ARGONNE NATIONAL LABORATORY
P. O. Box 299
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PARTICLE ACCELERATOR DIVISION
SUMMARY REPORT

April through September 1956

John J. Livingood, Division Director

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TABLE OF CONTENTS

	<u>Page</u>
I. Introduction	3
A. History	3
B. Previous Formal Reports	3
C. Informal Reports	4
D. Personnel	4
E. Temporary Office and Laboratory Space	5
II. Abstracts of Reports, April through Sept. 1956	6
III. General Description of the 12.5-Bev Proton Synchrotron	12
A. Choice of Energy	12
B. Type of Machine	14
C. Maximum Magnetic Field	14
D. Injection Energy	15
E. Type of Injector	15
F. Choice of Betatron Oscillation Frequencies	16
G. Size of Vacuum Chamber and Beam Intensity	17
H. Magnet Dimensions, Power Supply and Rise Time	18
I. RF Accelerating System	18
J. Tentative Parameters	19
IV. Digital Computer Work	22
V. General Instrumentation	23
VI. Power Supply for D.C. Model Magnets	24
VII. Magnetic Measurements Instrumentation	27
VIII. D.C. Model Magnet	33
A. Construction and B-I Characteristics	33
B. Measurements of Radial Gradient	34
IX. R.F. System	35
X. Ring Magnet Power Supply	38
XI. Magnet Cooling	40
XII. Vacuum Chamber	42
XIII. Soil Studies	43
XIV. Building Design	44

PARTICLE ACCELERATOR DIVISION SUMMARY REPORT

I. INTRODUCTION

A. History

Interest in the design and construction of a multi-Bev particle accelerator had been expressed by various members of the Argonne National Laboratory as far back as January 1953. At about that time several meetings were held at the Laboratory and at The University of Chicago with representatives from a number of mid-western Universities who were interested in this field. Three to four members of the Argonne staff joined in the technical discussions of the Midwest Accelerator Conference (later, Midwest Universities Research Association) which grew out of these initial meetings, and attendance at these conferences has continued ever since.

In the fall of 1953, a series of indoctrination lectures on the theory of constant gradient and alternating gradient machines was given by Argonne staff members for the benefit of those interested, and throughout 1954 and 1955 a small group at Argonne devoted its efforts to understanding and advancing the theory of orbits in magnetic fields of various sorts, including those involved in the Fixed Field Alternating Gradient (FFAG) variety of accelerator, after this idea was broached by K. R. Symon, then of Wayne University. In the summer of 1955, a proposal for a tandem array of two FFAG machines was made, but later given up, on the grounds that the theory of such accelerators was not yet so far advanced as to make construction possible in the immediate future.

Since then the Laboratory has been authorized to design, construct and operate a more conventional machine in the 10 to 15-Bev range. Preliminary plans for the present machine were formulated in early February 1956.

For administrative reasons it seemed desirable to remove the work of the Accelerator Group from the Physics Division and to establish a separate Particle Accelerator Division (PAD); this was done on April 2, 1956.

B. Previous Formal Reports

Earlier activities of the Particle Accelerator Group (largely in the shape of informal theoretical reports) from December 1952 to March 1956 have been recorded in the following Physics Division Quarterly Reports:

ANL-5031, 5080, 5140, 5174, 5273, 5317, 5412, 5420, 5497, 5498, and 5554, and in the Unclassified Quarterly Report on Physical Sciences, ANL-5573. Also, there is an article in the ANL Annual Report of 1955, ANL-5610, page 50.

The following articles have been published in professional journals:

E. A. Crosbie and M. Hamermesh, "Coupling of Betatron and Phase Oscillations in the Synchrotron," Phys. Rev. 98, 233 (1955).

L. C. Teng, "Continuous Injection into Circular Ion Accelerators," Rev. Sci. Instr., 27, 106-107 (1956).

L. C. Teng, "Constant Frequency Multi-Bev FFAG Accelerators," Bull. Amer. Phys. Soc., Vol. 1, p. 178, G7, April, 1956.

L. C. Teng, "Linear Theory of Betatron Oscillations in Sectorial Cyclotrons," (Rev. Sci. Instr. in press).

The present Summary Report is the first to be issued by the Particle Accelerator Division and covers its first six months of activity, from April 2 to September 30, 1956.

C. Informal Reports

Mimeographed short articles which may be of interest to others actively engaged in accelerator design have been distributed privately (and will continue to so be) under the titles "Progress Reports" (now discontinued) and "ANLAD" (Argonne National Laboratory Accelerator Development) reports. Titles and abstracts of those already issued may be found in the ANL publications listed above. The minutes of weekly staff meetings are as yet of too little general interest to warrant outside distribution.

D. Personnel

The recruitment program up to the present is exhibited in the following list, which gives relevant dates of association with the accelerator project, and the institution of origin of visitors.

Staff

E. A. Crosbie - 1/53	J. J. Livingood - 1/53
M. I. Ferentz - 1/53	M. H. Foss - 1/55
M. Hamermesh - 1/53	J. H. Martin - 5/55
(Physics Division, ANL, part time after 3/56)	L. C. Teng - 6/55

H. Berman - 8/55

H. J. Hausman - Summer
only '55 (Ohio State
University)

K. H. Weberg - 11/55

J. S. Moenich - 11/55

H. A. Kampf - 3/56

W. C. Davidon - 3/56
(Physics Div. ANL; part
time)

J. Marshall - 3/56
(U. of Chicago; Summer '56,
part time otherwise)

H. B. Phillips - 3/56

E. F. Frisby - 4/56

D. S. Manson - 4/56

D. E. McMillan - 5/56

R. H. Lykken - 6/56

R. Trcka - 6/56

J. Mech - 6/56

J. W. Dawson - 7/56

G. O. Calabrese - Summer
only '56 (New York
University)

R. Blum - Summer
only '56 (California Insti-
tute of Technology)

A. A. Strassenburg -
Summer only '56
(U. of Kansas)

L. K. Wadhwa - 9/56
(National Physical Labora-
tory, New Delhi)

R. Perry - 9/56

Technicians

K. Menefee - 4/55

R. B. Kickert - 1/56

E. C. Berrill - 4/56

H. M. Easton - 5/56

R. Johnston - 9/56

M. J. Eck - 9/56

A. Muehlhausen - 9/56

R. Ward - 9/56

R. J. Rezba - 9/56

Draftsmen

C. Brzegowy - 6/56

J. Bywater - 8/56
(ANL Central Shops)

D. Mitchell - 9/56
(ANL Central Shops)

Secretaries

Mrs. Rita Hatfield - 4/56

Mrs. Ruth McCluskey - 8/56

Miss Judith Rose - Summer
'56 (ANL Clerical pool)

E. Temporary Laboratory and Office Space

In order to afford office and laboratory space for approximately the next two years (prior to the design and construction of appropriate facilities in close conjunction with the accelerator proper), Buildings 805 and 806

have been made available and were extensively altered in the early months of 1956. The former is a Quonset hut, 160 feet x 80 feet, with concrete floor, formerly used as a cafeteria. One half is now set aside as an electrical laboratory, with three offices and wash rooms; the other half has been air conditioned and equipped with a five-ton bridge crane. This half is used for magnet studies and for housing a small machine shop and stock room. An annex of 2500 square feet has been built alongside the Quonset, to house the following equipment:

(a) 125-ton air conditioning unit

(b) Water cooling system, capable of circulating up to 400 gpm of demineralized water at pressures up to 200 psi, through copper pipes to a number of stations throughout the entire main Quonset. The system includes a 500-gallon storage tank, two heat exchangers, four pumps and an (out-of-doors) cooling tower capable of dissipating 440 kw.

(c) Direct current generators for model magnet studies; two Chandeysson units, each delivering 3000 amperes at 12 volts, and four General Electric units, each good for 1500 amperes at 70 volts.

Building 806, a Quonset hut 70 x 40 feet, formerly Plant Protection Headquarters, is now devoted to office and drafting space for the Division. (To permit proximity to the computing machines AVIDAC and GEORGE, three members of the theoretical group still have their offices in the Physics Division building, D-203.)

It is planned to clean up and refurbish Building 817, a former storehouse of about 12,000 square feet, to afford further office and laboratory space when the need arises - in particular, the office and drafting space to be required by the Architect-Engineer staff expected within a few months.

II. ABSTRACTS OF REPORTS, APRIL THROUGH SEPTEMBER 1956

ANLAD-17 - General Theory of Second Order Non-Linear Effects in an AG Accelerator with Median Plane

L. C. Teng, April 2, 1956.

The method for analyzing linear betatron oscillations in an AG accelerator developed in ANLAD-5, 7, and 9 is generalized to include second order non-linear terms. The general equations of betatron oscillations up to second order terms are first transformed into forms expressed in terms of orbit coordinates and orbit parameters.

A two-dimensional generalization of the smooth approximation technique formulated in ANLAD-3 is then developed and applied to these equations. The resulting smoothed equations contain, now, in addition to linear terms which are identical to those obtained before, quadratic terms in the smoothed deviation variables. These quadratic terms show couplings between the radial and vertical oscillations with coupling coefficients given in terms of azimuthal average values of the orbit parameters. The resulting formulas can be applied easily to any AG accelerator.

ANLAD-18 - Focusing Conditions with Homogeneous Fields in Each Half Sector

M. Foss, April 14, 1956

Formulas are developed giving the focusing conditions and the frequencies of betatron oscillations for AG cyclotrons where the magnetic field in each half sector is homogeneous. Parameters specifying the fields in the half sectors, the widths of the half sectors, and the spiralling of the half sector boundaries are derived geometrically. Formulas giving frequencies of betatron oscillations in terms of these parameters are then derived using the general results of Progress Report I. Specifically, the possibilities of simultaneously satisfying the constant frequency and the betatron focusing conditions are studied. The numerical results are summarized in the following table.

