5. COLLIDER COMPONENTS

In Chapter 4 we presented the physics design of PEP-II. The parameters we have adopted to achieve a luminosity of 3×10^{33} cm^{-2} s^{-1}, and the beam separation scheme we have arrived at (driven mainly by background considerations), impose many requirements on the various technical components of the project. In this chapter, we describe these technical components, paying particular attention to those aspects that are most crucial to reaching the high luminosity we have specified. In general, the challenges to be met are associated with the high beam currents that must be stored in the two rings, 0.99 A in the high-energy ring (HER) and 2.14 A in the low-energy ring (LER). In all cases, we have designed the hardware to have adequate operating margin to ensure reliability, and we have employed proven design concepts wherever possible.

In Section 5.1 we describe the magnets and supports. In the case of the HER, nearly all of these magnets are existing PEP magnets, but we describe them briefly for completeness. Though the LER magnets will be newly constructed, they are based (with the exception of the dipoles) on proven PEP designs and are therefore straightforward to design and build. Magnets in the interaction region (IR), however, are technically quite challenging and are the key to the successful implementation of the beam separation scheme; these are described in Section 5.1.3.

The vacuum systems for the two rings are described in Section 5.2. The design challenges here are to provide a low background gas pressure in the face of copious synchrotron-radiation-induced photodesorption and to manage the high thermal loads associated with many megawatts of synchrotron radiation power. We have adopted a copper chamber for our design, based on its desirable properties in both these regards. In this section, we also describe the design and cooling for the various IR hardware components, such as the synchrotron radiation masks, the beam dumps, and the vertex detector beam pipe.

The other technically challenging aspects of the PEP-II design include the RF cavities (Section 5.5) and the feedback system (Section 5.6). The RF cavities must be designed to dissipate approximately 150 kW of power and to permit the effective damping of dangerous higher-order modes (HOMs) to Q values of about 70. This damping is accomplished with an innovative design in which three waveguides are attached to the body of the room-temperature cavity to remove the HOM power. The feedback system utilizes a bunch-by-bunch approach that is designed to handle the full bunch repetition rate of 238 MHz; the system employs a novel digital processing scheme that is very flexible and can accommodate both injection and colliding-beam conditions. Detailed simulations of system performance and tests of a portion of the system at SPEAR have demonstrated the efficacy of the design.

The remaining design aspects covered in Chapter 5—survey and alignment (Section 5.3), power supplies (Section 5.4), instrumentation and electronics (Section 5.7), and control system (Section 5.8) are relatively straightforward. Here too we have paid attention to providing flexibility and reliability in all components to ensure that PEP-II will indeed function as a "factory."

5.1 MAGNETS AND SUPPORTS

The magnet system in PEP-II provides the guide fields that bend and focus the charged particles, electrons in the HER and positrons in the LER. In the case of the HER, the lattice is designed to make use of most of the existing PEP magnets. The LER is an entirely new ring for which all magnets must be newly constructed.

Because PEP was designed to operate at 18 GeV, whereas the PEP-II HER has a nominal energy of 9 GeV, the PEP magnets are very conservatively designed for their new function. As discussed in Section 7.2, it is prudent to inspect the magnets when they are removed from the tunnel; as needed, the magnet coils will be refurbished to ensure their reliability for long-term PEP-II service. In addition, some of the magnets will be measured after reassembly to ensure that their fields remain the same.

We plan to reuse all of the PEP dipoles and quadrupoles for the PEP-II HER. Because the HER lattice uses more quadrupoles than did PEP, additional magnets must be fabricated. In the case of the dipoles, we need 192 regular bending magnets and an additional 16 PEP low-field bending magnets, for a total of 208 PEP dipoles; four short LER-style dipoles will also be used, making a grand total of 212 dipoles for the HER. All 144 sextupoles are available from PEP. For completeness, however, we describe the existing PEP magnets briefly in Section 5.1.1.

The quadrupole and sextupole magnets for the LER are designed to have the same aperture as the present PEP magnets. This is justified because the required beam-stay-clear aperture in the LER is almost identical to that of the HER, as discussed in Section 5.2.2. Basing the LER designs on PEP magnets minimizes the engineering and design efforts required, because the already-optimized pole profiles of the PEP magnets can be used without modification. The LER dipoles are much shorter than the PEP dipoles (0.45 m compared with 5.4 m for PEP) and will not be based on that pole profile. Design details for the LER magnets are presented in Section 5.1.2.

5.1.1 HER Magnets

As mentioned above, most of the magnets for the HER are existing PEP magnets. The only exception is the quadrupoles. Additional quadrupoles are needed for the HER because the FODO focusing structure (see Section 4.1) will be maintained throughout the straight sections, except for the IR-2 straight that houses the detector.

5.1.1.1 Dipoles. The main parameters of the laminated PEP dipoles are summarized in Table 5-1 for conditions corresponding to the nominal PEP-II operating energy of 9 GeV. Physical dimensions of the magnet are shown in Fig. 5-1. Each magnet has a magnetic length of 5.4 m (212.607 in.) and weighs 7.4 tons. The coils, located above and below the midplane, are constructed of water-cooled aluminum, insulated with Mylar and fiberglass tape and vacuum potted in a radiation-hardened alumina-based epoxy. All dipoles will be disassembled and will have their coil insulation inspected and refurbished to ensure reliable service in PEP-II. After reassembly, a sample of magnets will be remeasured to ensure the constancy of their magnetic properties. To provide horizontal orbit correction, backleg windings are employed. Windings from a pair of dipoles on either side of a focusing quadrupole will be ganged together to form a single corrector.

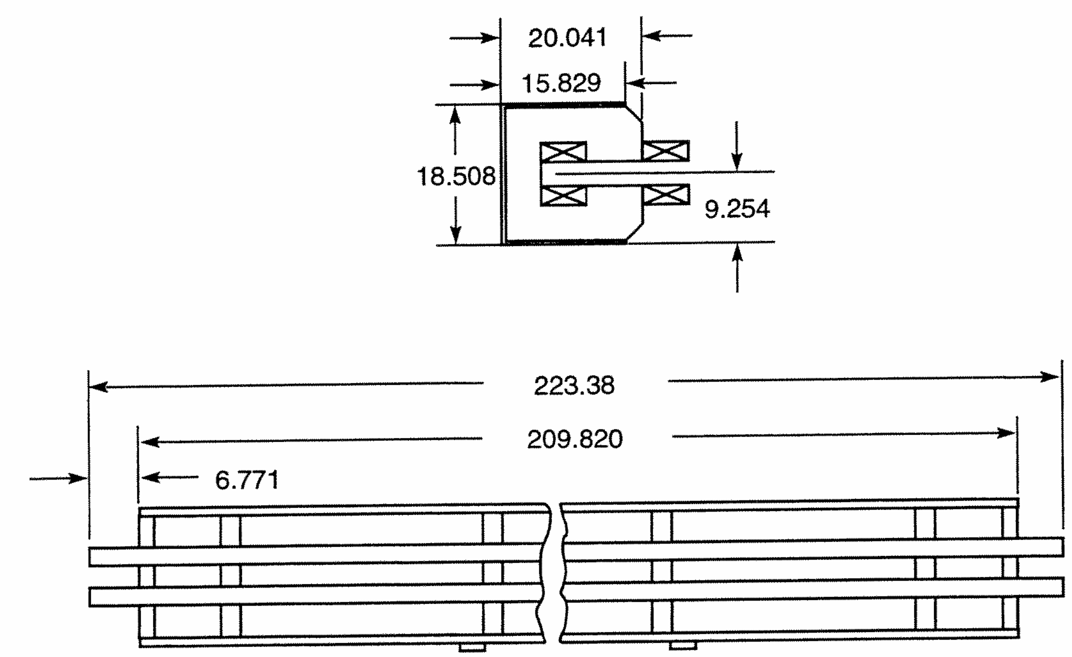

Fig. 5-1. End and side views of the HER bending magnet. Dimensions are given in inches.

Table 5-1. HER dipole parameters.

Magnet designation	2.8C212	2.8H17	5.8H85	5.8H80
Lattice designation	B	B4	B3	B2
Number of magnets	192	4	8	8
Field @ 9 GeV [T]	0.1819	0.0904	0.0216	0.0216
Integrated field @ 9 GeV [T·m]	0.9824	0.0407	0.0466	0.0431
Pole width [in.]	8.425	7.5	5.9	5.9
Gap height [in.]	2.787	2.787	5.875	5.875
Core length [in.]	209.820	14.930	79.085	72.685
Magnetic length [in.]	212.607	17.717	84.960	78.560
Width of useful field, 0.1% [in.]	4.725	4.00	3.15	3.15
Lamination height [in.]	15.433	16	13.38	13.38
Lamination width [in.]	18.19	17.8	10.47	10.47
Packing factor, minimum [%]	98	98	NA	NA
Core weight [lb]	14,168	2,000	1,500	1,500
Amp·turns @ 9 GeV	5,121	2,544	1,280	1,280
Turns	8	36	2	2
Pancakes per pole	1	1	1	1
Conductor dimensions [in.]	2.4 × 0.7	2.0 × 0.3125	2.4 × 0.7	2.4 × 0.7
Cooling hole diameter [in.]	0.25	0.1875	0.25	0.25
Conductor cross section [in.^{2}]	1.63	0.60	1.63	1.63
Current @ 9 GeV [A]	640.1	70.7	640.1	640.1
Resistance @ 40°C [mΩ]	5.1	7.2	0.4	0.4
Power @ 9 GeV [kW]	2.08	0.04	0.15	0.15
Voltage drop @ 9 GeV [V]	3.6	0.5	0.2	0.2
Coil weight [lb]	585	200	40	40
Number of water circuits	1	1	1	11
Water flow rate [gpm]	0.8	0.3	1.4	1.4
Water pressure drop [psi]	150	100	50	50
Temperature rise [°C]	5.3	0.4	0.4	0.4
Total power, magnets and bus [kW]	399.4	0.1	1.2	1.2
Total voltage, magnets and bus [V]	691.2	2.0	1.9	1.9
Total system water requirements [gpm]	144.4	1.4	11.0	11.4

5.1.1.2 Quadrupoles. As with the dipole magnets, all existing PEP quadrupoles will be reused for the HER. Altogether, 270 magnets are required for the PEP-II HER, of which 200 are available from PEP. The additional magnets will be fabricated using the same pole-tip profile developed for PEP, thus avoiding the need to develop a new design. Dimensions of a typical quadrupole magnet are shown in Fig. 5-2. The electrical characteristics of the existing quadrupoles, together with the new magnets, are summarized in Table 5-2. As is the case for the dipoles, the conductor for the quadrupoles is an aluminum extrusion. The insulating procedure used for the dipoles, employing Mylar, fiberglass tape, and alumina-loaded epoxy, will also be used for the quadrupole magnets.

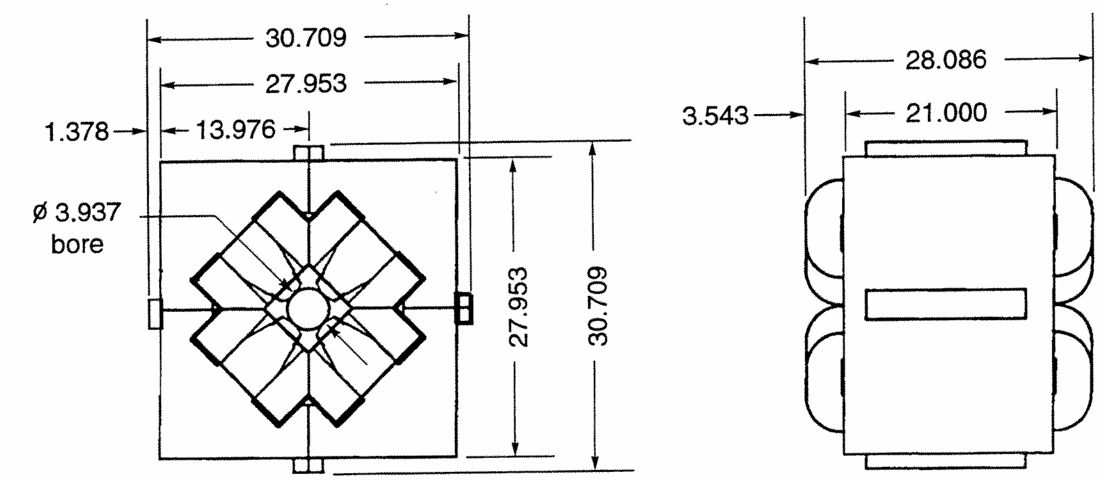

Fig. 5-2. End and side views of an HER quadrupole magnet. Dimensions are given in inches.

Table 5-2. HER quadrupole parameters. The column heads indicate whether the magnets are refurbished PEP quadrupoles or newly constructed magnets.

