ARGONNE NATIONAL LABORATORY
P. O. Box 299
Lemont, Illinois

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John J. Livingood, Division Director
John P. FitzPatrick, Associate Director
David S. Manson, Assistant Director

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TABLE OF CONTENTS

	<u>Page</u>
I. Abstracts of ANLAD Reports	3
II. Internal Memos	6
III. Theoretical Work	10
A. Orbit Studies for Synchrotrons with D. C. Magnets	10
B. Extraction Scheme for a Synchrotron with D. C. Magnets	11
C. Methods of Getting Longer Straight Sectors	12
D. Study of the $2\nu_z - \nu_x = 1$ Resonance	12
E. Data Reduction Code	13
F. Miscellaneous	13
IV. Model Magnet Studies	15
V. Magnetic Measurements Instrumentation	23
VI. 1/7-Scale D. C. Model Magnet Construction	27
VII. Model Magnet Cooling	28
VIII. Generator Regulator	29
IX. Pulsing Circuit for 1/4-Scale Model Magnet	31
X. 1/4-Scale Pulsed Model Magnet	33
XI. Additional D. C. Power Supply	33
XII. Instrumentation for Dynamic Magnet Studies	34
XIII. Ring Magnet Design	36
XIV. Foundation Studies	39
XV. Ring Magnet Power Supply	41
XVI. Master Oscillator	43
XVII. R. F. Power Amplifier	44
XVIII. Prototype R. F. Cavity	44
XIX. The Master Oscillator Radio Frequency Control System . . .	45
XX. Radio Frequency Program Measurements	51
XXI. Evapor-ion Pump Development	54
XXII. Vacuum Chamber	59

TABLE OF CONTENTS

	<u>Page</u>
XXIII. Injector System	59
XXIV. Transistors and Semiconductor Diodes in a Magnetic Field	62
XXV. Particle Beams	63
XXVI. Drafting	66
XXVII. Personnel	66

PARTICLE ACCELERATOR DIVISION

Summary Report

I. ABSTRACTS OF ANLAD REPORTS

ANLAD-31 "Radiation Damage in a Plastic Chamber" E. C. Crosbie (Oct. 2, 1956) - ERRATUM

In the second expression on page 8 of this report, the period of revolution of the protons is given as $2\pi \text{ sec}/(0.328 \times 10^6)$. This is in error and should read $2\pi \text{ sec}/(3.28 \times 10^6)$. All subsequent calculated results are, therefore, too large by a factor of 10.

ANLAD-36 "Coil Design for Poleless Picture Frame Magnet" Martyn Foss (April 17, 1957)

This is a mathematical treatment of the perturbation to be introduced into the field due to the proposed method of construction and errors that may be encountered: the effect of vertical and horizontal layers of insulation, of non-uniformity in the thicknesses thereof, of holes for water cooling, of a general shearing of the ideally rectangular bundle of conductors, or of a displacement of the bundle as a whole. It is concluded that it will be almost impossible for statistical errors to make the field unsatisfactory, but that systematic errors must be avoided. Practical means of correcting the latter, should they occur, are discussed.

ANLAD-37 "Evapor-ion Pump Development" J. S. Moenich, M. Otavka, K. Weberg (May 22, 1957)

This includes a brief description of the operation of the Evapor-ion pump but deals mainly with the new method of starting. Previously, the pump contained titanium primers or had to be backed by "Roots" blowers or diffusion pumps to bring it below pressures at which glow discharge occurred. Placing of the grid, normally used for ion pumping, at a negative potential during the starting period confines the glow discharge to a small region and permits starting of the pump at 10^{-3} mm Hg instead of 5×10^{-5} mm Hg.

ANLAD-38 "Program for Computer Studies of Non-Linear Betatron Oscillations." L. C. Teng (June 13, 1957)

In view of the fact that the chosen operating point at $\nu_x = 6/8$, $\nu_z = 7/8$, lies on the second-order coupling error resonance $2\nu_z - \nu_x = 1$, it is necessary to study this resonance more closely. This resonance

couples the radial and the vertical betatron oscillations through an error in the construction which gives rise to a first-order harmonic in the azimuthal variation of the magnetic field. During injection the amplitude of the radial oscillation can be as large as five times that of the vertical oscillation. If the resonance band is too wide and the feeding of the vertical oscillation by the radial oscillation too rapid, this resonance can be detrimental. The width and the strength of this resonance depends on the magnitude of the non-linearity in the fringing fields at the magnet ends. Therefore, the approximation of infinitely hard magnetic edges giving δ -function non-linearities is inapt for this investigation. The IBM-704 at NYU has been coded for this study. To begin with, the accelerator with eight identical sectors, consisting of eight identical zero-gradient magnets with equal angles at both ends and eight identical straight sectors, will be studied. The fringing field on the median plane of the soft edge is assumed to be of the form $\frac{1}{2} B_0 \left(1 + \tanh \frac{\ell}{\epsilon}\right)$, where ℓ is the perpendicular distance from the magnet end-edge, B_0 is the uniform field intensity inside the magnets, and ϵ is a length scaling-factor governing the "hardness" of the fringing field (infinitely hard when $\epsilon \rightarrow 0$). The exact coupled equations of the betatron oscillations are integrated numerically, first for an accelerator without error and the exact set of parameters giving $\nu_x = 6/8$ and $\nu_z = 7/8$ are found. With parameters in the neighborhood of this exact set, the equations with errors introduced into preassigned sectors of the accelerator are then integrated. This will, then, give the width and the strength of this coupling resonance.

ANLAD-39 "The Debuncher"

Rolland Perry (June 28, 1957)

The anticipated energy spread in the linac beam is $\Delta E = \pm 250$ kev, and the acceptance range for the ANL synchrotron is ± 75 kev. A debuncher of the type proposed at CERN (PS-KJ 29) will be used to reduce the energy error to the acceptable range.

The required debuncher voltage amplitude, V_0 , has been calculated as a function of drift distance for $\Delta E = \pm 250$ kev and also for $\Delta E = \pm 500$ kev. Some typical results are as follows:

Table I

Initial Energy Spread ΔE (kev)		Drift Distance	
		10 meters	15 meters
250	Debuncher Voltage V_0 (kv)	1040	710
	Final Energy Spread ΔE_f (kev)	74	50
	Acceptance Efficiency	100%	100%
500	Debuncher Voltage, V_0 (kv)	1090	790
	Final Energy Spread ΔE_f (kev)	147	100
	Acceptance Efficiency	65%	90%

Assuming that protons leaving the linac are located in phase space in an energy-phase plane within an elliptical envelope whose semi-axes ΔE and $\Delta\phi$ represent, respectively, the maximum errors in energy and phase, a point-by-point transformation of the envelope has been made, from which the final energy spread can be determined. For a drift distance, Z , of 10 meters, which requires a debuncher voltage $V_0 = 1.04 \times 10^6$ volts, the final energy spread, ΔE_f , is just within the acceptance range of the synchrotron for $\Delta E = 250$ kev. As can be seen in Table I increasing the drift distance from 10 meters to 15 meters results in the following improvements:

1. decreases final energy spread to ± 50 kev for $\Delta E = 250$ kev;
2. increases the acceptance efficiency from 65% up to 90% for $\Delta E = 500$ kev;
3. reduces the required debuncher voltage, V_0 , from 1040 kv to 710 kv.

The first two effects should result in increased output of the synchrotron beam and the third should help to insure stable operation of the machine. For these reasons a 15-meter drift distance is proposed.

ANLAD-40 "Solution of the Second-Order Radial Oscillation Equation With a Step Function Edge"
E. A. Crosbie, L. C. Teng (July 12, 1957)

With infinitely hard (step-function) fringing fields at the ends of a magnet, one has no available vertical aperture and, hence, no possible vertical motion of ions. The derivation given in ANLAD-14 of motions to the second order of ions through a step function fringing field is, therefore, incorrect. The radial motion through such a fringing field is, however, possible and is studied here to the second order. It is shown that the first-order equation of the radial motion through a step-function fringing field can be solved exactly, giving no discontinuity in position and the usual $(\tan \theta)/\rho$ discontinuity in slope. The second-order result shows discontinuities in both position and slope and agrees with the result obtained independently by an exact geometrical method. In order to study the effect of the $2\nu_z - \nu_x = 1$ second-order error resonance, we must, therefore, assume soft fringing fields at magnet ends and numerically integrate the equations of betatron oscillations with the help of computing machines.

ANLAD-41 "A Zero-Gradient Spiral Edge Focussing Synchrotron"
L. C. Teng, (July 23, 1957)

It is proposed to move the operating point out to either $\nu_x = 6/8$, $\nu_z = 15/8$ or $\nu_x = 7/8$, $\nu_z = 14/8$ and to introduce spiralling of the magnet ends to obtain reasonable, yet ample, lengths of straight sectors. The exact and approximate formulas for the linear orbit properties are given. It is found that for $B = 20.0$ kilogauss at $E = 12.5$ Bev and straight sector

lengths between 20 ft and 30 ft with either 8 or 16 sectors, the edge angles of the magnets are rather sharp, being of the order of 45° . This accentuates the trouble in the construction and the problem of uneven saturation at high fields. However, it does give longer straight sectors and, with these higher values of ν_z , cuts down the required vertical aperture and, hence, the required power.

ANLAD-42 "Orbit Properties of Synchrotrons with D. C. Magnets"
L. C. Teng (September 3, 1957)

Martyn Foss proposed using four tuned short D. C. magnets located in the short straight sectors to serve (1) as the correcting magnets for field errors, (2) as tuning elements to adjust the betatron oscillation frequencies at the beginning and the end of the acceleration cycle, and (3) as bending magnets so that the high-energy orbits will be radially tilted relative to the more strongly bent low-energy orbits. The following advantages would result: (a) It allows the insertion of a stationary Piccioni magnet placed radially inward of one of the D. C. magnets for beam extraction. (b) The tilted high-energy orbits wandering radially across the gaps of the guide magnets tend to average out local radial field gradients. (c) A weaker Piccioni magnet is required to tilt the already tilted orbit at extraction. The migration of the equilibrium orbit and the betatron oscillations of the orbits in such a synchrotron are studied in detail. Parameters for these synchrotrons of various designs are presented.

ANLAD-43 "Magnet Data Reduction Code - PAD 6501"
Melvin I. Ferentz (September 23, 1957)

A recording of the code for the reduction of model magnet data on the IBM-650.

II. INTERNAL MEMOS

The following is a list of the internal memos of most general interest which have been written to date; these have not been distributed outside the Division, but a few copies are available to interested groups.

HAK-1 Dynamic Measurements of Pulsed Magnetic Fields
H. A. Kampf (May 22, 1956)

MF-1 Optimum Current Density Distribution in Coil of Ring Magnet
Martyn Foss (June 15, 1956)

MF-3 Search Coils to Measure the Field at a Point
Martyn Foss (May 18, 1956)

- JM-1 Beam Deflecting Magnet
John Marshall (June 24, 1956)
- JM-2 Chamber Design to Eliminate Waste Magnetic
Field Volume
John Marshall (June 24, 1956)
- JM-3 Demagnetization
John Marshall (June 24, 1956)
- GOC-5 Power Requirements of Model Magnet and Ampere
Turns due to Eddy Currents
G. O. Calabrese (August 24, 1956)
- JM-4 Deflector Requirements on Ring Magnet Design
John Marshall (August 24, 1956)
- AS-1 Current, Field and Frequency vs Time in ANL Proton
Synchrotron
A. Strassenburg (August 28, 1956)
- AS-2 Frequency Programming with Saturable Ferrite
Oscillator
A. Strassenburg (August 29, 1956)
- AS-3 Discussion of RF Frequency Control System
A. Strassenburg (September 4, 1956)
- JM-5 Forces on Magnet
John Marshall (September 4, 1956)
- JM-6 Chomping Motion for Deflecting Magnets
John Marshall (September 4, 1956)
- RHL/JM-1 Magnet Supporting Structure
Robert Lykken, John Marshall (September 6, 1956)
- JM-7 Ring Magnet Design
John Marshall (September 6, 1956)
- JM-8 Facilities for Radiochemistry in Laboratory Buildings
John Marshall (October 15, 1956)
- RP-1 Eddy Currents Induced in Thin Metallic Sheets
Rolland Perry (October 15, 1956)
- JD-1 Measurement of Ferrite Characteristics
John Dawson (November 19, 1956)

- JM-9 Temperature Rise of End-Cooled Current-Carrying Jumpers
John Marshall (December 7, 1956)

- DEM-1 Proposal for Procuring Some Automatic Data Handling Equipment
D. E. McMillan (January 17, 1957)

- JJL-7 Inflector Calculations
J. J. Livingood (January 27, 1957)

- LW-1 A Method for Obtaining the Frequency Program of the Synchrotron
L. Wadhwa (February 15, 1957)

- JSM-2 Evapor-ion Pump
John Moenich (March 18, 1957)

- EAC-1 Shielding Requirements
E. A. Crosbie (March 8, 1957)

- RT-4 Evaluation of Test Program for Magnet Foundation
R. Trcka (March 4, 1957)

- EFF/KB-1 Preliminary Study of Magnet Power Supply
E. F. Frisby, K. Burba (March, 1957)

- JD-2 Multiple-Turn Cavity Bias
John Dawson (April 16, 1957)

- HAK-4 R. F. Frequency vs Time Measurements
H. A. Kampf (April 8, 1957)

- MF-4 Turns for Reduction of Time Ripple in Field
Martyn Foss (April 17, 1957)

- Accelerator Beginner's Course, J. J. Livingood (April, 1957)

- LCT-1 Parameters for 12.5-Bev Synchrotron
L. C. Teng (May 6, 1957)

- JM-11 Tunnel and Shielding Design
John Marshall (June 3, 1957)

- JM-12 Height of Beam above Floor Level
John Marshall (June 3, 1957)

- JM-13   Quadrupole Magnets for Focussing Beams
          John Marshall (June 12, 1957)
- LCT-2   Two Sets of New Preliminary Parameters for the
          ANL Synchrotron
          L. C. Teng (June 24, 1957)
- HF/AS-1   Magnetic Fields Due to Eddy Currents in the Vacuum
          Chamber
          Harry Fechter, A. Strassenburg (August 30, 1957)
- CHKW-1   Beam Height
          A. V. Crewe, R. H. Hildebrand, U. E. Kruse,
          S. C. Wright (July 5, 1957)
- CHKW-2   External Particle Beams
          A. V. Crewe, R. H. Hildebrand, U. E. Kruse,
          S. C. Wright (August 30, 1957)

III. THEORETICAL WORK

E. A. Crosbie, M. Ferentz, L. C. Teng

The efforts of the Theoretical Group during the period covered by this report were concentrated on the following fields of studies. Most of this work was published in ANLAD reports whose abstracts appear in Section I.

