Title
PEP TRANSPORT BEND MAGNET 25B5249, (B3 THROUGH B9)

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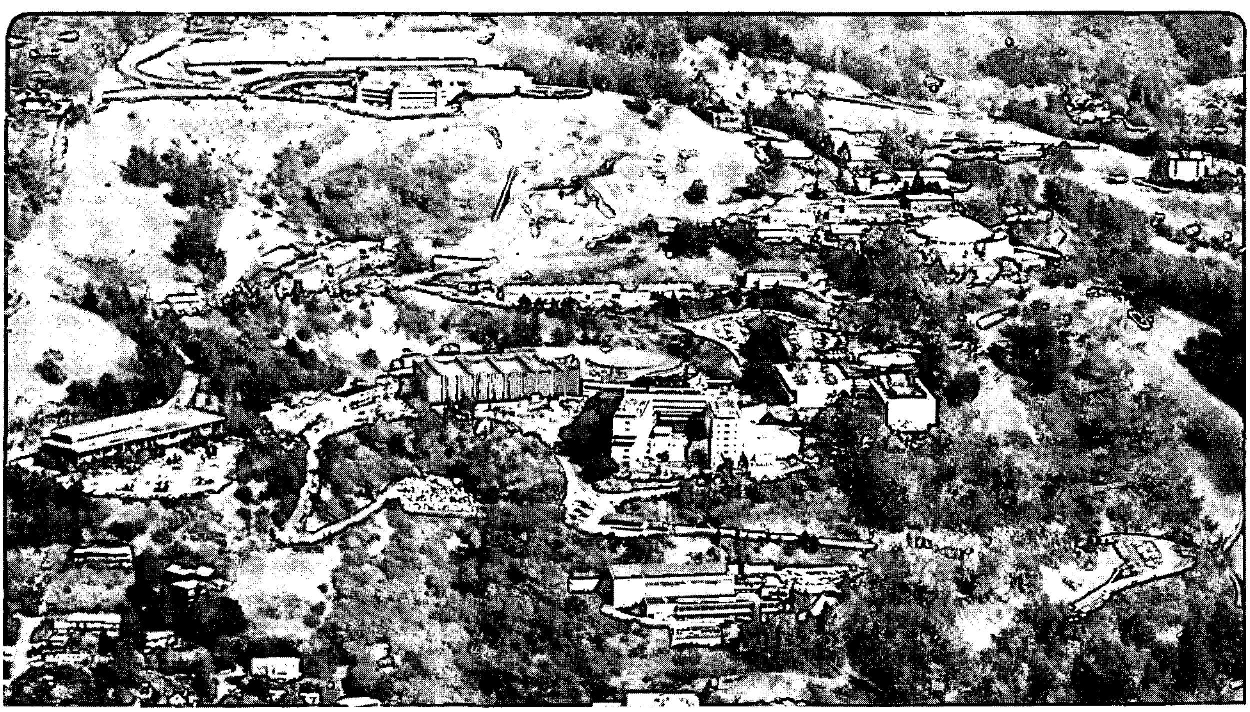

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AUTHOR R. Reimers, A. Lake / DEPARTMENT Mechanical Engineering	LOCATION Berkeley	DATE December 8, 1976	

PROGRAM – PROJECT – JOB

PEP

Injection

TITLE

PEP Transport Bend Magnet 25B5249, (B3 through B9)

Revisions: 'A' – R. Reimers – 9/79 – Delete 3 pages – Revise 8 pages to agree with measurements.
'B' – R. Reimers – 10/30/79 – Revise NI (p. 3) & 20 GeV cooling (p. 8).

The purpose of this note is to describe the criteria and the design of the above PEP injection system magnet.

1. The PEP Beam

Short intense pulses of electrons and positrons from the SLAC accelerator will be switched into the PEP beam transport and injection system by pulsed magnets. There will be two nearly identical transport systems connecting SLAC and the PEP ring; one will transport electrons, the other positrons. Each transport system will utilize 7 bend magnets of this design. The bend angle is 131 milliradians for beam energies up to 20 GeV. The magnet designations in the transport lines are 41B3 through 41B9 and 42B3 through 42B9.