	PEP	PEP	PEP	New	PEP	PEP
Magnet designation	4Q22	4Q40	4Q40	4Q18	4Q40	4Q40
Lattice designation	QD	QD6	QDI	QDO	QDOI	QDP1
Number of magnets	54	2	2	14	2	2
Operating gradient [T/m]	7.33	7.89	1.95	8.83	2.98	4.06
Pole-tip field @ operating gradient [T]	0.366	0.394	0.097	0.441	0.149	0.203
Gradient-length product [T]	4.03	7.89	1.95	3.97	2.98	4.06
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	19.69	37.40	37.40	15.75	37.40	37.40
Magnetic length [in.]	21.65	39.37	39.37	17.72	39.37	39.37
Lamination height [in.]	13.98	13.98	13.98	13.98	13.98	13.98
Lamination width [in.]	13.35	13.35	13.35	13.35	13.35	13.35
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	2898	5506	5506	2318	5506	5506
Amp-turns per pole @ 9 GeV	7280	7837	1935	8770	2965	4032
Turns per pole	57	57	57	57	57	57
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.197	0.197	0.197	0.197	0.197	0.197
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Current @ 9 GeV [A]	128	137	34	154	52	71
Resistance @ 40°C [mΩ]	82	127	127	72	127	127
Power @ 9 GeV [kW]	1.3	2.4	0.2	1.7	0.3	0.6
Voltage drop @ 9 GeV [V]	10.5	17.5	4.3	11.1	6.6	9.0
Coil weight [lb]	282	438	438	248	438	438
Number of water circuits	1	2	1	1	1	1
Water flow rate [gpm]	0.5	1.2	0.4	0.6	0.4	0.4
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	9.8	7.7	1.4	11.7	3.2	5.9
Total power (magnets and bus) [kW]	72.4	4.8	0.3	23.9	0.7	1.3
Total voltage [V]	567	35	9	156	13	18
Magnet system water requirements [gpm]	28	2	1	8	1	1

Table 5-2. HER quadrupole parameters. The column heads indicate whether the magnets are refurbished PEP quadrupoles or newly constructed magnets (continued).

	PEP	New	PEP	New	PEP	New
Magnet designation	4Q40	4Q18	4Q40	4Q18	4Q40	4Q18
Lattice designation	QDP3	QDP3	QDP5	QDP5	QDP7	QDP7
Number of magnets	2	2	2	2	2	2
Operating gradient [T/m]	4.02	8.94	4.00	8.89	3.99	8.88
Pole-tip field @ operating gradient [T]	0.201	0.447	0.200	0.444	0.199	0.444
Gradient-length product [T]	4.02	4.02	4.00	4.00	3.99	3.99
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	37.40	15.75	37.40	15.75	37.40	15.75
Magnetic length [in.]	39.37	17.72	39.37	17.72	39.37	17.72
Lamination height [in.]	13.98	13.98	13.98	13.98	13.98	13.98
Lamination width [in.]	13.35	13.35	13.35	13.35	13.35	13.35
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	5506	2318	5506	2318	5506	2318
Amp-turns per pole @ 9 GeV	3999	8887	3974	8832	3964	8819
Turns per pole	57	57	57	57	57	57
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.197	0.197	0.197	0.197	0.197	0.197
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Current @ 9 GeV [A]	70	156	70	155	70	155
Resistance @ 40°C [mΩ]	127	72	127	72	127	72
Power @ 9 GeV [kW]	0.6	1.8	0.6	1.7	0.6	1.7
Voltage drop @ 9 GeV [V]	8.9	11.3	8.9	11.2	8.9	11.2
Coil weight [lb]	438	248	438	248	438	248
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.4	0.6	0.4	0.6	0.4	0.6
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	5.8	12.0	5.7	11.8	5.7	11.8
Total power (magnets and bus) [kW]	1.3	3.5	1.2	3.5	1.2	3.5
Total voltage [V]	18	23	18	22	18	22
Magnet system water requirements [gpm]	1	1	1	1	1	1

Table 5-2. HER quadrupole parameters. The column heads indicate whether the magnets are refurbished PEP quadrupoles or newly constructed magnets (continued).

	PEP	PEP	PEP	PEP	New	New
Magnet designation	4Q29	4Q29	4Q29	4Q29	4Q18	4Q18
Lattice designation	QDSO1	QDSO1E	QDSO2	QDSO2E	QDSOL	QDSOR
Number of magnets	1	4	1	4	1	1
Operating gradient [T/m]	5.33	5.62	5.35	5.66	8.61	8.61
Pole-tip field @ operating gradient [T]	0.266	0.281	0.267	0.283	0.430	0.430
Gradient-length product [T]	3.89	4.10	3.91	4.13	3.87	3.87
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	26.77	26.77	26.77	26.77	15.75	15.75
Magnetic length [in.]	28.74	28.74	28.74	28.74	17.72	17.72
Lamination height [in.]	13.98	13.98	13.98	13.98	13.98	13.98
Lamination width [in.]	13.35	13.35	13.35	13.35	13.35	13.35
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	3941	3941	3941	3941	2318	2318
Amp-turns per pole @ 9 GeV	5297	5585	5317	5623	8550	8550
Turns per pole	57	57	57	57	57	57
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.197	0.197	0.197	0.197	0.197	0.197
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Current @ 9 GeV [A]	93	98	93	99	150	150
Resistance @ 40°C [mΩ]	100	100	100	100	72	72
Power @ 9 GeV [kW]	0.9	1.0	0.9	1.0	1.6	1.6
Voltage drop @ 9 GeV [V]	9.3	9.8	9.4	9.9	10.8	10.8
Coil weight [lb]	345	345	345	345	248	248
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.5	0.5	0.5	0.5	0.6	0.6
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	7.1	7.8	7.1	7.9	11.1	11.1
Total power (magnets and bus) [kW]	9	39	9	40	1.6	1.6
Total voltage [V]	1	39	9	40	11	11
Magnet system water requirements [gpm]	0	2	0	2	1	1

Table 5-2. HER quadrupole parameters. The column heads indicate whether the magnets are refurbished PEP quadrupoles or newly constructed magnets (continued).

	New	New	New	New	PEP	PEP
Magnet designation	4Q18	4Q18	4Q18	4Q18	4Q22	4Q22
Lattice designation	QDS11	QDS11E	QDS12	QDS12E	QDS1L	QDS1R
Number of magnets	1	4	1	4	1	1
Operating gradient [T/m]	8.61	9.37	9.79	9.41	7.98	8.01
Pole-tip field @ operating gradient [T]	0.430	0.468	0.489	0.470	0.399	0.400
Gradient-length product [T]	3.87	4.22	4.41	4.24	4.39	4.41
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.75	15.75	15.75	15.75	19.69	19.69
Magnetic length [in.]	17.72	17.72	17.72	17.72	21.65	21.65
Lamination height [in.]	13.98	13.98	13.98	13.98	13.98	13.98
Lamination width [in.]	13.35	13.35	13.35	13.35	13.35	13.35
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	2318	2318	2318	2318	2898	2898
Amp-turns per pole @ 9 GeV	8550	9309	9728	9352	7925	7960
Turns per pole	57	57	57	57	57	57
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.197	0.197	0.197	0.197	0.197	0.197
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Current @ 9 GeV [A]	150	163	171	164	139	140
Resistance @ 40°C [mΩ]	72	72	72	72	82	82
Power @ 9 GeV [kW]	1.6	1.9	2.1	1.9	1.6	1.6
Voltage drop @ 9 GeV [V]	10.8	11.8	12.3	11.9	11.4	11.5
Coil weight [lb]	248	248	248	248	282	282
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.6	0.6	0.6	0.6	0.5	0.5
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	11.1	13.1	14.3	13.2	11.6	11.7
Total power (magnets and bus) [kW]	1.6	7.7	2.1	7.8	1.6	1.6
Total voltage [V]	11	47	12	47	11	11
Magnet system water requirements [gpm]	1	2	1	2	1	1

Table 5-2. HER quadrupole parameters. The column heads indicate whether the magnets are refurbished PEP quadrupoles or newly constructed magnets (continued).

	PEP	PEP	PEP	PEP	New	New
Magnet designation	4Q22	4Q22	4Q22	4Q22	4Q18	4Q18
Lattice designation	QDS21	QDS21E	QDS22	QDS22E	QDS2L	QDS2R
Number of magnets	1	4	1	4	1	1
Operating gradient [T/m]	7.19	7.72	7.17	7.71	8.68	8.76
Pole-tip field @ operating gradient [T]	0.359	0.386	0.358	0.385	0.434	0.438
Gradient-length product [T]	3.95	4.25	3.94	4.24	3.90	3.94
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	19.69	19.69	19.69	19.69	15.75	15.75
Magnetic length [in.]	21.65	21.65	21.65	21.65	17.72	17.72
Lamination height [in.]	13.98	13.98	13.98	13.98	13.98	13.98
Lamination width [in.]	13.35	13.35	13.35	13.35	13.35	13.35
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	2898	2898	2898	2898	2318	2318
Amp-turns per pole @ 9 GeV	7140	7672	7119	7656	8621	8701
Turns per pole	57	57	57	57	57	57
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.197	0.197	0.197	0.197	0.197	0.197
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Current @ 9 GeV [A]	125	135	125	134	151	153
Resistance @ 40°C [mΩ]	82	82	82	82	72	72
Power @ 9 GeV [kW]	1.3	1.5	1.3	1.5	1.7	1.7
Voltage drop @ 9 GeV [V]	10.3	11.1	10.3	11.1	10.9	11.0
Coil weight [lb]	282	282	282	282	248	248
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.5	0.5	0.5	0.5	0.6	0.6
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	9.4	10.9	9.4	10.9	11.3	11.5
Total power (magnets and bus) [kW]	1.3	6.0	1.3	5.9	1.7	1.7
Total voltage [V]	10	44	10	44	11	11
Magnet system water requirements [gpm]	1	2	1	2	1	1

Table 5-2. HER quadrupole parameters. The column heads indicate whether the magnets are refurbished PEP quadrupoles or newly constructed magnets (continued).

	PEP	PEP	PEP	PEP	PEP	PEP
Magnet designation	4Q22	4Q22	4Q22	4Q22	4Q22	4Q22
Lattice designation	QDS31	QDS31E	QDS32	QDS32E	QDS3L	QDS3R
Number of magnets	1	4	1	4	1	1
Operating gradient [T/m]	7.33	7.33	7.33	7.33	7.33	7.33
Pole-tip field @ operating gradient [T]	0.366	0.366	0.366	0.366	0.366	0.366
Gradient-length product [T]	4.03	4.03	4.03	4.03	4.03	4.03
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	19.69	19.69	19.69	19.69	19.69	19.69
Magnetic length [in.]	21.65	21.65	21.65	21.65	21.65	21.65
Lamination height [in.]	13.98	13.98	13.98	13.98	13.98	13.98
Lamination width [in.]	13.35	13.35	13.35	13.35	13.35	13.35
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	2898	2898	2898	2898	2898	2898
Amp-turns per pole @ 9 GeV	7280	7280	7280	7280	7280	7280
Turns per pole	57	57	57	57	57	57
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.197	0.197	0.197	0.197	0.197	0.197
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Current @ 9 GeV [A]	128	128	128	128	128	128
Resistance @ 40°C [mΩ]	82	82	82	82	82	82
Power @ 9 GeV [kW]	1.3	1.3	1.3	1.3	1.3	1.3
Voltage drop @ 9 GeV [V]	10.5	10.5	10.5	10.5	10.5	10.5
Coil weight [lb]	282	282	282	282	282	282
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.5	0.5	0.5	0.5	0.5	0.5
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	9.8	9.8	9.8	9.8	9.8	9.8
Total power (magnets and bus) [kW]	1.3	5.4	1.3	5.4	1.3	1.3
Total voltage [V]	11	42	11	42	11	11
Magnet system water requirements [gpm]	1	2	1	2	1	1

Table 5-2. HER quadrupole parameters. The column heads indicate whether the magnets are refurbished PEP quadrupoles or newly constructed magnets (continued).

	PEP	PEP	PEP	New	PEP
Magnet designation	4Q29	4Q40	4Q40	4Q18	4Q40
Lattice designation	QF	QF7	QFI	QFO	QFOI
Number of magnets	60	2	2	16	2
Operating gradient [T/m]	5.48	5.96	1.92	8.83	4.08
Pole-tip field @ operating gradient [T]	0.274	0.298	0.096	0.441	0.204
Gradient-length product [T]	4.00	5.96	1.92	3.97	4.08
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457
Core length [in.]	26.77	37.40	37.40	15.75	37.40
Magnetic length [in.]	28.74	39.37	39.37	17.72	39.37
Lamination height [in.]	13.98	13.98	13.98	13.98	13.98
Lamination width [in.]	13.35	13.35	13.35	13.35	13.35
Packing factor, minimum [%]	98	98	98	98	98
Core weight [lb]	3941	5506	5506	2318	5506
Amp-turns per pole @ 9 GeV	5450	5923	1905	8770	4054
Turns per pole	57	57	57	57	57
Pancakes per pole	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.197	0.197	0.197	0.197	0.197
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25
Current @ 9 GeV [A]	96	104	33	154	71
Resistance @ 40°C [mΩ]	100	127	127	72	127
Power @ 9 GeV [kW]	0.9	1.4	0.1	1.7	0.6
Voltage drop @ 9 GeV [V]	9.6	13.2	4.3	11.1	9.1
Coil weight [lb]	345	438	438	248	438
Number of water circuits	1	1	1	1	1
Water flow rate [gpm]	0.5	0.4	0.4	0.6	0.4
Water pressure drop [psi]	150	150	150	150	150
Temperature rise [°C]	7.5	12.7	1.3	11.7	6.0
Total power (magnets and bus) [kW]	55.0	2.8	0.3	27.3	1.3
Total voltage [V]	575	26	9	178	18
Magnet system water requirements [gpm]	28	1	1	9	1

Table 5-2. HER quadrupole parameters. The column heads indicate whether the magnets are refurbished PEP quadrupoles or newly constructed magnets (continued).

