MAGNETS AND MAGNET POWER SUPPLIES FOR LAMPF II*

Martyn H. Foss, Walter F. Praeg,† and Kenneth Thompson†
Los Alamos National Laboratory, Los Alamos, NM 87545

Summary

Los Alamos National Laboratory is planning a synchrotron that will use LAMPF, the existing 1-mA, 800-MeV, proton linac as an injector. This synchrotron, known as LAMPF II, will supply 100 μA at tens of GeV. Cost estimates for magnets and magnet power supplies are presented. A booster-synchrotron combination is compared with a synchrotron.

The design of a 32-GeV LAMPF II synchrotron is reported at this meeting.[1] The magnet apertures are chosen to give a Laslett tune shift of -0.24 with a 30-Hz repetition rate and 200-μA average beam. It was assumed that $\epsilon_x = 2 \times \epsilon_y$ and that round beam pipes were employed outside the dipole magnets. There is an additional aperture allowance for vacuum chamber and alignment errors. The resulting magnets are described in Table I.

TABLE I

REQUIRED MAGNET APERTURES

Magnet	No. Required	Length (m)	B (T)	B' (T/m)	Aperture (mm) Height	Width	Diameter
Focusing dipole	100	2.88	1.198	5.31	56.6	91.7	
Defocusing dipole	100	2.88	1.198	-5.30	65.3	73.9	
Focusing quadrupole	30	1.00	0	15.08			103.4
Defocusing quadrupole	15	2.00	0	-13.81			92.8

Synchrotron Magnet Costs

The magnet costs were estimated with the aid of two computer codes under development at Argonne National Laboratory.[2,3] These costs were based on unit costs for materials, labor, and equipment, some of which are shown in Table II. The number of turns in each coil was chosen to match power-supply requirements. Minor gap adjustments were made so that the dipoles and quadrupoles could run in series. The magnet costs, given in Table III, are the results of detailed calculations. These figures include the cost of 10% spares and 20% contingency. The total is $19 million.

TABLE II

MAJOR UNIT COST

Steel sheet	$1.80/kg ($0.80/lb)
Conductor and insulation	$8.80/kg ($4.00/lb)
Stainless steel	$3.84/kg ($1.70/lb)
End-plate fabrication	$4500/magnet
Bending-magnet lamination stamping	$1.05/piece
Quadrupole-magnet lamination stamping	$1.20/two pieces
Lamination die(s):	
Bending magnet	$50 K/magnet type
Quadrupole magnet	$30 K/magnet type
Electrical power	$0.04/kW-hr
Labor costs	$3924/man-month

Magnet Power Supply

The rf requirements, accelerating volts per turn, and frequency range present a major problem. For this reason, a magnet-current waveform with a slow rise and rapid fall is desired. Also, a period of constant low field is useful for injection. A power supply with these features is discussed in Ref. 4 and is the basis of this cost estimate. A simplified circuit is illustrated in Fig. 1, and voltage and current waveforms are shown in Fig. 2. With switches S_I and S_{II} open, the circuit oscillates at the high frequency (60 Hz). When the magnet reaches injection field (t = 0), the condensers have zero voltage and are

TABLE III

MAGNET OPERATING PARAMETERS AND COSTS

	Defocusing Dipoles	Focusing Dipoles	Defocusing Quadrupoles	Focusing Quadrupoles	Totals
Bore or aperture (cm)	6.53 x 7.39	5.71 x 9.17	9.66	10.34	
Effective length (cm)	288	288	100	200	
Inductance (mH)	2.86	2.47	1.45	4.43	
Time constant (s)	0.92	1.02	0.67	0.86	
ê (V) at 30 Hz	1119	968	469	1432	
Iac (A)	2065	2065	1701	1701	
Idc (A)	2257	2257	1859	1859	
Irms (A)	2688	2688	2214	2214	
P (kW)	29.0	24.0	12.2	29.4	
W (kJ)	26.7	23.1	9.2	28.1	
Quantity	100	100	30	15	245
ΣP (kW)	3000	2443	375	449	6267
ΣW (kJ)	2668	2308	276	422	5674
ΣK$	8325	8213	1365	1086	18 989

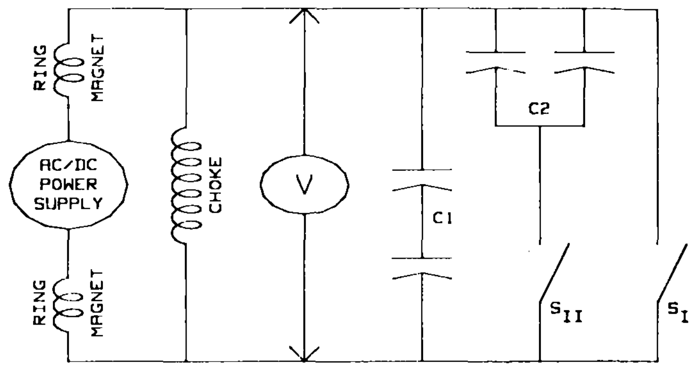

Fig. 1. Schematic of magnet circuit.

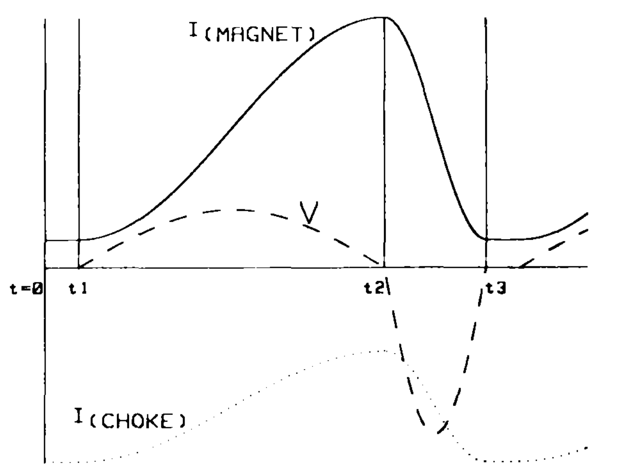

Fig. 2. Magnet and choke currents and V.