A. Orbit Studies for Synchrotrons with D. C. Magnets

The proposal made by M. Foss of putting D.C. magnets in the middle of short straight sectors to cause a separation between the high and the low-energy orbits was studied in detail. The linear betatron oscillation properties were investigated by the matrix method under the approximation of infinitely hard fringing fields at the ends of the guide and the D.C. magnets. The deformation of the equilibrium orbit during the acceleration cycle was computed in two different manners. A set of approximate formulas giving the pertinent parameters defining this deformation as functions of energy to within 0.25% were derived analytically under the assumption that the equilibrium orbit at any given energy is radially so positioned that the perpendicular distances at the two ends of a guide magnet between this equilibrium orbit and that at injection (50 Mev) are equal in magnitude and opposite in direction. This deformation, together with that caused by the Piccioni jump target and its lip, were further calculated exactly numerically, with the help of AVIDAC, during the acceleration cycle, the radial positioning assumed for this calculation being that the distances measured along the two end faces of a guide magnet between the equilibrium orbit at any energy and that at injection are equal in magnitude and opposite in direction. The general results of this investigation show that this arrangement not only is practically feasible but also has many advantages. Several sets of machine parameters with optimized operating conditions were worked out. The most promising and suitable set is reproduced below:

Main Guiding Magnets (Octants)

Radius of Curvature = $\rho_1 = 71.24$ ft

Turning angle = $\phi_1 = 0.7504 = 43.0^\circ$

Length = $S_1 = \rho_1 \phi_1 = 53.46$ ft

Angle of end at long straight sector = $\theta_1 = 0.2314 = 13.25^\circ$

Angle of end at short straight sector = $\theta_2 = 0.1250 = 7.16^\circ$

Slope of end at long straight sector = $\tan \theta_1 = 0.2356$

Slope of end at short straight sector = $\tan \theta_2 = 0.1256$

Focal length of end at long straight sector

$$= \frac{\rho_1}{\tan \theta_1} = 302.4 \text{ ft}$$

Focal length of end at short straight sector

$$= \frac{\rho_1}{\tan \theta_2} = 567.1 \text{ ft}$$

Field intensity at 50.0 Mev = $B_0 = 476.8$ gauss
 Field intensity at 12.50 Bev = $B_f = 21.50$ kilogauss.

D.C. Magnets

Radius of Curvature = $\rho_3 = 43.84$ ft
 Half turning angle = $\phi_3 = 0.0350 = 2.00^\circ$
 Half Length = $S_3 = \rho_3 \phi_3 = 1.53$ ft
 Angle of ends = $\theta_3 = 0.0677 = 3.88^\circ$
 Slope of ends = $\tan \theta_3 = 0.0678$
 Focal length of end = $\frac{\rho_3}{\tan \theta_3} = 647.0$ ft
 Field intensity = $B_d = 774.7$ gauss.

Straight Sectors

Half-length of long straight sector = 10.00 ft
 Half-length of short straight sector = 5.00 ft

Cross-Sectional Dimensions of Main Guiding Magnet

Inside dimensions of vacuum chamber = 5.25 in. x 32.00 in.
 Dimensions of cavity in magnet = 5.75 in. x 53.50 in.
 Outside dimensions of magnet = 55.25 in. x 101.00 in.
 Cross-sectional dimensions of main coil assembly =
 5.75 in. x 8.00 in.
 Radial bell-mouthing at ends = uniform taper of 2.50 in. in
 the length of the end magnet block of 7.15 ft.

B. Extraction Scheme for a Synchrotron with D.C. Magnet

The principal motivation of the introduction of the D.C. magnets was to cause the high-energy orbit to separate from those of low energy so that it can be deflected by the Piccioni jump target into a stationary D.C. Piccioni magnet. An entire system of extraction was worked out in conjunction with the accelerator, whose parameters were obtained in study A. The Piccioni magnet is 30.0 inches long with a field intensity of 20.3 kilogauss and is located in between a D.C. magnet and the upstream guide magnet. The extraction magnet is located in the long straight sector immediately downstream from the Piccioni magnet and has a minimum field intensity of 20.0 kilogauss. The jump target, if made of beryllium, should be 2.0 inches thick with a lip 1/16 inch thick and 1/2 inch wide radially and should be placed in the long straight sector immediately upstream from the short straight sector opposite the Piccioni magnet. The layout gives also the minimum radial bell-mouthing required at the ends of the guide magnets and shows that, if two sets of stationary extraction systems are to be installed to provide two external proton beams, these two beams must be 180° apart. Two scaled drawings were made to give the entire layout of the extraction system.

C. Methods of Getting Longer Short Straight Sectors

The half short straight sector on each side of a D.C. magnet for the set of parameters derived in study A is only 5.0 feet long. It seemed desirable to have more space available in the short straight sectors for vacuum and mechanical structures. Investigations were made on various means of obtaining longer short straight sectors.

1. The most straightforward way is simply to reduce the maximum field in the guide magnets and the field in the D.C. magnets, thereby making the entire accelerator bigger. Two sets of optimized parameters were worked out corresponding to maximum guide field of 20.0 kilogauss and D.C. fields of 647 gauss and 518 gauss, giving half lengths of short straight sectors 6.5 feet and 7.0 feet, respectively.

2. Longer short straight sectors can be obtained by moving the operating point out to $\nu_x = 7/9$, $\nu_z = 8/9$. This possibility was studied and found to be undesirable because of the proximity of this operating point to the $\nu_z = 1$ resonance.

3. Without actually lengthening the short straight sectors we might desire to arrange them so that they come in more useful whole pieces instead of the less useful two halves. This can be accomplished either by displacing the D.C. magnet to one end of the short straight sector or by splitting the D.C. magnets and displacing the halves to the ends of the short straight sectors. These possibilities together with the orbit properties were studied in detail. The results are given in ANLAD-42.

4. A more drastic alteration in the design of the synchrotron resulting in much longer short straight sectors is to introduce spiralling of the sectors and to move the operating point to either $\nu_x = 6/8$, $\nu_z = 15/8$ or $\nu_x = 7/8$, $\nu_z = 14/8$. This design has the advantage of longer short straight sectors and stronger vertical focussing, but the required large edge angles of about 45° make it rather unattractive.

The ultimate conclusion resulting from this lengthy wild goose chase is that the original design with parameters given by study A, although requiring some crowding of mechanical and electrical components in the short straight sectors, is still the best of all.

D. Study of the $2\nu_z - \nu_x = 1$ Resonance

During injection the operating point is chosen to be $\nu_x = 6/8$, $\nu_z = 7/8$ in order to make the beam injected above the median plane miss the inflector lip for eight revolutions. However, this operating point lies on the $2\nu_z - \nu_x = 1$ second-order error resonance. While this resonance is not essential, in the sense that it does not cause the beam to blow up, it does couple the radial and the vertical betatron oscillations. Toward

the end of the injection period the radial oscillation has an amplitude approximately six times that of the vertical oscillation. If the transfer of energy of the radial oscillation into the vertical oscillation is too rapid, this resonance could be detrimental to the perfect operation of the accelerator. Very lengthy and detailed studies of the strength and the width of this resonance band were started and are being continued at the present. In the first place, theoretical studies with infinitely hard magnetic field edges were pursued. This effort led to many interesting and illuminating results and understandings of the exact and expanded forms of the betatron oscillation equations. It was noticed, among others, that singularities appear in the nonlinear terms of the vertical oscillation at the infinitely hard edges and that for the radial oscillation, when proper care is taken in the evaluation of integrals containing δ -functions and their derivatives, the second-order terms in the radial oscillation equation can be calculated, giving discontinuities in the orbit at the hard edges which leads, in turn, to a geometrical construction of the exact orbits with pure radial oscillations. This analytical result forces the abandonment of the hard edge assumption in this investigation. The assumption of soft edges then calls for numerical integrations of the equations of betatron oscillations by electronic computers. The IBM-704 at N.Y.U. was coded for this purpose. The soft fringing field on the median plane at the end of a magnet is assumed to be of the form $\frac{1}{2}B_0 \left(1 + \tanh \frac{l}{\epsilon}\right)$, where B_0 is the uniform magnetic field inside the magnet, l is the distance perpendicular to the end face of the magnet, and ϵ is a scaling factor giving the "hardness" of the fringing field, being zero for an infinitely hard field. After more than two months of working on the code, its correctness is still questionable. This code is now being studied and revised here for the ANL-704 computing machine which is expected to be operating before the end of the year.

E. Data Reduction Code

The data obtained from the model magnet will be processed and reduced on the IBM-650 computing machine at ANL. The code for this purpose was written, debugged and is now in use. This code can take in 72 data per experimental run. The details are recorded in ANLAD-43.

F. Miscellaneous

Several miscellaneous studies were made in connection with problems of personal interests and those which arose from different groups in the division. Those of relatively major importance are listed below:

1. Re-examination of the space charge limitation shows that the ratio of space charge limitations of the ANL synchrotron (equivalent radius $\cong 90$ feet, cross-sectional dimensions of vacuum chamber $\cong 30$ inches x 6 inches, betatron oscillations per revolution $\cong 1$) to that of a "half-AGS"

(equivalent radius ≈ 140 feet, cross-sectional dimensions of vacuum chamber ≈ 6 inches $\times$ 3 inches, betatron oscillations per revolution ≈ 6) is about

$$\frac{2.6 \times 10^{13} \text{ protons}}{1.2 \times 10^{13} \text{ protons}} \approx 2.$$

The ratio of the intensities of the actual injected beams in the ANL synchrotron and the "half-AGS," even assuming a repetition rate for the latter four times that of the former, is, however,

$$\frac{10^{12} \text{ protons/pulse}}{5 \times 10^{10} \text{ protons/pulse}} = 20.$$

This indicates that for both machines the actual beam intensity is far below that limited by space charge and that the actual beam in the ANL synchrotron is closer to the space charge limit by a factor of about 10.

2. Gas scattering - In ANLAD-12 and 26 the gas scattering effect in the ANL synchrotron was calculated, assuming injection onto the median plane. This effect is re-calculated for the present scheme of injection above the median plane.

3. Debuncher calculation - Calculations were made for the debuncher required to obtain an energy homogeneity of $\pm 0.15\%$ out of the beam exit from the Linac having an energy spread of $\pm 0.5\%$ and a spread in phase of $\pm 5^\circ$.

4. General studies of injection processes - Unless a transparent inflector such as the jet-stream in the H_2^+ dissociation method of injection can be built, ordinary inflector lips are opaque. The inflected beam has to be moved away from the inflector within a small number of revolutions governed by the choice of ν_x and ν_z and the location of the inflector lip. The methods of accomplishing this fall into two categories:

(a) By moving the equilibrium orbit away from the inflector. This consists either of adding or subtracting energy from the inflected beam or of changing the guiding magnetic field intensity. All existing synchrotrons employ this method of injection. This straightforward process becomes rather brutal for injecting into a fixed-field accelerator at high energy and is incapable of utilizing all available phase space area of the betatron oscillations.

(b) By resonance damping of betatron oscillations. The method described in the ANL proposal of August 1955 is of this type. It is particularly suited for injecting into fixed field accelerators at high energies. The resonance process can further change the shape of the phase ellipses of the inflected beam to pack them into all available phase

space area, thus increasing the number of turns injected. The general properties of these processes and capabilities have been studied.

It is observed, however, that this method of injection requires much higher precision in the operations of more elaborate electric and magnetic components.

IV. MODEL MAGNET STUDIES

M. Foss, H. B. Phillips

A. General

Previous summary reports (ANL-5630, ANL-5713) discuss the justification and contain general descriptions for the choice of the zero-gradient, poleless "window-frame" main synchrotron magnet octants. Initial model studies have been also described. The following report discusses, occasionally in detail, a number of physical requirements of the main magnet octants, and the model studies which have been made and extended in order to ascertain experimentally the most satisfactory design parameters satisfying the requirements.

Two D.C. model types have been used. The first type is similar to the model of 6-inch length described in ANL-5713, with occasional minor changes in dimensions or construction details in order to satisfy particular experimental needs, but these early models were not scaled to the dimensions of the final magnet, particularly with respect to the width-to-height ratio of the gap, since these were not yet decided upon when this type of model was evolved. The second type is a 1/7-scale model with the expected dimensions of the final magnet, though with no curvature. Other 1/7-scale models are now under construction.