	PEP	New	PEP	New	PEP	PEP
Magnet designation	4Q40	4Q18	4Q22	4Q18	4Q22	4Q22
Lattice designation	QFP2	QFP4	QFP6	QFP8	QFS11	QFS11E
Number of magnets	4	4	4	4	1	4
Operating gradient [T/m]	4.29	9.46	7.61	9.22	9.48	8.06
Pole-tip field @ operating gradient [T]	0.214	0.473	0.380	0.461	0.474	0.403
Gradient-length product [T]	4.29	4.26	4.19	4.15	5.22	4.43
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	37.40	15.75	19.69	15.75	19.69	19.69
Magnetic length [in.]	39.37	17.72	21.65	17.72	21.65	21.65
Lamination height [in.]	13.98	13.98	13.98	13.98	13.98	13.98
Lamination width [in.]	13.35	13.35	13.35	13.35	13.35	13.35
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	5506	2318	2898	2318	2898	2898
Amp-turns per pole @ 9 GeV	4259	9403	7561	9163	9423	8005
Turns per pole	57	57	57	57	57	57
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.197	0.197	0.197	0.197	0.197	0.197
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Current @ 9 GeV [A]	75	165	133	161	165	140
Resistance @ 40°C [mΩ]	127	72	82	72	82	82
Power @ 9 GeV [kW]	0.7	2.0	1.5	1.9	2.3	1.6
Voltage drop @ 9 GeV [V]	9.5	11.9	10.9	11.6	13.6	11.6
Coil weight [lb]	438	248	282	248	282	282
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.4	0.6	0.5	0.6	0.5	0.5
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	6.6	13.4	10.6	12.7	16.4	11.9
Total power (magnets and bus) [kW]	2.8	7.9	5.8	7.5	2.2	6.5
Total voltage [V]	38	48	44	46	14	46
Magnet system water requirements [gpm]	2	2	2	2	1	2

Table 5-2. HER quadrupole parameters. The column heads indicate whether the magnets are refurbished PEP quadrupoles or newly constructed magnets (continued).

	PEP	PEP	PEP	PEP	New	New
Magnet designation	4Q22	4Q22	4Q22	4Q22	4Q18	4Q18
Lattice designation	QFS12	QFS12E	QFS1L	QFS1R	QFS21	QFS21E
Number of magnets	1	4	1	1	1	4
Operating gradient [T/m]	9.48	8.08	9.76	9.80	11.77	10.55
Pole-tip field @ operating gradient [T]	0.474	0.404	0.488	0.490	0.588	0.527
Gradient-length product [T]	5.22	4.44	5.37	5.39	5.30	4.75
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	19.69	19.69	19.69	19.69	15.75	15.75
Magnetic length [in.]	21.65	21.65	21.65	21.65	17.72	17.72
Lamination height [in.]	13.98	13.98	13.98	13.98	13.98	13.98
Lamination width [in.]	13.35	13.35	13.35	13.35	13.35	13.35
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	2898	2898	2898	2898	2318	2318
Amp-turns per pole @ 9 GeV	9423	8025	9696	9742	11695	10479
Turns per pole	57	57	57	57	57	57
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.197	0.197	0.197	0.197	0.197	0.197
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Current @ 9 GeV [A]	165	141	170	171	205	184
Resistance @ 40°C [mΩ]	82	82	82	82	72	72
Power @ 9 GeV [kW]	2.3	1.6	2.4	2.4	3.0	2.4
Voltage drop @ 9 GeV [V]	13.6	11.6	14.0	14.1	14.8	13.3
Coil weight [lb]	282	282	282	282	248	248
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.5	0.5	0.5	0.5	0.6	0.6
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	16.4	11.9	17.4	17.6	20.7	16.6
Total power (magnets and bus) [kW]	2.2	6.5	2.4	2.4	3.0	9.8
Total voltage [V]	14	46	14	14	15	53
Magnet system water requirements [gpm]	1	2	1	1	1	2

Table 5-2. HER quadrupole parameters. The column heads indicate whether the magnets are refurbished PEP quadrupoles or newly constructed magnets (continued).

	NEW	NEW	NEW	NEW	PEP	PEP
Magnet designation	4Q18	4Q18	4Q18	4Q18	4Q29	4Q29
Lattice designation	QFS22	QFS22E	QFS2L	QFS2R	QFS31	QFS31E
Number of magnets	1	4	1	1	1	4
Operating gradient [T/m]	11.75	10.53	11.68	11.74	5.61	6.16
Pole-tip field @ operating gradient [T]	0.588	0.526	0.584	0.587	0.280	0.308
Gradient-length product [T]	5.29	4.74	5.26	5.28	4.10	4.49
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.75	15.75	15.75	15.75	26.77	26.77
Magnetic length [in.]	17.72	17.72	17.72	17.72	28.74	28.74
Lamination height [in.]	13.98	13.98	13.98	13.98	13.98	13.98
Lamination width [in.]	13.35	13.35	13.35	13.35	13.35	13.35
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	2318	2318	2318	2318	3941	3941
Amp-turns per pole @ 9 GeV	11678	10465	11605	11666	5575	6117
Turns per pole	57	57	57	57	57	57
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.197	0.197	0.197	0.197	0.197	0.197
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Current @ 9 GeV [A]	205	184	204	205	98	107
Resistance @ 40°C [mΩ]	72	72	72	72	100	100
Power @ 9 GeV [kW]	3.0	2.4	3.0	3.0	1.0	1.2
Voltage drop @ 9 GeV [V]	14.8	13.3	14.7	14.8	9.8	10.8
Coil weight [lb]	248	248	248	248	345	345
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.6	0.6	0.6	0.6	0.5	0.5
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	20.7	16.6	20.4	20.6	7.8	9.4
Total power (magnets and bus) [kW]	3.0	9.7	3.0	3.0	1.0	4.6
Total voltage [V]	15	53	15	15	10	43
Magnet system water requirements [gpm]	1	2	1	1	0	2

Table 5-2. HER quadrupole parameters. The column heads indicate whether the magnets are refurbished PEP quadrupoles or newly constructed magnets (continued).

	PEP	PEP	PEP	PEP	NEW	NEW
Magnet designation	4Q29	4Q29	4Q29	4Q29	4Q60	4Q60
Lattice designation	QFS32	QFS32E	QFS3L	QFS3R	QD4	QF5
Number of magnets	1	4	1	1	2	2
Operating gradient [T/m]	5.62	6.16	5.61	5.62	7.37	6.00
Pole-tip field @ operating gradient [T]	0.281	0.308	0.281	0.281	0.369	0.300
Gradient-length product [T]	4.10	4.50	4.10	4.10	11.556	9.403
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	26.77	26.77	26.77	26.77	60.72	60.72
Magnetic length [in.]	28.74	28.74	28.74	28.74	61.70	61.70
Lamination height [in.]	13.98	13.98	13.98	13.98	10.5	10.5
Lamination width [in.]	13.35	13.35	13.35	13.35	10.5	10.5
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	3941	3941	3941	3941	5465	5465
Amp-turns per pole @ 9 GeV	5579	6123	5577	5579	7339	5961
Turns per pole	57	57	57	57	12	12
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.197	0.197	0.197	0.197	0.197	0.197
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Current @ 9 GeV [A]	98	107	98	98	611.6	497
Resistance @ 40°C [mΩ]	100	100	100	100	43.8	43.8
Power @ 9 GeV [kW]	1.0	1.2	1.0	1.0	16.4	10.8
Voltage drop @ 9 GeV [V]	9.8	10.8	9.8	9.8	26.8	21.8
Coil weight [lb]	345	345	345	345	125	125
Number of water circuits	1	1	1	1	4	4
Water flow rate [gpm]	0.5	0.5	0.5	0.5	4.8	4.8
Water pressure drop [psi]	150	150	150	150	50	50
Temperature rise [°C]	7.8	9.4	7.8	7.8	13	8.6
Total power (magnets and bus) [kW]	1.0	4.6	1.0	1.0	32.8	21.6
Total voltage [V]	10	43	10	10	54	44
Magnet system water requirements [gpm]	0	2	0	0	9.6	9.6

5.1.1.3 Sextupoles. For chromaticity correction in the PEP-II HER, 144 sextupoles are required; all are from PEP. The nominal operating point of the HER is quite similar to that of PEP, and since the sextupoles were designed for 18-GeV operation, they have ample margin for any reasonable HER operating parameters. The dimensions of the sextupole are shown in Fig. 5-3, and the electrical characteristics for the various sextupole types at the nominal HER energy are summarized in Table 5-3. Coil design and insulation are the same as for the dipoles and quadrupoles, discussed above.

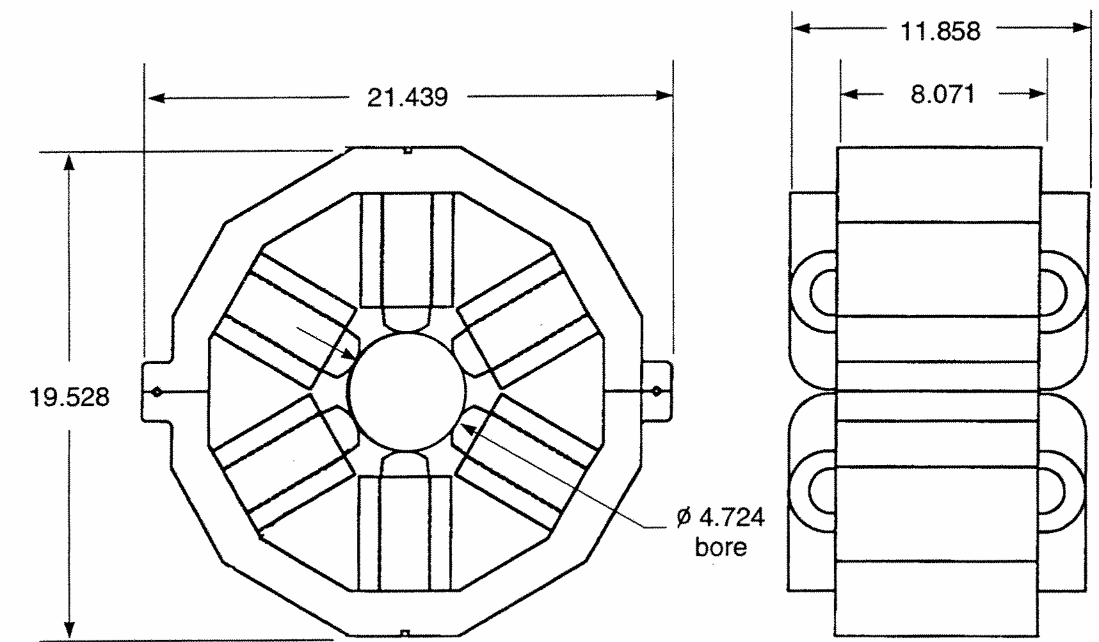

Fig. 5-3. End and side views of a PEP/HER sextupole magnet. Dimensions are given in inches.

Table 5-3. HER sextupole parameters.

Magnet designation	10 SD	10 SF	10 SD	10 SF	10 SD	10 SF
Lattice designation	SD	SF	SD6	SF6	SD5	SF5
Number of magnets	48	48	1	1	1	1
Operating gradient [T/m^2]	79.654	42.029	61.903	96.006	60.042	54.908
Pole-tip field @ operating gradient [T]	0.143	0.076	0.111	0.173	0.108	0.099
Integrated strength @ 9 GeV [T/m]	10.40	5.49	8.08	12.54	7.84	7.17
Aperture inscribed radius [in.]	2.362	2.362	2.362	2.362	2.362	2.362
Core length [in.]	8.071	8.071	8.071	8.071	8.071	8.071
Magnetic length [in.]	10.041	10.041	10.041	10.041	10.041	10.041
Core weight [lb]	170	170	170	170	170	170
Amp turns per pole	2269	1197	1763	2735	1710	1564
Turns per pole	24	24	24	24	24	24
Pancakes per pole	1	1	1	1	1	1
Square conductor dimensions [in.]	0.375	0.375	0.375	0.375	0.375	0.375
Cooling hole diameter [in.]	0.125	0.125	0.125	0.125	0.125	0.125
Conductor cross-sectional area [in.^{2}]	0.127	0.127	0.127	0.127	0.127	0.127
Current @ 9 GeV [A]	94.5	49.9	73.5	114.0	71.3	65.2
Coil length/pole [ft]	49.6	49.6	49.6	49.6	49.6	49.6
Resistance @ 40°C [mΩ]	31	31	31	31	31	31
Power @ 9 GeV [kW]	0.3	0.1	0.2	0.4	0.2	0.1
Voltage drop @ 9 GeV [V]	3.0	1.6	2.3	3.6	2.2	2.0
Coil weight [lb]	44	44	44	44	44	44
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.2	0.2	0.2	0.2	0.2	0.2
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	5.9	1.6	3.6	8.6	3.3	2.8
Total magnet power [kW]	20.1	5.6	0.3	0.8	0.3	0.3
Total voltage [V]	145.0	74.8	2.3	3.6	2.2	2.0
Total system water requirements [gpm]	13.0	13.0	0.4	0.4	0.4	0.4

Table 5-3. HER sextupole parameters (continued).

