20-T, 120-cm-I.R. Target Magnets with Large Axial Gaps at 4, 10, 15 &20 m

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Target Magnet IDS120j: three solenoids per cryostat; large axial gaps at z = 4, 10, 15 & 20 m [drawing courtesy Van Graves]. Target Magnet IDS120k is very similar, but the outboard solenoids in all cryostats except the first are of optimized (larger) inner radius, to improve field profile. U = 3.34 GJ.

Selected Parameters of Target Magnet IDS120k

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | 12.47 | kA | 0.1 | meters Lelec | 1.724 | cm at 20 oC | 7.0 | ncm/deg | 10.0 | oC T0 | 40.0 | atmospheres P | 0.10m | Lhy |  |  |
| Coil designation | Units |  | Cu 1 | Cu 2 | Cu 3 | Cu 4 | Cu 5 | SC 1 | SC 2 | SC 3 | SC 4 | SC 5 | SC 6 | SC 7 | SC 8 | SC 9 | SC 10 | SC 11 | SC 12 |
| SSt shell thickness | cm |  | 0.255 | 0.325 | 0.183 | 0.160 | 0.145 |  |  |  |  |  |  |  |  |  |  |  |  |
| Current density jcoil | kA/cm2 | 5.00 | 2.201 | 2.074 | 1.412 | 1.204 | 1.059 | 1.931 | 2.176 | 2.673 | 3.346 | 4.122 | 4.072 | 4.503 | 4.666 | 4.645 | 4.645 | 4.645 | 4.645 |
| Coil length | cm |  | 100.2 | 123.6 | 207.2 | 212.0 | 215.6 | 352.3 | 77.78 | 45.20 | 31.23 | 255.4 | 15.45 | 13.00 | 341.3 | 10.96 | 14.12 | 320.3 | 14.12 |
| Gap between coils | cm |  |  |  |  |  |  | 0.00 | 87.30 | 148.6 | 74.28 | 83.20 | 105.0 | 37.31 | 27.89 | 70.76 | 39.71 | 39.71 | 72.00 |
| Upstream end | cm |  | -87.6 | -111.0 | -121.0 | -125.8 | -129.5 | -240.9 | 111.4 | 276.5 | 470.2 | 575.7 | 914.3 | 1035 | 1085 | 1454 | 1536 | 1590 | 1950 |
| Downstream end | cm |  | 12.6 | 12.6 | 86.2 | 86.2 | 86.2 | 111.4 | 189.2 | 321.7 | 501.5 | 831.1 | 929.8 | 1048 | 1426 | 1465 | 1550 | 1910 | 1964 |
| Inner radius | cm |  | 18.34 | 23.85 | 29.58 | 36.21 | 43.30 | 120.0 | 120.0 | 120.0 | 120.0 | 89.65 | 118.3 | 72.36 | 69.92 | 69.94 | 71.88 | 50.08 | 71.88 |
| Radial depth of conductor | cm |  | 4.760 | 4.903 | 5.943 | 6.435 | 6.861 | 75.83 | 64.34 | 75.83 | 55.63 | 4.155 | 52.02 | 14.55 | 2.456 | 16.45 | 18.12 | 2.334 | 18.12 |
| Outer radius | cm |  | 23.10 | 28.76 | 35.52 | 42.64 | 50.16 | 195.8 | 184.3 | 195.8 | 175.6 | 93.81 | 170.3 | 86.91 | 72.38 | 86.39 | 90.00 | 52.42 | 90.00 |
| Volume, inc. SSt shell | m3 | 39.93 | 0.066 | 0.108 | 0.260 | 0.347 | 0.444 | 26.51 | 4.79 | 3.40 | 1.61 | 0.61 | 0.73 | 0.09 | 0.37 | 0.09 | 0.13 | 0.24 | 0.13 |
| Maximum on-axis field | T |  | 20.22 | 19.01 | 17.89 | 16.88 | 15.97 | 15.13 | 13.54 | 8.29 | 4.77 | 3.58 | 2.17 | 1.90 | 1.77 | 1.53 |  |  |  |
| SC , MPa & fr. | 6.00 | none | 0 |  |  |  |  |  | 0.093 | 0.070 | 0.029 | 0.018 | 0.017 | 0.011 | 0.011 | 0.011 | 0.010 | 0.010 | 0.010 | 0.010 |
| Cu , MPa & fr. | 8.95 | 100 | 0 | 0.550 | 0.550 | 0.550 | 0.550 | 0.550 | 0.154 | 0.174 | 0.214 | 0.268 | 0.330 | 0.326 | 0.360 | 0.373 | 0.372 | 0.372 | 0.372 | 0.372 |
| SSt , MPa & fr. | 7.80 | 700 | 700 | 0.051 | 0.062 | 0.030 | 0.024 | 0.021 | 0.521 | 0.495 | 0.436 | 0.313 | 0.159 | 0.174 | 0.088 | 0.056 | 0.061 | 0.061 | 0.061 | 0.061 |
| SSt cm & SC M$ | 30M | $87.5 | 0.000 | 0.256 | 0.326 | 0.183 | 0.160 | 0.145 | $74.2 | $10.0 | $2.96 | $.176 | $.062 | $.049 | $.006 | $.025 | $.005 | $.008 | $.014 | $.008 |
| Coil tons | $/m3 | 6.50 | 224.4 | 0.356 | 0.583 | 1.382 | 1.835 | 2.344 | 159.0 | 27.92 | 18.07 | 7.80 | 2.56 | 3.12 | 0.37 | 1.41 | 0.34 | 0.49 | 0.92 | 0.49 |
| M$@$400/kg | 0.40 | $2.60 | $89.8 | 4 | 4 | 4 | 4 | 4 | paths/layer |  |  |  |  |  |  |  |  |  |  |
| Magnet MW or MA-m | *11.26* | 86.49 | 1.53 | 2.28 | 2.58 | 2.46 | 2.41 | 51.19 | 10.41 | 9.09 | 5.40 | 2.52 | 2.97 | 0.43 | 1.75 | 0.41 | 0.60 | 1.12 | 0.60 |

