EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

NP Internal Report 68-29
4 September, 1968

# MEASUREMENT ON A SCALE MODEL OF AN OPEN MAGNET SYSTEM FOR ISR EXPERIMENTAL REGION

by

F. Krienen, W. Glessing, M. van Gulik, S. Gustar

## 1. SUMMARY

In an internal report, NP Int. 68-5, by French, Krienen, Massam and Morpurgo, a magnet has been described of rather unusual geometry. We thought it opportune to prepare a 1 : 50 scale model from which we may obtain with reasonable accuracy:

a) The central field, the downstream field and the transition between the two.

b) The stray field, in particular, the total flux collected by the adjacent ISR magnets.

c) A check on the main parameters estimated in the above-mentioned report.

## 2. SCALE MODEL

Fig. 1 shows the 1 : 50 scale magnet, made of Armco iron. The component parts are also to scale. Most of the members would have around 50 ton true size, though a few (pole pieces and the outer structural slabs) would attain 80 ton. The overall coils section and coil position is to scale (the section is 50 × 50 cm true size) and is made of 64 turns of 1.1 mm enamelled copper wire mounted on a water-cooled copper mandrel. See Fig. 2. The cooling is efficient, up to 30 A may be carried by the wire.

The compensators are not incorporated in this model: they would be too small.

## 3. METHOD

The measurement is done with a Hall plate. The Hall plate is mounted on a motor-driven support and scans the field along straight lines. Each scan line is manually set. The field views are displayed on a pen recorder. Marker pips equivalent to 5 mm in space are also recorded. In addition, a print-out of the field values in steps of 5 mm is obtained.

The model cannot be driven into saturation because of dissipation. Hence, curves and tables of fields generated by one pair of coils only are useful, because the field at any point of space would be a linear combination of the fields generated by the currents in each of the three pairs of coils.

The stray field picked up by the adjacent ISR magnets is not measured with a Hall plate. Instead, a coil is wound on the yoke of an non-energised ISR scale model, see Fig. 3. Practically all flux entering this model will be coupled with this coil and the average field in the yoke and in the median plane is measured by means of flux reversal and integration of the output voltage.

4. MEASUREMENTS

i) An equilibrium orbit for the circulating protons is in first approximation the straight line AOB of Fig. 1. Along this line is plotted in Fig. 4 the three (vertical) field components due to currents (15 A) in each of the three coil pairs. The principle of super position may be used to construct the field for any current in the coils. For instance, the measured curve shown in Fig. 5 is obtained for a current ratio of 1.2 of the centre coils to the downstream coils and may be shown to fit well with a curve constructed from Fig. 4. The chosen current ratio is on the assumption that, in the absence of saturation, the integral of the field across a gap is supported by the corresponding coils. This reflects a design feature that the integral of the field from top to bottom yoke be zero.

In Tables 1 and 2 is given the print-out of the field in steps of 5 mm. Also shown is the deflection y of the equilibrium orbit from the straight line A O B and the slope dy/ds, by performing the appropriate numerical integrations.

ii) In Fig. 6 is shown in the median plane contours of constant flux density compiled from a number of straight runs with the recorder. Note that the chosen current ratio of 1.2 of the centre coils to the downstream coils yields low flux densities outside the projected coil areas. Also the large rectangular slits in the top and bottom central pole pieces do not distort the field appreciably.

iii) In Table 3 is given a print-out of a three-dimensional mesh limited to the centre region of the magnet. These data may be used to compute trajectories and sagittas of particles emitted near the intersect.

iv. In Table 4 is computed the average flux density in the yoke and in the median plane of an ISR magnet as outlined in section 3. For the sake of convenience fluxes are given with only one pair of coils energised at a time. But in Table 5 the total measured flux is given for a current ratio 1.2 in the coils.

## 5. ACCURACY

The mechanical components are accurate to 1% overall. For the currents we have two inaccuracies. In the case that one pair of coils is energised the current is better than 1‰. In the case that the three coil pairs are energised the total current is better than 1‰ but the individual currents may be wrong by 3%.

The location of the marker pips and the mesh points may be out by 1 mm, but this is a systematic error. The recorder readings are precise to 20 gauss. The print-out is presumably better than 10 gauss.

## 6. CONCLUSION

The very reduced scale model yields sufficient information concerning the points mentioned in section 1. However, we are not able to run the model at true field strength, i.e. a factor 15 or so higher, which would give saturation in part of the magnet steel. Moreover the compensators are not incorporated and they are bound to influence the measured field locally. On the other hand, the results enable us to optimize on the compensators in particular the effect of changes in current ratio.

We wish to acknowledge the advice of Mr. E. Braunersreuther for the measurements, and the help of Mr. J. Belleville with the coils.