Magnet designation	10 SD	10 SF	10 SD	10 SF	10 SD	10 SF
Lattice designation	SD4	SF4	SD6	SF6	SD5	SF5
Number of magnets	1	1	1	1	1	1
Operating gradient [T/m^2]	105.073	11.618	61.903	96.006	60.042	54.908
Pole-tip field @ operating gradient [T]	0.189	0.021	0.111	0.173	0.108	0.099
Integrated strength @ 9 GeV [T/m]	13.72	1.52	8.08	12.54	7.84	7.17
Aperture inscribed radius [in.]	2.362	2.362	2.362	2.362	2.362	2.362
Core length [in.]	8.071	8.071	8.071	8.071	8.071	8.071
Magnetic length [in.]	10.041	10.041	10.041	10.041	10.041	10.041
Core weight [lb]	170	170	170	170	170	170
Amp turns per pole	2993	331	1763	2735	1710	1564
Turns per pole	24	24	24	24	24	24
Pancakes per pole	1	1	1	1	1	1
Square conductor dimensions [in.]	0.375	0.375	0.375	0.375	0.375	0.375
Cooling hole diameter [in.]	0.125	0.125	0.125	0.125	0.125	0.125
Conductor cross-sectional area [in.^{2}]	0.127	0.127	0.127	0.127	0.127	0.127
Current @ 9 GeV [A]	124.7	13.8	73.5	114.0	71.3	65.2
Coil length/pole [ft]	49.6	49.6	49.6	49.6	49.6	49.6
Resistance @ 40°C [mΩ]	31.29	31.29	31.29	31.29	31.29	31.29
Power @ 9 GeV [kW]	0.49	0.01	0.17	0.41	0.16	0.13
Voltage drop @ 9 GeV [V]	3.9	0.4	2.3	3.6	2.2	2.0
Coil weight [lb]	44	44	44	44	44	44
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.18	0.18	0.18	0.18	0.18	0.18
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	10.3	0.1	3.6	8.6	3.3	2.8
Total magnet power [kW]	1.0	0.0	0.3	0.8	0.3	0.3
Total voltage [V]	3.9	0.4	2.3	3.6	2.2	2.0
Total system water requirements [gpm]	0.4	0.4	0.4	0.4	0.4	0.4

Table 5-3. HER sextupole parameters (continued).

Magnet designation	10 SD	10 SF	10 SD	10 SF	10 SD	10 SF
Lattice designation	SD4	SF4	SD6A	SF6A	SD5A	SF5A
Number of magnets	1	1	1	1	1	1
Operating gradient [T/m^2]	105.073	11.618	150.104	75.742	60.042	107.835
Pole-tip field @ operating gradient [T]	0.189	0.021	0.270	0.136	0.108	0.194
Integrated strength @ 9 GeV [T/m]	13.72	1.52	19.60	9.89	7.84	14.08
Aperture inscribed radius [in.]	2.362	2.362	2.362	2.362	2.362	2.362
Core length [in.]	8.071	8.071	8.071	8.071	8.071	8.071
Magnetic length [in.]	10.041	10.041	10.041	10.041	10.041	10.041
Core weight [lb]	170	170	170	170	170	170
Amp turns per pole	2993	331	4276	2158	1710	3072
Turns per pole	24	24	24	24	24	24
Pancakes per pole	1	1	1	1	1	1
Square conductor dimensions [in.]	0.375	0.375	0.375	0.375	0.375	0.375
Cooling hole diameter [in.]	0.125	0.125	0.125	0.125	0.125	0.125
Conductor cross-sectional area [in.^{2}]	0.127	0.127	0.127	0.127	0.127	0.127
Current @ 9 GeV [A]	124.7	13.8	178.2	89.9	71.3	128.0
Coil length/pole [ft]	49.6	49.6	49.6	49.6	49.6	49.6
Resistance @ 40°C [mΩ]	31.29	31.29	31.29	31.29	31.29	31.29
Power @ 9 GeV [kW]	0.49	0.01	0.99	0.25	0.16	0.51
Voltage drop @ 9 GeV [V]	3.9	0.4	5.6	2.8	2.2	4.0
Coil weight [lb]	44	44	44	44	44	44
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.18	0.18	0.18	0.18	0.18	0.18
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	10.3	0.1	20.9	5.3	3.3	10.8
Total magnet power [kW]	1.0	0.0	2.0	0.5	0.3	1.0
Total voltage [V]	3.9	0.4	5.6	2.8	2.2	4.0
Total system water requirements [gpm]	0.4	0.4	0.4	0.4	0.4	0.4

Table 5-3. HER sextupole parameters (continued).

Magnet designation	10 SD	10 SF	10 SD	10 SF	10 SD	10 SF
Lattice designation	SD4A	SF4A	SD6A	SF6A	SD5A	SF5A
Number of magnets	1	1	1	1	1	1
Operating gradient [T/m^2]	150.104	13.659	150.104	75.742	60.042	107.835
Pole-tip field @ operating gradient [T]	0.270	0.025	0.270	0.136	0.108	0.194
Integrated strength @ 9 GeV [T/m]	19.60	1.78	19.60	9.89	7.84	14.08
Aperture inscribed radius [in.]	2.362	2.362	2.362	2.362	2.362	2.362
Core length [in.]	8.071	8.071	8.071	8.071	8.071	8.071
Magnetic length [in.]	10.041	10.041	10.041	10.041	10.041	10.041
Core weight [lb]	170	170	170	170	170	170
Amp turns per pole	4276	389	4276	2158	1710	3072
Turns per pole	24	24	24	24	24	24
Pancakes per pole	1	1	1	1	1	1
Square conductor dimensions [in.]	0.375	0.375	0.375	0.375	0.375	0.375
Cooling hole diameter [in.]	0.125	0.125	0.125	0.125	0.125	0.125
Conductor cross-sectional area [in.^{2}]	0.127	0.127	0.127	0.127	0.127	0.127
Current @ 9 GeV [A]	178.2	16.2	178.2	89.9	71.3	128.0
Coil length/pole [ft]	49.6	49.6	49.6	49.6	49.6	49.6
Resistance @ 40°C [mΩ]	31.29	31.29	31.29	31.29	31.29	31.29
Power @ 9 GeV [kW]	0.99	0.01	0.99	0.25	0.16	0.51
Voltage drop @ 9 GeV [V]	5.6	0.5	5.6	2.8	2.2	4.0
Coil weight [lb]	44	44	44	44	44	44
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.18	0.18	0.18	0.18	0.18	0.18
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	20.9	0.2	20.9	5.3	3.3	10.8
Total magnet power [kW]	2.0	0.0	2.0	0.5	0.3	1.0
Total voltage [V]	5.6	0.5	5.6	2.8	2.2	4.0
Total system water requirements [gpm]	0.4	0.4	0.4	0.4	0.4	0.4

Table 5-3. HER sextupole parameters (continued).

Magnet designation	10 SD	10 SF	10 SD	10 SF	10 SD	10 SF
Lattice designation	SD4A	SF4A	SD1A	SF1A	SD2A	SF2A
Number of magnets	1	1	1	1	1	1
Operating gradient [T/m^2]	150.104	13.659	130.921	17.952	150.104	86.190
Pole-tip field @ operating gradient [T]	0.270	0.025	0.236	0.032	0.270	0.155
Integrated strength @ 9 GeV [T/m]	19.60	1.78	17.10	2.34	19.60	11.26
Aperture inscribed radius [in.]	2.362	2.362	2.362	2.362	2.362	2.362
Core length [in.]	8.071	8.071	8.071	8.071	8.071	8.071
Magnetic length [in.]	10.041	10.041	10.041	10.041	10.041	10.041
Core weight [lb]	170	170	170	170	170	170
Amp turns per pole	4276	389	3730	511	4276	2455
Turns per pole	24	24	24	24	24	24
Pancakes per pole	1	1	1	1	1	1
Square conductor dimensions [in.]	0.375	0.375	0.375	0.375	0.375	0.375
Cooling hole diameter [in.]	0.125	0.125	0.125	0.125	0.125	0.125
Conductor cross-sectional area [in.^{2}]	0.127	0.127	0.127	0.127	0.127	0.127
Current @ 9 GeV [A]	178.2	16.2	155.4	21.3	178.2	102.3
Coil length/pole [ft]	49.6	49.6	49.6	49.6	49.6	49.6
Resistance @ 40°C [mΩ]	31.29	31.29	31.29	31.29	31.29	31.29
Power @ 9 GeV [kW]	0.99	0.01	0.76	0.01	0.99	0.33
Voltage drop @ 9 GeV [V]	5.6	0.5	4.9	0.7	5.6	3.2
Coil weight [lb]	44	44	44	44	44	44
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.18	0.18	0.18	0.18	0.18	0.18
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	20.9	0.2	15.9	0.3	20.9	6.9
Total magnet power [kW]	2.0	0.0	1.5	0.0	2.0	0.7
Total voltage [V]	5.6	0.5	4.9	0.7	5.6	3.2
Total system water requirements [gpm]	0.4	0.4	0.4	0.4	0.4	0.4

Table 5-3. HER sextupole parameters (continued).

Magnet designation	10 SD	10 SF	10 SD	10 SF	10 SD	10 SF
Lattice designation	SD3A	SF3A	SD1A	SF1A	SD2A	SF2A
Number of magnets	1	1	1	1	1	1
Operating gradient [T/m^2]	2.000	90.062	130.921	17.952	150.104	86.190
Pole-tip field @ operating gradient [T]	0.004	0.162	0.236	0.032	0.270	0.155
Integrated strength @ 9 GeV [T/m]	7.84	11.76	17.10	2.34	19.60	11.26
Aperture inscribed radius [in.]	2.362	2.362	2.362	2.362	2.362	2.362
Core length [in.]	8.071	8.071	8.071	8.071	8.071	8.071
Magnetic length [in.]	10.041	10.041	10.041	10.041	10.041	10.041
Core weight [lb]	170	170	170	170	170	170
Amp turns per pole	57	2566	3730	511	4276	2455
Turns per pole	24	24	24	24	24	24
Pancakes per pole	1	1	1	1	1	1
Square conductor dimensions [in.]	0.375	0.375	0.375	0.375	0.375	0.375
Cooling hole diameter [in.]	0.125	0.125	0.125	0.125	0.125	0.125
Conductor cross-sectional area [in.^{2}]	0.127	0.127	0.127	0.127	0.127	0.127
Current @ 9 GeV [A]	2.4	106.9	155.4	21.3	178.2	102.3
Coil length/pole [ft]	49.6	49.6	49.6	49.6	49.6	49.6
Resistance @ 40°C [mΩ]	31.29	31.29	31.29	31.29	31.29	31.29
Power @ 9 GeV [kW]	0.00	0.36	0.76	0.01	0.99	0.33
Voltage drop @ 9 GeV [V]	0.1	3.3	4.9	0.7	5.6	3.2
Coil weight [lb]	44	44	44	44	44	44
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.18	0.18	0.18	0.18	0.18	0.18
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	0.0	7.5	15.9	0.3	20.9	6.9
Total magnet power [kW]	0.0	0.7	1.5	0.0	2.0	0.7
Total voltage [V]	0.1	3.3	4.9	0.7	5.6	3.2
Total system water requirements [gpm]	0.4	0.4	0.4	0.4	0.4	0.4

Table 5-3. HER sextupole parameters (continued).

Magnet designation	10 SD	10 SF	10 SD	10 SF	10 SD	10 SF
Lattice designation	SD3A	SF3A	SD1	SF1	SD2	SF2
Number of magnets	1	1	1	1	1	1
Operating gradient [T/m^2]	60.042	90.062	104.863	5.674	105.073	78.654
Pole-tip field @ operating gradient [T]	0.108	0.162	0.189	0.010	0.189	0.142
Integrated strength @ 9 GeV [T/m]	7.84	11.76	13.70	0.74	13.72	10.27
Aperture inscribed radius [in.]	2.362	2.362	2.362	2.362	2.362	2.362
Core length [in.]	8.071	8.071	8.071	8.071	8.071	8.071
Magnetic length [in.]	10.041	10.041	10.041	10.041	10.041	10.041
Core weight [lb]	170	170	170	170	170	170
Amp turns per pole	1710	2566	2987	162	2993	2241
Turns per pole	24	24	24	24	24	24
Pancakes per pole	1	1	1	1	1	1
Square conductor dimensions [in.]	0.375	0.375	0.375	0.375	0.375	0.375
Cooling hole diameter [in.]	0.125	0.125	0.125	0.125	0.125	0.125
Conductor cross-sectional area [in.^{2}]	0.127	0.127	0.127	0.127	0.127	0.127
Current @ 9 GeV [A]	71.3	106.9	124.5	6.7	124.7	93.4
Coil length/pole [ft]	49.6	49.6	49.6	49.6	49.6	49.6
Resistance @ 40°C [mΩ]	31.29	31.29	31.29	31.29	31.29	31.29
Power @ 9 GeV [kW]	0.16	0.36	0.48	0.00	0.49	0.27
Voltage drop @ 9 GeV [V]	2.2	3.3	3.9	0.2	3.9	2.9
Coil weight [lb]	44	44	44	44	44	44
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.18	0.18	0.18	0.18	0.18	0.18
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	3.3	7.5	10.2	0.0	10.3	5.7
Total magnet power [kW]	0.3	0.7	1.0	0.0	1.0	0.5
Total voltage [V]	2.2	3.3	3.9	0.2	3.9	2.9
Total system water requirements [gpm]	0.4	0.4	0.4	0.4	0.4	0.4

Table 5-3. HER sextupole parameters (continued).