<u>Ratio of fields in half sectors</u>	<u>Half sectors with boundaries symmetric with respect to a radius</u>	<u>Half sectors with one boundary radial</u>	<u>Half sectors with both boundaries spiralling at 30° from radial</u>
2.0	$\nu_z = 0.12$	$\nu_z = 0.15$	$\nu_z = 0.31$
1.9	defocusing	$\nu_z = 0.04$	$\nu_z = 0.24$
1.8	defocusing	defocusing	$\nu_z = 0.18$
1.7	defocusing	defocusing	$\nu_z = 0.10$

ANALD-19 - Focusing Conditions with Homogeneous Fields in Each Half Sector

E. A. Crosbie, May 13, 1956

In this paper we consider a fixed field accelerator having alternating constant fields H_1 and H_2 in each of two "half" sectors. The relative width of these "half" sectors may vary with the energy of the particle, and the position of the centers of the "half" sectors are permitted to spiral. Exact and zero-order smooth approximation formulae are derived for the betatron

wave lengths. Applying the constant frequency condition determines the variation of the relative "half" sector sizes with energy. Numerical results are given showing the variation of the betatron wave lengths with energy for a constant frequency machine having no spiral, 3 sectors, $H_1/H_2 = 1/2$, and various initial ratios of the "half" sector sizes.

ANLAD-23 - Focusing Conditions for a Machine in Which the
Half-Sector Fields Can Vary with Momentum
 E. A. Crosbie, May 9, 1956

This paper gives the betatron wave length equations for a fixed field machine with no spiral made up of alternating sections of angular widths θ_1 and θ_2 having fields H_1 and H_2 , respectively. θ_1 and θ_2 are allowed to vary arbitrarily with the momentum of the particle subject to the condition that $\theta_1 + \theta_2 = \frac{2\pi}{N}$, where N , the number of sectors, is kept fixed. H_1 and H_2 are to be constant within each half sector along the equilibrium orbit for each momentum, but may otherwise vary arbitrarily with the momentum. The x and z motion betatron wave lengths are then given as a function of the momentum of the particles, using the second-order smooth approximation. The special case of a machine having one of the half sector fields equal to zero is also considered.

ANLAD-24 - Detailed Study of the Acceptance of the 12.5-Bev Zero
Gradient Proton Synchrotron with $\nu_x = 3/4$ and
 $\nu_z = 7/8$
 L. C. Teng, June 18, 1956

The acceptance of the Argonne synchrotron is studied in detail. For numbers of radial and axial betatron oscillations per revolution $\nu_x = 3/4$ and $\nu_z = 7/8$, respectively, the beam, if injected from the outside just above the median plane, and with sufficiently large amplitude of radial betatron oscillation, will miss the inflector lip for 8 revolutions; during that time the rising magnetic field will shrink the equilibrium orbit of the injected protons away from the inflector lip so as to miss it also on the 8th passage. At the beginning of the injection when the amplitude of radial betatron oscillation is too small, the angular divergence in the inflected beam will cause part of it to hit the inflector lip and the wall of the vacuum chamber. Moreover, errors in alignment, lengths and fields of the magnets, error in the frequency of the accelerating RF, energy spread in the injected beam, synchrotron oscillation and gas scattering effect, all contribute to reduce the number of protons accepted. General formulae taking into account all of these effects are given. As a numerical example, it is computed that for the following parameters:

frequency error = 0.03%
 magnetic field error = 0.01%
 magnet length error = 0.01%
 magnet vertical displacement error = 0.01 in.
 radial tilt of magnet = 0.2 milliradian
 quality of injected beam = ± 0.4 in. milliradian
 intensity of injected beam = 5 mamp
 harmonic number of RF = 8
 pressure in chamber = 2×10^{-6} mm Hg,

the vertical full width of the inflector lip should be 1.158 in., the vertical full width of the vacuum chamber should be 4.5 in. and for a full radial chamber width of 15 in., if the rate of rise of the magnetic field during injection is optimized at 7.42 kgauss/sec and if the radial full width of the inflector lip is set to be 0.5 in., then the expected beam intensity at 12.5 Bev is 3.4×10^{11} protons/pulse; and if the normal rate of rise of the magnetic field, namely 20 kgauss/sec, is held during injection, the radial full width of the inflector lip should be 1.317 in. and the expected beam intensity is 2.5×10^{11} protons/pulse.

ANLAD-25 - Acceptance of the 12.5-Bev Zero Gradient
Synchrotron with $\nu_x = 7/8$ and $\nu_z = 3/4$
L. C. Teng, June 26, 1956

Studies similar to those in ANLAD-24 are made for the case of $\nu_x = 7/8$ and $\nu_z = 3/4$. It is shown that if the vertical full width of the inflector lip is 1.104 in. and placed so that the lower edge of the lip is 1.104 in. above the median plane, the inflected beam, in spite of its angular divergence, will completely enter the vacuum chamber from the very beginning of the injection period. Assuming the same errors and other parameters as in ANLAD-24, we can show that the full vertical width of the vacuum chamber should be 6.0 in. For various radial chamber widths the calculated acceptances are given in the following table:

Radial width (inches)	Optimized $\frac{dB}{dt}$ (kgauss/sec)	Optimized radial width of inflector lip (inch)	Optimized beam intensity at 12.5 Bev (protons/pulse)	Beam intensity for normal $\frac{dB}{dt}$ (protons/pulse)
15	13.79	0.698	4.36×10^{11}	3.57×10^{11}
17	12.13	0.614	8.07	6.01
19	11.06	0.560	12.20	8.46
21	10.29	0.521	16.68	10.90
23	9.70	0.491	21.47	13.35
25	9.23	0.467	26.52	15.79

ANLAD-26 - Gas Scattering in the 12.5-Bev Ring - II
M. Ferentz - July 3, 1956

This is a supplementary report to ANLAD-12. The effect of gas scattering is studied for the specific mode of operation where the protons are left to circulate freely for a number of revolutions before the accelerating RF is applied. General formulae and necessary functions are given. Numerical results on the Argonne accelerator indicate that for an injection energy of 50 Mev and an energy gain of 8 kev/rev the increased effect of gas scattering when the RF is not applied until after 6250 revolutions of the protons can be compensated by improving the vacuum, by a factor of 2, over the necessary vacuum when the RF is applied immediately.

ANLAD-27 - Energy and Angular Spread of 12.5-Bev Protons in
Piccioni Targets - E. A. Crosbie, July 13, 1956

The target thickness required to produce a desired shift of the equilibrium orbit of 12.5-Bev protons for use with a Piccioni Ejection Scheme is given for three targets: Be, Al and Ni, and for two operating points: $\nu_x = 3/4$, $\nu_z = 7/8$, and $\nu_x = 7/8$, $\nu_z = 3/4$. The expected energy and angular spread are calculated for each of the above cases. The angular spread (in radians) for a one-inch shift of the orbit, for $\nu_x = 3/4$, $\nu_z = 7/8$, is about 0.25×10^{-3} for Be, 0.45×10^{-3} for Al and 0.66×10^{-3} for Ni. The energy spread for the same operating point is about 1.4 Mev for Be, 1.6 Mev for Al and 1.7 Mev for Ni with more particles below the average shift than above. The $\nu_x = 7/8$, $\nu_z = 3/4$ operating point gives slightly larger values for the angular and energy spreads.

ANLAD-28 - A Special Case of Alternating Gradient Focusing
E. A. Crosbie, July 13, 1956

A matrix treatment of the phase oscillation problem for a single cavity machine is presented. The method is then used to calculate the energy and phase oscillations for a machine having two cavities of equal frequency but different voltages spaced 180° apart. If the two oscillators are run in phase and operate on an odd harmonic or are 180° out of phase and operate on an even harmonic, the maximum energy excursion of the particle for a given initial phase error is larger than for a single oscillator operating at the same frequency and producing the same energy gain per turn. If the two oscillators are in phase and have an even harmonic frequency or are 180° out of phase and have an odd harmonic frequency then the maximum energy excursion is less than that for an equivalent single cavity.

ANLAD-29 - Linear Theory of Regenerative Deflectors Applied
to AG Accelerators

L. C. Teng, July 16, 1956

It is shown that regenerative deflectors of the type first applied to the Liverpool synchrocyclotron can be applied to all AG accelerators as well. The linear theory of the operation of such a system is formulated using the matrix method. The linear betatron focusing action of any AG accelerator can be specified by three parameters and the action of a narrow regenerative deflector element is characterized by a single parameter. The details of the geometry of the proton orbit going through one narrow deflector element are given in terms of these four parameters. Specifically, general formulae are derived for the gain of the amplitude of the forced radial oscillation, the expansion of the axial aperture of the beam and the azimuths of the maximum radial excursions. As deflector elements, two different types, the gradient type and the wedge type are proposed and studied. These general formulae are then applied to the Argonne synchrotron considered truthfully as a weak AG accelerator, and numerical tables of values of parameters necessary for the design of such a deflector are given. As an example, it was found that with either a gradient element having a width of 1 ft and a magnetic field gradient of 14 kgauss/ft or a wedge element having a uniform magnetic field of 20 kgauss and a wedge angle of 40.4° placed at the end of a long straight sector, one can obtain a radial amplitude gain of 1.414 per revolution. The expansion of the vertical aperture of the beam is 1.3, and the location of the maximum outward radial excursion of the deflected beam is near the beginning of the same straight sector. An extraction magnet of 20 kgauss and 20 ft long placed in this straight sector will then lead the deflected beam clearly out of the accelerator.

This study is closely connected with the proposal made last year* of transferring a high-energy ion beam between circular AG (or non-AG) accelerators. A graphical method of characterizing and studying the ion orbit in an AG accelerator is also given.

ANLAD-30 - Orbital Effects of Ripples in the Magnet Circuit of
the Argonne 12.5-Bev Synchrotron

L. C. Teng, Sept. 20, 1956

Because of the distributed capacitance to ground in the magnet circuit, the voltage ripples in the power supply will cause unequal currents to flow through different magnets of the accelerator at a given time, thus producing magnetic field errors. Three different power supply arrangements are studied as networks. If all the magnets are connected in series with

*L. C. Teng, Rev. Sci. Instr., 27, 106 (1956).

voltage applied to the terminals, it is shown that 6, 12 or 18 phase rectified and unfiltered D.C. will produce relative field errors larger than 0.02% at the time of injection. The arrangement where four power supplies with ripple phases $\pi/2$ apart are series connected in four symmetric locations of the magnet circuit is not substantially better. However, if these four power supplies operate with their ripples all in phase, analysis indicates that the currents flowing in the magnets are identical at all times. This is generally true of N magnets and $\frac{N}{2}$ power supplies. With the last arrangement, although the instantaneous field error vanishes at any time, the field of the magnets will fluctuate in time at the ripple frequency in addition to rising linearly. This may resonate with the synchrotron oscillation.