2. Aperture and Good Field Region

The clear aperture required for the beam at the bend locations is approximately elliptical with horizontal and vertical diameters of 50 and 20 millimeters respectively. The magnetic field in this area is required to be uniform to within $\pm 3 \times 10^{-3}$. The field quality analysis was done jointly by J. Peterson, K. Halbach, and J. Singh (LBL Mechanical Department). The relations between tips, beam envelope, and actual good field region are shown on LBL drawing 17M3653.

3. List of Personnel Involved in the Design

K. Brown, (SLAC), J. Peterson, R, Avery, K. Halbach, A. Lake, D. Morris, R. Reimers, J. Singh.

4. Parameters

The parameters' values chosen are as shown in Appendices A and B and Tables 1 and 2 attached.

5. Drawings

The design is shown on the following LBL drawings:

Core - 17M3714
Coil - 17M3666
Overall assy - 17M3726

6. Schedule

Procurement began December 1976. Installation of 14 magnets completed 8/79.

7. Direct B3 Costs (excludes design, inspection, measurement)

	Material Cost	Labor Cost	Total $	PO/JO	Date
Conductor	20,367	----	20,367[(a)]	2179902	1977
Coil Fabrication and Magnet Assy.	----	97,415	97,415	2439002	1977-78
Core steel	54,096	----	54,096	2773502	5/77
Anneal	----	8,965	8,965	2773512	6/77
Core Fab	----	142,030	142,030	2439012	3/77
Flatten steel	----	5,713	5,713	3269002	1977-78
Misc. Hardware	1,000	----	1,000	----	1977-78
Beam tubes	2,177	----	2,177	----	
Bend tubes	----	4,014	4,014	3585902	
TOTAL FAB			335,777		
TOTAL WEIGHT			172,200 lbs.		

Specific Cost = $335,777/172,200 lbs. = $1.95/lb.

(a) = pro rata, assume 90% if conductor used on B3 magnets.
$20,367 = .9 X $22,630.

8. Testing and Measurements

Done at SLAC by Don Nelson (LBL). He has the origninal data and Jack Peterson (LBL) has it also.

9. Operating Design Philosophy

Initially the magnets will be operated only up to 15 GeV. If 20 GeV is desired in the future, the below-ground hardware is adequate but additional power supplies and increased water pressure will be needed. Note that the temperature rise at 20 GeV energy requires more than 150 psig across the coils. A careful re-examination of the LCW requirements as well as a physical flow check at operating pressure and power is a must if these magnets are to be run above 15 GeV, since the measurements indicate that the efficiency at 20 GeV is only 71.5%, not 82.4% as originally calculated.

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Appendix A - Bend Magnet 25B5249 Design Parameters

	Symbol	Units	Value	Footnotes
1. Magnetic @ 15 GeV.				
A. Beam energy	E	GeV	15	
B. Size of good field required	-	mm	50 wide x 20 high ellipse	
C. Effective length	ℓ_{eff}	mm	5274	
D. Bend angle	θ	radians	.1312	
E. Beam stiffness	Bρ	kilogauss meters	500.4	
F. Gap Field	B gap	kilogauss	12.45	(1)
		Tesla	1.245	(2)
(B) G. NI (total required)	(NI) req.	Ampere turns	~~25,531~~ 26,560	(3)
H1. Yoke field @ 15 GeV	B_{yoke}	Tesla	Rt. 1.37 Left 1.46	(4)
(A) J. Magnet efficiency (measured)	η	none	15 GeV - .936	
K. Field Quality at 25 mm from ctr.	$\lvert\Sigma\Delta B_n\rvert/B$	none	15 GeV - .0029	(4)
2. Core				
(A) A. Vertical gap	g	mm	25.1	
B. Core length	ℓ_{core}	mm	5249	
C. Core width	-	mm	664	
D. Overall core height	-	mm	~341	
E. Core material	-	-	C1010 Annealed	
F. Total core weight	W_{core}	kg	5150	

Appendix A - Bend Magnet 25B5249 Design Parameters (Cont.)