 Coil dimensions are in rows 3 through 11. Anticipated for the complete magnet, but not tabulated above, are an additional seven sets of three solenoids each that repeat solenoids SC #10, SC #11 and SC #12 at multiples of 5 m, to a distance z = 50 m. The cost estimates in the columns with first-row entries “kA” and “0.1” include solenoids to z = 20 m.

 The cost of each solenoid is based on its mass of superconductor (if any), copper, stainless steel and insulation. The assumed unit cost of fabricated Nb3Sn (SC #1-#3) is 30 M$/m3; that of NbTi (SC #4 and up) is $6 M$/m3. The assumed cost of copper, stainless steel and insulation is $400/kg. Costs of cryostats, shielding vessels, shielding and other components have yet to be estimated.

 The estimated cost of the resistive magnet is 6.50 metric tonnes x $400/kg = $2.60 M. The cost of SC#1 is the sum of two components: superconducting and non-superconducting. The non-superconducting cost is 159.0 tonnes x $400/kg = 63.6 M$. The cost attributed to the superconductor is 26.51 m3 x 0.093 x 30 M$/m3 = 74.2 M$, for a total of $137.8. M$.

 The non-superconducting unit cost of $400/kg compares to the $250/kg reported for resistive magnets at the National High Magnetic Field Laboratory (NHMFL) at Tallahassee, Florida. The superconducting unit cost of 30 M$/m3 approximately doubles the non-superconducting unit cost a superconducting magnet. The average unit cost for all the superconducting magnets is (87.5 M$ + 89.8 M$ =177.3 M$) / 224.4 tonnes = $790/kg. This compares with the$400-$500/kg reported for superconducting and hybrid magnets at the NHMFL.