ANL-5615 - The Soviet 10-Bev Proton Synchrotron
John Marshall, Sept. 1956

The information contained was collected mostly from papers presented by various Soviet scientists and engineers during the Moscow Conference on the physics of high energy particles of May 1956. Some of it was obtained by personal observation and a small amount from information divulged during the CERN symposium of June 1956.

III. GENERAL DESCRIPTION OF THE 12.5-Bev PROTON SYNCHROTRON
E. A. Crosbie, M. Foss, L. C. Teng

A. Choice of Energy

The final energy of 12.5 Bev for the Argonne accelerator was decided from the following considerations. To begin with, in view of the fact that a wide gap exists between the energy of 10 Bev given by the Russian synchrotron and the energies of 25-30 Bev which will be supplied by the AG synchrotrons under construction at CERN and the Brookhaven National Laboratory, it seems desirable to have an accelerator furnishing an intermediate energy. From the accompanying tables of the energies available in the center-of-mass systems of different reactions corresponding to various energies in the laboratory system and of the threshold energies of production for various particles, it can be seen that even with the most inefficient mode of usage of the laboratory energy, namely, the nucleon-nucleon collision, 12.5 Bev in the laboratory system is adequate for the production of all known particles, including all baryon pairs. With higher available center-of-mass energies in nucleon-nucleus and pion-nucleon collisions, we are sufficiently above the production threshold of even Ξ -particle pairs to insure sizable yields. The energy of 2.5 Bev in excess of the Russian 10-Bev synchrotron, made available by the Argonne accelerator at the time of its completion, will open up a wide scope of experiments which cannot be performed until then. On the other hand, at this relatively

less ambitious energy of 12.5 Bev, existing techniques of particle detection and analysis, which become rapidly inadequate for energies above 20 Bev, are still readily applicable. Furthermore, it is rather doubtful that additional energies in the center-of-mass system of a few Bev will introduce anything other than more troublesome background problems due to multiple productions of L and K mesons.

Total Available Energies in the Center-of-Mass Systems of Different Reactions for Various Energies of the Incident Nucleon in the Laboratory System

Lab. K.E. of incident nucleon (Bev)	Total C.O.M. Kinetic Energy		
	Nucleon- nucleon (Bev)	Nucleon- nucleus ⁽¹⁾ (Bev)	Pion ⁽²⁾ nucleon (Bev)
2.3	0.92	1.11	1.08
6.2	2.02	2.34	2.36
10.0	2.84	3.27	3.27
12.5	3.32	3.79	3.78
15.0	3.75	4.28	4.24
20.0	4.53	5.15	5.08
25.0	5.23	5.92	5.78
50.0	7.99	8.99	8.61

(1) Binding energy per nucleon = 8 Mev
Fermi energy per nucleon = 20 Mev.

(2) Pion of maximum energy produced in nucleon-nucleon collision.

Threshold Center-of-Mass Energies for the Productions of Various Particles

Particle		Threshold C.O.M. Energy (Bev)
L-Mesons	π^+	0.1397
	π^-	0.1394
	π^0	0.1350
K-Mesons	τ^+	0.4937
	τ^-	0.4937
	θ^0	0.493
	$K_{\pi_2}^{(\pm)}$	} ~0.493
	$K_{\pi_3}^{(\pm)}$	
	$K_{\mu_2}^{(\pm)}$	
	$K_{\mu_3}^{(\pm)}$	
	$K_{e_3}^{(\pm)}$	
Baryons	Nucleons ρ	0.938214
	n	0.939508
	Hyperons Λ^0	1.1147
	Σ^+	1.189
	Σ^-	1.189
	Ξ^-	1.321

B. Type of Machine

The most important deciding factors in the choice of the type of machine are:

1. Assurance of successful operation;
2. Simplicity in design and expediency in construction;
3. Attainment of the highest beam intensity in conformity with the above criteria.

The FFAG type of accelerator, although offering interesting possibilities, does not conform to criteria 1 and 2 and was, therefore, discarded. Comparative studies of strong focusing AG synchrotrons and weak focusing synchrotrons show that, although an AG synchrotron requires smaller magnets and, therefore, somewhat less iron, copper, and electric power, the construction time of a weak focusing synchrotron is shorter because of the simplicity of its design and the relative ease in construction tolerances. Furthermore, because of the possibility of multi-turn injection, a weak focusing synchrotron can deliver a beam several orders of magnitude higher in intensity than a strong focusing AG synchrotron. For further simplification of construction it was decided to separate the guiding and the focusing functions of the magnetic field. The field in each magnet section is completely uniform and supplies only radial betatron focusing action. The vertical focusing is obtained entirely from the fringing fields at the ends of the magnets. A magnet with a poleless picture-frame cross section offers the most efficient usage of iron for such a uniform field and can be excited to nearer saturation than other forms of magnet and field without seriously affecting the uniformity of the field. No pole-face winding is needed for such magnets; corrections to focusing effects at the ends can be introduced exclusively in straight sections between magnets. The inaccessibility of the internal beam for such an H-magnet is not detrimental if external beams extracted from the straight sections are available. A synchrotron with eight such magnets has convenient lengths of magnets and straight sections between magnets for the specific choice of betatron focusing conditions below. Smaller numbers of magnets require inconveniently long and heavy magnet sections and larger numbers of magnets give straight sections too short for conveniently extracting the accelerated beam. Furthermore, with eight magnets the power can be supplied by four generators of convenient size symmetrically located in the magnet circuit and operating in phase; thus removing inequalities of the currents in the magnets due to voltage ripples.

C. Maximum Magnetic Field

Since the linear dimensions of a synchrotron with a given final energy are inversely proportional to the maximum magnetic field, the maximum total stored energy, being proportional to the square of the maximum

field times the cube of the linear dimension, is therefore inversely proportional to the maximum field. The total tonnages of iron and copper, being proportional to the cube of the linear dimension, are inversely proportional to the cube of the maximum field. Hence, within the limit of saturation of the magnet iron, it is advantageous in all respects to employ the highest possible maximum field. With the chosen H-magnet and uniform field a maximum magnetic field of 20 kilogauss is easy to achieve. Tests made on models indicate that higher maximum fields are possible. But we shall, at this time, conservatively limit the maximum field to 20 kilogauss at 12.5 Bev and reserve the possibility of raising it to higher values for the future.

D. Injection Energy

A high injection energy has many advantages, such as:

1. The reduction of the range of frequency modulation of the accelerating RF for a given final energy;
2. The relatively less disturbance caused by the remanent field and the eddy currents in the magnet on the higher injection field;
3. The relatively closer spacing between successive turns of injected protons enabling a greater number of protons accepted for a given radial width of the vacuum chamber;
4. The reduction of beam loss due to gas scattering and the relaxation of the space charge limitation; and,
5. The better quality of the beam obtainable from the injector at higher energies.

However, higher injection energies require more elaborate injectors and more complicated inflector systems for injection. As an appropriate compromise the injection energy was chosen to be 50 Mev, when it is still feasible to use an electrostatic inflector.

E. Type of Injector

The possibilities of using either a linear accelerator or a cyclotron for the injector were studied. In order to obtain a 50-Mev proton beam of sufficiently high intensity (of the order of milliamperes) and of sufficiently long pulse duration (several hundred micro-seconds, for multi-turn injection) one would have to use a constant frequency Thomas cyclotron. Such a cyclotron, although having the promise of giving an extremely high beam intensity (up to 500 milliamperes) has never been constructed and will require more studies and tests than a 50-Mev linear accelerator. In addition, the extraction of the accelerated beam from such a Thomas cyclotron without impairing the beam quality introduces further complications. On the other hand, a linear accelerator giving a 5 to 10-mamp beam of 50-Mev protons having a very

good beam quality of ± 0.4 inch-milliradian and a very small energy spread of $\pm 0.15\%$, is being designed and constructed at the Brookhaven National Laboratory. A similar linear accelerator will be used as the injector for the Argonne synchrotron.

F. Choice of Betatron Oscillation Frequencies

When the final energy and the maximum magnetic field are fixed, the betatron oscillation frequencies of the zero-gradient synchrotron described above depend only on the ratio between the total lengths of magnet sections and of straight sections, and the angle the equilibrium orbit makes with the end faces of the magnets. Four conditions must be met in choosing the values of ν_x and ν_z , the number of radial and vertical betatron oscillations per revolution.

1. The total length of straight sections should be large enough to supply adequate space for vacuum pumps, accelerating RF cavities, correcting magnetic lenses, beam detection and other types of probes, and beam extraction mechanisms; and not so large as to make the total length of magnet and, hence, the radius of the machine, inconveniently large.

2. The values of ν_x and ν_z should be adjusted so that the protons injected at a sufficiently large amplitude of radial betatron oscillations will miss the inflector lip for several revolutions; during that time the rising magnetic field will completely pull the protons away from the inflector. (The accelerating RF is not turned on until after the injection is completed.)

3. The vertical and radial displacements of the proton orbits due to constructional errors depend on the values of ν_x and ν_z . These values should, therefore, be chosen to minimize the effects of these errors.

4. The operating point on the ν_x versus ν_z diagram should not fall upon any serious resonance line.

The total length of magnet corresponding to a maximum magnetic field of 20 kilogauss at 12.5 Bev is 461 ft. The total length of straight sections chosen appropriately according to condition 1, above, is 130 ft. By adjusting the angle between the equilibrium orbit and the end faces of the magnets, two sets of values of ν_x and ν_z , namely, $\nu_x = 3/4$, $\nu_z = 7/8$ and $\nu_x = 7/8$, $\nu_z = 3/4$ can be obtained, either of which will enable the inflected beam to miss the inflector lip for eight revolutions. The first set of values, giving a smaller radial displacement corresponding to given constructional errors, requires injection just above the median plane, while the second set, giving a larger radial displacement, requires injection above the median plane by a considerably larger amount, thereby necessitating a larger gap of the magnet. Consequently, the first set was chosen to be the final values.

