEANING INSERTIONS

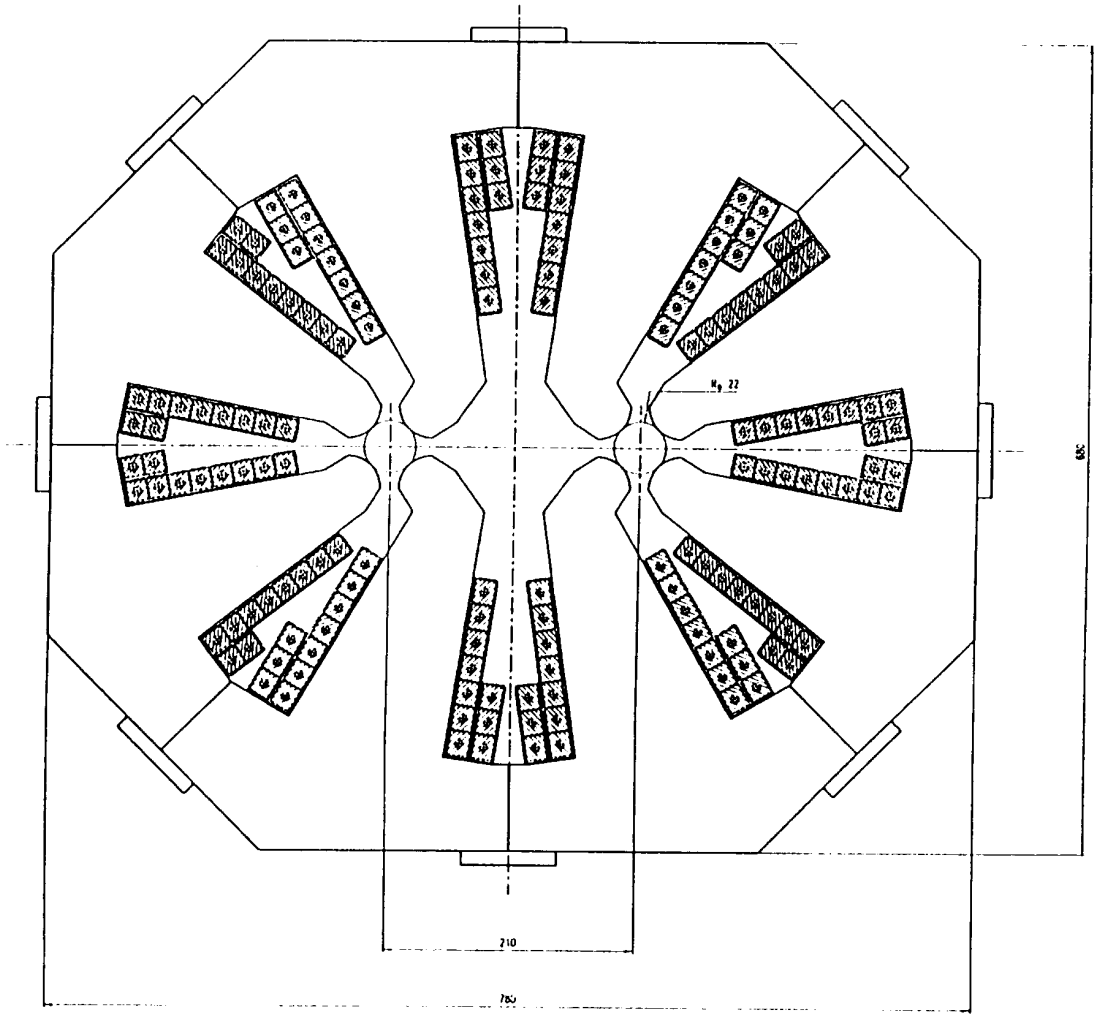


FIG.2 QUADRUPOLE FOR CLEANING INSERTION

LIQ 210

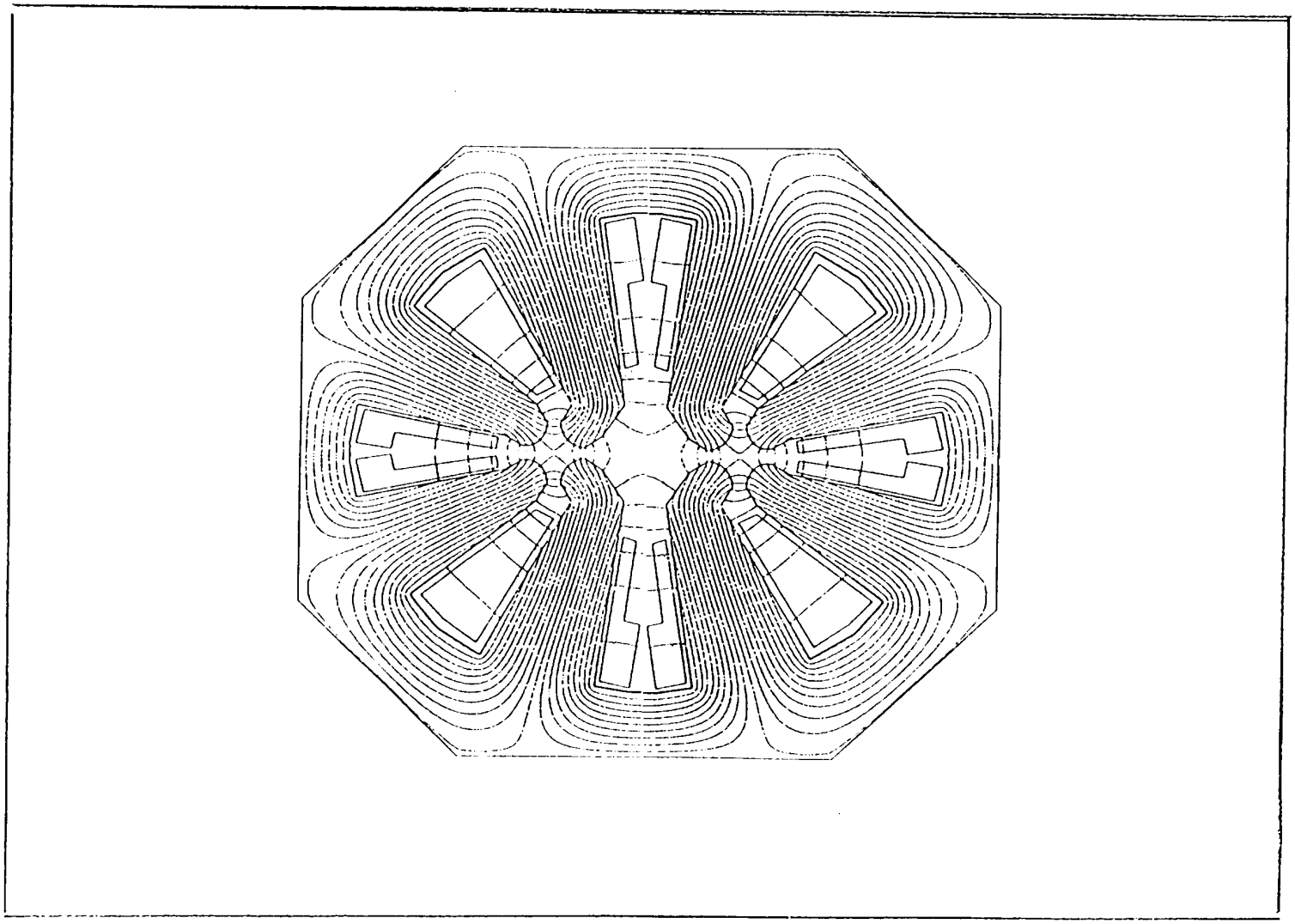

FIG.3 LIQ 210 FLUX PLOT

| | |
|---|---|
| **BASIC:** | |
| Gap height | 39 mm |
| Nominal Field | 1.8T |
| Magnetic length | 6.15 m |
| **DIMENSIONS:** | |
| Core length | 6.1m |
| Overall length | 6.5 m |
| Overall width | 1080mm |
| Overall heigh (core) | 660mm |
| **EXCITATION:** | |
| Current | 1370A |
| Resistance | 38 mΩ |
| Dissipated power | 50KW |
| Inductance | 015 H |
| **COOLING:** | |
| Pressure | 4 bar |
| Water flow | 30 l/min |
| Temperature rise | 30°C |
| **WEIGHT:** | |
| Copper | 2.4 t |
| Core | 31.0 t |
| **NO OF UNITS:** | 4 / ( 8 ) |
| **PRICE / UNIT:** | 340 / (310 ) KCHF |