B. Measurements in Regions Removed from End Effects

In order to simulate the magnetic guide field well removed from end effects, either the model must be sufficiently long, or the ends of a short magnet must be guarded in some manner to produce the effects at the center of a much longer magnet. For preliminary modeling, where much machining may be expected and it is convenient to keep the power requirements relatively low, it is desirable to use a short, guarded magnet. The short (6-inch) type of model with guards (each 3 inches long) was used for this particular series of measurements and is shown in Fig. 1. Over an azimuthal span of $2\frac{1}{2}$ inches at the magnet center the field variation was 2 gauss (at a central field of 24 kilogauss) with the guards as shown; this variation could have been further reduced by better choice of guard, but this was not felt to be necessary. The field variation over the same distance in a 12-inch magnet without guards was about 80 gauss, and the central field value decreased by about 300 gauss.

Fig. 1 Isometric view of a half section of short, guarded model type. Water lines not shown.

Fig. 2 Sketch of one-half of model cross-section, showing main and auxiliary coils.

Fig. 3 Data from model sketched in Fig. 2. The three numbers for each curve are central field in kilogauss, auxiliary coil current in amperes, and main coil current in amperes, respectively.

The property of the guide field measured and investigated in the central region was the radial variation of magnetic field as a function of the magnitude of the central field. The radial variation requirements in the final machine may be considered in three parts.

1. During injection, it is required that ν_x and ν_z be held close to the design values in order that the injected beam miss the back of the inflector for the desired 8 turns. The radial variation of field in the pulsed magnets is the most important source of error at low field, and will be corrected by placing magnets in straight sections, as discussed on page 14 of ANL-5713.

2. In the accelerating phase, the only requirement of the radial variation is that ν_x or ν_z does not move into the region of serious resonance at $\nu = 1$, which occurs when n is about ± 0.2 , corresponding to a change of 40 gauss in 11 radial inches at 20 kilogauss. Measurements show (ANL-5713) that this tolerance is easily held even for high fields in the central radial region where the beam is situated during acceleration.

3. For beam extraction, the particles will pass quite close to the coil at the end of one octant so that flatness of field in this region is desirable; furthermore, it is qualitatively evident that the better the constancy of ν_x and ν_z , the better is the focus at the Piccioni magnet and the better the quality of extracted beam, thus requiring less expensive bending and focusing magnets from there on. From this point of view much less variation than 40 gauss per 11 inches is desired in the outer radial region, though not absolutely necessary.

Two different experimental methods have been used to produce magnetic fields which are acceptably flat in a radial direction at field strengths above 18,000 gauss. One method was to bury a one-turn auxiliary winding in the upper magnet yoke, which was excited by an auxiliary generator. A sketch of the configuration used is shown in Fig. 2, and some of the results are presented in Fig. 3, where the radial variation of the magnetic field is shown for different combinations of currents in the main and auxiliary coils. All the field shapes shown in Fig. 3 are quite satisfactory, and conceivably one may properly program the auxiliary coil current by running the auxiliary coil in parallel with the main coil and allowing the auxiliary current to be controlled by the rate of change of back emf in the auxiliary coil. However, because of the tedious engineering problems of placement, insulation, and perhaps cooling of such coils in the final machine, one should seek a simpler solution to the radial-variation problem and keep this particular solution as insurance if simpler methods fail.

The simpler solution of removing iron from strategic locations in the upper and lower magnet yokes has been extensively investigated and appears to be very promising. One places holes, running in the azimuthal

direction, symmetrically about the vertical and horizontal median planes. Perhaps one way to qualitatively understand why such holes may be able to solve the radial-variation problem (at high fields) is to visualize the flux patterns in the iron without any correcting holes. Since the iron is being saturated, the reluctance for magnetic flux running along the vertical median plane (and around the yokes) is appreciably greater than the reluctance for flux running along a vertical plane near a coil, and the magnetic field in the central region will be weaker. If, however, holes are placed in such a way as to offer a greater reluctance to flux passing through the gap near the coil than to flux passing through the gap center (because the two flux lines take different paths through the yokes), the radial variation of magnetic field in the gap can be considerably decreased. At low fields, since the yoke reluctance is extremely low compared with the gap reluctance, the effects due to holes almost vanish.

The first measurements with a 12-hole model were discussed in ANL-5713; although the results were useful, it was felt that more investigations were necessary in order to further "flatten" the high fields and to simplify the hole structure. If holes are to exist in the main magnet octants, a hole structure should be found which minimizes the machining operations.

To simplify the experimental search for good hole arrangements, a model (with guards, 6-inch length type) was made of stacks of 3/16-inch steel plates; holes were drilled in each plate individually by standard techniques using drilling fixtures. Considerable time was spent on hole arrangements, many of which were found to be quite poor, but which indicated where holes should not be drilled. Eventually, quite good hole structures were found, and such a structure is shown in Fig. 4. Some results obtained from this particular set of holes are shown in Fig. 5, where the radial variations of magnetic field are shown for different values of the central field. However, less radial variation than is shown in Fig. 5 is desired and it should be pointed out that this particular model was not correctly scaled with respect to the final cross-sectional dimensions of the main magnet. Experiments of this sort on a properly scaled model have been started.

An important consideration in experiments of this kind is the reduction and presentation of voluminous data in a compact and meaningful form. In order to show concisely the interrelationships among the field intensity, hole size, hole location and field shape, several different artifices have been used. One such form of presentation is shown in Fig. 6, derived from a model similar to that of Fig. 4. The abscissas of Fig. 6 represent the exciting current and central field values of the magnet (related through the B vs I curve), while the ordinates in gauss-inches are a measure of the area under the field-shape curves, taken over the one and one-eighth-inch span (model dimension) closest to the exciting coil. A necessary, though not sufficient, condition for perfect radial behaviour is that the area vanish.

Fig. 4 Sketch of one-half of model cross-section, showing holes and coil.

Fig. 5 Data from model sketched in Fig. 4. Residual field, as in Fig. 3, has been subtracted out.

Fig. 6 Area under curves of types shown in Fig. 5, for radial extent of 1.125" centered about a point 1.687" from chamber center, plotted vs. coil current, for different hole sizes appropriate to Fig. 4.

An interesting feature of the curves shown in Fig. 6 is the appearance of a "bend," located in this case at about 3900 amperes, corresponding to 21.6 kilogauss. As the hole size is increased the "bend" is depressed, but its location does not move along the abscissa. By observing the behaviour of the "bend" as the hole size is changed, one may anticipate the hole size of best compromise, which in this case is about 0.466 inch diameter. This procedure will be used in the 1/7-scale model measurements.

C. Measurements in Regions near Magnet Ends

The behaviour of the magnetic field near the main magnet ends affects the betatron frequencies of the beam. The effective end of a magnet for a particular orbit is defined as the azimuthal point where $\int B \, d\ell = \int (B_0 - B) \, d\ell$, in which the first integral is evaluated from the effective end out into a straight section, and the second integral is evaluated from inside the magnet where the field has the constant value B up to the effective end point, along the orbit length ℓ . The values of ν_x and ν_z and the positions of the equilibrium orbits are functions of the effective magnetic lengths and of the radial variations of these lengths; the tolerances allowed in the magnetic lengths and in their variations are determined by the allowable variations in ν_x and ν_z and in the equilibrium orbit position during the various phases of the machine operation. The tolerances allowed for ν_x and ν_z during the three phases of acceleration have been outlined above in section B; the tolerances allowed for the equilibrium orbit position are somewhat more involved (due in part to Piccioni target and magnet considerations) and will not be discussed here. All these tolerances for effective end considerations may be summarized by invoking the criteria that at injection, ν_x and ν_z must not change by more than 3% from the designed operating point and must not move near either the $\nu_x = 1$ or the $\nu_z = 1$ resonances during any phase of operation. The tolerances are:

1. the effective length per full-scale octant cannot change by more than 2 feet, if all 16 ends move identically;
2. in general, no end may be displaced by more than 1 inch from the equivalent position of all other ends,
3. the maximum allowed angle between the locus of effective ends (a "bowed" curve from a top view) and the design edge line would be about $\pm 3/4$ degree at injection, if it were not for the possibility of applying corrections through auxiliary magnets; with such magnets, ± 5 degrees will be tolerable at all times.

Measurements on end-effects have been made on the 1/7-scale model magnet. One end was not used for end-effect experiments and was terminated in a step-wise fashion for "guarding" the interior region for radial-variation experiments mentioned previously. The other end, in which ramps have been cut, was used to find the effect of ramp shape, flaring of coil ends, jumpers which carried the current from one side of the magnet

to the other, and the magnet guards over the jumpers. A cutaway view of this magnet is shown in Fig. 7. The reason for cutting the two ramps is to minimize saturation in the end iron; such saturation would produce a rapid variation of effective end points with change in magnet current at high fields. The coil ends were flared vertically in order that the magnetic scalar equipotential surfaces from the coil should coincide at least to a first approximation with the equipotential surfaces determined by flux out of the iron; with such coincidence one ideally expects no significant disturbance in the coil regions of fields determined and calculated from iron shape, and no significant variation in equipotential surfaces in the coil regions when saturation begins to set in and the relative contributions of flux from iron and coil begin to change. The jumper shields are included in order to present a low-reluctance return path for the jumper flux, and so prevent this flux from extending far into the straight section.

Some care was given to choosing the dimensions used at both ends. At the "guard" end (not shown in Fig. 7) the step dimensions were chosen through relaxation potential calculations on the IBM-650 computer. The computer program, which was written for solving such two-dimensional problems, accommodates a 1446-point mesh and has been used to calculate the expected magnetic field at the ramp end of the magnet. In Fig. 8 the calculated and measured fields at the "ramp" end are shown for a low field value where there is no saturation and where such calculations are expected to be valid. The good agreement between the calculated and measured fields shows that the calculating method for such arrangements of iron and copper is a powerful one for choosing initial dimensions with which to experiment.

An example of the type of measurements made on the magnet end is shown in Fig. 9. This figure shows both the variation in the effective magnetic end position as a function of the central field value and also the radial shape of the effective end as a function of the central field value. It is seen that at low fields the effective end is 0.647 inch inside the model magnet (the calculated figure was 0.628 inch) and that the end moves outward toward the straight section as the field is increased; also, the radial shape changes with magnetic field strength. The former effect is due to improper choice of ramp and the latter effect due to improper vertical flaring of coils.

From the way in which the position of the effective end moves, at 17.8, 12.2, and 6.1 kilogauss, one can extrapolate the position at injection (500 gauss) as being almost identical with the 6.1-kilogauss data. The observed length change of 0.090 inch between the injection field and 21.8 kilogauss in the model corresponds to $7 \times 0.090 = 0.63$ inch in the full-sized machine, or the entirely trivial change in ν of 0.1%.

The maximum angle of the bowed effective end of the magnet at injection field is of the order of $3/4$ degree near the chamber edge, which corresponds to a change in ν of 3%; this is tolerable.

Fig. 7 Flared end of 1/7 - scale model, water lines and guarded end not shown.

Fig. 8 Calculated and experimental values of field variation along a central line, at low fields.

Fig. 9 Radial variation of effective magnetic end position as a function of central field value, for 1/7 - scale model shown in Fig. 7.

It should be emphasized that it is not the fringing fields which will be difficult to correct, but the average n -values at injection throughout the body of the magnet, as previously mentioned. The effects of residual fields and eddy currents will tend to compensate each other, but it is certain that corrective measures, in the form of D.C. magnets with properly shaped fields, will be employed, since the expected errors due to residual and eddy current fields will be far beyond tolerance.

With a somewhat different ramp shape, it is anticipated that the physical length of the magnet can be decreased for the same effective length. A gain of several inches for each straight section will be obtained.

Another 1/7-scale model magnet is being planned for further work of this type. It will be curved with vertical flaring at the ramped ends. The ends, from a top view, will not be perpendicular to the sides, but cut at an angle to conform to wedge-shaped ends which will exist in the final machine.

V. MAGNETIC MEASUREMENTS INSTRUMENTATION

Bruce Phillips

Instruments for magnetic measurements and for data processing are continually being developed to meet the changing requirements of the model study program.

A. Devices for Measuring Magnetic Effects

1. High-Current Mutual Inductor

A mutual inductor, whose primary circuit is suitable for carrying the full exciting current (6000 amperes) of the model magnets, has been constructed. The inductor consists of eight primary turns arranged in a double clover leaf pattern, each turn having a multiturn secondary winding centered within it. Figure 10 shows a view of the mutual inductor before being encased and potted. The primaries are made of 3/8-inch diameter copper tubing, and all of the secondaries are wound with a continuous length of wire in order to avoid thermoelectric voltages. The array of eight units is so constructed as to discriminate against stray magnetic fields.

The mutual inductor will be used to measure B vs I characteristics of magnets, as well as their hysteresis loops. By connecting the mutual secondary in series bucking with the magnet search coil, the servo fluxmeter may be used to measure $B - KI$, where B is the field within the magnet, I is the exciting current, and K is a constant. By this means, accurate B vs I data may be obtained rapidly.

Fig. 10 High current mutual inductor before potting.

Fig. 11 1/7 scale D. C. Model Magnet and coil manipulator.

2. Search Coil Manipulator

Certain modifications and additions have been made to the search coil manipulator in order to obtain semi-automatic operation. In Fig. 11 this device is shown in operating position at a model magnet. Because of the precision construction used in it, the manipulator can position search coils accurately and with negligible backlash. A remote control panel is located at the fluxmeter, from which the functions of the manipulator may be controlled; one man, therefore, is able to operate both the fluxmeter and the search coil motion.