One notices that these values fall on the $2\nu_z - \nu_x = 1$ non-linear difference resonance. However, numerical orbit tracings performed on the AVIDAC show that non-linear effects such as this are completely negligible for this type of weak focusing machine. Because of the need of long (20 ft) straight sections for beam extraction, the eight straight sections will be divided into four long ones with four short ones interposed.

G. Size of Vacuum Chamber and Beam Intensity

The necessary inside cross-sectional dimensions of the vacuum chamber depend on the constructional errors, the quality and energy spread in the injected beam, the amplitude of the synchrotron oscillation, and the expected acceptance. Assuming a quality of ± 0.4 inch-milliradian for the proton beam injected just above the median plane, the minimized vertical height of the beam is 1.15 in. Assuming the vertical displacement errors of the magnets to be ± 0.02 in. and the radial tilts of the magnets to be ± 0.4 milliradian, the vertical error displacement amplitude of the beam is 1.10 in. Allowing 0.75 in. for the end structures of the inflector lip we arrive at a full inside vertical chamber height of 6.0 in. Radially the errors of the fields and the lengths of the magnets are assumed to be $\pm 0.04\%$ each and the frequency error is conservatively assumed to be $\pm 0.15\%$. (It is expected that the frequency programming scheme described below will give much better performance than this. Actually, all the assumed errors should be understood as the estimated upper limits.) These errors cause a radial error displacement amplitude of 4.0 in. The energy spread of $\pm 0.15\%$ in the injected beam will cause an additional radial displacement amplitude of 0.78 in. The assumed frequency error of $\pm 0.15\%$ further necessitates using accelerating RF operating at the fourth harmonic of the particle circulation frequency. At an energy gain of 7.87 keV/revolution determined by the rise-time below, the amplitude of the synchrotron oscillation is 4.25 in. Altogether the above-mentioned displacement amplitudes amount to a reduction of the useful full radial width of the vacuum chamber by 18.1 in. With a full inside radial width of 36.0 in. for the chamber and the magnetic field rising at the rate of 19.54 kilogauss/second (determined by the rise-time discussed below) the 17.9 in. of effective full radial width of the chamber allows an injection of 55 turns. The computed loss due to gas scattering at a pressure of 2×10^{-6} millimeter mercury is 10% and the space charge limitation is 8×10^{13} protons. Assuming an intensity of 5 mamp for the injected beam and when all losses are accounted for, we get a beam intensity at 12.5 BeV of 10^{14} protons per pulse, which is the goal set for this accelerator. It should be emphasized that this beam intensity is based on very conservative estimates. It is believed that with additional improvements following the completion of the accelerator, the beam intensity can be raised to 10^{13} protons per pulse. The vacuum chamber is here assumed to be made of 1-inch thick, reinforced epoxy resin with 1 to 3-mil stainless steel lining.

H. Magnet Dimensions, Power Supply and Rise-Time

The poleless picture-frame construction of the magnets dictates that the full vertical height of the energizing coil be equal to the outside vertical dimension of the vacuum chamber, namely, 8.0 in. Increasing the radial width of the coil reduces the I^2R power loss but increases the tonnage of copper and steel and the stored energy, hence the necessary power rating of the generator for a given rise-time. A compromise coil width of 7.5 in. then determines the dimensions of the magnet yoke, the I^2R power loss, and the stored energy at 20 kilogauss. As the power supply, either D.C. generators or A.C. generators with ignitron-rectifiers can be used. In view of the experiences on the reliability of the latter system and the comparative lack of experience with the former, the A.C. generator ignitron-rectifier system may be preferred. Four six-phase generators running in phase on the same shaft with energy storage fly-wheels are connected in series symmetrically in the magnet circuit with two magnets between generators. The power rating of these generators is determined by the rise-time, a moderate value of which is decided to be one second. With this rise-time a probable repetition rate is one pulse every four seconds.

I. RF Accelerating System

Acceleration of the protons is effected by ferrite loaded RF cavities of relatively low Q and tuned to the 4th harmonic of the circulation frequency. Increasing the number of cavities reduces the necessary peak voltage on each cavity for given energy gain per revolution and equilibrium phase angle, and smoothes out the phase focusing actions. For operating at the 4th harmonic, a maximum number of four cavities oscillating in phase can be employed. These cavities will be symmetrically located in the short straight sections and driven by one master oscillator through separate amplifiers. Frequency self-tracking systems are provided to regulate the frequency by signals picked up on sensing probes from the proton beam after it has become sufficiently well bunched. Beam-positioning electrodes will control the peak voltage on the cavities from information on the radial position of the beam. (In order to make the frequency tracking scheme operative immediately after injection, the proton beam from the injector will have to be pre-bunched before entering the accelerator and the energy of the injected protons will have to be programmed according to the rising magnetic field through the whole period of injection so that the protons will stay bunched after entering the accelerator. This requires fairly elaborate electronic systems. It is expected that such frequency self-tracking immediately after the injection process is complete will reduce the frequency error to $\pm 0.03\%$, thereby substantially increasing the beam intensity at 12.5 Bev.)

J. Tentative Parameters of the Argonne 12.5-Bev Synchrotron

Injection

Energy = 50 Mev
 $(\beta = 0.3141, \gamma = 1.0533, \eta = 0.3308)$
 Magnetic field = 463 gauss
 Average magnetic field = 361 gauss
 Circulation frequency = 0.523 mc/sec
 Circulation period = 1.914 microsec

Final

Energy = 12.5 Bev
 $(\beta = 0.9976, \gamma = 14.323, \eta = 14.288)$
 Magnetic field = 20.0 kilogauss
 Average magnetic field = 15.59 kilogauss
 Circulation frequency = 1.660 mc/sec
 Circulation period = 0.6025 microsec

Orbit

Length = 591.1 ft
 Mean radius = 94.08 ft
 Length of magnet = 460.9 ft
 Length of straight section = 130.2 ft
 Radius of curvature in magnet = 73.36 ft
 Focal length of fringing field at end of magnet
 $= \pm 319.05 \text{ ft} \begin{pmatrix} + \text{vertical} \\ - \text{radial} \end{pmatrix}$
 Radial betatron oscillation per revolution = 0.75
 Vertical betatron oscillation per revolution = 0.875
 Momentum compaction $\alpha = 0.554$
 Average field index $k = \alpha - 1 = -0.446$

Acceleration

Energy gain per revolution = 7.87 keV
 Equilibrium RF phase = 30° (measured from voltage zero)
 Phase oscillation frequency = $2.946 \times 10^4 \text{ c/sec}$
 Rate of rise of magnetic field = 19.54 kilogauss/sec
 Rate of rise of average field = 15.23 kilogauss/sec
 Rise time = 1 sec
 Repetition rate = $1/4 \text{ sec}^{-1}$

Magnet

Structure - Laminated with poleless picture-frame cross-section (see diagram)

TENTATIVE MAGNET CROSS SECTION

Number of magnets = 8
 Length of each = 57.61 ft
 Magnet radius = 73.36 ft
 Angle between end face and radius of magnet
 = 13.0° (such that extension of magnet faces would
 intersect beyond the center of curvature of the
 magnet)
 Max. total stored energy = 58 mega-joules
 Max. m.m.f. = 280 kiloampere-turns
 Max. I^2R loss = 30 megawatts (with 30-turn water-cooled
 coil)
 Length of long straight section = 20.0 ft
 Length of short straight section = 12.56 ft
 Mean radius of machine = 94.08 ft
 Weight of steel - 6150 tons
 Weight of copper - 100 tons

Vacuum Chamber

Structure - Rectangular cross section made of reinforced epoxy resin with stainless steel lining.

Inside cross-sectional dimensions = 36.0 in. (width) by 6.0 in. (height)

Wall thickness = 1.0 in.

Accelerating RF Cavities

Ferrite loaded

Number of cavities = 4 (located in the short straight sections)

Harmonic number = 4

Q value = 20 to 40

Peak voltage = 3.94 kv

Frequency range = 2.09 to 6.64 mc/sec

Injector

Type - 110-ft single tank linear accelerator

Energy = 50 Mev

Beam current = 5 - 10 mamp

Beam quality = ± 0.4 inch-millirad

Energy spread = $\pm 0.15\%$ (with debuncher)

Estimated Beam Intensity

Assumed constructional errors

1. vertical displacement of magnet = ± 0.02 in.
2. radial tilt of magnet = ± 0.4 millirad
3. error in length of magnet = $\pm 0.04\%$
4. error in field of magnet = $\pm 0.04\%$
5. frequency error = $\pm 0.15\%$
6. energy spread in injected beam = $\pm 0.15\%$

Rate of rise of magnetic field during injection
= 19.54 kilogauss/sec

Cross-sectional dimensions of inflector lip
= 1.32 in. (radial) x 1.15 in. (vertical)

Current of injected beam = 5 mamp

Total time of injection = 210 microsec

Gas scattering loss = 10% at 2×10^{-6} mm Hg pressure

Space charge limitation = 8×10^{13} protons

Beam intensity at 12.5 Bev = 10^{12} protons/pulse

Estimated Beam Intensity under Improved Conditions

Assumed reduced constructional errors

1. vertical displacement of magnet = ± 0.01 in.
2. radial tilt of magnet = ± 0.2 millirad
3. error in length of magnet = $\pm 0.02\%$
4. error in field of magnet = $\pm 0.02\%$
5. frequency error = $\pm 0.03\%$
6. energy spread in injected beam = $\pm 0.15\%$

Improved operations of injection and acceleration

1. harmonic number of RF = 8
2. frequency range = 4.18 to 13.28 mc/sec
3. phase oscillation frequency = 4.167×10^4 c/sec
4. reduced rate of rise of magnetic field during injection = 9.77 kilogauss/sec
5. cross-sectional dimensions of inflector lip = 0.66 in. (radial) x 1.15 in. (vertical)
6. total time of injection = 420 microsec
7. current of injected beam = 10 mamp
8. rise time = 1.0 sec

Improved beam intensity at 12.5 Bev = 10^{13} protons/pulse

IV. DIGITAL COMPUTER WORK

W. C. Davidon, M. Ferentz

A code for AVIDAC has been prepared to analyze, in detail, the uncoupled synchrotron oscillations in order to determine quantitatively the requirements on the frequency accuracy of the RF oscillator. The code calculates the time required to go from one accelerating station to the next for a particular energy and magnetic field distribution. At each subsequent time, the energy is changed by the value of the RF signal at that time and the magnetic field distribution is changed to that corresponding to the new time. The time at which the particle exceeds preselected limits in radius is recorded. Various types of programming for the RF and magnetic field can be used as the basis of the calculation.

