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

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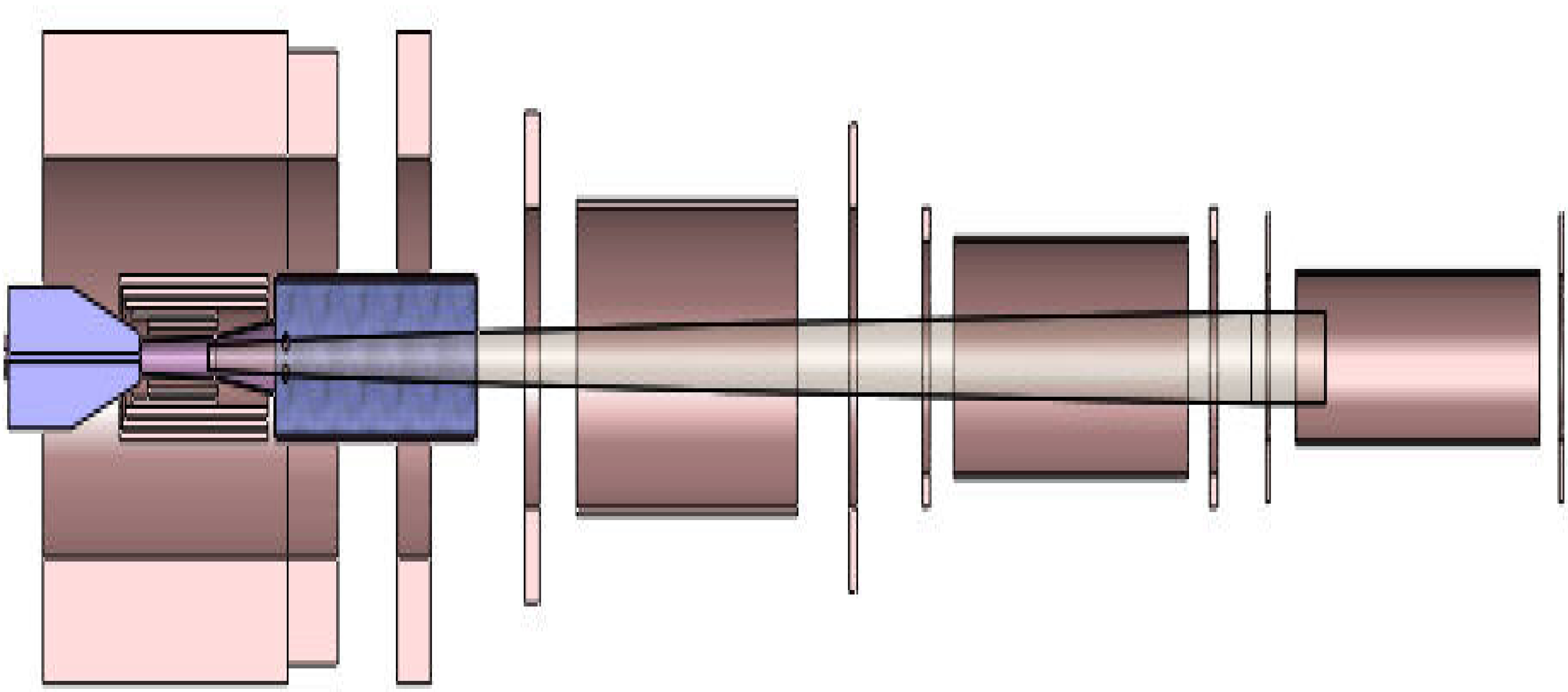

Target Magnet IDS120j: three solenoids per cryostat; large axial gaps at z = 4, 10, 15 & 20 m [drawing courtesy Van Graves]. Target Magnet IDS120k is very similar, but the outboard solenoids in all cryostats except the first are of optimized (larger) inner radius, to improve field profile. U = 3.34 GJ.

Selected Parameters of Target Magnet IDS120k

	12.47	kA	0.1	meters ΔL_{elec}		1.724	$\mu\Omega$cm at 20 °C		7.0	nΩcm/deg		10.0	°C T_0	40.0	atmospheres ΔP		0.10m	ΔL_{hy}		
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 $j\lambda_{coil}$		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 γ, 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 γ, 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 γ, 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 Nb_3Sn (SC #1-#3) is 30 M$/m^3; that of NbTi (SC #4 and up) is $6 M$/m^3. 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 m^3 x 0.093 x 30 M$/m^3 = 74.2 M$, for a total of $137.8. M$.

The non-superconducting unit cost of $400/kg compares to the $250/kg reported for resistive magnets at the National High Magnetic Field Laboratory (NHMFL) at Tallahassee, Florida. The superconducting unit cost of 30 M$/m^3 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.