3. Servo Fluxmeter

Some relatively minor improvements have been made in the servo fluxmeter in order further to reduce changes in drift rate. For example, a new adjustable lamp housing has been installed in the photoelectric galvanometer in order to increase the mechanical rigidity of the lamp support. Also, additional vibration absorbers have been used under the photoelectric galvanometer. At present, typical changes in drift rate of about one line/sec/min are observed.

B. Devices for Processing D.C. Magnet Data

Because of the great quantity of data which can be collected in a short time, we are relying, to an increasing extent, upon various data-gathering and reducing devices.

1. IBM-650 Computer

The Data Processing Section at ANL has an IBM-650 computer which is used by us; by punching the servo fluxmeter output into IBM cards, the computer may be used to reduce and analyze the data rapidly. A program has been written (M. I. Ferentz, ANLAD-43) which allows the rapid calculation of field shapes. Additional programs are in the process of being written for calculating the effects of coil error and other quantities of interest.

2. IBM-523 Summary Punch

In order to more fully utilize the IBM-650 computer, a 523 summary punch has been acquired. This machine has been modified to accept input information from different devices and for reading cards into a curve plotter. The use of the 523 punch will greatly speed the taking of magnet data, since the services of the key punch operators will be largely eliminated.

3. Shaft Digitizer

A device for converting the output of the servo fluxmeter directly into digital form is being installed. This digitizer (G. M. Giannini Co.) will allow the fluxmeter output to be fed directly into the 523 summary punch, thereby eliminating the tedious (and oftentimes error-producing) process of transcribing data by hand. Control circuitry has been completed for controlling the search coil manipulator, the servo fluxmeter, the digitizer, and the summary punch. Provisions have been made for punching constants into the data cards and for automatically numbering each data point.

4. Curve Plotter

When large quantities of data are to be expressed in the form of graphs it is convenient to have an automatic curve plotter. A Moseley flat-bed recorder is being used, with the added accessories of a keyboard, an IBM card translator, and a point plotter. Points may be plotted either by means of the manual keyboard, from cards read by the summary punch, or by a combination of both.

The various pieces of data processing equipment are shown in Fig. 12 (with the exception of IBM-650 computer). These devices, used in various combinations, provide a versatile system for the rapid and accurate processing of data.

Fig. 12 Magnet data processing equipment.

VI. 1/7-SCALE D.C. MODEL MAGNET CONSTRUCTION

W. A. Siljander

The model magnet iron and its associated mounting and clamping devices were designed in a straightforward, easily fabricated manner to expedite construction time. The upper and lower poles of the 1/7-Scale Model Magnet each consist of four inside blocks, 4 inches by 15 inches by 3.731 inches high, and two end blocks, one of which contains the vertical bell-mouthing. The side yokes are of one-piece construction with horizontal adjustment available. All the pieces were rough cut and then ground to the required dimension from a large forged AISI 1010 steel billet. The blocks were then assembled and held in place with suitable brass and stainless steel clamping fixtures. The whole assembly rests on a large aluminum base plate. The test bench was rigged up beforehand with the necessary water headers and electrical bus work.

The coil presented a fabrication challenge. The height, width and spacing tolerances were extremely rigid since permissible errors had to be scaled. It consists of 20 turns of 3/16 x 0.032 inch wall square copper tubing, four high and five across. It is bell-mouthed vertically on one end and has solid jumpers on the other. The forty conductors were first bent in a bending fixture. They were then clamped in the potting fixture with shims for accurate spacing, and the ends were silver soldered a row at a time. After silver soldering and acid dipping for cleaning, the conductors were reassembled in the potting fixture using epoxy fiberglass shims and linen-base Bakelite wedges for the insulating spacing. The heights, widths, and bell-mouthing were held to within 0.001 inch. Potting was done by the National Electric Coil Co. of Columbus, Ohio as follows:

The fixture with the assembled coil was clamped tightly together, plastered with mold release, and placed in a vacuum tank. After evacuating the tank and coil for a few hours, liquid epoxy (Epon 815 with BF 3-400 hardener) was introduced into the tank, completely submerging the coil. Pressure of around 75 psi was applied, forcing out the excess epoxy. The coil and fixture were clamped on a "rotisserie" which rotated the coil during the curing cycle of 12 hours at around 450°F.

The successful potting of the 1/7-scale model magnet coil with its associated high degree of accuracy was very encouraging. A 1/4-scale coil is already underway using the same potting technique. The information and experience gained from these coils will undoubtedly greatly hasten the main magnet coil program.

VII. MODEL MAGNET COOLING

Wayne Nestander, Richard Trcka

The 1/7-scale model magnet uses about 200 kilowatts of power which must be dissipated in the form of heat. Demineralized water flows through the 3/16-inch square copper tubing that is used for the coil conductors and also through the jumper connections from the electrical bus bar to the coil ends. These jumpers are composed of a bundle of six 1/8-inch copper tubes.

Two-inch flexible metal hoses deliver the water from 4-inch mains to the 2-inch copper pipe headers mounted on the model table. The dielectric material used between the coil and the water headers at ground potential is 1/4-inch I.D. x 10-inch rubber hose. A hose of this type supplies each individual water loop, which is electrically one-half a coil turn.

A flow switch and temperature switch interlock are used with the cooling system. The flow switch is adjusted to shut down power to the magnet if water flow in the jumper connection falls below 2.0 gallons per minute. Power will also be interrupted if the water temperature in the return header rises above 120°F. The normal temperature rise between the supply and return headers is 12°F when the coil current is 2000 amp.

Prior to the assembly of the copper coils for the 1/7-scale model magnet, hydraulic flow tests were conducted to determine the actual head loss per foot occurring in the tubing used for the coil.

It was learned that results of an empirical formula for head loss were not sufficiently accurate for design purposes when used with small-size tubing. The Darcy formula in the range of turbulent flow was considered:

$$h_L = 0.0311 \frac{f Q^2}{d^5} ,$$

where

h_L = loss of static head due to fluid flow, in feet of liquid

f = friction factor for smooth pipe, dependent on Reynold's number

Q = rate of flow in gallons per minute

d = internal diameter of pipe in inches.

Flow measurements were made for the various sizes of copper tubing that could be used for model magnet coils. The variations between calculated and actual head losses were determined and a correction factor

was obtained. Our laboratory tests indicated as much as a 28% difference between actual and calculated results. The following table shows the variation for the different tubing sizes.

$$\text{Correction Factor} = \frac{\text{Actual Head Loss}}{\text{Calculated Head Loss}}$$

<u>O.D. (inch)</u>	<u>I.D. (inch)</u>		<u>Correction Factor</u>
1/4	0.186	(Round)	1.20
3/16	0.123	(Round)	1.07
1/8	0.061	(Round)	0.72
3/16	0.123	(Square)	1.08*

*The calculated head loss for a square tube is based on a round tube of equivalent cross-sectional area.

As an example, the actual head loss per foot for 1/4-inch tubing is 1.20 times the calculated head loss per foot.

VIII. GENERATOR REGULATOR J. F. Mech

A new generator regulator for the G.E. generators has been constructed and is now ready to operate. This regulator differs from the previous models in two respects:

1. This regulator may be controlled in steps or continuously at the option of the user.
2. The regulator employs an enclosed feedback loop about the amplidyne used as a pilot exciter, which causes the amplidyne to follow a controlling voltage with a high degree of precision.

It has been found desirable, when rapid response of the generator is necessary, to influence the control characteristics of the exciter and pilot exciter by means of such a feedback loop about each exciting stage. Future developments will include such feedback arrangements and will also be along lines to decrease the number of such stages by decreasing the number of generators required to control the main power generator. The following diagram (Figure 13) is a block diagram of the system now in use.

Fig. 13 Block diagram of generator regulator (used as current control).

Fig. 14 Schematic diagram of pulse circuit.

Fig. 15 Voltage on inductive load.

Briefly, the method of operation is as follows: A signal is received from the shunt in the load circuit. This is first amplified by the pre-amplifier. The amplified signal is then compared with a reference voltage and the difference or error signal obtained is further amplified. This signal is always of such a phase and amplitude as to hold the generator current constant and to correct any deviation or perturbation which may occur. The output current is then controlled by the value of the reference voltage. The amplidyne employs voltage feedback in such a way that the output voltage of the amplidyne has a very close correspondence to the output voltage of the first amplifier.

The accuracy of control possible with this system is about $1/3$ ampere out of 3,000 amperes in current regulation, and about the same relative accuracy in voltage regulation.

IX. PULSING CIRCUIT FOR $1/4$ -SCALE MODEL MAGNET

J. F. Mech

A circuit has been developed and the components tested at currents sufficient to drive the proposed $1/4$ -scale model magnet. This circuit will control the pulse duration accurately to the time ($1/16$ -sec rise time) required in scaling the proposed synchrotron pulse. The interval between pulses, however, will not be scaled, but will be determined by the recovery time of the generators and the electronic circuits involved. A schematic diagram of this circuit is shown in Fig. 14.

The operation of this circuit will be as follows:

1. The excitron will be fired with the circuit breaker closed and the generators at the proper operating voltage.
2. When a time of $1/16$ second has elapsed, the circuit breaker will be opened, initiated by a signal somewhat in advance of the actual opening of the breaker. The voltage across the magnet will invert and current will flow through the diodes, discharging the magnet.
3. When a time sufficient for the magnet to completely discharge and for the excitron to recover has elapsed, the circuit breaker is closed preparing the circuit for another pulse.

The timing signals originating these actions will be supplied by apparatus associated with the Rea machine.* These signals were supplied during initial testing by a simple electronic circuit constructed for this purpose.

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*See page 34.

Pulse tests were made using resistive and inductive loads at currents ranging from 100 to 2600 amperes and included the value of current (2050 amperes) necessary to pulse the 1/4-scale model magnet. However, this entire series of tests was made at voltages low compared to the voltage required to test the model magnet. This fact should lead to no undue difficulty since the equipment is rated at voltages considerably greater than the voltage required in model magnet pulsing. Since it is in the nature of an excitron to operate with a constant voltage drop, this factor did lead to the exaggeration of some of the voltage fluctuations experienced on the generator bus. Due to this property of a mercury arc tube, voltage perturbations are placed directly on the terminals of the load where they are compared with a fraction of the generator voltage. The fraction of the generator voltage is in this case small. Records were made of these phenomena and an idealized voltage waveform on an inductive load is presented in Fig. 15.

When the ignitron (a GL-5553 ignitron rather than the excitron was used during initial tests) is fired, using a magnet as load, the full generator voltage minus the ignitron drop appears on the magnet terminals. As the magnet current increases, the IR and ignitron voltage drops increase, yielding the initial drop in voltage shown in Fig. 15. The voltage then remains essentially constant for the duration of the pulse - 1/16 second. The breaker is then opened and, since there are three contacts in each leg of the breaker to be opened, the voltage drops in steps as shown in Fig. 15. The third step is associated with arcing of the arcing contact in the breaker. During this time, the voltage is not dropping as rapidly as previously. This is a measure of the speed at which the arcing contact is being withdrawn. The voltage across the arcing contact continues to increase until two conditions are satisfied, namely:

1. The voltage becomes sufficiently large to force current in the reverse direction through the generator (i.e., the back EMF of the magnet exceeds the generator terminal voltage), and
2. The generator inductance allows acceptance of the full magnet current.

The generator transient then subsides and energy is discharged at a smaller voltage from the magnet into the generator unit until all of the energy stored in the magnet is removed.

The primary purpose of this unit is to permit the testing of larger model magnets than can be handled with generators now on hand. A secondary use will be in checking the characteristics of full scale magnet blocks as they are received from the fabricator. Ultimately this power supply will be used to energize auxiliary magnets of the completed accelerator.

A cost estimate which includes foundation, temporary housing and the necessary expansions of the present 13.0-kv substation for the M.G. set has been prepared.

Further details of this project are under development and it is hoped the actual installation will start before January 1, 1958.

XII. INSTRUMENTATION FOR DYNAMIC MAGNET STUDIES

Dean E. McMillan

As mentioned in the last Summary Report, a fast multichannel analog to digital converter system is being purchased from the J. B. Rea Co. for use in the pulsed model magnet program. In order to synchronize its operation with the pulsed model, a control system is in the process of being assembled. Practically the entire unit has been "bread boarded" and made to work.

This system performs the following functions:

1. Determines the pulse magnet repetition rate;
2. puts out signals to do the following:
  - (a) bring generator fields up to maximum value (Note - This is not used unless generators are to be over-excited enough to cause overheating of the generators on a continuous basis.);
  - (b) start the magnetic tape recorder of the Rea machine;
  - (c) unclamp the integrators or other recording elements in the analog data channels;
3. produces the following pulses, which can be independently delayed in time from the signals in 2. above in steps of 0.100 millisecond from zero to 9.9999 seconds:
  - (a) fire ignitron signal which will put the generator voltage on the magnet;
  - (b) start data sample pulse which determines the initiation of a burst of pulses which are commands to the Rea machine to sample the analog channels;
  - (c) open circuit breaker pulse which will remove the applied voltage to the magnet and allow the stored energy of the magnet to be fed back through diodes to the generators or a battery rack;

X. 1/4-SCALE PULSED MODEL MAGNET

W. A. Siljander

The 1/4-scale pulsed model magnet design and fabrication program is moving rapidly to the completion stage. The model will be a curved center portion of an octant, 24 inches long. Each lamination will be formed as is now anticipated for the final magnet, i.e., the laminations will be in two parts, with the gap for coils and vacuum chamber cut out of the lower portion. Seventeen plates of 1/8-inch thick AISI 1010 steel, ground flat, will be assembled into a "slab," the end plates of the slab being machined to the appropriate taper. Fourteen such slabs will constitute the model.