The code has been debugged and an initial set of constants based on the present machine design have been prepared. The calculations will be started as soon as machine time is available.

V. GENERAL INSTRUMENTATION

H. Kampf

The experimental work carried on in the Particle Accelerator Division will require, in addition to specialized equipment which will be secured as required, certain commercial pieces of test equipment which will be used to measure voltage, current, frequency, and time. A selection of overlapping voltmeters and ammeters have been bought, of the A.C. and D.C. type, capable of measurements from D.C. to 500 mc and from one millivolt to several thousand volts.

Five of the most versatile Tektronix oscilloscopes have been purchased. These have several different plug-in type preamplifiers which cover signal displays from 50 microvolts and frequency components from D.C. to 40 megacycles. Signal generators are available, or on order, covering the frequency spectrum from 5 cps to 500 megacycles. Digital counter type of frequency and time-measuring instruments are on order which will allow frequency measurements up to 100 mc with an accuracy of one part in 10^6 . It is planned to increase this accuracy by two orders of magnitude with the use of a radio receiver and the standard frequency signals transmitted by the National Bureau of Standards on WWV.

Recording equipment has been purchased and devised to record electrical voltages. Two servo recorders are available for recording signals up to one cps with an accuracy of about 0.5%. An ink-paper recorder is on order which will record from D.C. up to 100 cps with an accuracy of 1%. An oscilloscope camera has been purchased which will allow recordings having a writing speed as high as 80 inches per microsecond.

In addition, common electronic tools such as regulated power supplies, D.C. amplifiers, pulse generators, etc., are being purchased and built as the need arises.

The use of transistors in control and instrumentation circuitry appears attractive from several standpoints. The operating power required can be reduced by as much as two-thirds the amount of that required by comparable circuits using vacuum tubes. Circuits can be miniaturized, enabling amplifiers to be physically located near pickup coils, etc. The most important advantage is reliability. In instrumentation systems involving thousands of tubes, tube failures can be expected to occur with alarming frequency even with premium tubes having life expectancies in the neighborhood of 10,000 hours. On the other hand, transistors in properly designed circuits can be expected to have a life expectancy of 100,000 hours and longer. It is felt that transistorized circuitry properly used can significantly augment the entire instrumentation program. The need for a complete set of transistor test equipment is quite apparent.

An investigation has been made into all the commercially available test equipment. Most of these testers and analyzers were found deficient in one respect or another. In particular, none of them allowed the measurement of high frequency transistor performance and the measurement of power transistor parameters in the same instrument.

It was therefore decided to design and construct three pieces of test equipment that would allow testing power transistors up to collector voltages of 100 volts and at currents as high as one ampere. The same equipment would allow the measuring of high frequency transistor characteristics up to two megacycles.

The Beta and I_{CO} tester will measure the D.C. and A.C. transistor current gain of the common base configuration. It will also measure the collector saturation current.

The "h" parameter analyzer will measure the hybrid transistor parameters which are needed when a circuit is to be designed, using small signal linear design equations.

The "F and C" tester is used to measure the collector capacity and the frequency cut-off value of the transistor current gain.

VI. POWER SUPPLY FOR D.C. MODEL MAGNETS

E. F. Frisby and J. Mech

Preparatory to the organization of PAD, model magnet power requirements were studied, and a search was begun to satisfy these requirements. After a detailed survey, a decision was made to obtain two Chanveysson electro-plating motor generator sets by purchase and four General Electric welding sets on loan from the naval shipyards at Seneca, Illinois. The nominal output voltages and amperes of these generators are, respectively, the Chanveyssons (each) 12 volts at 3000 amperes, and the General Electric (each) 70 volts at 1500 amperes.

The total driving power required for these generators amounted to 580 kilowatts. This power consumption was considerably more than could be allowed in any existing installation, so a short transmission line and a 750-kilowatt substation were installed in Building 805. The generators were mounted and power connections were made.

Prior to installation (Fig. 1), the Chanveysson generators were sent to a repair shop and placed in good operating condition, but the General Electric generators needed some minor reconditioning after being installed. A visual inspection indicated that the brushes were worn and

would have to be replaced. This was done. The bearings on three of the machines were found to overheat. Plant Operations checked the alignment and made adjustments to correct this condition. A special water-cooled load box was constructed and each machine was thoroughly tested.

FIG. 1. D. C. MOTOR GENERATORS - BLDG. 805

An examination of the characteristics of the General Electric generators indicated that they were too heavily self-excited by the series field to be of use in the applications planned, so the series fields were effectively removed from the circuit.

Voltage measurements were then made to determine the feasibility of operating the machines in parallel. The Chandeysson machines were found to generate, with the same excitation current, essentially identical voltages over the entire voltage range. They were paralleled and found satisfactory.

The General Electric machines were not as close to being identical as were the Chandeyssons. The voltages varied considerably with identical shunt field current and the loads were found to be unequal when they were placed in parallel. They now can be balanced in parallel operation, using standard power-station techniques.

A feature not accomplished at the time of installation was the provision of a system of controls for laboratory use. Here, ease of operation and fine control are essential. In addition, some provision had to be made for simultaneously controlling a given group of generators in tandem. To accomplish this, instrument leads and certain key controls were moved from the power room into the laboratory. Smaller generators (Lincoln welders slightly modified) were used to provide separate excitation. A considerable amount of electrical wiring plus some construction was necessary to achieve this end.

A system of raceways was installed, interconnecting the six generators, a control panel in the generator room, and two control panels in the laboratory. Separate wires were brought to a terminal strip at a control panel from each generator shunt field. The exciting generators (three Lincoln welders) were wired in and also connected to terminal strips at the control panels. Direct current was supplied at these panels for energizing the motor fields and the generator control system. Additional electrically operated switches and relays were purchased and are being used to interlock the generators with laboratory equipment. The goal of this system is to secure easy changeover in the use of the generators by using electrical jumpers at a terminal strip rather than by making difficult modifications in the generator panel each time a new demand is placed on a generator.

Safety is an important consideration in the use of these generators. As constructed, they are adequately safeguarded for any normal usage, and care has been taken not to remove any of the existing safeguards. In addition, several precautions were taken to prevent other foreseen difficulties. The generators were interlocked with a model magnet in such a way that they cannot be started unless the cooling water supply is adequate.

In order to alleviate the disturbances in magnetic field measurements due to brush noise and commutator ripple, a battery filter is under construction. This will have taps at 2-volt intervals in the range 0 to 30 volts, so a number of operating points will be available. There will be room for adding 18 volts of additional battery capacity and provision can be made for extending the voltage to even high ranges.

VII. MAGNETIC MEASUREMENTS INSTRUMENTATION

M. Foss, D. McMillan, J. Moenich, H. B. Phillips

Accurate magnetic measurements on model magnets require studies of both field intensities and field shapes. The latter are particularly critical in determining the design of particle accelerators, and more delicate and sophisticated instruments are required than are needed for intensity measurement.

A. Field Intensity

For rapid, conveniently made measurements, good to about one per cent, one may measure the voltage produced in a coil rotating in the unknown field. Such a rotating coil gaussmeter, manufactured by the Rawson Electrical Instrument Company, has been used in most of the surveys made thus far.

For field intensity measurements good to one part in 10^4 , the nuclear magnetic resonance technique may be used. This involves the determination of the radio frequency at which a particular isotope becomes resonant in the unknown field. An instrument of this type, made by Nuclear Magnetics Corp. has been acquired.

B. Field Distribution

Field variations in space of a few gauss are significant in determining the performance of model magnets, and, therefore, good accuracy in measurement is required. At a field intensity of twenty kilogauss, for example, a variation of two gauss represents a change of 0.01%. We have, therefore, made considerable effort in the design of an accurate servo fluxmeter and have investigated the related problems of galvanometry and magnetic standards.

1. Servo Fluxmeter

The basic design of the servo fluxmeter follows the Cioffi circuit for mutual inductance integration. In addition to this, however, there is a second mutual inductance feed-back loop which is driven by an electromechanical servo system. This latter system is used to return the galvanometer to a null position rapidly, so that galvanometer drift due to restoring torque is minimized. The actual integration, therefore, is performed by the servomechanism, the Cioffi integrator merely acting as a storage device, or memory, until the electromechanical integrator has responded.

In this type of circuit the mutual inductor (MI) included in the servo integrator becomes a reference standard, and, therefore, extra effort was spent in design considerations of the MI. An initial

design of the MI was based upon a toroidal configuration, but difficulties in winding (because of size) led to a unit composed of 16 individual coils, each relatively easy to wind. Each coil consists of a secondary and two primaries. Ideally, the secondaries of all 16 coils should be wound continuously (to avoid thermal junctions), but for convenience the coils were wound in two groups of eight, the junctions being carefully joined with special low-thermal solder (there are two additional junctions so joined, caused by the accidental breaking of the wire during winding). Over each secondary winding, and separated from it by an electrostatic shield, is a servo feed-back winding, and over each of the latter is wound a "memory" winding. The 16 individual inductors are mounted in a special array designed to minimize pickup of external fields (60 cycles, in particular) and vacuum impregnated with wax. The resulting mutual inductance values are: outer winding to secondary, 0.38 henry, total; inner winding to secondary, 0.24 henry, total. The latter servo winding, therefore, gives the fluxmeter a capacity of 1.2×10^5 lines per 5 milliamperes. Although this type of fluxmeter minimizes error due to galvanometer restoring torque, other difficulties may be caused by electrical and mechanical defects in the galvanometer circuit and by errors in calibration. Accordingly, much attention has been given to galvanometry techniques and to calibration standards.

2. Galvanometry

A system using a photoelectric galvanometer may have several sources of drift, such as thermoelectric currents, amplifier drift, and mechanical instability. Each of these difficulties has been considered in the over-all design of the fluxmeter. Thermoelectric currents are reduced by avoiding unnecessary junctions and by preventing rapid temperature fluctuations at those junctions which are present. All low-level junctions, with the exception of the galvanometer element and the search coils, are contained within a massive aluminum box which is surrounded by a Styrofoam case, covered with a reflecting layer of aluminum foil. Within the central box is a cluster of four copper blocks, to each of which is clamped one junction. Ideally, the galvanometer coil-suspension system should be all copper, preferably constructed from a single length of wire. Our galvanometer, however, has a gold-alloy suspension, and, therefore, some care has been taken to reduce heat entering the galvanometer enclosure; this is done by using both optical filters and masks in the light path.