TABLE 1

Flux Density on, Slope and Deflection of Equilibrium Orbit

| S cm | 15 A in upstream coils: B gauss | 15 A in upstream coils: ∫Bds gauss cm | 15 A in upstream coils: ∫ds∫Bds gauss cm² | 15 A in centre coils: B gauss | 15 A in centre coils: ∫Bds gauss cm | 15 A in centre coils: ∫ds∫Bds gauss cm² | 15A in downstream coils: B gauss | 15A in downstream coils: ∫Bds gauss cm | 15A in downstream coils: ∫ds∫Bds gauss cm² |
|---|---|---|---|---|---|---|---|---|---|
| -12.5 | +115 | | | + 77 | | | - 58 | | |
| -12 | +146 | | | + 82 | | | - 64 | | |
| -11.5 | +179 | | | + 86 | | | - 66 | | |
| -11 | +216 | | | + 92 | | | - 70 | | |
| -10.5 | +255 | | | + 96 | | | - 74 | | |
| -10 | +291 | | | + 98 | | | - 77 | | |
| - 9.5 | +316 | | | + 98 | | | - 77 | | |
| - 9 | +309 | | | + 93 | | | - 77 | | |
| - 8.5 | +262 | | | + 80 | | | - 73 | | |
| - 8 | +177 | | | + 57 | | | - 66 | | |
| - 7.5 | + 91 | | | + 31 | | | - 60 | | |
| - 7 | + 30 | | | - 5 | | | - 54 | | |
| - 6.5 | - 4 | | | - 47 | | | - 51 | | |
| - 6 | - 26 | | | - 94 | | | - 48 | | |
| - 5.5 | - 38 | | | -146 | | | - 47 | | |
| - 5 | - 42 | | | -192 | | | - 46 | | |
| - 4.5 | - 46 | | | -233 | | | - 47 | | |
| - 4 | - 48 | | | -264 | | | - 47 | | |
| - 3.5 | - 50 | | | -286 | | | - 48 | | |
| - 3 | - 50 | | | -303 | | | - 48 | | |
| - 2.5 | - 49 | | | -312 | | | - 48 | | |
| - 2 | - 49 | | | -317 | | | - 48 | | |
| - 1.5 | - 49 | | | -320 | | | - 48 | | |
| - 1 | - 49 | | | -321 | | | - 48 | | |
| - 0.5 | - 48 | | | -320 | | | - 49 | | |
| 0 | - 48 | 0 | 0 | -320 | 0 | 0 | - 49 | 0 | 0 |
| + 0.5 | - 48 | - 12 | - 6 | -320 | - 80 | - 40 | - 49 | - 12 | - 6 |
| + 1 | - 48 | - 36 | - 24 | -320 | - 240 | - 160 | - 50 | - 37 | - 24 |
| + 1.5 | - 49 | - 60 | - 54 | -319 | - 400 | - 360 | - 50 | - 62 | - 55 |
| + 2 | - 48 | - 84.5 | - 96 | -316 | - 559 | - 639 | - 50 | - 87 | - 99 |
| + 2.5 | - 50 | - 108.5 | - 150 | -310 | - 717 | - 998 | - 50 | - 112 | - 155 |
| + 3 | - 49 | - 133.5 | - 217 | -300 | - 872 | - 1434 | - 50 | - 137 | - 223 |
| + 3.5 | - 48 | - 158 | - 296 | -283 | -1022 | - 1946 | - 49 | - 162 | - 304 |
| + 4 | - 48 | - 182 | - 387 | -257 | -1164 | - 2528 | - 47 | - 186 | - 397 |
| + 4.5 | - 48 | - 206 | - 490 | -224 | -1292 | - 3174 | - 44 | - 210 | - 502 |
| + 5 | - 48 | - 230 | - 605 | -181 | -1404 | - 3876 | - 38 | - 232 | - 618 |
| + 5.5 | - 51 | - 254 | - 732 | -132 | -1495 | - 4624 | - 25 | - 251 | - 744 |
| + 6 | - 54 | - 279.5 | - 872 | - 80 | -1561 | - 5404 | - 0 | - 263 | - 876 |
| + 6.5 | - 57 | - 306.5 | - 1025 | - 29 | -1601 | - 6205 | + 50 | - 263 | - 1007 |
| + 7 | - 68 | - 335 | - 1192 | + 18 | -1615 | - 7012 | + 164 | - 238 | - 1127 |
| + 7.5 | - 79 | - 369 | - 1377 | + 64 | -1606 | - 7816 | + 346 | - 156 | - 1205 |
| + 8 | -100 | - 408.5 | - 1581 | +110 | -1574 | - 8603 | + 613 | + 16 | - 1197 |
| + 8.5 | -124 | - 458.5 | - 1810 | +149 | -1519 | - 9363 | + 853 | + 323 | - 1035 |
| + 9 | -132 | - 520.5 | - 2071 | +169 | -1445 | -10085 | + 921 | + 749 | - 660 |
| + 9.5 | -136 | - 586.5 | - 2364 | +174 | -1360 | -10765 | +1012 | + 1210 | - 55 |
| +10 | -136 | - 654.5 | - 2691 | +174 | -1273 | -11402 | +1019 | + 1716 | + 802 |
| +10.5 | -135 | - 722.5 | - 3052 | +173 | -1186 | -11995 | +1018 | + 2225 | + 1914 |
| +11 | -135 | - 790 | - 3447 | +172 | -1100 | -12545 | +1016 | + 2734 | + 3282 |
| +11.5 | -133 | - 857.5 | - 3876 | +172 | -1014 | -13052 | +1010 | + 3242 | + 4903 |
| +12 | -133 | - 924 | - 4338 | +171 | - 928 | -13516 | +1006 | + 3747 | + 6777 |
| +12.5 | -133 | - 990.5 | - 4833 | +171 | - 842 | -13938 | +1008 | + 4250 | + 8902 |
| +13 | -133 | -1057 | - 5362 | +170 | - 757 | -14316 | +1004 | + 4754 | +11279 |
| +13.5 | -130 | -1123.5 | - 5924 | +167 | - 672 | -14652 | + 985 | + 5256 | +13907 |
| +14 | -122 | -1188.5 | - 6518 | +157 | - 588 | -14946 | + 914 | + 5749 | +16782 |
| +14.5 | -100 | -1249.5 | - 7143 | +129 | - 510 | -15201 | + 728 | + 6206 | +19885 |
| +15 | - 74 | -1299.5 | - 7792 | + 98 | - 445 | -15424 | + 474 | + 6570 | +23170 |
| +15.5 | - 57 | -1336.5 | - 8461 | + 73 | - 396 | -15622 | + 259 | + 6807 | +26573 |
| +16 | - 43 | -1365 | - 9143 | + 53 | - 360 | -15802 | + 120 | + 6936 | +30042 |
| +16.5 | - 33 | -1386.5 | - 9836 | + 41 | - 333 | -15969 | + 50 | + 6996 | +33540 |
| +17 | - 25 | -1403 | -10538 | + 33 | - 313 | -16126 | + 11 | + 7021 | +37051 |
| +17.5 | - 20 | -1415.5 | -11246 | + 27 | - 296 | -16274 | - 0 | + 7027 | +40564 |
| +18 | - 16 | -1425.5 | -11958 | + 21 | - 283 | -16415 | - 5 | + 7027 | +44078 |
| +18.5 | - 13 | -1433.5 | -12675 | + 17 | - 272 | -16552 | - 8 | + 7024 | +47590 |
| +19 | - 11 | -1440 | -13395 | + 14 | - 264 | -16684 | - 8 | + 7020 | +51100 |
| +19.5 | - 9 | -1445.5 | -14118 | + 11 | - 257 | -16812 | - 8 | + 7016 | +54608 |
| +20 | - 8 | -1450 | -14843 | + 9 | - 251 | -16938 | - 7 | + 7012 | +58115 |
| | | -1454 | -15570 | | - 247 | -17061 | | + 7009 | +61619 |