Each plate will be sprayed with an insulating plastic varnish such as Glytol, Formvar, or Coreplate; while still tacky, capacitor paper, 0.00075 in. thick, will be laid on, followed by another plate. The total insulation thickness between laminations will be 0.0015 inch. The plates will be aligned by linen phenolic dowels inserted into the shimming holes, which will be drilled before varnishing and assembling. A fixture will be used such that a slab can be compressed, baked in an oven and tack welded together on the two sides and top or bottom with steel straps. A finishing cut will then be given the tapered ends, and external dowels will be positioned in the straps to mate the two parts of each slab. The top and bottom portions will be doweled and bolted together on the outside and placed on the base plate. Adjoining slabs will be doweled together for alignment with small brass dowels placed within the larger plastic pins in the shimming holes. The whole assembly can then be clamped longitudinally together.

The 1/8-inch steel sheets, the steel welding strips, and the clamping fixtures are being machined at the present time. The slab spraying and bonding method is being developed and set up at the Rock Island Arsenal. The coil potting and bending fixture is about completed. The same technique as described and used on the 1/7-scale model magnet coil will be applied to this model. Building layouts for machine location arrangements have been completed. The designs of the water and electrical connections are scheduled to be completed by the later part of October. It is hoped that the model magnet will be operating before the first of the year.

XI. ADDITIONAL D.C. POWER SUPPLY

K. Burba

Some effort in the past months has been devoted toward establishing the magnitude and some criteria for the D.C. power supply for present and future needs. As a result, an investigation of the available sources has been undertaken and the most suitable D.C. power supply selected. The choice is a second-hand rebuilt motor generator set, with two identical D.C. generators. Each generator is of 1100 kw, 415 v D.C., driven by a common 3-phase, 60-cycle synchronous motor of 2800 H.P., 2300/4000 v at 720 rpm.

- (d) stop data sample pulse which will stop the sample command pulses to the Rea machine and also at the same time stop the tape recorder, and reclamp the integrators; the generator fields will be deactivated and the circuit breaker closed after nominal delays generated in the associated generator equipment since the timing of these events is not critical;
- 4. supplies a 100-kc clock signal to replace the Rea machine internal clock; this procedure removes the 10- μ sec jitter in timing which would otherwise result;
- 5. provides a variable sampling command rate to the Rea machine during the data taking interval; any rate that can be obtained by dividing 10 kc by an integer between 1 and 999 is available;
- 6. supplies a signal for triggering and Z-axis modulation of an oscilloscope which initially will be used to double check the dynamic operation of the Rea machine and later may be used as a visual monitor for the input signals.

Since a complete step-by-step description of the operation of this system will be included in a forthcoming operator's manual, it is not pertinent here. It is a completely digital system which is not sensitive to drifts due to temperature fluctuations, normal component aging, etc. The capacity of the system (i.e., maximum delays available, etc.) has been chosen so as to be great enough to allow this system to be used when testing the final magnet blocks.

The initial layout of the Rea converter system, the pulse model magnet, and auxiliaries is being designed to keep this complex compatible with the best possible signal to noise ratio at the input to the Rea machine. Pertinent features are:

- 1. the installation of floor trenches to keep the leads as short and as accessible as possible;
- 2. provision of a 1/4-inch x 4-inch ground bus for low D.C. resistance and low inductance;
- 3. tying the system to the earth or building ground (whichever proves best) at one point only;
- 4. reducing the size of ground loops on multicable connections between various racks;
- 5. placing the breaker rack as far from the preamplifiers as is practical in an attempt to prevent microphonics.

Though the Rea machine was scheduled for shipment in August, unavoidable difficulties have postponed delivery until early November at best.

XIII RING MAGNET DESIGN

R. H. Lykken

During the past few months, the basic parameters of the machine have been established. These parameters determine the arrangement and approximate dimensions of the Ring Magnet. Figure 16 is a plan view of the machine showing the basic dimensions of the Ring Magnet and a proposed arrangement of the various basic components which will occupy the straight sections. Various studies and layouts have been made of the straight sections to determine if it will be possible properly to design and install these components with adequate clearances.

The ideal magnet, which serves as a goal for our various design studies, will consist of plate averaging $1/2$ inch in thickness. This thickness will vary or taper to achieve the proper arc at assembly. At the thick end, on the outside of the ring, each plate will be approximately 60 mils thicker than at the thin end. These tapered plates will then be assembled with an insulating material of minimum thickness between each plate. Figure 17 is a typical section of the Ring Magnet.

It is readily apparent that machining or grinding the surfaces of 26,000 plates approximately 100 by 24 or 30 inches is a serious problem from both a cost and time standpoint. Before an intelligent decision can be made on the most economic design of the magnet, it is necessary that the answers to the following questions be obtained:

1. What possible tolerances can be held on the plate thickness, flatness, and crown?
2. What methods may be used to improve these factors and at what additional cost in time and money?
3. What means can be used to machine or grind every plate either flat or to a taper?
4. What means can be used to taper a group of plates?
5. What percentage of steel can be achieved, and what is the difference in cost between a $4\frac{1}{2}$ block laminated from as-rolled plate, flattened plate, machined flat plate, and tapered plate?

To determine these answers, several simultaneous studies have been conducted. With the cooperation of several large steel companies, particularly Bethlehem Steel, what tolerances that possibly can be held on the basic plate are being determined. By rolling the plate in a 30-inch sheet mill instead of a plate mill, better than standard plate tolerance can be obtained.

Fig. 16 Plan view - Ring Magnet

Fig. 17 Magnet cross-section.

The plates could then be stack-annealed for flattening, as was done on the Cosmotron. A top pole segment or slab of seventeen 1/2-inch plates treated in the above manner will be fabricated either at Rock Island Arsenal or Bethlehem Steel Company. This will be a full size, "quick and dirty job" that will quickly tell the quality of magnet that can be obtained without machining each plate.

At the same time, various methods of grinding each plate are being investigated. Another top pole segment is being fabricated from plates which are being taper ground by the Carborundum Corporation of America on their 84-inch wide belt grinder. These models will provide much information on production time and cost as well as quality of the finished piece.

On the basis of many discussions with prospective fabricators, it seems possible that the edges of the plate forming the pole face and the correction holes could be machined a group of plates at a time. The plates could then be deburred and cleaned individually.

A laminating fixture could be used to accurately line up the plates while the insulating adhesive is interleaved and the stack of plates compressed. The stack could then be tested for electrical shorts and the tie straps welded to each plate on the three exterior edges.

Various experiments have been made to obtain an economical adhesive insulation. Adhesive formulators and suppliers of the necessary equipment for its application have been consulted. Although we are not depending on the adhesive between plates for strength, it will provide an extra margin of safety comparatively inexpensively.

One of the methods that is being tested further on a full-size slab assembly was recommended by Shell Chemical Company. It consists of an epoxy system and cotton cloth insulation between plates.

The method of laminating would be as follows:

1. Lay first plate on fixture and spray epoxy mixture with catalyst mixing gun on top surface.
2. Lay cloth on freshly sprayed plate and roll out to cause mixture to ooze through cloth.
3. Stack on next plate and repeat the cycle.

Various formulas are being tried to obtain the best results with a room-temperature cure. This cure would continue for a long time before maximum strength would be achieved, however, and the stack of plates would be held together by the tie bars and possibly by tension members through the correcting holes.

When several of the full-size models now being constructed have been completed, the necessary information will be available to complete the design. It is probable that a practical method of machining or grinding each plate may be found but also it may be determined that the time element would make it impractical; that is, a year's delivery time on a new machine tool may necessitate using the as-rolled method to keep on scheduled production dates.

XIV FOUNDATION STUDIES

David Cosgrove, Wayne Nestander, Richard Trcka

The completion of the pile test and load test program in April 1957 has provided data for preliminary calculations for the design of the ring magnet support and magnet octant deflection investigations.

As reported in the last PAD Summary Report, October 1956 - March 1957 (ANL-5713), the design load for each pipe pile has been established as 30 tons per pile. The number of piles has been tentatively determined under each magnet octant and the pile spacing has been considered. Calculations are in progress to locate the structural support needed to hold deflections in the magnet octant within tolerable limits.

Piles may be conveniently driven in groups of three to form a pile bent as shown in Fig. 18. A reinforced concrete pile cap poured over the top of the three piles will effectively tie the individual piles into a unit; thus, each pile bent will be capable of supporting a design load of 90 tons. It is proposed that these pile bents will be placed radially under the magnet octant and aligned on the octant radius. Six pile bents support each octant which has a total weight, including iron, coil, estimated structural members and accessory lifting gear, of 510 tons; this is well within the design load of six pile bents at 90 tons per bent. However, it is recognized that further economy studies pertaining to the use of a magnet ring girder in conjunction with structural supporting members for the octant may indicate the need for using seven or eight pile bents under the octant in order to obtain the required stability.

The spacing of the pile bents beneath the magnet octant is determined by two criteria:

1. The loads imposed on each pile bent by the magnet octant should be equal to assure uniform settlement of the pile bents, assuming equal soil conditions.
2. The deflections of the magnet octant at the overhanging ends and at all the midpoints between the pile bents should be equal, to design, economically, a structural supporting member of uniform strength.

Fig. 18 Plan view - magnet octant.

Fig. 19 Pile spacing and pile bent loads for equal deflections.

Pile spacing dimensions that will yield equal deflections will not produce equal bent loads, and, conversely, when dimensions are used that will load all pile bents equally, the deflections vary greatly at the various points on the magnet octant. However, by allowing the end bents to carry less load than the interior bents, dimensions may be chosen to make the deflections at all points essentially equal.

In Figure 19 are shown the pile bent spacing dimensions and bent loadings when deflections at the overhanging ends and at all the midpoints of the spans are equal. The length of the overhanging end is 0.4 times the length of the spans between pile bents, while the exterior bent load is 0.9 times the interior bent load.

This work is being carried out in conjunction with the mechanical design of the magnet to determine the foundation arrangement and structural support that will be economical for meeting conditions such as pile settlement, ring magnet alignment (leveling) and load transfer resulting from lifting the upper portion of the magnet octant.

XV RING MAGNET POWER SUPPLY

G. O. Calabrese, E. F. Frisby

The power requirements for the magnet of the 12.5-Bev, 21500-gauss proton synchrotron having a vacuum chamber with inside dimensions of 32 x 5.25 inches were calculated on the basis of data giving flux densities (B) vs magnetic field intensities (H) obtained from the Bethlehem Steel Co. for a 1010 steel used by that company in fabricating a large cyclotron. The power requirements were determined assuming the cycle to be composed of a one-second rise, one-second fall and two-second rest, under two different assumptions, referred to as Case A and Case B for the purpose of identification. These cases differ from one another in the degree of saturation of the magnetic paths and represent, respectively, the most conservative and the expected values.

The magnetization curves of the magnet of the 12.5 Bev proton synchrotron calculated for the two cases are shown in Fig. 20. The results of the calculations for the two cases are summarized in Table II. In Fig. 20 it will be noted that the curve for Case B closely coincides with the preliminary B-I curve obtained from the 1/7-scale D.C. model. Though the analysis of the results obtained with the model is only preliminary and has not been completed, it seems to indicate that the assumptions made under Case B closely simulate the actual conditions in the magnet, at least to the extent that may be anticipated from the 1/7-scale D.C. model magnet. Under Case B the voltage, at the ignitron terminals, required to force through the magnet a current rising linearly to its maximum in one second and dropping linearly to zero in another second is calculated to vary as shown in Fig. 21.

Table II

	Case A	Case B
Ampere turns	297,600	274,700
Stored energy in magnet and D.C. connection to the rectifiers, millions of joules	39.0	38.5
Maximum instantaneous power, kw	103,500	98,800
Incremental inductance including D.C. connections to the rectifiers, Henries		
$0 < B < 1.0$ weber/m ²	1.215	1.225
$B = 1.8$ weber/m ²	0.958	1.115
$B = 2.15$ weber/m ²	0.743	0.899
Resistance (32 turns) including D.C. connections to rectifiers, ohm	0.2925	0.2925
Maximum voltage, volts	12,300	11,800

Fig. 20

Fig. 21 Approximate time characteristics of magnet power supply.

Under Case A the variation of the voltage is similar in shape, but the maximum voltage is 12,300 volts instead of 11,800 volts.

Calculations have also been made of the eddy currents and losses in the iron of the magnet and in the roof and floor of the rough vacuum chamber if one such rough chamber is used.

The magnet will be composed mostly of 0.5-inch laminations separated by 0.007-inch insulation. The roof and chamber of the rough vacuum chamber, if used, were assumed to be made of 0.010-inch thick stainless steel. On this basis the calculated ampere turns produced by the eddy currents at the orbit, that is, at the center of the vacuum chamber, for Case B are:

Iron laminations of the magnet	700 A.T.
Roof plus floor of rough vacuum chamber	150 A.T.

Under the same conditions the heat energy generated by the eddy currents averages 8200 joules/sec/sector in the magnet and a total of 1260 joules/sec/sector in the roof and floor of the rough vacuum chamber.

Further exploratory study has also been made concerning possible circuitry between the rectifiers and the ring magnet terminals. In this study consideration was given to balancing the instantaneous currents and voltages in the various magnet coils. Other points considered were: Circuit lay-out scheme, switching arrangement, and type of construction.

XVI MASTER OSCILLATOR

Lachman K. Wadhwa

The ferrite-tuned master oscillator described in ANL-5713 has been tested for frequency repeatability as a function of bias current, after the construction of a stable current supply which can alter the bias in finite steps. The frequency was measured with a Hewlett-Packard electronic counter Model 524 B. Provided, as will be the case in actual dynamic operation, that each biasing field is approached from a lower value, without overshoot (so as to avoid hysteresis), repeatability of the following accuracy is obtained, over the frequency range of interest: from 2.1 to 7 mc/sec.