Another possible source of drift is mechanical in nature. If any of the elements in the optical path, including the lamp, are deformed or shifted in position, the instrument will have a new zero, so that drifting will result. Such effects were encountered in our first galvanometer, obtained commercially, and therefore a new optical-mechanical system was designed. The predominant source of drift was caused by erratic movements

of the lamp filament. The lamp, therefore, has been replaced by a slit which is illuminated by a diffuse light source; small motions of the lamp have little effect upon the galvanometer zero. All optical elements, including the galvanometer, have been placed in massive mountings which contribute both thermal mass and mechanical rigidity. Difficulties due to vibrations (produced largely by six rotating machines in the vicinity) have been eliminated by decoupling the galvanometer from the concrete slab floor of the building. This was done by sinking a concrete pier into the sub-floor earth and by mounting an 850-pound concrete block upon the pier; the two concrete members are separated by a layer of rubberized hair which provides both elasticity and damping.

Even if all thermal and mechanical drift sources could be eliminated, drifts in the photoelectric amplifier may give difficulty. Such effects have been largely eliminated by conventional means. Balanced (common-cathode) circuits and rugged tubes are used in conjunction with stable resistors where required; regulated power supplies also contribute to stability. Adjustable damping of the servo integrator is provided by tachometer feedback.

Since the fluxmeter is calibrated in lines (three ranges: 10^5 , 10^4 , 10^3 lines full-scale) measurements in terms of gauss will depend upon search coil design and calibration, attention, therefore, has been given to the design of such coils.

3. Search Coils and Calibration Standards

An ideal search coil for our present purposes should measure the field at a point and should have sufficient area (turns-cm²) to provide adequate sensitivity. These conflicting requirements have been studied and several designs, based on a theory by Foss, have been evolved. A thick solenoid has three dimensions: inside diameter, outside diameter and length; the shape of the coil is specified by any two ratios of these dimensions. By choosing these two parameters appropriately, the coil may be made insensitive to first-order errors of field measurement. Pairs of such coils of about 5000 cm² area (matched to about one cm²) have been made; one may be mounted on a coil manipulator and moved from the point under observation in the magnet gap to a position in close proximity to the mate coil, located in the region of uniform field. Higher-order field errors may be discriminated against by the use of more complicated search-coil designs. For example, a pair of concentric solenoids gives five parameters which can be so chosen as to minimize both first and second order errors simultaneously. Such coils of about 200 cm² area, together with views of typical forms before winding, are shown in Figs. 2, 3 and 4.

FIG. 2. MUTUAL INDUCTANCE BEFORE POTTING

FIG. 3. COMPONENTS OF SEARCH COIL MINIMIZING FIRST AND SECOND ORDER ERRORS

FIG. 4. ASSEMBLED SEARCH COIL AND MANIPULATOR

Calibration of search coils requires a uniform field of known magnitude. In addition to the usual long solenoid, other types of coils may be used, several designs of which have been calculated. One interesting design involves the use of a short solenoid wound uniformly with the exception of three gaps; the gaps are of the appropriate size and location to eliminate first and second-order errors in the central field. For higher fields uniform over a larger volume, a group of Helmholtz-like coil designs have been made. Such coils, resembling thick Helmholtz coils, can utilize space efficiently (for windings), and, therefore, give good performance in terms of gauss/watt as well as uniformity of field.

FIG. 5. COIL NO. 1 FOR D. C. MODEL MAGNET WITH SUPPORTING JIG
IN POSITION OF VACUUM CHAMBER

FIG. 6. MAGNET NO. 2 (1010 STEEL) COMPLETE WITH COIL NO. 1
SEARCH COIL MANIPULATOR IN PLACE

VIII. D.C. MODEL MAGNET

H. Berman, M. Foss, D. McMillan, J. Moenich. B. Phillips

A. Construction and B-I Characteristics

A direct current model magnet of the poleless "H" magnet type has been built for the purpose of determining flux distributions and B vs. I characteristics. The coil with its cooling water connections, and the complete magnet, are shown in Figs. 5 and 6. The coil consists of 16 turns of approximately $1/8" \times 1/2"$ copper bars to which $1/8"$ copper water tubes are silver soldered. The turns are insulated with glass tape and epoxy resin. Two turns of both the top and bottom half of the coil have separate connections brought out to permit independent control of the current through these turns. Water is supplied to the coil at 200 psi and at temperatures down to 50°F . Under these conditions, water at the rate of 60 liters per minute flows through the coil, which is safeguarded by 12 flow switches to shut down the generators should one of the cooling tubes become blocked.

Two magnet cores have been used to date. One is of Armco iron and the other of 1010 steel. The two cores are identical except that the magnetic return path (or yoke) for the Armco is 4" thick while that for the 1010 is $3\frac{3}{4}"$. The gap is 1.002" high and 6.5" wide which, with the present coil, leaves a free space of about 1" x 4". The cores are 12" long.

A Rawson rotating coil flux meter and a 3000 ampere - 60 millivolt shunt have been used to obtain the B vs. I curve for the 1010 core shown in Fig. 7. The straight line is the corresponding curve for a core of infinite permeability. The coil became overheated at currents above 3000 amperes, so the data above that point were taken by running the current up, reading the meters and then reducing the current as quickly as possible. From the shape of this curve it looks as though the most economical operating point for the machine may be somewhat above 20 kilogauss.

FIG. 7. B vs. I CURVE FOR THE 1010 STEEL CORE

The present coil seems to be failing because of poor silver solder joints between the conductor and the 1/8" water tubes. A new coil having 12 turns is now under construction to allow operation up to 72,000 ampere-turns and also more accurately to scale our present estimates for the final guide ring magnet. This coil is being built of copper tubing having an O.D. of 0.250" and wall thickness of 0.065".

B. Measurements of Radial Gradient

At low values of exciting current, one can expect an extremely uniform field across the entire vacuum chamber, but at high values, when iron saturation becomes important, it is anticipated that the field will be lower at the chamber middle than at its boundaries, close to the coils, thus producing a negative gradient in the radial inner half of the chamber and a positive gradient in the outer half. The usable width of the chamber is determined at its inner boundary by that negative gradient which increases the vertical restoring force to such an extent that the number of vertical betatron oscillations per revolution, ν_z , moves from its value 7/8 (at zero gradient) up to $\nu_z = 1$, at which point a disastrous integral resonance is encountered. Similarly, the outer boundary of usable chamber is encountered when the positive gradient so increases the radial stiffness that ν_x moves from its zero-gradient value of 3/4 up to $\nu_x = 1$, where another serious resonance is met with.

Calculations of the adiabatic damping effects on the betatron oscillations, synchrotron oscillations and on beam amplitude due to errors of mechanical construction and of frequency, give the following total radial width of the beam at various fields and energies:

<u>Kinetic Energy</u> (Bev)	<u>Magnetic Field</u> (kgauss)	<u>Radial Beam Width</u> (inches)
0.050	0.463	36.0
0.704	2.010	15.7
3.753	6.857	10.2
8.444	13.927	8.6
12.500	20.000	8.0

Figure 8 illustrates preliminary observations on the gradients observed in the middle section of the D.C. model, at the median plane. No great accuracy is claimed for these data, which have been obtained under adverse conditions ascribable largely to commutator ripple in the exciting generators. The curves have been scaled to be appropriate to a 36" wide vacuum chamber set in a machine with a radius of 94 feet, and exhibit the variation of the field index n against radial departure from the center of the chamber. (The figure is symmetrical in the diagonally opposite quadrant.)

FIG. 8. GRADIENTS OBSERVED IN THE MIDDLE SECTION OF THE 1010 STEEL CORE D. C. MODEL

It may be seen that at 14,000 gauss (and below) essentially the entire chamber width is available. At 20,000 gauss, the good region extends from 2" inside the center to 10" outside, while at 22,800 gauss the corresponding figures are about 1.5 and 6.5". As far as particles acceleration is concerned, it is evident that the useful width of field is entirely adequate.

Beam extraction may require a wider region of good field. This can be attained by the use of corrective magnetic lenses in the straight sectors, introducing radial gradients of opposite sign to those encountered in the guide field.

IX. RADIO FREQUENCY ACCELERATING SYSTEMS

R. Blum, J. Dawson, H. Kampf, J. Martin, A Strassenburg, K. Weberg

During the past several months attention has been concentrated upon the RF system for the ring magnet. This system will include four equally spaced, ferrite-loaded accelerating cavities operating on the fourth harmonic of the particle frequency, which calls for a frequency program of about 2.1 to 6.7 megacycles per second. Such a low frequency greatly eases the problem of the choice and operation of ferrites in the accelerating cavities of such a size as to go around the vacuum chamber. Also, the problem of procurement or design of test equipment and of circuits to sense the beam position and beam phase will be considerably easier than if a higher harmonic were chosen.

The driving signal for these cavities will come initially from a programmed master oscillator, then from beam sensing electrodes after the beam is large enough and adequately bunched. The master oscillator signal possibly will be used to prebunch the particles from the linac before injection into the ring. A signal from sensing the radial position of the

beam in the ring will be used to control the cavity voltage to shrink the beam into the machine at the time of injection and to hold it in the proper radial position during the remainder of the program.

Some detailed study has been made upon the characteristics of four ferrite samples with the idea of using some of them in the large accelerating cavities, in programming the length of delay lines, and possibly in the master RF oscillator. The samples are Types C 131/5 and 1568 from Steatit Magnesia Corp., Type 519 from Philips Laboratories, and Type G from General Ceramics Corp. Measurements made at low RF magnetic flux densities indicate that the Type C 131/5 is subject to the least losses of all so far. However, it will require approximately twice as much DC bias as the Type 519 to produce the required change in permeability by a factor of 10.2.

Measurements at high RF magnetic fields are far from complete, but it seems clear that Q values of 50 or more will be obtainable at RF values of 3×10^8 gauss cycles per second. This necessitates the application of some bias even at the lowest frequency of operation, which is desirable also in order to reduce the effects of remanent magnetic fields.