	Symbol	Units	Value	Footnotes
3. Coil				
A. Number of turns per coil	N_{coil}	Turns	16	(3)
B. Conductor material	-	-	Alum. Alloy 1060F	
C. Conductor outside dims.	-	mm	80 x 8	
D. Conductor I.D. (coolant hole)	-	mm	3 holes @ 4.7 x 8.0	
E. Conductor net area	-	mm^2	539.5	
F. Conductor length/ coil	-	meters	184.3	(5)
G. Conductor weight/ coil	-	kg	268	(11)
H. Conductor overall length/magnet	-	meters	368.	
I. Conductor weight/ magnet	-	kg	537	
J. Coil packing factor	-	-	.73	(6)
K. Number of coils per pole	-	-	1	
L. Coils per magnet	-	-	2	
4. Electrical @ 15 GeV				
A. Voltage type	-	-	DC	
(A) B. Current per magnet (measured)	I	Amps.	830	
C. Current density (calculated)	I/A	$Amps/mm^2$	1.54	(10)
D. Resistance or impedance per magnet	R	ohms	.02069	(7)
(A) E. Voltage drop across magnet @ 15 GeV	ΔV	Volts	17.2	(8)
(A) F. Power per magnet	P	kilowatts	14.26	(9)

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA ENGINEERING NOTE		CODE PE0103	SERIAL M5017B	PAGE 5 OF 8
AUTHOR R. Reimers, A. Lake	DEPARTMENT Mechanical Engineering	LOCATION Berkeley	DATE December 8, 1976	

Appendix A - Bend Magnet 25B5249 Design Parameters (Cont.)

5. Cooling @ 15 GeV

		Symbol	Value	Units
A.	Beam Energy	E	15	GeV
B.	Heat removal rate/waterhole	P	2.38	kW
C.	Pressure drop avail/waterhole	p	100	psig
D.	Length of coolant circuit	L	608	feet
E.	Min. coolant ckt. I.D., equiv.	d	.224 in	inches
F.	Specific press. drop	k	16.5	psig/100 ft
G.	Specific press. drop	k	38.2	ft/100 ft
H.	Flow/hole (from LBL DD10)	q	.433	gpm
I.	Flow/magnet= 6 X flow/hole	6q	2.60	gpm
J.	Coil temp. rise = $\frac{3.8P}{q}$ (from LBL DD57)	T	20.8	deg. C
K.	Water input temp., max.	T_{in}	35	deg. C
L.	Water output temp., max.	T_{out}	55.3	deg. C

Footnotes to Appendix A

1) $B = \theta B\rho/\ell_{eff}$ = .1312 (500.4)/5.274 = 12.448 kGauss

2) [illegible]

3) Let NI = Ampere truns

then $NI = Bg \div 4\pi\ 10^{-7}\ \eta$

where B = magnetic field in Tesla

g = gap in meters

η = magnetic efficiency, dimensionless, value less than 1.

Values are as follows:

B = 1.245 Tesla

g = .0251 meters (measured)

η = .97 (From POISSON program, predicted)

η = .936 From measurements

AUTHOR R. Reimers, A. Lake | DEPARTMENT Mechanical Engineering | LOCATION Berkeley | DATE December 8, 1976

Footnotes to Appendix A (Cont.)

Then NI = 26560 Ampere turns per magnet

and for N = 32 I = 830 amps.

4) Per J. Singh, dated 11/16/76

5) Length of conductor per turn = 5274(2) + 2π 109 + (202-60) 2 = 11516 mm

" " " coil = 16 turns x 11.516 meters/turn = 184.3 meters

6) Conductor area 10,209 sq. mm

Potted cross section 13,920 sq. mm

Thus: packing factor = 10209/13920 = .73

7) $R = \frac{\rho L}{A} = \frac{.00003053 \text{ ohm-mm} \times 368{,}512 \text{ mm}}{539.5 \text{ sq. mm}} = .02085$ ohms @ 45° C

8) ΔV = IR = 830 x .02085 = 17.2 volts

9) Power per magnet = .001 IΔV = .001 x 830 x 17.2 = 14.26 kilowatts @ 45° coil temp.