<u>Bias (oersteds)</u>	<u>$\frac{\Delta f}{f}$</u>
3	0.01%
7	0.002%
9	0.002%
15	0.0002%
30	0.0001%

The worst figure indicated is somewhat better than what is anticipated as necessary. If required, it will be a simple matter to shift the biasing program (for the same range of frequency) to slightly higher values, thus bringing the repeatability of frequency to even more accurate values.

XVII R.F. POWER AMPLIFIER

Henry Kampf

A one-half power model of the video power amplifier is being constructed. It will use two ML 6696 tubes in the final stage and be capable of about a 40-kw output over the frequency range of 2 mc to 7 mc. The driver stage, which will be transformer coupled to the final stage, consists of two 3 x 2500 F 3 tubes.

The entire amplifier will be double ended with a single-ended input at a one-volt level.

The 12-kw power supply for the driver has been designed and is being constructed. It is a three-phase full wave rectifier employing GL 8008 mercury vapor rectifier tubes giving the supply an output of 500 to 4000 volts at three amperes.

XVIII PROTOTYPE R.F. CAVITY

John Martin

A copper-lined plywood full-scale prototype of one section of the double R.F. cavity for accelerating the protons in the synchrotron ring has been constructed. The dimensions of the copper surfaces on the outside wall are 28 inches high x 58 inches wide x 36 inches long in the direction of travel of the beam. The dimensions of the copper surface of the particle channel are 8 inches high x 38 inches wide. (These latter dimensions are somewhat greater than now seem to be necessary because of excessive allowance for vacuum wall thickness and a decision to operate the magnetic guide field at higher peak values than were originally planned.)

The first of the ferrite slabs with which to load this cavity are expected to arrive within a few weeks. They are made of Keraperm Type Cl31/5 manufactured by Steatit-Magnesia in Porz, West Germany. From twelve slabs (each 4 cm x 10 cm x 28 cm in size) rectangular frames will be constructed to follow the R.F. magnetic field lines in the cavity. In order that the cavity may be brought into resonance in the 2 to 7 mc frequency range when it contains only as little as a single pair of ferrite frames (since the ferrite slabs will be delivered over a period of several

months), a rather large Teflon-loaded condenser has been built across the $2\frac{1}{2}$ -inch gap in the cavity. Its maximum capacity is about 12,000 pf which resonates the empty cavity at about 4.75 mc.

This cavity is designed to test a number of things and ideas. It will serve as a realistic load for the model power amplifier now under construction. It will test the characteristics of the ferrite prepared in large pieces. In this cavity, air cooling of the ferrite will be employed, at least until the arrangement of the material is settled; then a system for water cooling may be developed. The model is made to accept more than 50 kw of power, which is believed to be considerably more than necessary for producing the required 8000 volts (peak) across the gap. In this model the problem of applying 10,000 ampere turns of peak bias will be worked out. The first attempt will be to use as many as about 100 bias turns.

In mid August, four Type C131/5 test rings made from the first production lot were received from Stemag. They were found to be of good quality, having slightly lower loss and being slightly harder, magnetically, than the first samples upon which the cavity design was based. These tests were made on the ferrite tester recently constructed in this Laboratory for this purpose. This type of test will be repeated a few times during the course of production of the 950 kilograms of ferrite for this cavity. A request is under way to obtain a spare, full-size slab of ferrite out of which test rings will be cut to test the quality of the material made in large pieces.

XIX THE MASTER OSCILLATOR RADIO FREQUENCY CONTROL SYSTEM

J. H. Martin, L. K. Wadhwa

It has been decided that two systems will be developed for controlling the signal frequency for the proton-accelerating cavity in the ring magnet. One will be an incoherent, beam self-tracking system to be used when the beam is larger than about 10^7 particles per pulse and when the beam is well bunched. The other will be a master oscillator which gains its information for frequency determination from the magnetic guide field. It will be used in bunching the beam at the beginning of a pulse and when self-tracking cannot be employed due to the beam being too small, etc. Self-tracking will involve closing a servo loop to correct the master oscillator according to the sensing of error between the beam bunch and R.F. cavity phases. It is the master oscillator system which gains its information from the magnetic guide field which will be described here.

In order to conserve radial width of the aperture of the synchrotron only rather small errors in frequency are allowed. The system under discussion is expected to hold this over-all error to less than 0.03% at any one time and to keep the jitter in frequency considerably less than this, particularly when the jitter frequency is approximately that of the synchrotron oscillations. The plan is to obtain this program by suitably biasing

the ferrite in a permeability tuned self-excited oscillator. It has already been shown that carefully chosen and used ferrites are stable and repeatable enough under static conditions to meet these demands. There still remains the question of oscillator noise under dynamic conditions and the problem of generating the ferrite bias program with sufficient accuracy. An answer to the noise question is being sought. In this paper will be described the proposed method for obtaining the ferrite bias program.

A previously reported plan (ANL-5713) for programming the master oscillator involved two or three ferrite tuned coils in the tank circuit. Each of these coils was to make a certain contribution to the shaping of the program. In the interest of simplifying the oscillator tank circuitry it has been decided to sum all of the contributions into the bias program for only one ferrite-loaded coil.

For a given set of machine parameters it is the magnetic guide field which determines the frequency. In the Argonne machine, this field consists of two parts, the long pulsed sectors and the short correcting magnets with non-pulsed field strengths. At least during the tune-up stages of operating the synchrotron the correcting magnets may have their values changed from pulse to pulse. Each change will call for a differently shaped R.F. program, particularly at the beginning of the pulse. The frequency determining system must have flexibility and accuracy to meet the requirements mentioned.

If the over-all frequency accuracy of 0.03% is to be obtained, the pulsed magnetic guide field, B , must be read out with an accuracy of about 0.01%. Since, at injection time, the frequency is about 2.2 megacycles per second and the rate of rise of this frequency is about 82 megacycles per second per second, fluctuations in the B readout time must not be larger than 2.6 microseconds. One obvious way for reading B is by using a pulsed guide field induction loop and an integrator. An attempt will be made to make a good integrator, but it is very doubtful that one can be made to have a repeatability of 0.01% at the time in the acceleration cycle when this accuracy is most needed. The system under consideration does not require the integrators to have a repeatability better than about 0.2%. One of the most difficult places to make an integrator have very high repeatability is shortly after the integration period is begun when irregularities in injecting the initial conditions are comparable in size to the value of the integral. If the entire readout of B is from a $\dot{B}$ integrator, this large error comes at the beginning, the time when the highest precision is required. The system under consideration requires a very small contribution from integrators at the beginning and nowhere is the contribution larger than about 5%.

This system places the responsibility for a high degree of repeatability upon things which can be made very stable such as a current shunt, a mutual inductance, an induction coil around a pulsed magnet sector,

Calculations indicate clearly that a coaxial shunt can be made that will have the required stability and freedom from dependence upon variations in $\dot{I}$. The readout error from such a shunt under transient conditions is less than

$$E = \frac{t^2 4\pi u \dot{I}}{3 \times 10^9 r I}$$

In this equation, t is the thickness of the shunt-strip in centimeters, u is the permeability of the shunt material relative to vacuum, r is its specific resistance in ohm-centimeters, I is the current and $\dot{I}$ is the rate of change of the current per second. As an example, for the Argonne synchrotron injection may occur at $I = 200$ amperes and $\dot{I} = 8000$ amperes/sec. A manganin shunt-strip thickness of 0.030 inch could be made to introduce a dynamic error less than 0.0025%. Other errors can be kept less than 0.01%.

It is expected that an induction coil can be wound around one of the guide field octants, giving a signal that will be stable and representative of the conditions in the entire pulsed field. Both the I and $\dot{B}$ signals are fed through near unity gain amplifiers and stable passive networks. At the beginning of a pulse, H is determined largely through the contributions from these two sources, I and F . Except for ripple in I these two should produce a program which is stable to better than 0.02%. Early in the pulse the contribution from S should be practically zero except for irregularities in $\dot{I}$. At this time, I will be an accurate measure of B except for contributions from these irregularities. With a proper adjustment of attenuation the integral of $(\dot{B} - K\dot{I})$ will be accurately the amount by which I fails to represent B . This is true throughout the pulse rise, even when iron saturation sets in. Since the contribution from S will never be more than 5% of H , its repeatability needs never to be better than 0.2%. Therefore, the integrator yielding this signal never needs to be better than this. The mutual inductance for giving $\dot{I}$, the coil for giving $\dot{B}$, and the attenuator, however, must be repeatable to within 0.02%.

Later in the pulse a larger and larger part of the contribution to H comes from I , meaning that severe repeatability requirements are confined more and more to the shunt and its near unity gain amplifier. The integrated portion of the F contribution becomes larger and larger so as to pull F downward, but the dependence of H upon F becomes less and less so that this integrator, too, does not have to have repeatability requirements better than about 0.2%.

Approximately one-eighth way through the pulse rise it does not appear to be convenient for the sum of I , F , and H_0 to come closer than about 10% to producing the desired bias. At the present it seems best to make up this misfit by a multipoint diode correcting network. Since the

size of the correction is rather small, it should be easy to make the diode switching transients small. Furthermore, it is in this region that a larger frequency error can be tolerated. The diode switching irregularities probably will need to be less than about 0.1% of H .

Toward the end of the pulse rise the contribution from S will have its largest value due to the saturation of the magnet iron. Since its contribution will be no more than about 5% of H , its repeatability will need to be no better than about 0.2%.

The bias at the time of beam injection into the synchrotron ring is adjusted by controlling H_0 so as to give the radio frequency required at that time. The amplifier producing the F signal will probably be unclamped shortly before the time for injection. The steep slope of the bias program at the time will be furnished primarily from the $\dot{B}$ coil through the F signal. This slope can be adjusted by network parameter changes to produce the required rate of rise of frequency. It is not yet clear that adjustments of these parameters and of H_0 have adequate flexibility to accommodate the changes in the strength of the D.C. correcting magnets in the short straight sections.

Self-tracking of the master oscillator may be accomplished by sensing the relative phase of the R.F. accelerating voltage and the bunches of protons rotating about the ring. A deviation from the proper phase relationship will produce a signal E for correcting the ferrite bias and, hence, the frequency of the master oscillator. In no case should this correction be larger than about 0.25% of H .

The voltages developed across the shunt and across the mutual inductance will be approximately the same as those required for H . Therefore, the amplifiers can operate with approximately unity gain which should make it perfectly feasible to obtain the repeatabilities of about 0.01%.

The system just described depends upon time in generating the bias program. An analysis of this dependence was made to determine the magnitude of the frequency error that would result if a change occurred in the pulsed magnet program. Experience with the Bevatron indicates that variations in the $\dot{B}$ program are somewhat less than 1% from pulse to pulse. The frequency error that would occur if $\dot{B}$ changed by 1% over a sizeable part of the pulse is shown in Fig. 24. At injection it is held to zero by the choice of program initiation sequences. It remains between +0.02 and -0.04% for about 0.06 second; then it becomes objectionably large, going to 0.25%. By this time, considerable adiabatic damping of the beam oscillations should have occurred. This may make the large error tolerable. If self-tracking is employed, this error should be easily handled. This time dependence should pose no problem which cannot be solved later in the development of the system.

Fig. 24

Certain portions of this bias function generating system have been assembled and partially tested. They have been found to have repeatabilities within the accuracy of the test equipment available to measure it (about 2%). The next major step in developing this system will involve the Rea converter described elsewhere in this report, which will be used to measure the repeatability of the frequency program generated and the accuracy of its fit, within about 0.25%, to that called for by the synchrotron. Also, it will permit testing the flexibility of the bias function generator to accommodate various strengths of the D.C. correcting magnets.

The idea for reading out the magnetic guide field by use of a combination of Kerr and Faraday cells, described in ANL 5713, has been abandoned since a suitable Kerr rotational material was not found. All materials tested which produced useful rotation also produced a birefringence which was annoying to compensate. It appeared that the best solution would be to use a suitable Faraday material such as very dense lead glass in an iron-free solenoid in the place of the Kerr cell. There was never found a suitable location for the measuring cell in the magnetic guide field that would not interfere with the beam. The employment of a separate magnet section would partly defeat the object of direct measurement of the desired field and would be expensive and cumbersome.

XX. RADIO FREQUENCY PROGRAM MEASUREMENTS

John Dawson

A system has been developed for checking dynamically the radio frequency program yielded by the function generator and master oscillator against that demanded by the synchrotron. An analog-to-digital converter is being built by the J. B. Rea Company for making simultaneous observations and conversions of five analog quantities. A controller for this converter has been constructed which will allow the recording of a radio frequency sample taken simultaneously with three analog quantities. The frequency observations are made by cycle counting for a sampling period of two milliseconds. Such samples of the frequency and of the analog quantities are made at the rate of 200 per second. The accuracy of the frequency measurement is set primarily by the number of counts within the 2 msec interval and is better than 0.025% throughout the frequency range of 2.2 to 6.8 Mc of the program. The accuracy of the analog observations is set by the amplifiers and holding devices and is estimated to be about 0.25%.

The plan is to simulate a pulsed magnet and to read out the radio frequency generated corresponding to certain parameters such as magnetic field and magnetizing current. Anticipated irregularities and ripples will be introduced into these parameters. The presence of the D.C. correcting magnet in the synchrotron short straight sections will be simulated. This radio frequency program measuring system will then be used to determine when the function generator properly accommodates these perturbations. The correctness of the R.F. program to within an accuracy of about 0.25% will be established by comparing the program observed by this system with that obtained from calculations.