TABLE 2

Flux Density on, Slope + Deflection of Equil.Orbit

14 A in upstream coils
17 A in centre coils
14 A in downstr.coils

| B gauss | ∫Bds gauss cm | ∫ds∫Bds gauss cm² | S cm |
|---|---|---|---|
| + 140 | | | -12.5 |
| + 169 | | | -12 |
| + 202 | | | -11.5 |
| + 232 | | | -11 |
| + 276 | | | -10.5 |
| + 309 | | | -10 |
| + 333 | | | - 9.5 |
| + 319 | | | - 9 |
| + 268 | | | - 8.5 |
| + 170 | | | - 8 |
| + 64 | | | - 7.5 |
| - 27 | | | - 7 |
| - 107 | | | - 6.5 |
| - 176 | | | - 6 |
| - 241 | | | - 5.5 |
| - 299 | | | - 5 |
| - 346 | | | - 4.5 |
| - 391 | | | - 4 |
| - 414 | | | - 3.5 |
| - 431 | | | - 3 |
| - 444 | | | - 2.5 |
| - 449 | | | - 2 |
| - 451 | | | - 1.5 |
| - 451 | | | - 1 |
| - 451 | | | - 0.5 |
| - 451 | 0 | 0 | 0 |
| - 451 | - 112 | - 56 | + 0.5 |
| - 451 | - 338 | - 225 | + 1 |
| - 451 | - 563 | - 507 | + 1.5 |
| - 448 | - 789 | - 902 | + 2 |
| - 441 | - 1013 | - 1408 | + 2.5 |
| - 428 | - 1233 | - 2025 | + 3 |
| - 408 | - 1447 | - 2749 | + 3.5 |
| - 379 | - 1651 | - 3575 | + 4 |
| - 336 | - 1841 | - 4495 | + 4.5 |
| - 283 | - 2009 | - 5500 | + 5 |
| - 218 | - 2150 | - 6575 | + 5.5 |
| - 138 | - 2259 | - 7705 | + 6 |
| - 36 | - 2328 | - 8870 | + 6.5 |
| + 111 | - 2346 | -10043 | + 7 |
| + 325 | - 2291 | -11189 | + 7.5 |
| + 602 | - 2128 | -12253 | + 8 |
| + 854 | - 1827 | -13167 | + 8.5 |
| + 980 | - 1400 | -13867 | + 9 |
| +1015 | - 910 | -14323 | + 9.5 |
| +1023 | - 403 | -14524 | +10 |
| +1023 | + 108 | -14470 | +10.5 |
| +1020 | + 619 | -14160 | +11 |
| +1013 | + 1129 | -13595 | +11.5 |
| +1012 | + 1636 | -13777 | +12 |
| +1012 | + 2142 | -11706 | +12.5 |
| +1009 | + 2648 | -10382 | +13 |
| + 989 | + 3152 | - 8806 | +13.5 |
| + 920 | + 3647 | - 6982 | +14 |
| + 737 | + 4107 | - 4928 | +14.5 |
| + 486 | + 4475 | - 2691 | +15 |
| + 274 | + 4718 | - 331 | +15.5 |
| + 136 | + 4855 | + 2096 | +16 |
| + 61 | + 4923 | + 4558 | +16.5 |
| + 26 | + 4954 | + 7035 | +17 |
| + 10 | + 4967 | + 9518 | +17.5 |
| + 3 | + 4972 | +12005 | +18 |
| - 1 | + 4973 | +14491 | +18.5 |
| - 1 | + 4973 | +16978 | +19 |
| - 3 | + 4972 | +19464 | +19.5 |
| - 3 | + 4977 | +21950 | +20 |
| | + 4969 | +24435 | |