TABLE 1 : PARAMETERS FOR SEPARATION DIPOLES D2

LHC D2 DIPOLE GAP=39 mm I=1370 A

FIELD MAP FOR AIR REGION, CYCLE NUMBER 6
X AND Y ARE GIVEN IN MM, FIELDS IN GAUSS.

| X | | Y = 0.0 | 5.0 | 10.0 | 15.0 |
|---|---|---|---|---|---|
| 0.0 | BX = | 0.000 | 0.000 | 0.000 | 0.000 |
| | BY = | 18022.950 | 18022.937 | 18022.895 | 18022.800 |
| 5.0 | BX = | 0.000 | 0.024 | 0.047 | 0.070 |
| | BY = | 18022.962 | 18022.951 | 18022.922 | 18022.901 |
| 10.0 | BX = | 0.000 | 0.048 | 0.093 | 0.127 |
| | BY = | 18022.997 | 18022.984 | 18022.941 | 18022.859 |
| 15.0 | BX = | 0.000 | 0.076 | 0.151 | 0.226 |
| | BY = | 18023.059 | 18023.045 | 18023.001 | 18022.927 |
| 20.0 | BX = | 0.000 | 0.105 | 0.210 | 0.314 |
| | BY = | 18023.150 | 18023.135 | 18023.091 | 18023.019 |
| 25.0 | BX = | 0.000 | 0.135 | 0.269 | 0.402 |
| | BY = | 18023.270 | 18023.255 | 18023.210 | 18023.136 |
| 30.0 | BX = | 0.000 | 0.165 | 0.329 | 0.491 |
| | BY = | 18023.419 | 18023.404 | 18023.358 | 18023.283 |
| 35.0 | BX = | 0.000 | 0.196 | 0.391 | 0.584 |
| | BY = | 18023.599 | 18023.584 | 18023.536 | 18023.457 |
| 40.0 | BX = | 0.000 | 0.228 | 0.455 | 0.680 |
| | BY = | 18023.811 | 18023.795 | 18023.746 | 18023.666 |
| 45.0 | BX = | 0.000 | 0.261 | 0.521 | 0.779 |
| | BY = | 18024.055 | 18024.039 | 18023.988 | 18023.904 |
| 50.0 | BX = | 0.000 | 0.295 | 0.589 | 0.880 |
| | BY = | 18024.333 | 18024.316 | 18024.264 | 18024.178 |
| 55.0 | BX = | 0.000 | 0.330 | 0.658 | 0.985 |
| | BY = | 18024.645 | 18024.627 | 18024.574 | 18024.485 |
| 60.0 | BX = | 0.000 | 0.365 | 0.730 | 1.093 |
| | BY = | 18024.992 | 18024.974 | 18024.920 | 18024.829 |
| 65.0 | BX = | 0.000 | 0.402 | 0.804 | 1.203 |
| | BY = | 18025.376 | 18025.357 | 18025.301 | 18025.208 |
| 70.0 | BX = | 0.000 | 0.440 | 0.879 | 1.316 |
| | BY = | 18025.797 | 18025.778 | 18025.721 | 18025.626 |
| 75.0 | BX = | 0.000 | 0.478 | 0.956 | 1.432 |
| | BY = | 18026.255 | 18026.236 | 18026.178 | 18026.080 |
| 80.0 | BX = | 0.000 | 0.517 | 1.033 | 1.551 |
| | BY = | 18026.753 | 18026.733 | 18026.675 | 18026.577 |
| 85.0 | BX = | 0.000 | 0.555 | 1.112 | 1.670 |
| | BY = | 18027.289 | 18027.270 | 18027.212 | 18027.113 |
| 90.0 | BX = | 0.000 | 0.593 | 1.189 | 1.789 |
| | BY = | 18027.864 | 18027.846 | 18027.790 | 18027.692 |
| 95.0 | BX = | 0.000 | 0.626 | 1.261 | 1.908 |
| | BY = | 18028.474 | 18028.458 | 18028.409 | 18028.316 |
| 100.0 | BX = | 0.000 | 0.650 | 1.322 | 2.018 |
| | BY = | 18029.115 | 18029.106 | 18029.072 | 18028.992 |
| 105.0 | BX = | 0.000 | 0.652 | 1.350 | 2.113 |
| | BY = | 18029.774 | 18029.781 | 18029.777 | 18029.725 |
| 110.0 | BX = | 0.000 | 0.598 | 1.347 | 2.196 |
| | BY = | 18030.419 | 18030.465 | 18030.532 | 18030.514 |
| 115.0 | BX = | 0.000 | 0.393 | 1.237 | 2.309 |
| | BY = | 18030.969 | 18031.128 | 18031.375 | 18031.391 |
| 120.0 | BX = | 0.000 | -0.262 | 0.897 | 2.718 |
| | BY = | 18031.204 | 18031.701 | 18032.449 | 18032.364 |
| 125.0 | BX = | 0.000 | -2.339 | -0.105 | 4.639 |
| | BY = | 18030.445 | 18032.074 | 18034.355 | 18033.521 |
| 130.0 | BX = | 0.000 | -8.989 | -3.616 | 13.530 |
| | BY = | 18026.526 | 18031.597 | 18039.427 | 18034.873 |