The final shaping of the R.F. program will have to be done on the synchrotron itself. Tests with the Rea system will permit an examination for a program fit good to 0.25% and an examination for adequate flexibility of the function generator in making the more accurate fit and in accommodating certain perturbations which will occur in the magnetic guide field. It will not be very useful in examining the R.F. program for noise in the form of frequency jitter or transients due to such things as diode switching. A separate system is under development for this.

The operation of the controller for making the Rea analog to digital converter read out radio frequency and up to three analog quantities may be understood by referring to the block diagram in Fig. 25. A recording cycle is initiated by a pulse from the external or manual sample command. This pulse serves to start the storage tape in the Rea converter. The pulse is also delayed 10 msec after which it does three things:

1. triggers a variable delay, the output of which serves to start the R.F. function generator program;

Fig. 25 RF measurement control system - block diagram.

2. triggers a set-reset flip-flop, the output of which provides an interrogate signal for the main gate;
3. triggers a variable 0.5 to 2.5-sec phantastron delay, the output of which serves to stop the measurements.

After the main gate is opened the first 1-kc clock pulse will trigger the fast flip-flop opening the R.F. gate and providing a pulse which, after a 10-microsecond delay, triggers a 1.5-msec phantastron. The output of this phantastron does two things:

1. provides an inhibit signal for the main gate, which does not allow the second clock pulse to pass to the fast flip-flop;
2. provides an interrogate pulse for the hold-analog gate, allowing the second clock pulse to pass and send a signal to the Rea converter to hold the analog values which prevail at this instant.

After 1.5 msec the phantastron flips, again opening the main gate so that the third clock pulse triggers the fast flip-flop which closes the R.F. gate with a negative pulse. Also when this 1.5-msec phantastron flips it closes the hold-analog gate to prevent clock pulses 3, 4, 5 and 6 from going to the Rea converter. While the R.F. gate has been open for 2 msec the one Hewlett-Packard 520-A high speed scaler and three AC-4A slow scalars have been counting the R.F. cycles and now hold this number. The negative flip from the fast flip-flop also starts a 2.5-msec phantastron. After 1 msec it issues a command to the Rea converter to read the number in the scalars. During the course of this 2.5 msec this phantastron provides an inhibit signal to the main gate to prevent it from passing pulses 4 and 5. At the completion of the 2.5 msec the phantastron resets the scalars to zero ready for another counting period and the cycle is repeated. The decade code of the scalars is adapted to that of the Rea converter by the diode matrices preceding the buffer amplifier.

The length of time during which the system operates in this fashion is set manually from 0.5 to 2.5 sec by another phantastron. This triggers a 20-msec delay to stop the storage tape in the Rea converter and a 5.5-msec delayed interrogate pulse to the turn-off gate to insure that the system is left in condition for operation when the next external sample command comes.

XXI. EVAPOR-ION PUMP DEVELOPMENT

J. Moenich, R. Trcka, K. Weberg

To avoid a glow discharge which prevents adequate heating of the post, Evapor-ion pumps as normally used must be brought to a pressure of 5×10^{-5} mm Hg or less, before the post voltage can be turned on. This is customarily attained either by the use of a "primer" (which evaporates very large quantities of Ti) or by the use of a Roots blower or by a diffusion pump. All these methods have disadvantages. A novel solution avoiding these difficulties has been found by Michael Otavka, a member of the vacuum group. The grid (normally placed at a positive potential with respect to the filament so as to produce ions of the noble gases which are then driven into the evaporated titanium) is, for starting purposes, made negative to the filament. This precludes ion-pumping, but, on the other hand, it confines the glow discharge to such a small region that the post can be brought to operating temperature when the pressure is as high as 5×10^{-3} mm. Gettering action of the non-noble gases thus commences and is continued until the pressure falls to 5×10^{-5} mm, when the polarity of the grid is changed to positive and ion pumping can then begin. With this method it is possible to start a blanked-off Evapor-ion pump within fifteen minutes after turning on a Welch 1397 Duo-seal mechanical pump aided initially by a liquid nitrogen cold trap. A detailed description of this development can be found in ANLAD-37.

Pumping speed tests have been run using nitrogen and air. As complete curves as desired could not be taken because of the large pressure surges between titanium feed strokes at high leak rates. Speed curves for diffusion pumps show, with pressure rising from the ultimate, a rise in speed, then a plateau, and finally a rapid drop, but Evapor-ion pumps (as used normally, with positive grid) can be made to show an increase in speed, rather than a fall, at pressures above those of the plateau, providing the rate of evaporation of Ti is sufficiently great. This can be seen in Fig. 26, for nitrogen. Curve I, at 545 mils/min of Ti (23.3 milligrams per inch) is similar to the speed curve of a diffusion pump, while Curves II and III, at 1090 and 1440 mils/min, respectively, indicate the rise in pumping speed at about 1×10^{-5} mm. The critical feed rate appears to lie between 0.5 and 0.7 inch per minute. At pressures above those indicated, an intense glow discharge occurs, resulting in unsteady conditions which preclude the taking of meaningful data.

The above information was obtained with the post voltage and post current held constant. The glow could also be induced by an increase in post voltage or post current with a fixed titanium feed. It is believed the increased pumping speed is associated with a glow discharge in the neighborhood of the post.

A slight increase in the ultimate pressure, as the feed rate is raised, may perhaps be associated with the presence of impurities in the titanium wire.

Fig. 26 Evapor-Ion pump speeds with nitrogen.

Fig. 27 Evapor-Ion pump speeds with nitrogen.

Fig. 28 Evapor-Ion pump speeds with air.

To obtain these high feed rates, it was necessary to install a multiple cam in the feeder mechanism and to improve the annealer, in order to insure the wire being sufficiently straight to hit the post. This was successfully accomplished by introducing current at the middle of the annealer tube and grounding its ends, thereby producing two hot regions.

Pumping speeds for nitrogen were also measured with a negative grid, as shown in Fig. 27, for 720 mils/min feed. Once again, there is evidence of an abrupt increase in the neighborhood of 1×10^{-5} mm, but unsteady electrical conditions associated with the glow discharge prevented the attainment of conclusive data. Data at higher feed rates could not be obtained for the same reasons.

Figure 28 shows the curves for air, with positive grid. There is a marked rise in speed (up to about 1000 liters/sec) as the pressure rises above 5×10^{-5} mm. Speeds at pressure above 7×10^{-5} mm could not be measured, due to the violence of electrical disturbances, but observation of the rate of fall of pressure when pumping down through the 10^{-3} to 10^{-4} mm region suggests a speed exceeding the greatest actually measured. Speed curves for air with a negative grid were impossible to obtain because of the in-leak of argon which is pumped only with a positive grid.

Data for air speed at lesser Ti feed rates than shown in Fig. 28 are incomplete at present, but it is surmised that the abrupt increase in slope at about 5×10^{-5} mm is conditioned by a feed rate in excess of 0.5 inch/min, as is the case with nitrogen. On the other hand, at pressures below this figure, the air pumping speed appears to be not markedly dependent on Ti feed rate.

As reported in previous papers, the titanium getter in the Evapor-ion pump is very inefficient for trapping the noble gases and it is believed that the 0.94% argon in air is responsible for the Evapor-ion's inability to pump air at the same speeds as the common gases. This, of course, is the reason for the grid in the Evapor-ion pump, but it is very inefficient. The pumping speed curves for air in Fig. 28 indicate the change in pumping speed that takes place at approximately 5×10^{-5} mm Hg when glow discharge, considered to be ionization, is present, and, if this glow discharge were present through the complete pressure range of the pump, it would greatly enhance the pump's usage. For this reason, attempts are now being made to increase the ion pumping ability of the Evapor-ion pump by installing multiple grids. These will consist of three concentric grids, each of which is separated electrically from the other, and each will have a separate source of voltage which can be varied.

An eight-inch stainless steel pipe (23 feet in length) and fittings were installed for studying various start-up procedures for the Evapor-ion pump, obtaining ultimate pressures, and determining a suitable system for

opening the Evapor-ion pump to a volume. Prior to installation, the interior of pipe and fittings were washed with trichlorethylene and steam cleaned.

The initial installation included a "Roots" VPR 350 pump and Kinney 110 cfm pump connected at one end of the eight-inch pipe and the Evapor-ion pump to the opposite end of the pipe. Using the two mechanical pumps as roughing pumps (the Kinney pump is used as a backing pump for the Roots pump) approximately 14 minutes of pump-down time were required to cut the Evapor-ion pump into the system, with the grid negative. The ultimate vacuum (for air) obtained with the Evapor-ion pump (while evaporating titanium and ion pumping) was 1×10^{-6} mm Hg at the end of the vacuum system most distant from the pump. With ion pumping alone, after pump walls were well coated with titanium, ultimate pressures of 4×10^{-7} mm Hg have been obtained.

Table III lists typical pump-down data of the 23-foot chamber. The pressures tabulated were recorded by a thermocouple gauge when the pressure was greater than or equal to 10^{-3} mm Hg. The gas pumped was air. The pressure had reached the 10^{-6} mm Hg range within one hour. After a total of 2,256 pulses of titanium, the pressure within the system attained a minimum of 8.0×10^{-7} mm Hg.

A second important feature of the Evapor-ion pump is its ability to pump down the 23-foot chamber from a starting pressure of 100 microns of air in the chamber to the 10^{-7} mm Hg range within two hours. A Duo-seal backing pump was used to reduce the pressure within the pump, which was isolated from the 23-foot chamber, to the operating point of 10^{-3} mm Hg. After the Evapor-ion pump was operating satisfactorily, it was isolated from the Duo-seal and the gate valve between the chamber and the Evapor-ion pump was slowly opened. Within 20 minutes the pressure was below one micron, low enough to open the valve completely. The pressure reached the 10^{-7} mm Hg range within two hours.

Since it is questionable, at this time, as to whether the Evapor-ion could be developed to pump air at speeds desired and in the development time available, a diffusion pump program is being carried on simultaneously. A 16-inch oil diffusion pump and a 16-inch pneumatically operated valve have been purchased from Consolidated Electrodynamics Corporation. Various baffle designs will be tested for efficiency in backstreaming elimination and for maximum conductance.

Comparative tests will be run between the Evapor-ion pump and the diffusion pump on pump-down time and ultimates obtainable. A study will also be made of control circuitry requirements of both systems and to what extent automation is practical and economically feasible.

Table III

PUMP-DOWN DATA FOR AIR IN 23-FOOT STAINLESS STEEL
CHAMBER WITH EVAPOR-ION PUMP

<u>Time (Min)</u>	<u>Pressure (mm Hg)</u>	<u>Remarks</u>
0	atmospheric	Cooling water off. System opened to Kinney Backing Pump
2	less than 1	Roots blower on
5	$\sim 10^{-3}$	Filament on, current at 35 amp. Add liquid N ₂ to cold trap.
10	$\sim 10^{-3}$	Negative grid (2000 volts) Post voltage at 2500 volts Post current at 20 mamp Filament current at 35 amp
16	8×10^{-4}	Negative grid (2000 volts) Post voltage, 2600 volts Post current, 120 mamp First pulse of titanium
20	6×10^{-4}	Cooling water on, isolate system from mechanical pumps.
35	3×10^{-5}	Change to positive grid (i.e., start "ion pumping") (1200 volts)
50	$\sim 10^{-5}$	
60	$\sim 10^{-6}$ range	All the above at 13.6 pulses of Ti per minute, at about 0.08 inch of Ti wire per pulse (23.3 milligrams per inch)
1020 (17 hr)	8×10^{-7}	During overnight run of 16 hours, the Ti feed was reduced to 1.5 pulses per minute.

XXII. VACUUM CHAMBER

F. W. Markley, D. Hafemeister

In ANLAD-31, abstracted in the last summary report, Crosbie calculated the radiation dose rate to be expected for the vacuum-supported plastic vacuum chamber of the Argonne Synchrotron. When an error in this report is corrected, the calculation gives a radiation dose rate of 0.029 joules/sec in³ or 147.5 rads/sec. This calculation assumes that all the protons lost at injection strike only the sidewalls of the tube and are spread uniformly over their area.

Of the various plastics which could be used to construct such a tube, the epoxy resins appear the most promising. Available information shows that there is no change in the mechanical strength of some epoxy resin glass fabric laminates after radiation doses of 7.9×10^8 rads. This would correspond to the dose received by the tube after 62 days of continuous machine operation.

This does not necessarily mean that a longer tube life cannot be expected, however. In the first place, a comparison of recorded damage to epoxy formulation and other plastics leads us to believe that a combination of resin and hardener may perhaps be found which can withstand considerably more radiation without significant damage. Secondly, within the limits of accuracy of calculation as to the angle at which most of the lost protons will strike the walls, it appears that the radial penetration will be small enough so that a large measure of protection can be supplied by a wall covering of stainless steel not so thick as to be deleterious from other considerations. Successful use of this technique implies an adhesive for the steel which can withstand the residual irradiations to which it is subjected.

An experimental program of radiation damage has been started, with measurements made on the elastic modulus, ultimate compressive strength and compressive yield of various resins and hardeners. This will be continued and will include the effects of the addition of inorganic fillers and of materials to produce a plastic of adequate electrical conductivity.

XXIII. INJECTOR SYSTEM

A. Space Requirements Rolland Perry

Estimates of space requirements for the various components of the injector system have been made for the purpose of determining the building and tunnel dimensions in first approximation. These include the following lengths:

Preaccelerator	36 ft
Drift Space (Preaccelerator to Linac)	10 ft
Linac	110 ft
Drift Space (Linac to debuncher)	50 ft
Debuncher to first inflector	10 ft
First inflector magnet	4 ft
Total Length	220 ft

The preaccelerator length is based upon the BNL unit. If another type unit is selected this length may be altered.