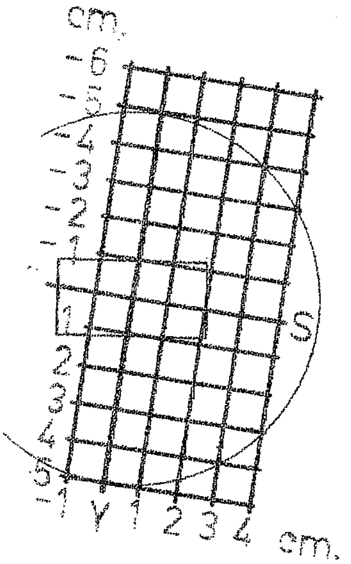


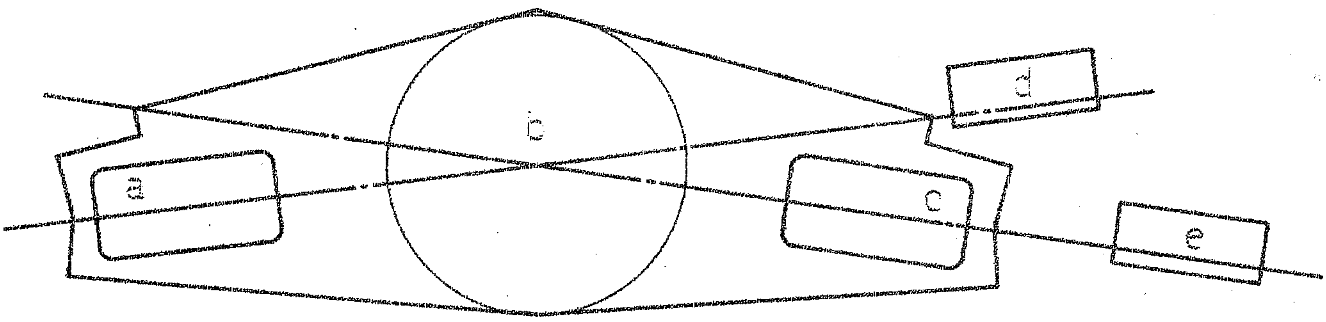

Table 3

Flux density in Gauss (negative!) on three dimensional mesh points in centre region of magnet. Current centre coils = 17 A. Current in downstream coils = 14 A.
Note: The principal coordinate S coincides with one of the equilibrium orbits, and the origin coincides with the intersect.