LHC-D2 DIPOLE GAP=39 mm I=1370 A  DATE 17/01/95  TIME 15.23.03

PERMEABILITY MAP, CYCLE NUMBER 6

DISTANCE BETWEEN COL. = 30.00 MM (= 3 TIMES H)
DISTANCE BETWEEN ROWS = 10.00 MM (= 1 TIMES H)

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 300 | 6288 | 6980 | 5349 | 3463 | 1721 | 895 | 595 | 501 | 464 | 478 | 610 | 1134 | 2517 | 4353 | 6176 | 7180 | | |
| 2708 | 6705 | 6951 | 5336 | 3462 | 1722 | 895 | 595 | 501 | 464 | 478 | 609 | 1135 | 2518 | 4349 | 6148 | 7251 | | |
| 4453 | 7086 | 6873 | 5298 | 3458 | 1724 | 895 | 594 | 501 | 463 | 477 | 609 | 1137 | 2521 | 4336 | 6066 | 7142 | | |
| 6300 | 7253 | 6742 | 5234 | 3449 | 1727 | 894 | 594 | 501 | 463 | 476 | 608 | 1142 | 2526 | 4313 | 5946 | 6937 | 7157 | |
| 7120 | 7215 | 6535 | 5143 | 3436 | 1732 | 893 | 594 | 501 | 463 | 475 | 606 | 1148 | 2533 | 4279 | 5802 | 6761 | 7136 | |
| 7239 | 7015 | 6306 | 5027 | 3416 | 1738 | 892 | 594 | 501 | 462 | 473 | 604 | 1158 | 2541 | 4229 | 5645 | 6536 | 7079 | |
| 6949 | 6704 | 6025 | 4885 | 3386 | 1745 | 890 | 594 | 501 | 462 | 470 | 602 | 1169 | 2550 | 4164 | 5470 | 6318 | 6939 | |
| 6446 | 6243 | 5600 | 4710 | 3343 | 1803 | 887 | 593 | 502 | 461 | 468 | 599 | 1182 | 2557 | 4081 | 5255 | 6066 | 6607 | |
| 5825 | 5687 | 5270 | 4495 | 3284 | 1810 | 883 | 592 | 502 | 461 | 464 | 596 | 1198 | 2561 | 3979 | 5023 | 5750 | 6288 | |
| 5118 | 5040 | 4706 | 4242 | 3202 | 1815 | 878 | 590 | 503 | 460 | 460 | 591 | 1216 | 2560 | 3858 | 4764 | 5387 | 5798 | |
| 4402 | 4381 | 4275 | 3905 | 3091 | 1817 | 872 | 588 | 503 | 459 | 456 | 585 | 1236 | 2551 | 3713 | 4471 | 4941 | 5238 | |
| 3645 | 3660 | 3663 | 3515 | 2942 | 1812 | 863 | 586 | 504 | 459 | 450 | 579 | 1259 | 2528 | 3538 | 4141 | 4472 | 4639 | |
| 2868 | 2911 | 3011 | 3045 | 2737 | 1795 | 853 | 582 | 505 | 458 | 444 | 571 | 1283 | 2486 | 3322 | 3744 | 3954 | 4048 | |
| 2072 | 2130 | 2293 | 2484 | 2450 | 1760 | 839 | 578 | 506 | 456 | 437 | 562 | 1308 | 2416 | 3052 | 3315 | 3402 | 3420 | |
| 1393 | 1445 | 1609 | 1869 | 2071 | 1686 | 823 | 572 | 506 | 455 | 428 | 553 | 1329 | 2303 | 2735 | 2912 | 2815 | 2700 | |
| 889 | 920 | 1023 | 1252 | 1586 | 1562 | 801 | 566 | 507 | 454 | 419 | 541 | 1345 | 2133 | 2339 | 2299 | 2213 | 2152 | |