Magnet designation	10 SD	10 SF	10 SD	10 SF	10 SD	10 SF
Lattice designation	SD3	SF3	SD1	SF1	SD2	SF2
Number of magnets	1	1	1	1	1	1
Operating gradient [T/m^2]	60.042	90.272	104.863	5.674	105.073	78.654
Pole-tip field @ operating gradient [T]	0.108	0.162	0.189	0.010	0.189	0.142
Integrated strength @ 9 GeV [T/m]	7.84	11.79	13.70	0.74	13.72	10.27
Aperture inscribed radius [in.]	2.362	2.362	2.362	2.362	2.362	2.362
Core length [in.]	8.071	8.071	8.071	8.071	8.071	8.071
Magnetic length [in.]	10.041	10.041	10.041	10.041	10.041	10.041
Core weight [lb]	170	170	170	170	170	170
Amp turns per pole	1710	2572	2987	162	2993	2241
Turns per pole	24	24	24	24	24	24
Pancakes per pole	1	1	1	1	1	1
Square conductor dimensions [in.]	0.375	0.375	0.375	0.375	0.375	0.375
Cooling hole diameter [in.]	0.125	0.125	0.125	0.125	0.125	0.125
Conductor cross-sectional area [in.^{2}]	0.127	0.127	0.127	0.127	0.127	0.127
Current @ 9 GeV [A]	71.3	107.2	124.5	6.7	124.7	93.4
Coil length/pole [ft]	49.6	49.6	49.6	49.6	49.6	49.6
Resistance @ 40°C [mΩ]	9	31.29	31.29	31.29	31.29	31.29
Power @ 9 GeV [kW]	0.05	0.36	0.48	0.00	0.49	0.27
Voltage drop @ 9 GeV [V]	0.6	3.4	3.9	0.2	3.9	2.9
Coil weight [lb]	44	44	44	44	44	44
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.18	0.18	0.18	0.18	0.18	0.18
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	1.0	7.6	10.2	0.0	10.3	5.7
Total magnet power [kW]	0.1	0.7	1.0	0.0	1.0	0.5
Total voltage [V]	0.6	3.4	3.9	0.2	3.9	2.9
Total system water requirements [gpm]	0.4	0.4	0.4	0.4	0.4	0.4

Table 5-3. HER sextupole parameters (continued).

Magnet designation	10 SD	10 SF
Lattice designation	SD3	SF3
Number of magnets	1	1
Operating gradient [T/m^2]	60.042	90.272
Pole-tip field @ operating gradient [T]	0.108	0.162
Integrated strength @ 9 GeV [T/m]	7.84	11.79
Aperture inscribed radius [in.]	2.362	2.362
Core length [in.]	8.071	8.071
Magnetic length [in.]	10.041	10.041
Core weight [lb]	170	170
Amp turns per pole	1710	2572
Turns per pole	24	24
Pancakes per pole	1	1
Square conductor dimensions [in.]	0.375	0.375
Cooling hole diameter [in.]	0.125	0.125
Conductor cross-sectional area [in.^{2}]	0.127	0.127
Current @ 9 GeV [A]	71.3	107.2
Coil length/pole [ft]	49.6	49.6
Resistance @ 40°C [mΩ]	31.29	31.29
Power @ 9 GeV [kW]	0.16	0.36
Voltage drop @ 9 GeV [V]	2.2	3.4
Coil weight [lb]	44	44
Number of water circuits	1	1
Water flow rate [gpm]	0.18	0.18
Water pressure drop [psi]	150	150
Temperature rise [°C]	3.3	7.6
Total magnet power [kW]	0.3	0.7
Total voltage [V]	2.2	3.4
Total system water requirements [gpm]	0.4	0.4

5.1.2 LER Magnets

All magnets for the LER will be newly constructed. However, the beam-stay-clear aperture requirements for the LER are sufficiently similar to those of the HER (and PEP) that it is justifiable to use the same magnet aperture dimensions. (It is worth noting here that a review of the anticipated gas loads in both the HER and the LER indicates very little difference between the two; this argues for the choice of a vacuum chamber of similar aperture in the two rings.)

The main benefit of keeping the same magnet aperture is that the new LER magnets can take advantage of the well-proven pole-tip profiles developed for PEP and PETRA (using the computer program POISSON); that is, the magnets can be very similar to PEP magnets, with only the external dimensions changed to reflect the lower field requirements at the nominal 3.1-GeV operating point. In this way, we substantially reduce our R&D and engineering costs.

The design of the new magnets will be optimized by minimizing the sum of the installed capital cost plus ten years of operating cost at the design energy. This means that prudent attention is paid to reducing power consumption. Despite this, the LER magnets use proportionately more power than the PEP/HER magnets. This comes about because the PEP magnets were optimized for 18-GeV operation, where the power consumption is higher than at 9 GeV.

5.1.2.1 Dipoles. The LER dipole design was dictated by several considerations. First, the LER magnets must be mounted above the HER. To minimize the weight that must be rigidly supported, it is important to reduce the size of the dipoles considerably, compared with the PEP design. Second, the problems with synchrotron-radiation-induced gas desorption are eased considerably if the dipole is kept short enough to permit its synchrotron radiation fan to exit the magnet completely (as discussed in detail in Section 5.2). Finally, the lattice parameters of the LER call for a relatively high emittance and short damping times compared with what would result from a low-field bending magnet lattice. Although we have chosen to provide wigglers to adjust these parameters, the choice of a short, higher-field dipole helps to reduce the demands on the wigglers and to spread the synchrotron radiation power around more of the ring.

The LER arc dipole magnet physical dimensions are shown in Fig. 5-4. The key

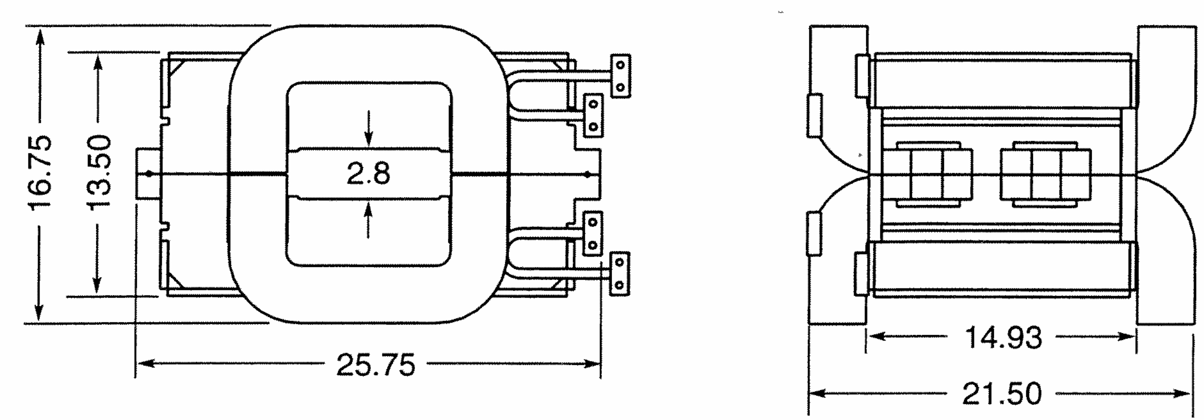

Fig. 5-4. End and side views of the LER bending magnet. Dimensions are given in inches.

dimensions are the core length of 14.92 in. and the gap of 2.8 in. The electrical properties of the LER dipole at its nominal operating energy of 3.1 GeV are summarized in Table 5-4.

To reduce production costs and to maximize magnet-to-magnet uniformity, the main ring magnets for the LER are of laminated construction. The dipole magnets will be constructed of one-piece laminations, 1/16-in. thick, punched from a decarburized, annealed, low-carbon steel sheet, such as Armco special magnet steel. This material—which has been used successfully for many accelerator applications, including those at PEP and Fermilab—exhibits high saturation induction, modest coercive force, and low remanent field. The estimated steel weight to manufacture the required 222 bending magnets is 250 tons.

Laminations will be punched with built-in fiducials to provide convenient external references for alignment, as discussed in Section 5.3. In addition, for reasons explained below, new witness marks will be introduced into the die at each heat-change to ensure magnet uniformity. Particular attention will be paid to the wear on the die. The vendor will be required to keep track of the number of laminations punched between die sharpenings and to provide SLAC with sample laminations on a regular basis, so that in-house inspections can be made to ensure that undue wear (>0.0005 in.) has not taken place on the critical surfaces (thereby producing out-of-tolerance laminations).

The vendor responsible for stacking the laminations will be required to deburr and then stack them, using laminations from consecutive heats. If this is done, the pattern generated by the witness marks will be obvious upon visual inspection. If the observed pattern is regular, the core will be acceptable, whereas an irregular pattern will indicate a lack of quality control on the part of the manufacturer and will be sufficient cause for rejecting the magnet core.

Laminations will be rotated after stacking each (approximately) 4-in. segment of the core. In this way, errors due to the slight variation in the thickness of the laminations will be eliminated. (This thickness error, referred to as "crowning," is well known to occur in flat rolled sheet due to curvature in the rollers caused by forces generated during the production of the sheet.) The precise number of laminations that are stacked before performing such a rotation, which can only be determined when the number of heats is known, will be sufficient to ensure that the regular periodicity of the witness marks is retained.

The magnets operate at low fields, well below saturation, and thus are more sensitive to core length than to the density of the lamination packing. Therefore, to maximize magnet-to-magnet reproducibility, particular attention will be paid to the length of the core (rather than its packing factor).

The magnet end-plates will be manufactured by numerically controlled mills and will contain the necessary holes for mounting coil retainers and other such devices. Angle plates welded to both the end-plates and the laminations will provide the torsional rigidity necessary to stabilize the cores and prevent twisting or bending.

Magnet coils will be of water-cooled aluminum, extruded from billets using porthole dies to provide continuous lengths up to several thousand feet. This technique obviates the need to make joints in the coil, thus eliminating the possibility of leaks. The length of a typical coil is about 150 ft, so there will be minimal waste at the end of each reel of conductor. The estimated weight of one dipole, including coils, is 2200 lb.

Table 5-4. LER dipole parameters.

Magnet designation	2.8H18	2.8H40	2.8H24	2.8H29	2.8H24	2.8H98
Bending angle [deg]	1.875	3.657	0.321	2	1.329	6.925
Lattice designation	B	B1	B2	B3	B4	B5
Number of magnets	192	8	2	4	2	2
Field [T]	0.752	0.660	0.097	0.481	0.400	0.500
Integrated field [T·m]	0.338	0.660	0.058	0.361	0.240	1.250
Pole width [in.]	8	8	8	8	8	8
Gap height [in.]	2.87	2.8	2.8	2.8	2.8	2.8
Core length [in.]	14.85	36.57	20.82	26.73	20.82	95.63
Magnetic length [in.]	17.72	39.37	23.62	29.53	23.62	98.43
Width of useful field, 0.1% [in.]	4.00	4.00	4.00	4.00	4.00	4.00
Lamination height [in.]	6.75	6.75	6.75	6.75	6.75	6.75
Lamination width [in.]	23	23	23	23	23	23
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1,306	4,903	1,832	2,352	1,832	8,415
Amp·turns	21,804	18,665	2,731	13,614	11,308	14,142
Turns	36	36	36	36	36	36
Pancakes per pole	1	1	1	1	1	1
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Cooling hole diameter [in.]	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875
Conductor cross section [in.^{2}]	0.22	0.22	0.22	0.22	0.22	0.22
Conductor length/pole [ft]	202	352	238	273	238	687
Current [A]	605.68	518.47	75.87	378.18	314.12	392.83
Resistance @ 40°C [mΩ]	24.4	42.5	28.7	33.0	28.7	82.9
Power [kW]	4.47	11.42	0.08	2.36	1.42	6.39
Voltage drop [V]	7.4	20	1.1	6.2	4.5	16.3
Coil weight [lb]	104	182	122	140	122	353
Number of water circuits	2	4	1	2	2	2
Water flow rate, total [gpm]	1.3	1.92	0.4	1.1	1.2	0.7
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	13.2	22.6	0.8	8.2	4.6	36.4
Total power (magnets and bus) [kW]	858	91.2	0.2	9.4	2.8	18.2
Total voltage (magnets and bus) [V]	1420	160	2	25	9	33
Total system water requirements (gpm)	248	15	1	4	2	1

Table 5-4. LER dipole parameters (continued).