| S cm \ Y cm | -6 | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | z = 0 (median plane) | | | | | | | |
| -1 | 211 | 307 | 386 | 431 | 449 | 453 | 452 | 452 | 449 | 430 | 383 | 303 |
| 0 | 218 | 315 | 392 | 435 | 451 | 453 | 452 | 454 | 451 | 434 | 391 | 312 |
| 1 | 210 | 306 | 383 | 430 | 448 | 452 | 452 | 453 | 449 | 429 | 383 | 383 |
| 2 | 187 | 277 | 359 | 412 | 438 | 446 | 448 | 447 | 437 | 412 | 357 | 272 |
| 3 | 154 | 230 | 313 | 370 | 407 | 425 | 431 | 425 | 409 | 371 | 311 | 228 |
| 4 | 113 | 175 | 243 | 309 | 352 | 375 | 382 | 334 | 352 | 308 | 240 | 172 |
| | | | | | z = 0.5 cm | | | | | | | |
| -1 | 215 | 318 | 398 | 439 | 454 | 454 | 451 | 454 | 453 | 436 | 389 | 303 |
| 0 | 224 | 327 | 403 | 441 | 454 | 453 | 451 | 454 | 455 | 438 | 395 | 313 |
| 1 | 214 | 316 | 396 | 436 | 451 | 452 | 452 | 454 | 452 | 434 | 386 | 301 |
| 2 | 188 | 287 | 371 | 420 | 443 | 449 | 451 | 450 | 442 | 435 | 357 | 268 |
| 3 | 151 | 234 | 323 | 382 | 418 | 430 | 435 | 431 | 415 | 377 | 310 | 221 |
| 4 | 113 | 175 | 251 | 314 | 359 | 384 | 385 | 382 | 356 | 308 | 238 | 165 |
| | | | | | z = 1 cm | | | | | | | |
| -1 | 215 | 337 | 421 | 452 | 457 | 454 | 445 | 455 | 460 | 452 | 414 | 322 |
| 0 | 223 | 343 | 422 | 452 | 457 | 454 | 445 | 455 | 460 | 452 | 418 | 330 |
| 1 | 214 | 332 | 415 | 451 | 457 | 454 | 452 | 455 | 459 | 451 | 409 | 317 |
| 2 | 184 | 297 | 389 | 436 | 452 | 454 | 454 | 455 | 454 | 436 | 381 | 282 |
| 3 | 143 | 237 | 339 | 404 | 432 | 444 | 448 | 444 | 433 | 399 | 328 | 222 |
| 4 | 107 | 168 | 255 | 336 | 384 | 406 | 411 | 404 | 382 | 327 | 244 | 157 |
| | | | | | z = 1.7 cm | | | | | | | |
| -1 | 199 | 383 | 476 | 483 | 482 | 459 | 431 | 456 | 483 | 488 | 485 | 391 |
| 0 | 210 | 392 | 476 | 483 | 482 | 452 | 429 | 460 | 483 | 488 | 485 | 403 |
| 1 | 195 | 375 | 473 | 483 | 483 | 454 | 436 | 467 | 483 | 488 | 481 | 385 |
| 2 | 159 | 325 | 456 | 483 | 484 | 476 | 467 | 482 | 487 | 488 | 464 | 326 |
| 3 | 113 | 236 | 395 | 468 | 484 | 486 | 487 | 490 | 487 | 475 | 399 | 229 |
| 4 | 72.8 | 145 | 267 | 395 | 459 | 482 | 483 | 480 | 458 | 398 | 268 | 136 |

Table 4

Average flux density in the yoke and in the median plane of an ISR magnet, due to currents in the coils of the proposed magnet.