| 565 | 585 | 652 | 789 | 1040 | 1331 | 774 | 557 | 508 | 452 | 407 | 531 | 1338 | 1885 | 1899 | 1781 | 1676 | 1614 | |
| 404 | 411 | 435 | 495 | 645 | 962 | 730 | 548 | 509 | 450 | 396 | 522 | 1301 | 1566 | 1447 | 1307 | 1213 | 1162 | |
| 309 | 311 | 318 | 336 | 395 | 571 | 680 | 536 | 510 | 448 | 382 | 512 | 1179 | 1163 | 1023 | 940 | 894 | 871 | |
| 260 | 260 | 263 | 268 | 283 | 336 | 529 | 529 | 511 | 446 | 368 | 502 | 938 | 831 | 748 | 701 | 675 | 662 | |
| 217 | 216 | 215 | 213 | 214 | 232 | 332 | 512 | 513 | 444 | 351 | 490 | 635 | 557 | 530 | 523 | 522 | 521 | |
| 183 | 182 | 178 | 173 | 167 | 161 | 183 | 507 | 515 | 443 | 340 | 435 | 415 | 419 | 432 | 441 | 446 | 449 | |
| 168 | 167 | 164 | 157 | 146 | 128 | 107 | 476 | 519 | 442 | 331 | 271 | 296 | 332 | 362 | 380 | 390 | 394 | |
| 159 | 158 | 155 | 148 | 135 | 115 | 77 | | | | | 146 | 246 | 305 | 331 | 344 | 351 | 354 | |
| 153 | 152 | 149 | 143 | 134 | 121 | 106 | | | | | 272 | 289 | 309 | 322 | 330 | 334 | 336 | |
| 149 | 148 | 146 | 143 | 137 | 128 | 117 | | | | | 295 | 302 | 311 | 318 | 322 | 324 | 324 | |
| 146 | 146 | 145 | 145 | 143 | 141 | 137 | | | | | 309 | 311 | 315 | 318 | 318 | 318 | 315 | |
| 144 | 144 | 145 | 147 | 151 | 162 | 172 | | | | | 319 | 318 | 319 | 319 | 317 | 313 | 307 | |
| 142 | 142 | 143 | 146 | 154 | 190 | 470 | | | | | 329 | 325 | 325 | 323 | 319 | 311 | 296 | |
| 139 | 139 | 140 | 140 | 138 | 129 | | | | | | 340 | 335 | 332 | 330 | 325 | 315 | 277 | 300 |
| 137 | 137 | 136 | 136 | 135 | 96 | | | | | | 353 | 347 | 344 | 343 | 345 | 357 | 406 | 719 |
| | | | | | | | | | | | 366 | 358 | 356 | 359 | 368 | 387 | 422 | 455 |
| | | | | | | | | | | | 369 | 361 | 360 | 365 | 375 | 393 | 416 | 429 |

TABLE 2 : DIPOLE D2 FIELD PLOT AND PERMEABILITY MAP

| | |
|---|---|
| **BASIC:** | |
| Aperture (diam.) | 44mm |
| Gradient | 30T/m |
| Magnetic length | 3.55 m |
| **DIMENSIONS:** | |
| Core length | 3.5 m |
| Overall length | 3.75 m |
| Overall width | 800mm |
| Overall heigh | 700mm |
| **EXCITATION:** | |
| Current | 600 A |
| Resistance | 40 mΩ |
| Dissipated power | 14 KW |
| **COOLING:** | |
| Pressure | 4 bar |
| Water flow | 10 l/min |
| Temperature rise | 23°C |
| **WEIGHT:** | |
| Copper | 1.5 t |
| Core | 10 t |
| **NO OF UNITS:** | 24 |
| **PRICE / UNIT:** | 130 KCHF |