The measurements on the toroidal samples of ferrite are being made by placing a few turns of copper wire around the rings, connecting two such coils in series for application of DC bias current, and also connecting these two in parallel to form the inductance of a resonant circuit. A low reactance resistor is connected in series with this combination across a 250-watt class A RF driver. Assurance of small waveform distortion is obtained by oscilloscopic observation. Vacuum tube voltmeter measurements across these circuit elements give the information for calculating Q and permeability under suitably chosen conditions of bias, frequency, RF flux density and temperature. Temperature control is obtained by immersing the ferrite rings in an agitated oil bath.

In the case of the Philips 519 an interesting result of ferrite studies is that the permeability can be made to have almost no temperature dependence by the application of a suitable bias. This property appears to occur at a fairly low bias which is also suitable for use in the frequency region of 2 Mc/sec where master oscillator tolerance problems at the time of injection will be the greatest. A search for corresponding phenomena in the other ferrites is being started.

Two possible methods for developing the master oscillator frequency with adequate accuracy have been under investigation. One consists of a loop closed around a multivibrator such as to give a linear relation between a command voltage from a function generator and the period of oscillation of the multivibrator. This requires that approximately the entire functional relationship between particle guide field and oscillator frequency must be

developed within this generator and with the required accuracy of somewhere between 0.1% and 0.01%. This scheme also will require frequency multiplication to reach the desired driving frequency.

Another method under consideration for developing the master frequency involves a radio frequency oscillator having a ferrite-loaded tuned circuit. It has already been shown that simple conditions can be chosen by which such an oscillator will produce within 1% of the required frequency over the entire acceleration cycle; these conditions involve only the proper choice of a fixed ferrite bias plus a bias which is proportional to the magnetizing current producing the guide field. This is somewhat similar to the scheme employed at the Bevatron. However, we feel it is desirable to tie the master oscillator program to the guide field itself in order to minimize the influences of changing iron characteristics and changes in rate of rise of the magnetic field. If a suitable way can be devised to measure the guide field strength, it is felt that the master oscillator again can be made to have the required frequency to within 1% by using only a fixed bias and a bias proportional to the guide field, and that it can be made to remain stable, against temperature, age, etc., to within about 0.01%. The plan is then to produce, by a multipoint switching diode system, the required 1% correction with an accuracy of about 1%, thus giving an overall frequency accuracy of about 0.02%. During the time of injection and bunching the requirement on accuracy will be about 0.03%. After this period, the accuracy requirement will be met by beam-tracking mechanisms.

An idea under consideration for producing a voltage signal which is accurately proportional to the magnetic guide field involves a combination of the Kerr and Faraday optical effects. A Faraday cell may be placed in the magnetic field such as to produce a rotation of the plane of polarization of a beam of light which is proportional to the field strength. The same light beam may then pass through a Kerr cell and have its plane of polarization rotated back to zero by an electric field proportional to the angle of rotation. By reducing the angle of rotation to zero (with a closed servo loop) the Kerr cell voltage should be a linear function of the magnetic guide field. Materials are available which will produce large angular rotations in reasonable path lengths and in the fields involved. Presumably, certain split beam techniques can yield a high degree of precision in sensing zero angular rotation.

X. RING MAGNET POWER SUPPLY

G. O. Calabrese, E. F. Frisby

Power requirements for a proton accelerator are unique because of the special characteristics of the load. The ring magnet must be excited by power pulses wherein the current in the magnet circuit is allowed to rise to a predetermined maximum value and then caused to decay at a fairly rapid rate to zero. The pulse must be repeated at the prescribed rate and output current wave form must be duplicated as exactly as possible on each pulse.

To select the proper type of power supply system to meet these requirements, many factors must be considered. In addition to the usual requirements of economy and reliability, numerous factors related to performance must be evaluated. Other related problems must be considered, such as utilizing available capacity in the Laboratory's existing electric power system, modifying the system to meet the additional requirements, and assuring compatibility with the electric company's power source.

The information gained from manufacturers through technical discussions indicates that three types of power supply equipment are possible for this application: (a) motor-generator with mercury-arc rectifiers, (b) unipolar machine, and (c) direct-current commutating machine.

Information at hand tends to favor mercury-arc rectifiers because of their ability to rectify as well as invert. Other advantages are, (a) operational timing can be controlled with extreme response accuracy, (b) high voltage of rectifying tubes coincides with voltage values desired for the ring magnet coil, (c) capability of high peak currents (d) ability to withstand greater overload, (e) requirement of lighter foundations, and (f) greater efficiency than other types.

Due to recent advancement in the development of unipolar machines, consideration is also being given to this type. Engineering progress in the development of the liquid metal brush principle (which eliminates the previous cumbersome brush rigging) has enhanced this machine's possibilities for accelerator application. Another favorable point of the unipolar is that the ripple problem would probably be less difficult than in the case of either the D.C. commutating machine or the mercury-arc rectifier. More information is being obtained in order to evaluate the possibilities of this machine. The various aspects of utilizing the D.C. commutating machine are also being investigated.

Magnet power supply requirements have been given extensive study in relation to various magnet parameters under consideration, and many combinations have been analyzed. From this study it has been estimated that the peak power requirements will vary from 85,000 to 158,000 kw when

the vacuum chamber is varied in size from 6" x 18" to 6" x 36", inside measurement, assuming upper and lower chamber walls of non-magnetic material. Over this range it is estimated that the initial cost of the power supply will increase about 75%. However, if it is assumed that the upper and lower walls of the vacuum chamber are constructed of laminated iron, the peak power will range from 71,000 to 117,000 kw over the same range of chamber width. In this case the initial power supply cost will increase about 35%.

Studies have been made concerning the magnitude of the effects of magnet eddy currents and hysteresis on the power supply. It was found that these effects contribute relatively small additional burden on the power supply equipment (assuming half-inch laminations). Calculations have been made to determine the optimum cross-sectional copper area from an economy standpoint for the ring magnet coil. In the case of the magnet with the 6" x 36" vacuum chamber (now considered the best choice), cost calculations were made for copper areas ranging from approximately 21 square inches to 58 square inches. The main factors taken into consideration as affecting cost were iron, copper, initial power supply equipment cost, and operational power costs over a period of ten years. Over the given range of copper areas from minimum to maximum, the required amount of additional iron increases approximately 18% and the quantity of copper increases approximately 35%, with corresponding increases in estimated costs. Initial power supply equipment estimated costs increase only about 1% while estimated operational power costs (for the ten-year period) decrease about 70%. Taking the above factors into consideration, including operational power costs, it appears from an economical standpoint that the optimum copper area should be about 30 square inches. If only initial costs are considered, it appears more economical to utilize the minimum copper area of 21 square inches. However, preliminary investigations show that other technical factors such as current densities, cooling, etc. become more important as the cross-sectional area of copper is reduced. At this stage of the survey, it is believed that the optimum copper area will fall between 25 and 35 square inches. It is calculated that cooling and insulation will require an additional cross-sectional area of approximately 15 square inches in the optimum range when about 30 turns are assumed in the magnet coil.

Work has been in progress during this report period to determine the extent of additions and modifications required to be made to the existing electrical distribution system in order to accommodate the accelerator power requirements. Preliminary studies indicate that a total transformer capacity of about 15,000 kva will be needed, along with associated distribution lines and switchgear for the entire project. Power company engineers have indicated during discussions that a load swing of 10,000 kw at 80% P.F. could be permitted on the interconnection without causing undesired voltage dips in the power company system. Further investigation is under way to obtain regulation data on the Laboratory distribution system in order to gain knowledge for design criteria in expanding outside electrical utilities.

Other work during this report period includes assemblage of manufacturing data on copper for magnet coils, studies on various shapes for the coil conductor, voltage, insulation, and development of criteria for bus and circuit layout, and investigations concerning both temperature and equipment control. Estimated costs have been calculated on all electrical components and criteria developed on interior electrical features for the purpose of executing an Architect-Engineer contract for design of buildings and foundations.

XI. MAGNET COOLING

R. Trcka

Several preliminary schemes of the magnet water cooling system are being studied, and a cost analysis of the sources of water supply is being compiled for evaluation. Information concerning the several possibilities of water supply has been obtained from the Plant Engineering and Operations Division of the Laboratory.

The most economical and feasible source of water is the use of the existing facilities of the Laboratory water system for cooling tower make-up water. The existing plant installation consists of three shallow wells, approximately 300 feet deep, capable of delivering a total of 1200 gpm, and one deep well, 1600 feet, extending into the Galesville Sandstone strata, with a capacity of 390 gpm. All the well water passes through the treatment plant and into the Laboratory distribution system. Make-up water for the accelerator water cooling system would be supplied from this distribution system; however, additional water treatment may be required for cooling tower make-up water. The wells and treatment plant are operating at maximum capacity at present, and any additional demand such as water cooling for the accelerator and other proposed facilities will require an expansion of the water and treatment plants. Such a program is now in the planning stage at the Laboratory.

The possibility of using canal water for water cooling is being considered to some extent. If a future demand for cooling water for the Particle Accelerator and other proposed facilities is greater than can be supplied by the water plant, including a substantial expansion, the logical source of water would be the canal which is filled chiefly with Lake Michigan water and which could be made suitable for heat exchangers and cooling tower use if some treatment were added. It would be necessary to construct a pumping station in the vicinity of the canal, install a large sedimentation tank, sand filter bed, provide chlorination for bacteria control, and run piping approximately $1\frac{1}{2}$ miles across the Des Plaines river and onto the Laboratory site.

The use of water from the Des Plaines River for cooling is not recommended because the river flow is intermittent during the summer season and, as a result, cannot be considered a reliable source of water supply.

The use of well water for water cooling by directing the flow through heat exchange equipment and discharging the water back into the ground has been investigated and found to be impractical at this site, primarily for the reason that the well water is excessively hard (460-480 ppm hardness), which would result in scaling and heat transfer difficulties. The treatment of the large quantity of water required would be excessively costly.

At the present time, the most economical magnet water cooling system consists of a closed system made up of centrifugal pumps, piping, valves, heat exchangers and expansion tank. By utilizing a closed system for circulating the cooling water the effects of copper corrosion and scale deposits are markedly reduced.