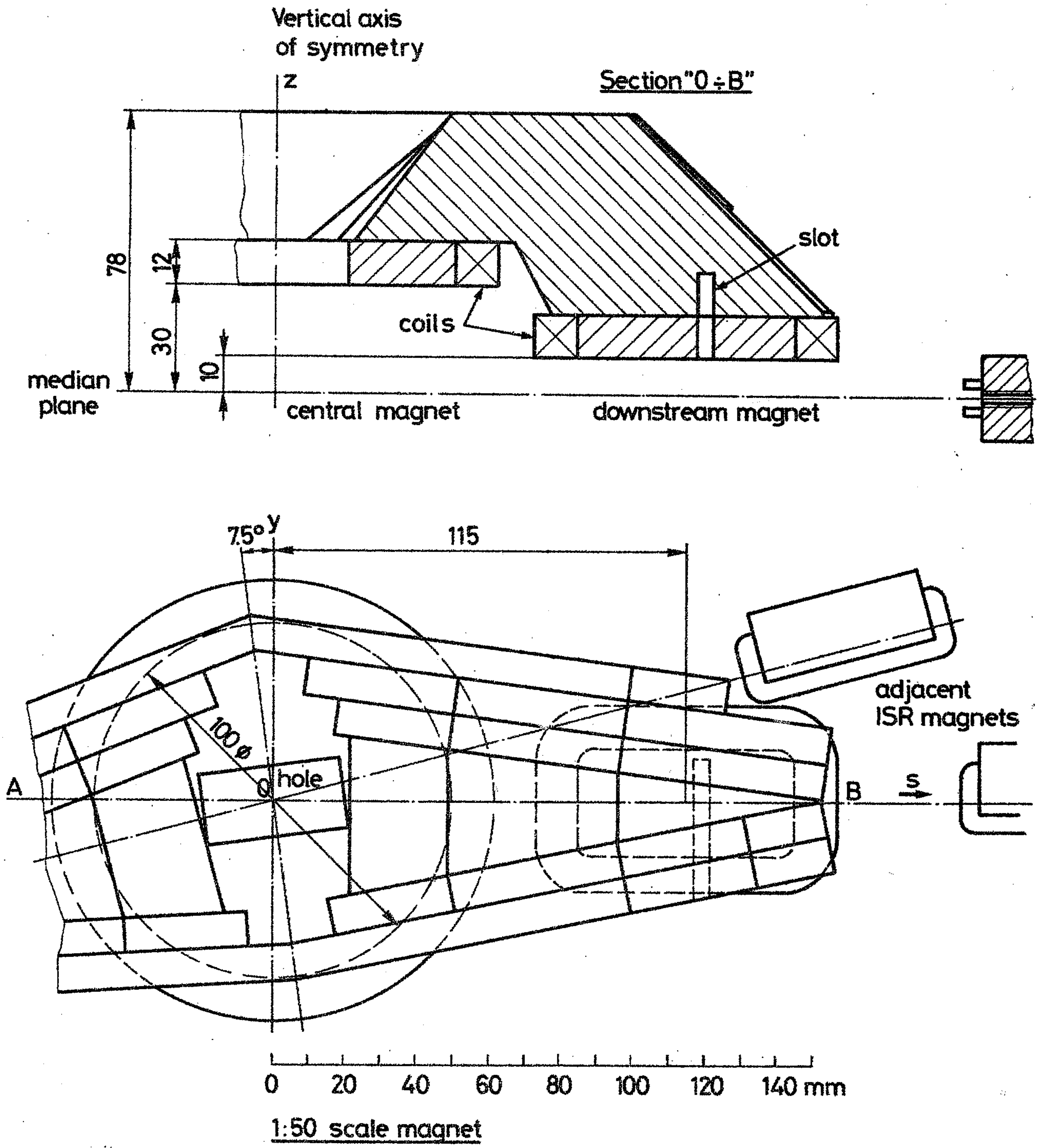

| 15 A in ↓ | Gauss in d | Gauss in e |
|---|---|---|
| a | - 162 | - 45 |
| b | 215 | 59 |
| c | - 72 | - 43 |

* * *

Table 5

Average flux density in the yoke and in the median plane of an ISR magnet.

| | | |
|---|---|---|
| 14.6 A in a<br>17.1 A in b<br>14.6 A in c | 10 Gauss in d | -18 Gauss in e |



Vertical axis
of symmetry
z
Section "0 ÷ B"
slot
78
12
30
10
coils
median
plane
central magnet
downstream magnet
7.5°
y
115
100 ⌀
hole
0
A
B
s
adjacent
ISR magnets
0
20
40
60
80
100
120
140 mm
1:50 scale magnet