TABLE 3 : PARAMETERS FOR TWIN APERTURE QUADRUPOLES LIQ210

```
*****************************************
*     CEDRAT                   MAGSOFT    *
* Grenoble, France             Troy, N.Y. *
*                                         *
*              FLUX2D  7.11               *
*                                         *
*     Numero de serie   940726            *
*                                         *
*     copyright (all rights reserved)     *
* ENSIEG - LABORATOIRE D'ELECTROTECHNIQUE *
* BP46 38402 Saint Martin d'Heres France  *
*****************************************

   LIQ210.25  2/03/95  9:38:44   LIQ210.25 Low Carbon St. I = 6000 At

Actual depth of the object (mm) 1000

.............
Flux density
.............

Straight segment : X 70 Y 0 , X 140 Y 0

        Abscissa          Magnitude        Normal Comp   Tangential Comp.
          mm               Tesla            Tesla            Tesla
  .0000000E+00       .8697879         .8680016         -.3694322E-01
  5.000000           .8777566         .8772228          .3060879E-01
  10.00000           .7506338         .7506174         -.4948226E-02
  15.00000           .6115722         .6115714         -.9598651E-03
  20.00000           .4579497         .4579497         -.2330161E-03
  25.00000           .3047797         .3047796         -.1360617E-03
  30.00000           .1524179         .1524179         -.6320691E-04
  35.00000           .8761594E-03     .5702146E-04      .8241194E-05   Center
  40.00000           .1523442        -.1523442          .1463059E-05
  45.00000           .3047546        -.3047546         -.6906149E-04
  50.00000           .4577488        -.4577488         -.1491465E-03
  55.00000           .6115580        -.6115572         -.9653495E-03
  60.00000           .7633963        -.7632961         -.2021314E-01
  65.00000           .8603021        -.8594714          .4208173E-01
  70.00000           .8911699        -.8911866         -.3307062E-01

.............
Flux density
.............

Straight segment : X 105 Y 0 , X 105 Y 25

        Abscissa          Magnitude        Normal Comp   Tangential Comp.
          mm               Tesla            Tesla            Tesla
  .0000000E+00       .5761392E-04     -.8241194E-05      .5702146E-04
  2.500000           .7616261E-01      .7616252E-01      .1170437E-03
  5.000000           .1523705          .1523704          .1607189E-03
  7.500000           .2284784          .2284783          .2044391E-03
  10.00000           .3046364          .3046363          .2482102E-03
  12.50000           .3807945          .3807943          .2935299E-03
  15.00000           .4569373          .4569371          .3616818E-03
  17.50000           .5330784          .5330778          .8109648E-03
  20.00000           .6101289          .6101279          .1139332E-02
  22.50000           .6836148          .6836126          .1745082E-02
  25.00000           .7571009          .7570973          .2350849E-02

........
Director
........
```



Flux density
arc : center X=105 Y=0R = 10 (.100E-04 -> 180 deg.)
Normal_comp

| Harmonic number | Tesla | Phase (degree) | % fundamental |
|---|---|---|---|
| 0 | -.23205E-04 | .00 | |
| 1 | .30468 | -89.98 | |
| 2 | .11589E-03 | -133.58 | .038 |
| 3 | .41042E-04 | -34.56 | .013 |
| 4 | .11423E-04 | -133.14 | .004 |
| 5 | .19272E-04 | -81.11 | .006 |
| 6 | .12147E-04 | -59.60 | .004 |
| 7 | .99556E-05 | -22.71 | .003 |
| 8 | .86219E-05 | -97.04 | .003 |
| 9 | .12419E-04 | -39.85 | .004 |
| 10 | .58013E-05 | -6.88 | .002 |

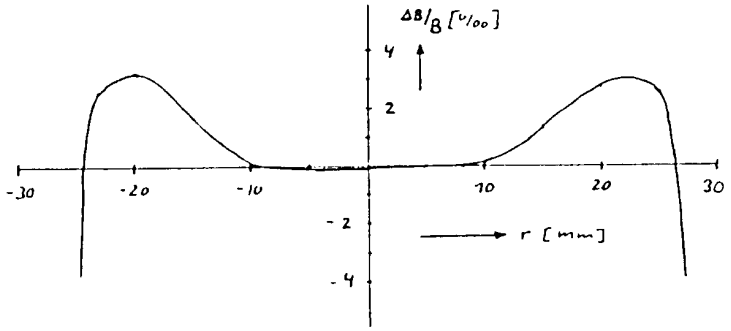


TABLE 4 : LIQ210 FIELD CALCULATION