*Work supported by the US Department of Energy.
†Argonne National Laboratory, Argonne, IL 60439.

shorted by S_I. The power supply maintains the injection field until $t = t_1 = 1$ ms. At this time, switch S_{II} is closed and S_I is opened. The circuit now contains both C_1 and C_2 in parallel, and the synchrotron field rises at the lower frequency (20.83 Hz). When the peak field is reached at $t = t_2 = 25$ ms, the condensers again have zero voltage and switch S_{II} is opened. The synchrotron field falls at the higher frequency to the injection field and the cycle is completed in one-thirtieth of a second.

Power Supply Costs

The costs included are the power supplies, condensers, switches, chokes, and interconnection. Some of the assumptions used are

- Circuit losses are estimated to have the following distribution:

Ring magnets	35%
Chokes	35%
Capacitors	5%
Interconnections	5%
Filters	4%
Power supplies	16%

- Large 12-phase dc power supplies cost $125/kW. This figure is increased by 50% to include the phase-shifting auto transformers to obtain 48-phase systems and to cover additional power supply modifications such as feedback and feed-forward loops and filters, etc. This brings the cost to $187.5/kW.
- Used throughout are 400-kV•A, 60-Hz capacitors with two bushings. Cost of each is $600, as of January 1983. An additional 50% is added to this cost for support structures, fuses, and interconnections within the capacitor bank.
- Chokes have twice the inductance of the magnets and are estimated to cost 20% of the magnet cost.
- Interconnections. With a total of 248 magnets (245 + 3 spare quadrupoles) and 2 resonant circuits, the total cost is estimated to be 25% of the magnet cost.

Power supply costs are summarized in Table IV. The total is $15 million.

TABLE IV

COST ESTIMATE FOR POWER SYSTEMS IN $K

	Power System		
	Dipoles	Quadrupoles	Totals
Rating (kV•A)	10 x 1515	4 x 400	
Power supplies	2835	300	3135
C_1	1279	216	1495
C_2	602	272	874
S_1	560	119	679
S_2	224	48	272
Chokes	3300	489	3789
Interconnections	4125	612	4737
Totals	13 000	2000	15 000

Total Cost of 0.8- to 32-GeV Synchrotron

The magnets cost $19 million and the power supplies cost $15 million, giving a total of $34 million for the hardware. The cost of power for five years of continuous operation at $0.04 per kWh is $30 million. These added together give $64 million for the total.

Cost of a Booster-Synchrotron Combination

Because of the rapid acceleration to high energy, the rf requirements are formidable. The rf is greatly simplified if the acceleration is divided into two steps. Unit magnet costs are reduced also. Booster magnets, in which the protons are accelerated to a few GeV, have the large injection aperture but only go to low $B\rho$. The synchrotron magnets that go to high field have a smaller aperture.

The cost of a 0.8- to 32-GeV synchrotron was recalculated and factors were adjusted to give the previous results. Using this program, the costs of a 0.8- to 6-GeV booster and a 6- to 32-GeV synchrotron were calculated. For the most part the design of the single synchrotron was copied for both the booster and the 6- to 32-GeV synchrotron. However, the booster dipoles were half as long, and the chamber sizes in the synchrotron were reduced. The space allowed for the beam was reduced by 50% in each direction, but the allowances for error and vacuum chamber were kept the same.

The resulting costs are shown in Table V. Total cost for the booster and synchrotron is ~$38 million. The cost of power to run these machines for five years is ~$22 million, and the total is ~$61 million, about the same as that for the 0.8- to 32-GeV synchrotron.

TABLE V

BOOSTER AND SYNCHROTRON COSTS ($ MILLION)

	Magnets	Power supplies, etc.	Total Machine	Five-year power	Machine + Power
0.8- to 6-GeV booster	9.0	3.7	12.7	4.4	17
6- to 32-GeV synchrotron	16.5	9.1	25.6	18.0	44
Booster + 6- to 32-Gev synchrotron	25	13	38	22	61
0.8- to 32-GeV synchrotron	19	15	34	30	64

Conclusion

These designs have not been optimized, and the costs of vacuum chamber, controls, rf, etc., have not been included. The costs of magnets and power supplies for the 0.8- to 32-GeV synchrotron have been calculated. Including power for five years of operation, this cost is $64 million. Calculated on the same basis, the cost for the 0.8- to 6-GeV booster and 6- to 32-GeV synchrotron combination is $61 million.

Further work will bring all costs down. The rf problems may dictate using the two-ring booster synchrotron system.

References

1. Warren, J. L., and Thiessen, H. A., "A Reference Design for LAMPF II," 12th Int. Conf. on High-Energy Accelerators, Fermi National Accelerator Laboratory, August 11-16, 1983, Los Alamos National Laboratory document LA-UR-83-2367.

2. Thompson, K., "An Interactive Code for the Optimization of Water-Cooled Conductors," Proc. 4th Int. Conf. on Magnet Technology, Report CONF-720908, p. 725 (1972).

3. Thompson, K., "An Interactive Computer Program for the Design and Costing of Magnets," Proc. 8th Int. Conf. on Magnet Technology, September 1983 (to be published).

4. Praeg, W. F., "Dual Frequency Ring Magnet Power Supply with Flat-Bottom," Proc. 1983 Particle Accelerator Conf., Santa Fe, NM, March 21-23, 1983, IEEE Trans. Nucl. Sci. 30, No. 4, p. 2873 (1983).