FIG. 1

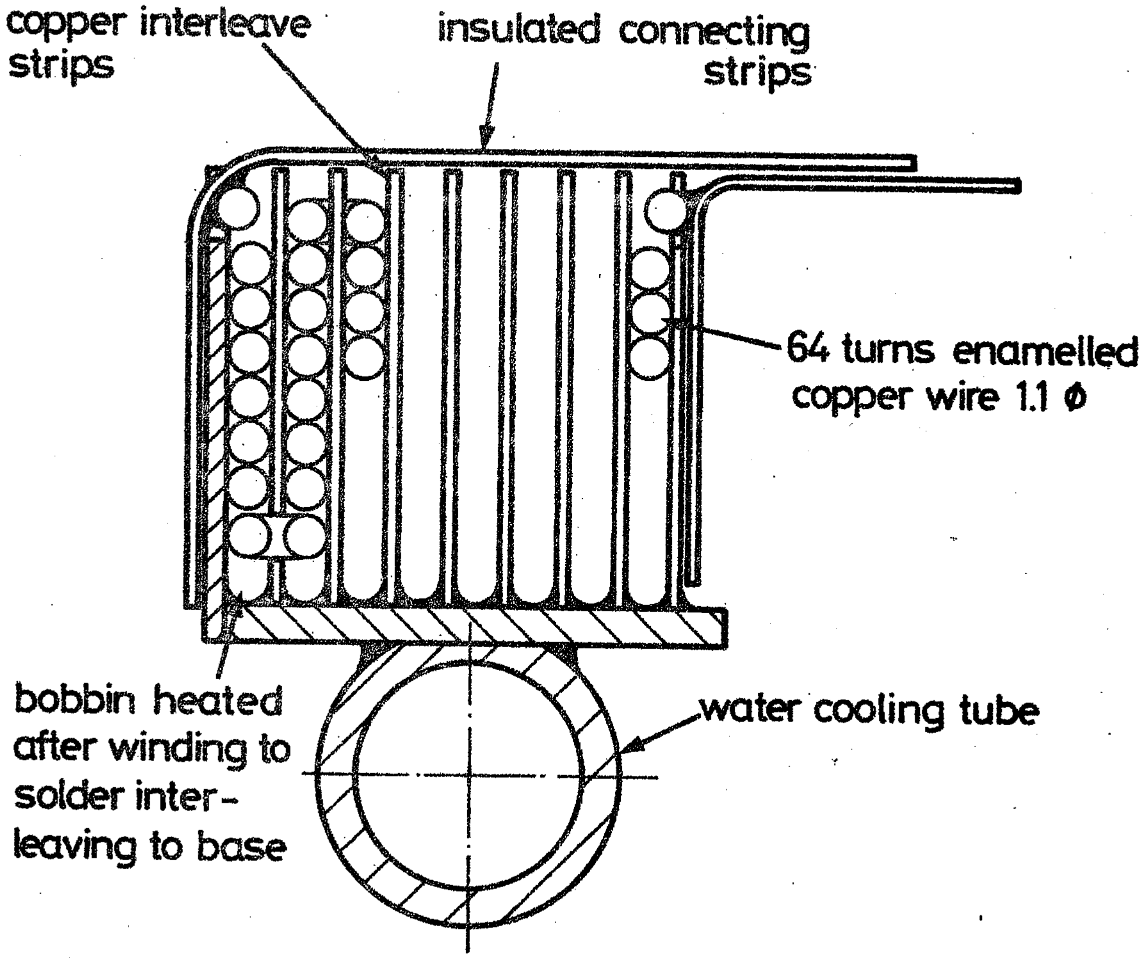



FIG. 2 Section of 1:50 coil

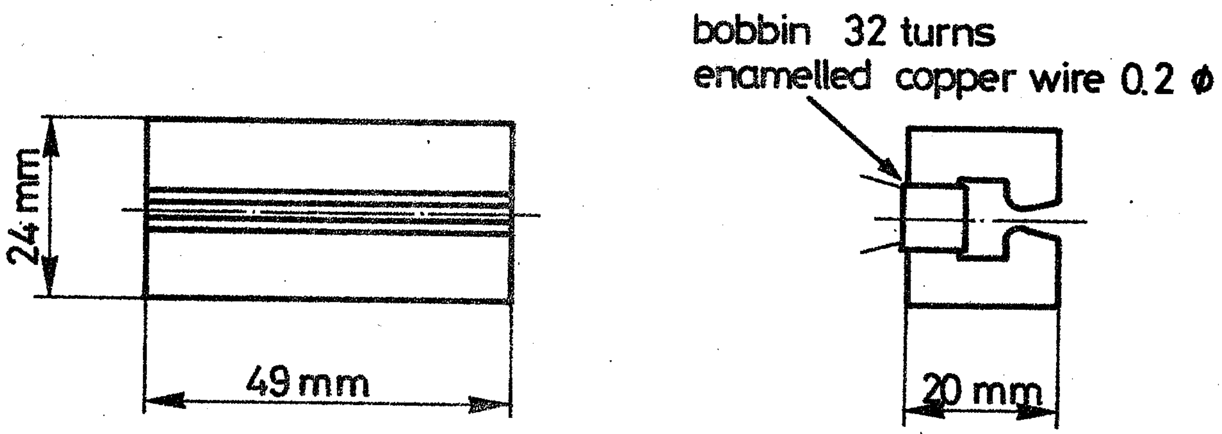



FIG. 3 1:50 Dummy ISR magnet

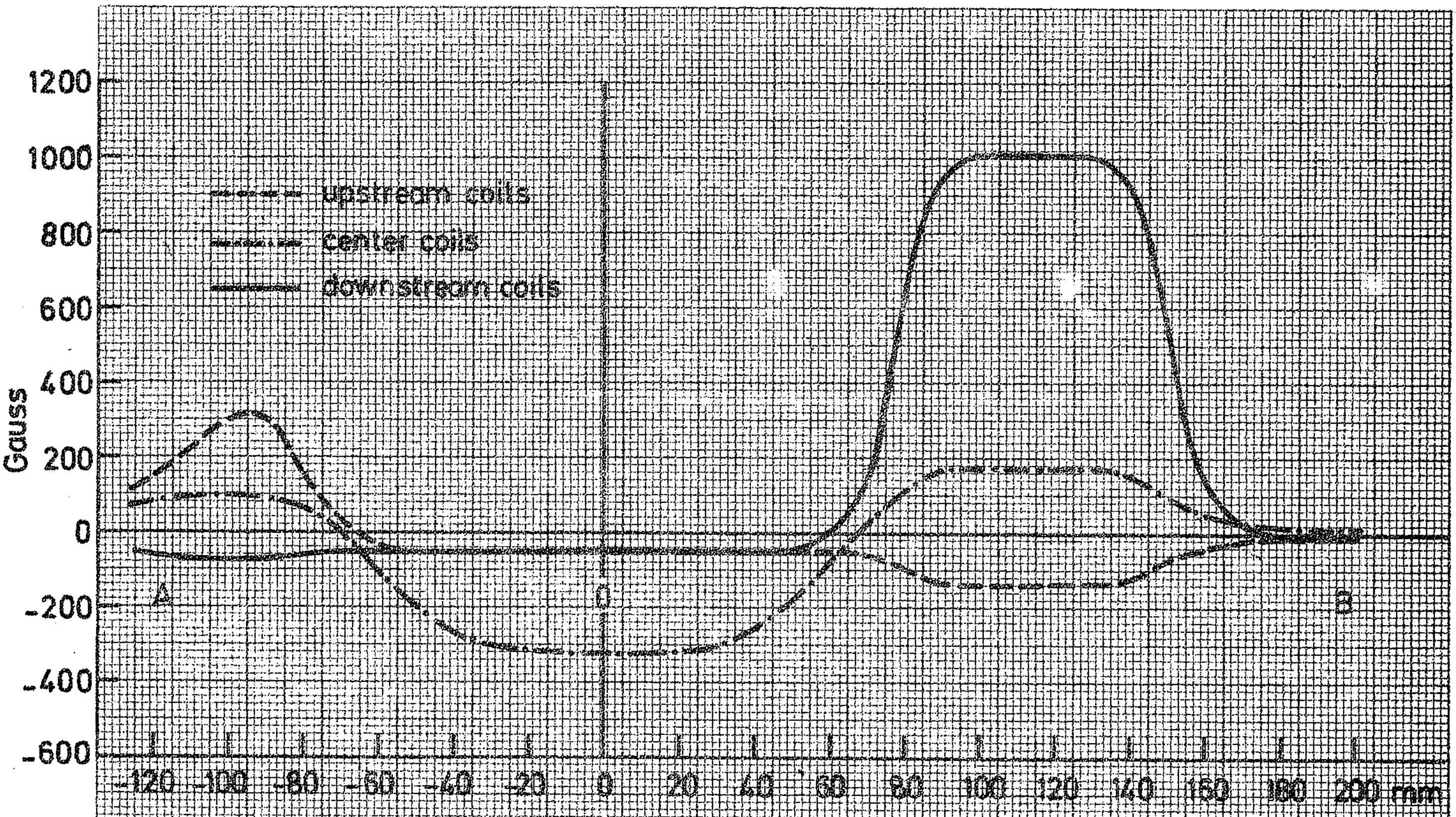



FIG. 4 Field components along equilibrium orbit due to 15 A currents in one pair of coils only.