Magnet designation	2.8H49	2.8H28	2.8H12	2.8H59
Bending angle [deg]	4.973	1.5	0.166	10.048
Lattice designation	B6	B7	B8	B9
Number of magnets	4	2	2	2
Field [T]	0.718	0.451	0.100	1.209
Integrated field [T·m]	0.898	0.271	0.030	1.814
Pole width [in.]	8	8	8	8
Gap height [in.]	2.8	2.8	2.8	2.8
Core length [in.]	46.41	20.82	9.01	56.26
Magnetic length [in.]	49.21	23.62	11.81	59.06
Width of useful field, 0.1% [in.]	4.00	4.00	4.00	4.00
Lamination height [in.]	16	6.75	6.75	6.75
Lamination width [in.]	23	23	23	23
Packing factor, minimum [%]	96	98	98	98
Core weight [lb]	4,084	1,832	793	4,950
Amp·turns	20,313	3.1	2,825	34,199
Turns	36	36	36	96
Pancakes per pole	1	1	1	1
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Cooling hole diameter [in.]	0.1875	0.1875	0.1875	0.1875
Conductor cross section [in.^{2}]	0.22	0.22	0.22	0.22
Conductor length/pole [ft]	392	238	167	1202
Current [A]	564.24	0.09	78.47	356.24
Resistance @ 40°C [mΩ]	47.2	28.7	20.2	145.0
Power [kW]	7.52	0.00	0.06	9.20
Voltage drop [V]	13.3	0.0	0.8	25.8
Coil weight [lb]	201	122	86	617
Number of water circuits	2	2	2	4
Water flow rate, total [gpm]	0.9	1.2	1.4	2.1
Water pressure drop [psi]	150	150	150	150
Temperature rise [°C]	31.6	0.0	0.2	16.8
Total power (magnets and bus) [kW]	30	0.0	1.2	18.4
Total voltage (magnets and bus) [V]	53	0.0	2	52
Total system water requirements (gpm)	4	2	3	4

5.1.2.2 Quadrupoles. The standard LER quadrupole has a length of 17.0 in. and a bore diameter of 3.937 in.; its physical dimensions are shown in Fig. 5-5. The electrical properties of the quadrupoles corresponding to the nominal energy are summarized in Table 5-5.

The LER quadrupoles will be constructed, and the laminations handled, in the same manner described for the dipole magnets, except that they will use four-piece construction. The anticipated weight of steel is larger than that for the dipoles, about 550 tons, thus requiring more heats (about eight rather than five).

The design will include numerically machined end-plates with predrilled holes to mount the beam position monitors. These end-plates will be used to sandwich the laminations together. As with the dipoles, angles welded to the corners of the laminations will provide the required torsional rigidity and stiffness. Four cores, fitted with water-cooled aluminum coils approximately 180 ft long and extruded by the same technique as used for the bending magnets, will be bolted together to form one quadrupole weighing an estimated 2000 lb.

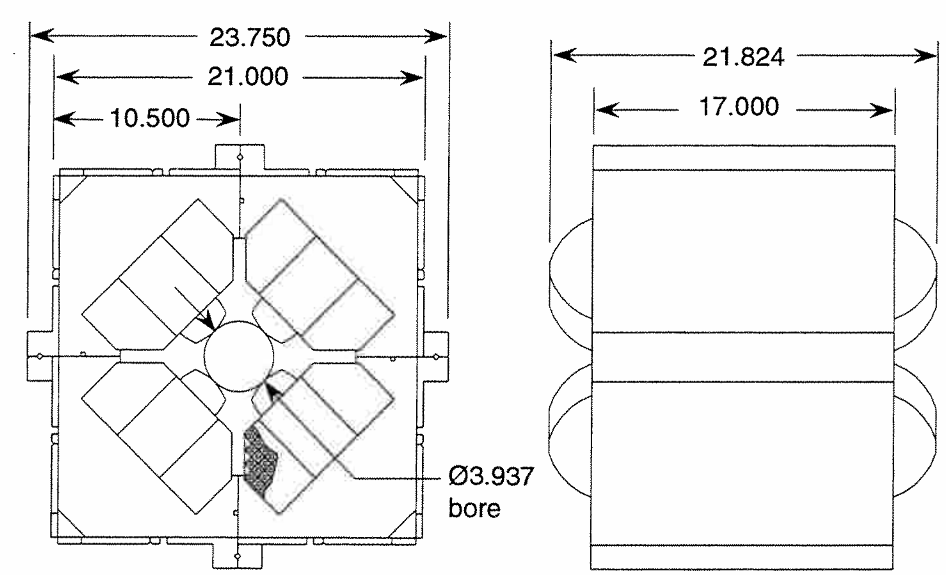

Fig. 5-5. End and side views of an LER quadrupole magnet. Dimensions are given in inches.

Table 5-5. LER quadrupole parameters.

Magnet designation	4Q17	4Q17	4Q17	4Q40	4Q40	4Q40
Location in ring	Arc	Arc	R2	R2	R2	R2
Lattice designation	QF	QD	IQF1	IQD2	IQF3	IQD4
Number of magnets	74	80	2	2	2	2
Operating gradient [T/m]	4.55	4.50	7.12	5.04	4.53	5.05
Pole-tip field @ operating gradient [T]	0.227	0.225	0.356	0.252	0.226	0.253
Gradient length product [T]	1.96	1.93	3.06	5.04	4.529	5.05
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	38.39	38.39	38.39
Magnetic length [in.]	16.93	16.93	16.93	39.37	39.37	39.37
Lamination height [in.]	11.88	11.88	11.88	13.98	13.98	13.98
Lamination width [in.]	10.50	10.50	10.50	13.35	13.35	13.35
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	1786	1786	6142	6142	6142
Amp·turns per pole	4521	4467	7075	5006	4500	5022
Turns per pole	37	37	37	56	56	56
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	476	476	476
Current [A]	122	121	191	89	80	90
Resistance @ 40°C [mΩ]	47	47	47	127	127	127
Power [kW]	0.70	0.69	1.72	1.02	0.82	1.02
Voltage drop [V]	5.8	5.7	9.0	11.4	10.2	11.4
Coil weight [lb]	81.4	81.4	81.4	220.2	220.2	220.2
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.7	0.7	0.7	0.4	0.4	0.4
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	3.80	3.71	9.32	9.43	7.62	9.49
Total magnet power [kW]	52.0	54.8	3.4	2.0	1.6	2.0
Total magnet water requirements [gpm]	51.9	56.1	1.4	0.8	0.8	0.8

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Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q40	4Q40	4Q40	4Q40	4Q17
Location in ring	R2	R2	R2	R2	R2	R2
Lattice designation	IQF5	IQF6	IQD7	IQF8	IQD9	IQD10
Number of magnets	2	2	2	2	2	4
Operating gradient [T/m]	10.35	5.20	5.98	9.80	7.31	7.12
Pole-tip field @ operating gradient [T]	0.517	0.260	0.299	0.490	0.365	0.356
Gradient length product [T]	4.45	5.20	5.98	9.80	7.31	3.06
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	38.39	38.39	38.39	38.39	15.95
Magnetic length [in.]	16.93	39.37	39.37	39.37	39.37	16.93
Lamination height [in.]	11.88	13.98	11.88	13.98	13.98	11.88
Lamination width [in.]	10.50	13.35	10.50	13.35	13.35	10.50
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	6142	4299	6142	6142	1786
Amp·turns per pole	10285	5163	5942	9739	7261	7079
Turns per pole	37	56	56	56	56	37
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	476	476	476	476	176
Current [A]	278	92	106	174	130	191
Resistance @ 40°C [mΩ]	47	127	127	127	127	47
Power [kW]	3.63	1.08	1.43	3.85	2.14	1.72
Voltage drop [V]	13.1	11.7	13.5	22.1	16.5	13.1
Coil weight [lb]	81.4	220.2	220.2	220.2	220.2	81.4
Number of water circuits	1	2	2	4	2	1
Water flow rate [gpm]	0.7	1.2	1.2	3.5	1.2	0.7
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	19.69	3.45	4.57	4.22	6.82	9.33
Total magnet power [kW]	7.3	2.2	2.9	7.7	4.3	6.9
Total magnet water requirements [gpm]	1.4	2.4	2.4	6.9	2.4	2.8

Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q17	4Q17	4Q40	4Q17	4Q17
Location in ring	R2	R2	R2	R2	R2	R2
Lattice designation	IQF11	IQD12	IQD13	IQF14	IQD15	IQF16
Number of magnets	4	2	2	2	2	2
Operating gradient [T/m]	11.75	10.46	7.04	8.25	5.87	19.21
Pole-tip field @ operating gradient [T]	0.587	0.523	0.352	0.413	0.293	0.960
Gradient length product [T]	5.05	4.50	3.03	8.25	2.52	8.26
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	38.39	15.95	15.95
Magnetic length [in.]	16.93	16.93	16.93	39.37	16.93	16.93
Lamination height [in.]	11.88	11.88	11.88	13.98	11.88	11.88
Lamination width [in.]	10.50	10.50	10.50	13.35	10.50	10.50
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	1786	1786	6142	1786	1786
Amp-turns per pole	11670	10388	6991	8200	5834	19084
Turns per pole	37	37	37	56	37	37
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	476	176	176
Current [A]	315	281	189	146	158	516
Resistance @ 40°C [mΩ]	47	47	47	127	47	47
Power [kW]	4.68	3.71	1.68	2.73	1.17	12.51
Voltage drop [V]	14.8	13.2	8.9	18.6	7.4	24.3
Coil weight [lb]	81.4	81.4	81.4	220.2	81.4	81.4
Number of water circuits	2	2	1	2	1	4
Water flow rate [gpm]	2.0	2.0	0.7	1.2	0.7	5.9
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	8.72	6.91	9.10	8.70	6.33	8.02
Total magnet power [kW]	18.7	7.4	3.4	5.5	2.3	25.0
Total magnet water requirements [gpm]	8.2	4.1	1.4	2.4	1.4	11.9

Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q17	4Q17	4Q17	4Q17	4Q17
Location in ring	R2	R2	IR DS	IR DS	IR DS	IR DS
Lattice designation	IQD17	IQF18	QF1	QD2	QF3	QD4
Number of magnets	2	2	2	2	2	2
Operating gradient [T/m]	10.54	8.89	7.07	6.33	5.18	3.46
Pole-tip field @ operating gradient [T]	0.527	0.444	0.354	0.316	0.259	0.173
Gradient length product [T]	4.53	3.82	3.04	2.72	2.23	1.49
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	15.95	15.95	15.95
Magnetic length [in.]	16.93	16.93	16.93	16.93	16.93	16.93
Lamination height [in.]	11.88	11.88	11.88	11.88	11.88	11.88
Lamination width [in.]	10.50	10.50	10.50	10.50	10.50	10.50
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	1786	1786	1786	1786	1786
Amp-turns per pole	10469	8834	7027	6291	5147	3436
Turns per pole	37	37	37	37	37	37
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	176	176	176
Current [A]	283	239	190	170	139	93
Resistance @ 40°C [mΩ]	47	47	47	47	47	47
Power [kW]	3.76	2.68	1.70	1.36	0.91	0.41
Voltage drop [V]	13.3	11.2	8.9	8.0	6.5	4.4
Coil weight [lb]	81.4	81.4	81.4	81.4	81.4	81.4
Number of water circuits	2	2	1	1	1	1
Water flow rate [gpm]	2.0	2.0	0.7	0.7	0.7	0.7
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	7.02	5.00	9.19	7.37	4.93	2.20
Total magnet power [kW]	7.5	5.4	3.4	2.7	1.8	0.8
Total magnet water requirements [gpm]	4.1	4.1	1.4	1.4	1.4	1.4

Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q17	4Q17	4Q17	4Q17	4Q17
Location in ring	IR DS	R4	R4	R4	R4	R4
Lattice designation	QF5	QDT4	QFT4	QDT3	QFT3	QDT2
Number of magnets	2	1	2	2	2	2
Operating gradient [T/m]	4.55	1.88	3.29	3.57	4.14	3.48
Pole-tip field @ operating gradient [T]	0.227	0.094	0.165	0.178	0.207	0.174
Gradient length product [T]	1.96	0.81	1.42	1.53	1.78	1.50
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	15.95	15.95	15.95
Magnetic length [in.]	16.93	16.93	16.93	16.93	16.93	16.93
Lamination height [in.]	11.88	11.88	11.88	11.88	11.88	11.88
Lamination width [in.]	10.50	10.50	10.50	10.50	10.50	10.50
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	1786	1786	1786	1786	1786
Amp·turns per pole	4518	1870	3270	3542	4113	3460
Turns per pole	37	37	37	37	37	37
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	176	176	176
Current [A]	122	51	88	96	111	94
Resistance @ 40°C [mΩ]	47	47	47	47	47	47
Power [kW]	0.70	0.12	0.37	0.43	0.58	0.41
Voltage drop [V]	5.7	2.4	4.2	4.5	5.2	4.4
Coil weight [lb]	81.4	81.4	81.4	81.4	81.4	81.4
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.7	0.7	0.7	0.7	0.7	0.7
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	3.80	0.65	1.99	2.34	3.15	2.23
Total magnet power [kW]	1.4	0.1	0.7	0.9	1.2	0.8
Total magnet water requirements [gpm]	1.4	0.7	1.4	1.4	1.4	1.4

Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q17	4Q17	4Q17	4Q17	4Q17
Location in ring	R4	R4	R4	R3	R3	R3
Lattice designation	QFT2	QDT1	QFT1	QF1	QD1	QF2
Number of magnets	2	2	2	1	1	1
Operating gradient [T/m]	4.83	4.04	4.90	4.16	5.58	4.38
Pole-tip field @ operating gradient [T]	0.242	0.202	0.245	0.208	0.279	0.219
Gradient length product [T]	2.08	1.74	2.11	1.79	2.40	1.88
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	15.95	15.95	15.95
Magnetic length [in.]	16.93	16.93	16.93	16.93	16.93	16.93
Lamination height [in.]	11.88	11.88	11.88	11.88	11.88	11.88
Lamination width [in.]	10.50	10.50	10.50	10.50	10.50	10.50
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	1786	1786	1786	1786	1786
Amp·turns per pole	4801	4011	4871	4137	5544	4348
Turns per pole	37	37	37	37	37	37
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	176	176	176
Current [A]	130	108	132	112	150	118
Resistance @ 40°C [mΩ]	47	47	47	47	47	47
Power [kW]	0.79	0.55	0.82	0.59	1.06	0.65
Voltage drop [V]	6.1	5.1	6.2	5.3	7.1	5.5
Coil weight [lb]	81.4	81.4	81.4	81.4	81.4	81.4
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.7	0.7	0.7	0.7	0.7	0.7
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	4.29	3.00	4.42	3.19	5.72	3.52
Total magnet power [kW]	1.6	1.1	1.6	0.6	1.1	0.6
Total magnet water requirements [gpm]	1.4	1.4	1.4	0.7	0.7	0.7

Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q17	4Q17	4Q17	4Q17	4Q17
Location in ring	R3	R3	R3	R3	R3	R6
Lattice designation	QD2	QF3	QD3	QF4	QD4	QFW1
Number of magnets	1	1	1	1	1	2
Operating gradient [T/m]	4.95	4.84	4.12	4.77	4.55	2.52
Pole-tip field @ operating gradient [T]	0.247	0.242	0.206	0.239	0.227	0.126
Gradient length product [T]	2.13	2.08	1.77	2.05	1.96	1.08
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	15.95	15.95	15.95
Magnetic length [in.]	16.93	16.93	16.93	16.93	16.93	16.93
Lamination height [in.]	11.88	11.88	11.88	11.88	11.88	11.88
Lamination width [in.]	10.50	10.50	10.50	10.50	10.50	10.50
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	1786	1786	1786	1786	1786
Amp·turns per pole	4917	4810	4097	4744	4520	2505
Turns per pole	37	37	37	37	37	37
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	176	176	176
Current [A]	133	130	111	128	122	68
Resistance @ 40°C [mΩ]	47	47	47	47	47	47
Power [kW]	0.83	0.79	0.58	0.77	0.70	0.22
Voltage drop [V]	6.3	6.1	5.2	6.0	5.7	3.2
Coil weight [lb]	81.4	81.4	81.4	81.4	81.4	81.4
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.7	0.7	0.7	0.7	0.7	0.7
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	4.50	4.31	3.12	4.19	3.80	1.17
Total magnet power [kW]	0.8	0.8	0.6	0.8	0.7	0.4
Total magnet water requirements [gpm]	0.7	0.7	0.7	0.7	0.7	1.4

Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q17	4Q17	4Q17	4Q17	4Q17
Location in ring	R6	R6	R6	R6	R6	R8
Lattice designation	QDW2	QFW3	QFW4	QDW5	QFW6	QDI
Number of magnets	2	2	2	2	2	2
Operating gradient [T/m]	1.64	3.92	0.28	2.02	3.58	0.66
Pole-tip field @ operating gradient [T]	0.082	0.196	0.014	0.101	0.179	0.033
Gradient length product [T]	0.70	1.69	0.12	0.87	1.54	0.28
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	15.95	15.95	15.95
Magnetic length [in.]	16.93	16.93	16.93	16.93	16.93	16.93
Lamination height [in.]	11.88	11.88	11.88	11.88	11.88	11.88
Lamination width [in.]	10.50	10.50	10.50	10.50	10.50	10.50
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	1786	1786	1786	1786	1786
Amp·turns per pole	1628	3895	283	2009	3553	654
Turns per pole	37	37	37	37	37	37
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	176	176	176
Current [A]	44	105	8	54	96	18
Resistance @ 40°C [mΩ]	47	47	47	47	47	47
Power [kW]	0.09	0.52	0.00	0.14	0.43	0.01
Voltage drop [V]	2.1	5.0	0.4	2.6	4.5	0.8
Coil weight [lb]	81.4	81.4	81.4	81.4	81.4	81.4
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.7	0.7	0.7	0.7	0.7	0.7
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	0.49	2.82	0.01	0.75	2.35	0.08
Total magnet power [kW]	0.2	1.0	0.0	0.3	0.9	0.0
Total magnet water requirements [gpm]	1.4	1.4	1.4	1.4	1.4	1.4

Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q17	4Q17	4Q17	4Q17	4Q17
Location in ring	R8	R8	R8	R10	R10	R10
Lattice designation	QFI	QDOI	QFOI	QDT4A	QFT4A	QDT3A
Number of magnets	2	2	2	1	2	2
Operating gradient [T/m]	1.47	2.34	4.17	1.88	3.29	3.57
Pole-tip field @ operating gradient [T]	0.074	0.117	0.208	0.094	0.165	0.178
Gradient length product [T]	0.63	1.01	1.79	0.81	1.42	1.53
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	15.95	15.95	15.95
Magnetic length [in.]	16.93	16.93	16.93	16.93	16.93	16.93
Lamination height [in.]	11.88	11.88	11.88	11.88	11.88	11.88
Lamination width [in.]	10.50	10.50	10.50	10.50	10.50	10.50
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	1786	1786	1786	1786	1786
Amp·turns per pole	1464	2323	4138	1870	3270	3542
Turns per pole	37	37	37	37	37	37
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	176	176	176
Current [A]	40	63	112	51	88	96
Resistance @ 40°C [mΩ]	47	47	47	47	47	47
Power [kW]	0.07	0.19	0.59	0.12	0.37	0.43
Voltage drop [V]	1.9	3.0	5.3	2.4	4.2	4.5
Coil weight [lb]	81.4	81.4	81.4	81.4	81.4	81.4
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.7	0.7	0.7	0.7	0.7	0.7
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	0.40	1.00	3.19	0.65	1.99	2.34
Total magnet power [kW]	0.1	0.4	1.2	0.1	0.7	0.9
Total magnet water requirements [gpm]	1.4	1.4	1.4	0.7	1.4	1.4

Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q17	4Q17	4Q17	4Q17	4Q17
Location in ring	R10	R10	R10	R10	R10	R5
Lattice designation	QFT3A	QDT2A	QFT2A	QDT1A	QFT1A	QF1
Number of magnets	2	2	2	2	2	1
Operating gradient [T/m]	4.14	3.48	4.83	4.04	4.90	4.16
Pole-tip field @ operating gradient [T]	0.207	0.174	0.242	0.202	0.245	0.208
Gradient length product [T]	1.78	1.50	2.08	1.74	2.11	1.79
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	15.95	15.95	15.95
Magnetic length [in.]	16.93	16.93	16.93	16.93	16.93	16.93
Lamination height [in.]	11.88	11.88	11.88	11.88	11.88	11.88
Lamination width [in.]	10.50	10.50	10.50	10.50	10.50	10.50
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	1786	1786	1786	1786	1786
Amp·turns per pole	4113	3460	4801	4011	4871	4137
Turns per pole	37	37	37	37	37	37
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	176	176	176
Current [A]	111	94	130	108	132	112
Resistance @ 40°C [mΩ]	47	47	47	47	47	47
Power [kW]	0.58	0.41	0.79	0.55	0.82	0.59
Voltage drop [V]	5.2	4.4	6.1	5.1	6.2	5.3
Coil weight [lb]	81.4	81.4	81.4	81.4	81.4	81.4
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.7	0.7	0.7	0.7	0.7	0.7
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	3.15	2.23	4.29	3.00	4.42	3.19
Total magnet power [kW]	1.2	0.8	1.6	1.1	1.6	0.6
Total magnet water requirements [gpm]	1.4	1.4	1.4	1.4	1.4	0.7

Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q17	4Q17	4Q17	4Q17	4Q17
Location in ring	R5	R5	R5	R5	R5	R5
Lattice designation	QD1	QF2	QD2	QF3	QD3	QF4
Number of magnets	1	1	1	1	1	1
Operating gradient [T/m]	5.58	4.38	4.95	4.84	4.12	4.77
Pole-tip field @ operating gradient [T]	0.279	0.219	0.247	0.242	0.206	0.239
Gradient length product [T]	2.40	1.88	2.13	2.08	1.77	2.05
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	15.95	15.95	15.95
Magnetic length [in.]	16.93	16.93	16.93	16.93	16.93	16.93
Lamination height [in.]	11.88	11.88	11.88	11.88	11.88	11.88
Lamination width [in.]	10.50	10.50	10.50	10.50	10.50	10.50
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	1786	1786	1786	1786	1786
Amp·turns per pole	5544	4348	4917	4810	4097	4744
Turns per pole	37	37	37	37	37	37
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	176	176	176
Current [A]	150	118	133	130	111	128
Resistance @ 40°C [mΩ]	47	47	47	47	47	47
Power [kW]	1.06	0.65	0.83	0.79	0.58	0.77
Voltage drop [V]	7.1	5.5	6.3	6.1	5.2	6.0
Coil weight [lb]	81.4	81.4	81.4	81.4	81.4	81.4
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.7	0.7	0.7	0.7	0.7	0.7
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	5.72	3.52	4.50	4.31	3.12	4.19
Total magnet power [kW]	1.1	0.6	0.8	0.8	0.6	0.8
Total magnet water requirements [gpm]	0.7	0.7	0.7	0.7	0.7	0.7

Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q17	4Q17	4Q17	4Q17	4Q17
Location in ring	R5	R9	R9	R9	R9	R9
Lattice designation	QD4	QF1A	QD1A	QF2A	QD2A	QF3A
Number of magnets	1	1	1	1	1	1
Operating gradient [T/m]	4.55	4.16	5.58	4.38	4.95	4.84
Pole-tip field @ operating gradient [T]	0.227	0.208	0.279	0.219	0.247	0.242
Gradient length product [T]	1.96	1.79	2.40	1.88	2.13	2.08
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	15.95	15.95	15.95
Magnetic length [in.]	16.93	16.93	16.93	16.93	16.93	16.93
Lamination height [in.]	11.88	11.88	11.88	11.88	11.88	11.88
Lamination width [in.]	10.50	10.50	10.50	10.50	10.50	10.50
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	1786	1786	1786	1786	1786
Amp·turns per pole	4520	4137	5544	4348	4917	4810
Turns per pole	37	37	37	37	37	37
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	176	176	176
Current [A]	122	112	150	118	133	130
Resistance @ 40°C [mΩ]	47	47	47	47	47	47
Power [kW]	0.70	0.59	1.06	0.65	0.83	0.79
Voltage drop [V]	5.7	5.3	7.1	5.5	6.3	6.1
Coil weight [lb]	81.4	81.4	81.4	81.4	81.4	81.4
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.7	0.7	0.7	0.7	0.7	0.7
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	3.80	3.19	5.72	3.52	4.50	4.31
Total magnet power [kW]	0.7	0.6	1.1	0.6	0.8	0.8
Total magnet water requirements [gpm]	0.7	0.7	0.7	0.7	0.7	0.7

Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q17	4Q17	4Q17	4Q17	4Q17
Location in ring	R9	R9	R9	R11	R11	R11
Lattice designation	QD3A	QF4A	QD4A	QF1A	QD1A	QF2A
Number of magnets	1	1	1	1	1	1
Operating gradient [T/m]	4.12	4.77	4.55	4.16	5.58	4.38
Pole-tip field @ operating gradient [T]	0.206	0.239	0.227	0.208	0.279	0.219
Gradient length product [T]	1.77	2.05	1.96	1.79	2.40	1.88
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	15.95	15.95	15.95
Magnetic length [in.]	16.93	16.93	16.93	16.93	16.93	16.93
Lamination height [in.]	11.88	11.88	11.88	11.88	11.88	11.88
Lamination width [in.]	10.50	10.50	10.50	10.50	10.50	10.50
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	1786	1786	1786	1786	1786
Amp-turns per pole	4097	4744	4520	4137	5544	4348
Turns per pole	37	37	37	37	37	37
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	176	176	176
Current [A]	111	128	122	112	150	118
Resistance @ 40°C [mΩ]	47	47	47	47	47	47
Power [kW]	0.58	0.77	0.70	0.59	1.06	0.65
Voltage drop [V]	5.2	6.0	5.7	5.3	7.1	5.5
Coil weight [lb]	81.4	81.4	81.4	81.4	81.4	81.4
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.7	0.7	0.7	0.7	0.7	0.7
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	3.12	4.19	3.80	3.19	5.72	3.52
Total magnet power [kW]	0.6	0.8	0.7	0.6	1.1	0.6
Total magnet water requirements [gpm]	0.7	0.7	0.7	0.7	0.7	0.7

Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q17	4Q17	4Q17	4Q17	4Q17
Location in ring	R11	R11	R11	R11	R11	R12
Lattice designation	QD2A	QF3A	QD3A	QF4A	QD4A	QFW1A
Number of magnets	1	1	1	1	1	2
Operating gradient [T/m]	4.95	4.84	4.12	4.77	4.55	2.52
Pole-tip field @ operating gradient [T]	0.247	0.242	0.206	0.239	0.227	0.126
Gradient length product [T]	2.13	2.08	1.77	2.05	1.96	1.08
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	15.95	15.95	15.95
Magnetic length [in.]	16.93	16.93	16.93	16.93	16.93	16.93
Lamination height [in.]	11.88	11.88	11.88	11.88	11.88	11.88
Lamination width [in.]	10.50	10.50	10.50	10.50	10.50	10.50
Packing factor, minimum [%]	98	98	98	98	98	98
Core weight [lb]	1786	1786	1786	1786	1786	1786
Amp-turns per pole	4917	4810	4097	4744	4520	2505
Turns per pole	37	37	37	37	37	37
Pancakes per pole	1	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	176	176	176
Current [A]	133	130	111	128	122	68
Resistance @ 40°C [mΩ]	47	47	47	47	47	47
Power [kW]	0.83	0.79	0.58	0.77	0.70	0.22
Voltage drop [V]	6.3	6.1	5.2	6.0	5.7	3.2
Coil weight [lb]	81.4	81.4	81.4	81.4	81.4	81.4
Number of water circuits	1	1	1	1	1	1
Water flow rate [gpm]	0.7	0.7	0.7	0.7	0.7	0.7
Water pressure drop [psi]	150	150	150	150	150	150
Temperature rise [°C]	4.50	4.31	3.12	4.19	3.80	1.17
Total magnet power [kW]	0.8	0.8	0.6	0.8	0.7	0.4
Total magnet water requirements [gpm]	0.7	0.7	0.7	0.7	0.7	1.4

Table 5-5. LER quadrupole parameters (continued).