The width of the Linac and drift space tunnels will be contingent upon whether they are used as an access tunnel for moving components into the ring tunnel. If so used they should be at least 10 feet wider than would otherwise be required.

B. The Preaccelerator Rolland Perry

Some preliminary studies have been made of the problems associated with the preaccelerator, but no decision has been reached on the final unit. Two companies in Europe and one in the U.S. are building Cockcroft-Walton units on a commercial basis, either of which might supply a satisfactory machine. A French concern is producing an electrostatic unit which operates on the charge-induction principle, at relatively high current (4 ma at 600 kv, with plans for 8 ma at 1200 kv). This machine is considerably more compact than either of the C-W units and is asserted to be susceptible of good voltage regulation characteristics with high-gain electronic control. Further examination of the characteristics of this and the available C-W machines will be made with long-time continuous operation as a prime consideration, although cost and space requirements will influence the final selection.

The feasibility of reducing the length of the accelerating tube is being investigated with a view to reducing the tendency of the beam to blow up from space charge effects at low velocity. The accelerating tube might be encapsulated in a pressurized dielectric cylinder whose outside surface would provide adequate leakage and sparkover path for stable operation at atmospheric pressure. (This is a modification of a proposal of Dr. Bruce Cork of U.C.R.L. to enclose the accelerating tube in a pressurized dielectric bubble.) The beam dynamics of the accelerating tube will be examined for high and low electrical gradients to determine the relative merits of the shorter tube; then the pressurizing system will be developed if it appears to be justified.

C. The Buncher
Rolland Perry

The characteristics of the buncher are being examined in order to determine the optimum drift distance and buncher voltage. Preliminary results indicate that a drift distance of 1.5 to 2 meters with buncher voltage in the neighborhood of 15 kv will be satisfactory, but further study will be given to this problem, and also to the matter of the related problem of voltage error of the preaccelerator, which is reflected as a phase error at the Linac, and therefore affects the phase acceptance efficiency of the Linac.

D. Linac Focusing Magnets
Rolland Perry

The quadrupole focusing magnets in the Linac drift tubes must provide a steady field during the beam injection pulse of about 200 μ sec. This requirement presents two difficulties in the design of the magnets for pulsed operation: (a) adequate cooling of the coil, and (b) maintaining a flat-topped current pulse of the required duration. To obviate these difficulties it was suggested by Foss that the magnets be operated on D.C. and that water-cooled coils be used.

Preliminary tests on water flow through 1/8-inch O.D., 1/16-inch I.D. copper tubing indicates that the required cooling can be supplied with moderate temperature rise at the anticipated current. A prototype quadrupole magnet has therefore been built with a two-turn winding of 1/8-inch O.D. copper tubing. Field measurements in the magnet will begin as soon as a special search coil is completed. If the field characteristics prove to be satisfactory, it is expected that only minor changes inside the BNL Linac drift tubes will be required to accommodate the D.C. system.

E. Precision R. F. Cavity
Rolland Perry

A 95-cm cylindrical R. F. cavity has been designed for modeling work at 200 megacycles, and construction is nearing completion on this unit. The design incorporates the possibility of modeling either a half-cell or a full cell assembly of a drift tube of any length. This will make it possible to install any completed drift tube and its supporting stems in the cavity and to make R.F. measurements in the cell on the assembly.

F. Electrostatic Inflector
Harry R. Fechter

In order to estimate voltage breakdown levels for several geometries (using available data) field plots have been made, and a number of electrode configurations have been mapped to arrive at a geometry with the

least deviation from a uniform field. Selecting the most favorable of these, a relaxation method was used to obtain accurate field values. Further work is planned using an electrolytic tank.

Literature surveys indicate a need to examine breakdown experimentally to determine the effect of high local field gradients, the effect of dirt, metallic particles, and oil vapor deposited on electrodes, and the starting mechanism below 10^7 volts/cm gradient.

An experimental test device is under construction. This unit will enable measurements to be made of the breakdown between arbitrary electrode configurations. Tests will be made under several conditions: breakdown as a function of "typical" accelerator conditions, and breakdown under "ideal" conditions (very clean, glass-metal system with mercury pumps).

Studies to date indicate we should be able to operate an inflector at nearly 100 kilovolts (1.25-inch gap). This includes the possibility of isolating the inflector from the main synchrotron system by means of a thin low Z foil.

G. Magnetic Inflector Harry R. Fechter

A magnetic inflector has been studied also. This is of window-frame construction using current sheets instead of coils. Using lengths of the order of 4 feet and fields up to 1500 gauss, this method will allow injection closer to the median plane, decreasing losses caused by betatron oscillations and gas scattering. Preliminary exact calculations show that tilting of current sheets or changing the current distribution by providing for cooling will not introduce appreciable field distortion.

Sets of curves and tables have been prepared from which the length of a magnet - drift space - inflector - magnet system can be readily obtained under arbitrary variation of field and inflector parameters.

XXIV. TRANSISTORS AND SEMICONDUCTOR DIODES IN A MAGNETIC FIELD Henry Kampf

Tests of various germanium and silicon transistors and diodes were carried out in magnetic fields as high as 10 kilogauss to determine the magnitudes of Hall and magneto-resistive effects. Results of these tests indicate that both germanium and silicon devices can be operated in normal circuits at fields many times stronger than vacuum tubes can tolerate. Some silicon transistors exhibited no magnetic effects to fields as high as 10 kilogauss.

XXV. PARTICLE BEAMS

A. V. Crewe, R. H. Hildebrand, U. E. Kruse, S. D. Warshaw
and S. C. Wright (University of Chicago)

A study of factors affecting the usefulness of the machine has lead to the following conclusions.

A. Number of External Beams

There should be two external proton beams and they should be capable of simultaneous operation on the same beam pulse. It should be possible to divide the total intensity between the two beams so that one can have either equal intensities or intensities differing by any desired factor. It must be possible to reduce the intensity of either beam. It is obvious that any beam switching device which can only send alternate beam pulses into different experimental areas is inferior to the arrangement recommended above.

It appears that the most convenient arrangement of the two beams is such that they emerge at 180° to one another. In this orientation we see no problem of the degraded beam from one Piccioni target striking the other one, etc.

One method of achieving the two external beams is the following. Let the first Piccioni target consist of a thin lip together with a thick degrader which has only a small vertical extent but is placed in the median plane. Let the second target be placed 180° from the first one but consist only of a thick degrader situated above the median plane and with its inner edge projecting beyond that of the first target. The two targets are shown superimposed in Fig. 29. Then the thin lip serves its usual purpose of reducing the amplitude of the radial oscillations and shrinking the beam onto the thick targets. Particles with large amplitudes of vertical oscillation will be degraded by target No. 2 and can be extracted into the corresponding external beam. Particles with small amplitudes of vertical oscillation will be unaffected by target No. 2 and will collide with target No. 1 to be extracted into its external beam. It is apparent that the relative intensities of the two beams can be adjusted by suitably altering the height of target No. 2. It is to be noted that the height of the circulating proton beam is expected to be 0.2-inch and consequently the movements which are required in target No. 2 are small and will not affect the beam optics.

Fig. 29 Positions of the two Piccioni targets. The two targets are separated by 180° in azimuth.

B. Meson Beams

Although we have not yet studied the meson area there is one feature which we consider to be of extreme importance. It must always be possible to have a beam of secondary particles in this area whether or not either or both of the proton beams are being used. This is quite possible by programming the R.F. voltage in a suitable way to expand the circulating beam on to a target at the outside of the vacuum chamber until sufficient secondaries have been obtained and then to contract the remainder of the beam on to the Piccioni targets. Indeed, by using a target disposition similar to Fig. 29 (i.e., one target on the median plane and another one above but radially inwards of the first one) it is possible to obtain two or more beams of secondary particles from the same beam pulse.

C. Beam Height

An estimate of the maximum beam-to-floor clearance required by all the particle-detecting and beam-handling devices in common use or in construction (e.g., large bubble chambers, cloud chambers, diffusion chambers, giant liquid scintillators, focusing and analyzing magnets, and very high field magnets) has indicated that all such devices can be operated with a 4-foot high beam but that this height should be considered a lower limit. At the other extreme there is no incentive for a beam higher than 8 feet above the floor. The optimum position of the beam within these limits is found by weighting the following points.

Advantages of a Low Beam

For the great majority of experiments, it is believed that a beam near the lower limit will allow faster set-up time, less costly and more stable supporting structures, and less fatigue and hazard from climbing high platforms. For beams below five feet, the experimenter may usually enjoy the convenience of adjusting his apparatus while standing on the floor.

Furthermore, a beam near the lower limit will allow considerable saving in the cost of shielding as compared with a beam near the upper limit. It may be noted that uncovered machines have "sky shine" and require high walls to provide adequate shielding. For such machines there is relatively little saving in shielding costs in having a low beam. For a covered machine like the Argonne accelerator, the cost of the shielding is much more dependent on beam height. Further the radiation leaking through the necessary thick shielding will be so diffuse that almost no reduction in exposure due to general background radiation could be expected from having personnel a few feet below the median plane.

Advantages of a High Beam

The principal advantages of a beam near the upper limit are that it allows personnel to walk freely around the machine underneath the beams and to move all but major pieces of equipment without the necessity of going over or around the beams. A high beam will, in some cases, allow apparatus brought from other laboratories to be used in the trailers in which they were transported. Also, in some cases, it is convenient to use elaborate supporting structures, such as gun mounts, which require large clearance from the floor. Finally, a high beam will accommodate nearly all apparatus so that it should never be necessary to dig holes in the floor.

Disadvantages of a Medium Height Beam

Just above a height of five feet, already some of the convenience of a low beam is lost without yet gaining the advantages of a beam above seven feet. Therefore, this range (5 to 7 feet) seems to be particularly inappropriate.

Considering the above factors it is concluded that:

1. The beam should be $4\frac{1}{2}$ ft (137 cm) above the floor.
2. Those few experiments which require greater clearance should normally be accommodated by piping the beams beyond the side or end of the main concrete floor where lower levels can be provided with ease. The buildings over the experimental areas must, therefore, have walls which are easily removed or opened to let beams out. Such outdoor beams will also assist experiments requiring very long beam paths.

3. Roads or clear paths must be arranged for equipment to be moved around the ends of the beams. Convenient stiles must be provided to allow personnel to walk over the beams. Adequate safety precautions must be provided to prevent personnel from walking through the beams.
4. The floors should be flat to within 1/4 inch and at the same level in all experimental areas to within one inch. Closer tolerances would be desirable.

XXVI. DRAFTING

Roy Tuma

The Drafting Room, consisting of two designers, one of whom is the Group Leader, and four draftsmen, provides the Division with approximately 875 man hours of drafting and design time per month. The majority of this, since the last report, has been devoted to design and development of various models and prototypes. Included in these have been several model magnets, 1/4 and 1/7 scale, a full-size prototype of RF accelerating cavity, a vacuum chamber 25 feet long, with a cross section to simulate the magnet gap, several vacuum systems used to check the characteristics of Evapor-Ion and diffusion pumps, and the equipment relative to all these projects.

Work has been progressing on the conceptual drawing for various components of the machine such as the fabricating and machining of the ring magnet, the ring magnet coil and coil end connections, and the connection of the ring magnet vacuum chamber to the straight sections.

In July, an upright drafting board six feet high and 14 feet long was acquired by the Division. This board is fitted with a precision drafting machine. Thus far this equipment has been used for accurate layout of the theoretical orbits through the ring magnets and straight sections.

XXVII. PERSONNEL

The following additions to the Division occurred in the past six months.

Staff

Wayne W. Nestander	April 29
Guiseppe O. Calabrese	June 3
Finley W. Markley	June 3
David W. Hafemeister	July 8
Harry R. Fechter	July 17
David F. Cosgrove	July 29
George W. Bryan	August 26
David Cohen	September 10

Technician Pool

Gerald Dorn	April 15
Dale Bassett	May 6
Charles F. Leonard	May 8
Charles W. Testin	June 16
Howard M. Schmidt	August 26

Secretarial

Sophie Baloy	May 6
Judith Rose	Summer only
Nancy Perry	September 3

Drafting Room (On loan from Central Shops)

Walter P. Pelczarski	May 28
Chester W. Rogers	July 12

Co-operative Students

Joal A. Teresko - University of Detroit - July 1 - Sept. 1
 Matt E. Simon, Jr. - University of Detroit - August 7 -

Summer Visitors

Resident Research Associate

Arnold A. Strassenburg, University of Kansas - June 3 - Aug. 20

Resident Student Associate

Robert E. Rothe, Calif. Inst. of Technology - June 3 - Aug. 30

Student Aides

James H. Boyd	DePauw University	June 10 - August 23
Joseph Carroll	St. Mary's College	June 3 - August 23
Yates Keir	Purdue University	June 3 - August 30
Robert Saunders	Mass. Inst. of Tech.	June 3 - August 15
Edward F. Sidor	Wabash College	June 10 - September 11

Resignations

Melvin I. Ferentz	September 30
John Dawson	September 30

Consultants

The following men have been retained by the Physics Division of Argonne to advise on the facilities for experimental use of the accelerator.

A. V. Crewe	The University of Chicago
R. D. Hildebrand	The University of Chicago
U. E. Kruse	The University of Chicago
S. D. Warshaw	The University of Chicago
S. C. Wright	The University of Chicago