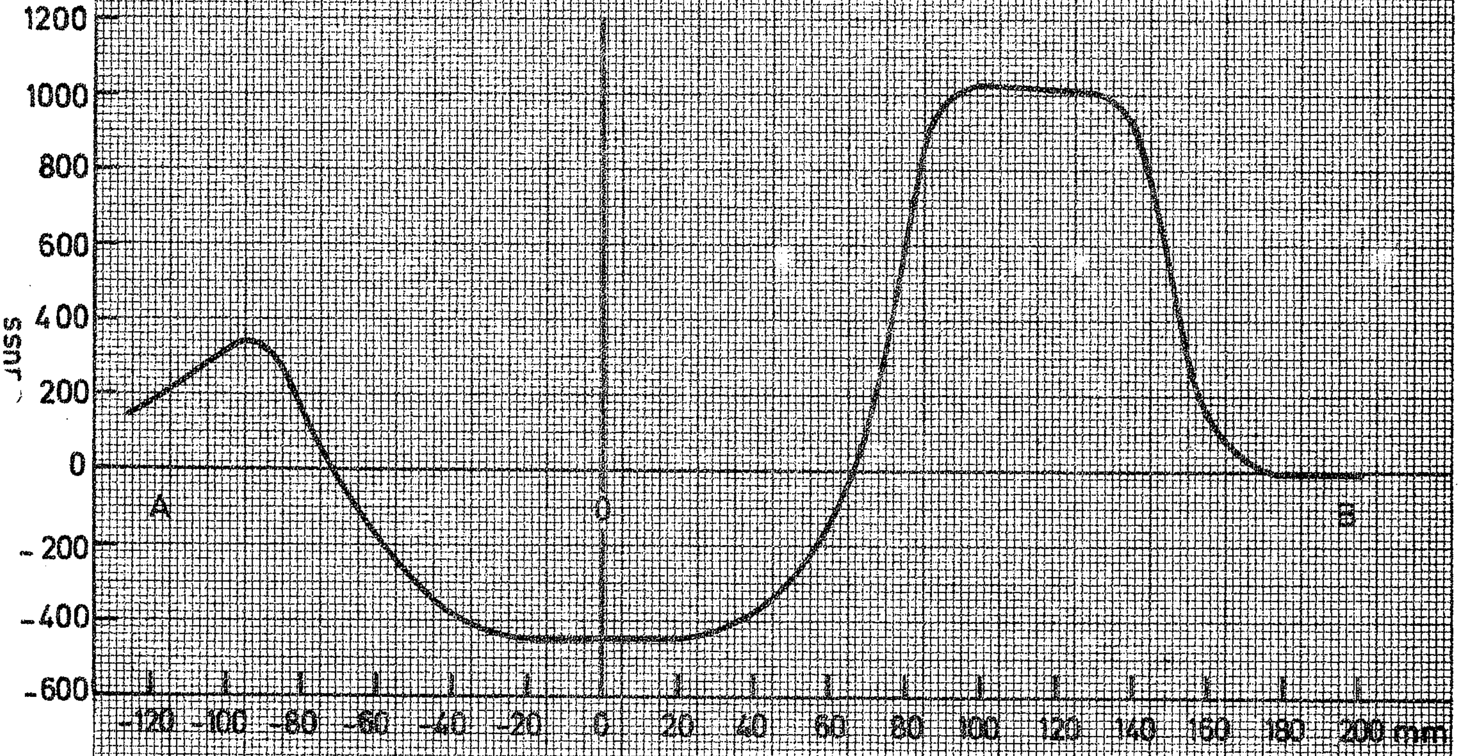



FIG 5 Field shape along equilibrium orbit. Current ratio 1.2 (14 A in downstream coils, 17 A in center coils.)

FIG.6 <u>Lines of constant flux in the median plane</u>

current ratio = 1.2
i.e. downstream coils = 14 A
center coils = 17 A