Magnet designation	4Q17	4Q17	4Q17	4Q17	4Q17
Location in ring	R12	R12	R12	R12	R12
Lattice designation	QDW2A	QFW3A	QFW4A	QDW5A	QFW6A
Number of magnets	2	2	2	2	2
Operating gradient [T/m]	1.64	3.92	0.28	2.02	3.58
Pole-tip field @ operating gradient [T]	0.082	0.196	0.014	0.101	0.179
Gradient length product [T]	0.70	1.69	0.12	0.87	1.54
Inscribed radius [in.]	1.968	1.968	1.968	1.968	1.968
Minimum gap [in.]	1.457	1.457	1.457	1.457	1.457
Core length [in.]	15.95	15.95	15.95	15.95	15.95
Magnetic length [in.]	16.93	16.93	16.93	16.93	16.93
Lamination height [in.]	11.88	11.88	11.88	11.88	11.88
Lamination width [in.]	10.50	10.50	10.50	10.50	10.50
Packing factor, minimum [%]	98	98	98	98	98
Core weight [lb]	1786	1786	1786	1786	1786
Amp·turns per pole	1628	3895	283	2009	3553
Turns per pole	37	37	37	37	37
Pancakes per pole	1	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.198	0.198	0.198	0.198	0.198
Cooling hole diameter [in.]	0.25	0.25	0.25	0.25	0.25
Conductor dimensions [in.]	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5	0.5×0.5
Conductor length/pole [ft]	176	176	176	176	176
Current [A]	44	105	8	54	96
Resistance @ 40°C [mΩ]	47	47	47	47	47
Power [kW]	0.09	0.52	0.00	0.14	0.43
Voltage drop [V]	2.1	5.0	0.4	2.6	4.5
Coil weight [lb]	81.4	81.4	81.4	81.4	81.4
Number of water circuits	1	1	1	1	1
Water flow rate [gpm]	0.7	0.7	0.7	0.7	0.7
Water pressure drop [psi]	150	150	150	150	150
Temperature rise [°C]	0.49	2.82	0.01	0.75	2.35
Total magnet power [kW]	0.2	1.0	0.0	0.3	0.9
Total magnet water requirements [gpm]	1.4	1.4	1.4	1.4	1.4

5.1.2.3 Sextupoles. The LER sextupole physical dimensions are shown in Fig. 5-6. These magnets have a length of 8.071 in. and a bore of 4.724 in. Their electrical properties, corresponding to the nominal energy, are summarized in Table 5-6.

The LER sextupoles will be identical to the present PEP short (8-in.) sextupoles. This will permit us to interchange magnets between the LER and HER, if necessary, and minimizes the required number of spares. Manufacturing techniques will be the same as those described above for the LER dipoles and quadrupoles, although the anticipated steel requirement of about 50 tons will come from only a single heat. For this reason, witness marks will not be needed for the sextupoles. Laminations will still be reversed periodically, however, to account for the crowning referred to above.

Table 5-6. LER sextupole parameters.

Magnet designation	4.5S	4.5S	4.5S	4.5S
Lattice designation	SF1	SD1	SX	SY
Number of magnets	72	72	4	4
Operating gradient [T/m^2]	25.62	45.60	113.75	186.13
Pole tip field @ operating gradient [T]	0.046	0.082	0.205	0.335
Integrated strength [T/m]	7.53	13.40	33.43	54.70
Aperture inscribed radius [in.]	2.362	2.362	2.362	2.362
Core length [in.]	8.071	8.071	8.071	8.071
Magnetic length [in.]	10.041	10.041	10.041	10.041
Core weight [lb]	170	170	170	170
Amp·turns per pole	730	1299	3240	5302
Turns per pole	24	24	24	24
Pancakes per pole	1	1	1	1
Conductor cross-sectional area [in.^{2}]	0.127	0.127	0.127	0.127
Cooling hole diameter [in.]	0.125	0.125	0.125	0.125
Conductor dimension [in.]	0.375	0.375	0.375	0.375
Current [A]	30.4	54.1	135.0	220.9
Resistance @ 40°C [mΩ]	31	31	31	31
Power [kW]	0.03	0.09	0.57	1.53
Voltage drop [V]	1.0	1.7	4.2	6.9
Coil weight [lb]	44	44	44	44
Number of water circuits	1	1	1	1
Water flow rate [gpm]	0.2	0.2	0.2	0.2
Water pressure drop [psi]	150	150	150	150
Temperature rise [°C]	0.6	1.9	12.0	32.2
Total magnet power [kW]	2.1	6.6	2.3	6.1
Total voltage [V]	68.5	121.9	16.9	27.6
Total system water requirements [gpm]	13.0	13.0	0.7	0.7

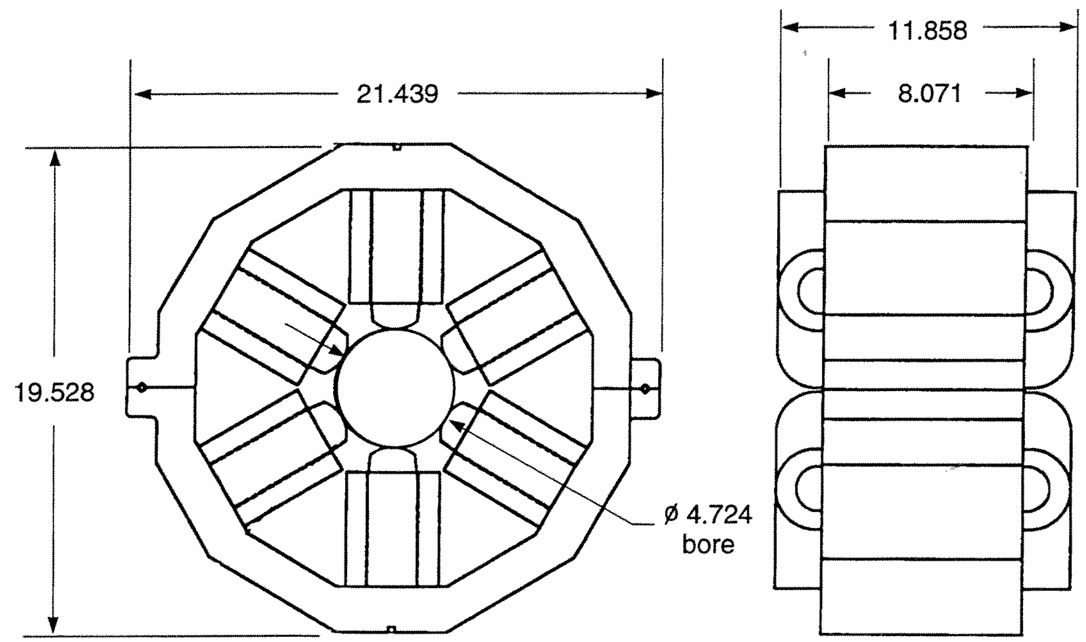

Fig. 5-6. End and side views of the LER sextupole magnet. Dimensions are given in inches.

5.1.3 Interaction Region Magnets and Supports

5.1.3.1 Permanent Magnets. Only the final focusing quadrupoles, Q1, and the magnetic separation dipoles, B1, are located within 2 m of the interaction point (IP). At these close distances, they will be inside the detector and immersed in its solenoidal magnetic field. The only viable magnet technologies for such an environment are superconducting or permanent magnets. A conventional electromagnet with iron pole tips would have its iron saturated and its field distorted by the detector field. For the IR magnets, required field strengths and apertures are within the reach of modern rare-earth–cobalt (REC) alloys, and superconducting technology is not demanded. For PEP-II, the choice of a permanent-magnet design was based on the following characteristics of such magnets:

- Their interaction with the external detector solenoid is minimal. Because magnetized REC is a magnetically hard material with little free magnetic moment left over to interact with external fields, it is magnetically transparent with a permeability μ near the μ_0 of free space. In the standard Halbach configuration [Halbach, 1981] these magnet assemblies project little external field to generate forces between the detector solenoid and the REC assembly.
- They avoid the complexity, cost, and reliability problems inherent in cryogenic operation.
- They are compact and avoid cryogenic plumbing and cryostats, both of which would significantly reduce the detector acceptance solid angle.

- They are nearly free of fringe fields that could otherwise complicate particle tracking in the detector.
- They avoid the safety aspects of superconducting systems; they will not quench—a possible advantage in a high-current storage ring.

There are also drawbacks to our choice of permanent magnet technology. Foremost among these is the fact that permanent magnets offer only a limited adjustment capability. In our design, we have added trim windings on all permanent magnets in the IR to alleviate this lack of flexibility. Other issues include the following:

- The field quality of a REC magnet depends on accurate magnetization of its constituent blocks; special techniques and equipment must be developed to measure block magnetization, and to assemble and adjust blocks.
- Strong demagnetizing external fields and high temperatures must be avoided if field quality is to be preserved. Quadrupole and dipole fields are assembled from sector-shaped REC blocks arrayed in a circle around the magnet aperture [Halbach, 1981]. Each block is magnetized in an appropriate direction so that the magnetic field varies approximately as $\cos(N\theta)$ around the bore, where $N = 1$ for dipoles, $N = 2$ for quadrupoles, etc. The optimal compromise between the number of blocks, M, and the field quality is to use $M = 16$ for a quadrupole and $M = 8$ for a dipole. These configurations are shown in Fig. 5-7.

The magnetic and mechanical properties of the PEP-II IR magnets are summarized in Table 5-7.

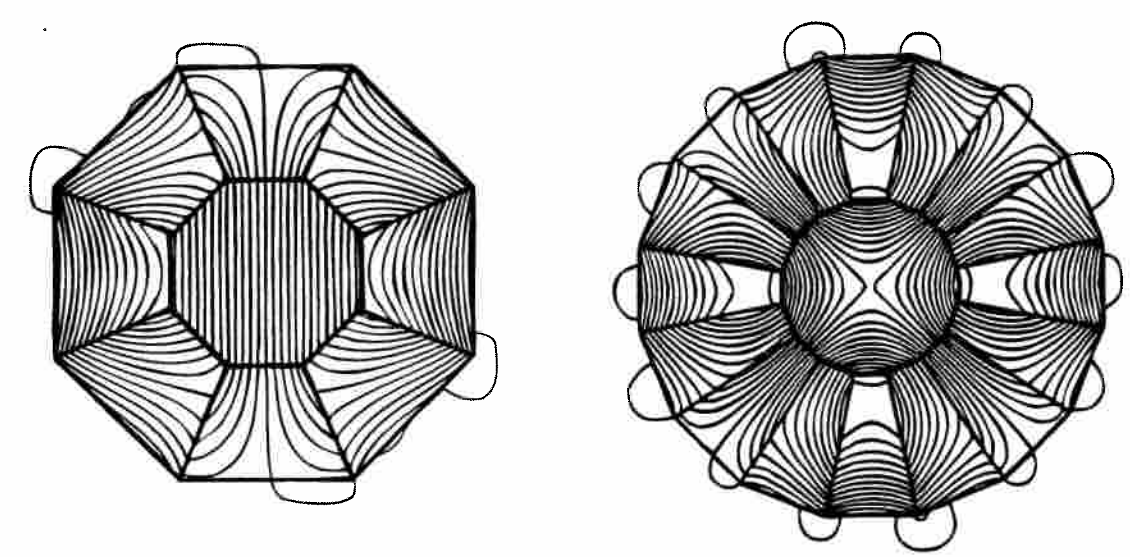

Fig. 5-7. Field lines for an 8-block permanent magnet dipole (left) and a 16-block quadrupole (right).