10) j = I/A = current density = 830 amperes ÷ 539.5 square mm

= 1.57 amperes per square mm

11) conductor wt/turn = 11,516 mm/turn (539.5 mm) 2.7 (10^{-6}) kg/mm^3

= 16.77 kg

conductor wt/coil = 16 (16.77 kg) = 268 kg

conductor wt/mag = 2 coils (268) = 537 kg

= 2.2 lb/kg (537 kg) = 1181 lb.

Conductor inside dia. at min. hole tolerances:

$$m = \text{hydraulic radius} = m = \frac{\text{Area}}{\text{wetted perimeter}} \text{ (definition)}$$

$$= \frac{\frac{\pi}{4}(4.4)^2 + 2.9(4.4)}{\pi(4.4) + 2(2.9)} = 1.42$$

Equivalent dia. = 4m = 4(1.42) = 5.70 mm

= .224 inches

Appendix B - Bend Magnet 25B5249 Design Parameters at 20 GeV (Future)

		Symbol	Units	Value	Footnotes
	1. Magnetic @ 20 GeV				
	A. Beam energy	E	GeV	20	
	B. Size of good field required	-	mm	50 wide x 20 high ellipse	
	Beam stiffness	B	kG-m	667.2	
	C. Gap Field	B	Kilogauss	16.60	(1)
			Tesla	1.66	(2)
⚠A	D. NI (required)	$(NI)_{req.}$	Ampere turns	46,400	(3)
	E. Yoke field	"	"	1.85	
⚠A	F. Magnet efficiency	η	none	.715	(8)
	G. Field Quality at 25 mm from CTR	$\lvert\Sigma\Delta B_n\rvert/B$	none	.0035	(4)
	2. Electrical @ 20 GeV				
	A. Voltage type	-	-	DC	
⚠A	B. Current per magnet	I	Amps.	1450	(3)
⚠A	C. Current density	I/A	Amps/mm	2.69	(7)
	D. Resistance or impedance per magnet	R	ohms	.02085	(7A)
⚠A	E. Voltage drop across magnet @ 20 GeV	ΔV	Volts	30.2	(5)
⚠A	F. Power per magnet	P	kilowatts	43.84	(6)

LAWRENCE BERKELEY LABORATORY · UNIVERSITY OF CALIFORNIA ENGINEERING NOTE	CODE PE0103	SERIAL M5017B	PAGE 8 OF 8
AUTHOR R. Reimers, A. Lake / DEPARTMENT Mechanical Engineering	LOCATION Berkeley	DATE December 8, 1976	

3. Cooling @ 20 GeV

		Symbol	Value	Units
A.	Beam Energy	E	20	GeV
B.	Heat removal rate/waterhole	P	7.31	kW
C.	Pressure drop avail/waterhole	p	316	psig
D.	Length of coolant circuit	L	608	feet
E.	Min. coolant ckt. I.D., equiv.	d	.224	inches
F.	Specific press. drop	k	52	psig/100 ft
G.	Specific press. drop	k	118	ft/100 ft
H.	Flow/hole (from LBL DD10)	q	.79	gpm
I.	Flow/magnet = 6 X flow/hole	6q	4.76	gpm
J.	Coil temp. rise = $\frac{3.8P}{q}$ (from LBL DD57)	T	35	deg. C
K.	Water input temp., max.	T_{in}	35	deg. C
L.	Water output temp., max.	T_{out}	70	deg. C

B

Footnotes to Appendix B

1) B = 12.448 (20/15) = 16.60 kGauss = 1.66 Tesla.

2)

3) Let NI = Ampere turns

then $NI = Bg \div 4\pi\ 10^{-7}\ \eta$

where B = magnetic field in Tesla

g = gap in meters

η = magnetic efficiency, dimensionless, value less than 1.

Values are as follows:

B = 1.66 Tesla

A a = .0251 meters (From design value)

A η = .715 (measured 1979 by D. Nelson)

Then NI = 46400 Ampere turns per pole

and for N = 32, I = 1450 amps.

4) Per J. Singh 11/16/76

5) ΔV = IR = 1450 x .02085 = 30.2 volts

6) Power per magnet = .001 IΔV = .001 x 1450 x30.2 = 43.84 kilowatts

7) j = I/A = current density = 1450 amperes ÷ 539.5 square mm. = 2.69 amperes/mm.

A 8) Measured value

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