The preliminary study of the magnet water cooling is based on an estimated power requirement of 3000 kw for the magnet coils and an additional 4200 kw for experimental magnets, RF equipment and vacuum system. This quantity of heat can be dissipated by the use of an evaporative cooling circuit that is connected through the heat exchangers in order to remove the heat given up to the heat exchangers by the water of the closed system. Generally, the evaporative cooling circuit consists of centrifugal pumps, piping, valves and cooling tower.

The cooling of the magnet coils will probably require about 8000 gpm of water circulating in the closed system with a maximum temperature rise of 3°F across the coils. This water will have to be treated so as to remove substantially all of the ions so that its conductivity will be sufficiently low to provide good insulation from ground by inserting a reasonable length of non-metallic piping between the inlet and outlet headers and the copper coil connectors at each end of the magnet octants. The operating temperature of the coils will ultimately be determined by the design and size of the cooling tower; however, it is expected that an economical installation will provide a temperature in the range of 85°F to 88°F. The magnet coil windings preferably should remain at the operating temperature during a shutdown period; provision for incorporating a flow of tempered water will require an auxiliary by-pass water system.

A preliminary design of the cooling system piping and equipment is in progress and data for a definitive design will be assembled concurrently with the selected parameters of the machine.

XII. VACUUM CHAMBER

H. Berman, R. Lykken, J. Marshall

Several schemes for the attainment of a vacuum chamber are under consideration:

1. A self-supporting plastic chamber in which are embedded stainless steel ribs. This is in accord with the design for the chamber of the electron synchrotron at Saclay. The wall thickness required to prevent intolerable deformation will be reflected in increased stored energy and power requirements.

2. A cosmotron-type self-supporting chamber, of insulated stainless steel ribs, outside of which lies a membrane of Myvaseal or similar material. This structure again involves an increased demand on the power supply.

3. A structure similar to (1), but with wall thickness so greatly reduced that support must be supplied by a series of wires or rods passing through the top and bottom of the magnet yoke. The initial cost and the nuisance value of assembling such a structure must be balanced against the reduced cost of the power supply.

4. A double vacuum system, wherein an extremely thin-walled particle chamber is kept from collapsing by rough evacuation of the entire iron core, which has some sort of air-tight covering. This scheme requires bottling the exciting coils, to prevent corona and discharge, and a rapid means for pressure equalization in case of failure of the outer vacuum.

5. Bonded iron laminations of the magnet, so as to eliminate entirely the wall thickness of a separate vacuum chamber, thus reducing the demands on the generator to the ideal minimum. There are a number of variants to this scheme; one which seems to be fairly promising involves a vacuum chamber in which the roof and floor are each composed of iron laminations (of sufficient height to be extremely rigid against distorting forces) bonded together and hermetically sealed to vertical walls of stainless steel. This structure would lie between the exciting coils and within the major mass of the iron yoke, the top portion of which would be removable for access. Sections of this chamber, perhaps not over four or five feet long for ease in handling, might be joined by corresponding sections only a few inches long, to the faces of which inflatable gaskets are attached. The cost of fabrication of the additional mating surfaces of the laminations of this design may outweigh the reduced cost of generators.

In addition to preliminary paper-and-pencil studies of this sort, experimental work is under way.

A small chamber of glass tape, glass fibre roving and epoxy resin has been built and found to leak, due to the failure of the resin to wet the roving. Improved winding techniques and better curing agents will be tried in a second model.

Two chambers of epoxy resin with reinforcing ribs are under construction. In one, the iron roof and floor ribs are welded to stainless steel vertical walls which run the full length; in the other, the iron ribs are welded to individual wall pieces of stainless, so as to present a picture frame shape. Radiation damage studies to resins are contemplated for the near future.

XIII. SOIL STUDIES

D. Deere (U. of Illinois), R. Trcka

In the fall of 1955, the Laboratory acquired the services of Don U. Deere, Associate Professor of Civil Engineering and Geology at the University of Illinois, in the capacity of Consultant on soil conditions at the tentatively chosen site for the accelerator. A Preliminary Report was rendered on March 1, 1956, summarizing the geological setting of the site and subsoil data from analysis of some 200 previous test borings and well-digging records; a set of test borings was recommended at the chosen location, as the earlier data did not cover this region.

Under Deere's supervision, the Raymond Concrete Pile Company was engaged and made five borings between March 13 and May 17, 1956. Soil samples were taken at intervals ranging from $2\frac{1}{2}$ to 5 feet, and cores were removed from the hard limestone bed rock which was reached at depths between 112 to 145 feet.

In the laboratory at the University of Illinois, the soil samples were examined visually and were classified. Natural moisture content was recorded and unconfined compressive strengths were determined on all cohesive samples. Plasticity characteristics were determined on representative samples by means of Atterberg limit tests.

These explorations indicate that the subsoil is variable but of quite high strength and entirely capable of supporting the intended load. Because of the small tolerances in movement imposed for the magnet, however, special considerations will have to be taken in the design of its foundations, particularly in the vicinity of the target area, where heavy and movable shielding loads will exist. With slab footings, intolerable movements of the magnet will be expected unless means of adjustment by jacks are incorporated in the supports. On the basis of the present data, it is believed that motion could be kept within tolerable limits by the use of pile foundations.

To obtain quantitative data confirming this opinion, bids have been requested on a test program of pile driving and loading, which is expected to get under way in the near future, subject to difficulties caused by the recent steel strike, in acquiring the appropriate piling.

XIV. BUILDING DESIGN

R. Lykken, D. Manson, J. Marshall, R. Trcka

For the past six months, effort has been devoted to the task of developing design requirements and conceptual drawings for the structures which will house the accelerator with its component parts, and the experimental areas and service buildings necessary to provide a complete operating and experimental facility (Fig. 9).

FIG. 9. PROTON SYNCHROTRON MACHINE & BUILDING LAYOUT

INDEX

A. MOTOR GEN. CONTROL	H. EXTERNAL PROTON BEAM	M. MAGNET OCTANT
B. MOTOR GEN. SET	EXP. BLDG. 60 X 100 X 34	N. RADIAL MEASURING CHANNELS
C. MAIN CONTROL ROOM	HIGH, 50-TON CRANE	O. INJECTOR BUILDING 10-TON CRANE
D. RECTIFIER	J. ACCESS TUNNEL	P. MACHINE SHOP & ASSEMBLY
E. MACHINE & PUMP ROOM	K. RAILWAYS FOR MOVING HEAVY	AREA, 50-TON CRANE
F. ENCLOSED WALKWAY	SHIELDING & MAGNETS	Q. TRACKS FOR SHIELDING CARTS
G. COUNTER & AUXILIARY	L. SECONDARY PARTICLE AREA	R. RETRACTABLE HEAVY CONCRETE
CONTROL ROOM	50-TON CRANE	SHIELDING BLOCKS

Knowledge gained from the review of reports and building plans of other accelerator development groups, field trips to accelerators now operating, or under construction, plus the previous experience gained by several members of the Division in planning, building or operating accelerators, provided the background for the plans currently proposed.

Building design studies necessarily start with the structure to house the ring magnet. All other structures for the facility will have to be located with reference to the ring.

In the interest of economy, earth will be used to cover the tunnel and to provide radiation shielding and thermal insulation wherever practical. The general appearance will be that of a flat topped ring of earth, 320 feet in outside diameter, 30 feet high, with a 120-foot diameter hole in the center. The tunnel will be air conditioned to provide operational stability. Bridge cranes of appropriate size will be available to travel completely around the tunnel on a circular track (Fig. 10). A series of reference and bench marks and sighting channels are planned for alignment of the ring.

FIG. 10. TYPICAL TUNNEL SECTION

The structure housing the injector (a linac) is visualized as a building with 10,000 square feet of floor space, one end being of two-story construction. A 10-ton bridge crane, temperature and humidity control and radiation shielding will be provided.

Since the fundamental purpose of the accelerator is to be able to use it, the maximum amount of experimental space is planned consistent with available funds, in order that time consuming set-up of detecting equipment in one area can be carried out while observations are going on in another.

A meson, or secondary particle, experimental area of 10,000 square feet is planned, separated from the ring tunnel by heavy concrete shields in order to reduce the distance to detecting equipment for reasons of intensity (Fig. 11). These shields will be assembled on carts moving on rails and will be so designed that beam channels in various directions can be located within them. Special foundations in this area will be required, so that variable loads will not be reflected in excessive motion of the ring magnet. A 50-ton bridge crane will be provided.

Fig. 11. SECTION ILLUSTRATION OF THE SECONDARY PARTICLE EXPERIMENTAL AREA

Two experimental areas, each of 6000 square feet, for use with external proton beams are contemplated. Earth shielding can be used with these, focusing magnets and beam collimators being placed in the connecting tunnels with concrete blocks stacked around the beam tubes. Fifty-ton cranes will cover each experimental area. Paved areas outside each are contemplated for truck-mounted equipment assembled elsewhere. Electric power, water and drain lines will be located at strategic intervals throughout all experimental areas.

The railway spur on the Laboratory grounds will be extended to the accelerator site, possibly entering the large meson area which can serve as an assembly area during construction. Railroad tracks (possibly narrow gauge) will be laid to connect the machine shop with the three experimental areas.

In addition to the ring tunnel, experimental areas and injector building, structures to house offices, laboratories, counting rooms, control rooms, shops and equipment are planned, with an area tentatively set at 53,000 square feet.

The buildings are designed to house the following personnel:

Administrative and Clerical	10
Staff - Physicist and Engineers	40
Technicians and Operators	50
Draftsmen	10
Machinists	10
Maintenance and Janitorial	15
Total permanent occupancy	135
Transient Personnel	25
(Visiting scientists using the facility for the duration of a particular experiment)	
Total	160

A prospectus has been prepared under the title "Preliminary Design Requirements for a 12.5-Bev Proton Synchrotron," and submitted to the Business Manager of the Laboratory as an aid in negotiating a contract with a firm of Architect-Engineers. It describes, briefly, the principles of operation and defines areas of endeavor in which detailed design will be carried out, (1) exclusively by the Laboratory, (2) exclusively by the A-E, based on requirements established by the Laboratory, and (3) jointly by the A-E and the Laboratory.