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INSTALLATION OF THE BEVATRON POWER SUPPLY

Robert Harry West

(E. E. Thesis)

April 19, 1955

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Please make the indicated changes in your copy of "Installation of the Bevatron Power Supply":

Page	Line	Change
5	2nd from bottom	from "6.4" to "6.21"
6	3rd from bottom	from "0.16" to "0.36" and from "2.2" to "2.47"
12	4, Sec. C	delete "(Equation: $E = mc^2$)".
	16, Sec. C	replace the sentence beginning "This means that ......" with "This means that the rate of change of the frequency of the impulses on the accelerating electrode must be greater at first, then less as the velocity of the particles approaches the speed of light and their mass increases correspondingly (according to relativity theory)."
	21, Sec. C	from "regulate" to "program"
	22, Sec. C	from "...discrete increments in the..." to "...change of..."
	3rd from bottom	from "...the start of the build-up of..." to "...a peaking strip in the..."
13-14		replace with new pages
15	12	from "The high-energy beam... pair production." to "The high-energy beam could lead to the production of proton-negative proton pairs."
16	10	from "...solid steel." to "...three steel discs bolted together."

INSTALLATION OF THE BEVATRON POWER SUPPLY

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INSTALLATION OF THE BEVATRON POWER SUPPLY

Robert Harry West

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Berkeley, California

April 19, 1955

ABSTRACT

This is a historical report on the installation of the Bevatron power supply at the University of California Radiation Laboratory from the viewpoint of a project engineer. The report is an outline indication of how the actual physical installation was completed, as well as some of the theoretical problems involved in planning to direction of the work. The installation was unique: such an atomic accelerator as the Bevatron had not been designed or built before. The entire Bevatron project was new, therefore most of the applications of the electrical equipment composing the power supply were to be tried for the first time.

To accomplish the construction phase numerous drawings had to be prepared to represent the work required of the contractors. None of these drawings were applicable to this document in their original form, but some segments of a few of them are incorporated in the accompanying figures. The Appendixes are copies of the specifications, written and compiled by the author, that accompanied the construction drawings.

During the long installation period the Radiation Laboratory, fortunately, took many photographs of the work as it progressed. Many of these photographs are incorporated into the text as exact illustrations of the installation.

INSTALLATION OF THE BEVATRON POWER SUPPLY

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Radiation Laboratory
University of California
Berkeley, California

April 19, 1955

I. INTRODUCTION

A. Scope of Document

It is the purpose of this document to give a historical report of the installation of the Bevatron power supply. This will specifically cover two major achievements: (1) the mechanical installation of the two flywheel-motor-generator sets, (2) the electrical installation of the magnet power supply. Each of these two major divisions of work was performed by outside contractors, one for each division, under the supervision of Radiation Laboratory and Westinghouse Electric Corporation Engineers. The construction and installation work of each division was carried on concurrently so each unit could be completed in proper sequence. In order to engage the above contractors it was necessary to provide a complete set of drawings and specifications which outlined and defined the required performance. These documents were prepared through the joint effort of Radiation Laboratory and Westinghouse Engineers. The Westinghouse Electric Corporation designed and manufactured all the electrical and mechanical equipment for the Bevatron power supply. Appendix I and Appendix II are copies of the specifications for the contracts.

B. General Description of Bevatron Components

The Bevatron is at present the largest atomic particle accelerator in existence. It is situated in the Berkeley hills overlooking San Francisco Bay above the University of California Campus, and is a part of the University of California Radiation Laboratory. Using protons as the atomic particles to be accelerated, the Bevatron is able to produce a beam energy of 6.4 Bev (billion electron volts). To create such a beam energy it was necessary to construct the world's most powerful electromagnet and couple it to a power supply that would produce a peak energy of 100,000 kva. The floor plan is shown in Fig. 1.

Physically the Bevatron may be divided into four major elements: (1) the magnet and its associated components, (2) the injector, (3) the accelerating electrode, and (4) the magnet power supply. (See Fig. 2.)

The magnet is formed by four quadrants with a mean radius of curvature of fifty feet. The quadrants are connected by four straight sections twenty feet long, called "tangent tanks." The steel portion of the magnet contains more than 10,000 tons and the magnet-coil windings contain more than twenty-six miles of copper cable with a circular cross section of 1.31 square inches (Fig. 3). The magnet field coils were wound separately for each quadrant, with the coil turns parallel to the beam orbit and divided into two sections so as to give an upper and a lower coil. A huge hollow stainless steel ring forms the vacuum chamber, and it is located within the coils and the steel yokes of the magnet. The vertical center of this ring is the plane of the beam orbit, with a total mean orbit length of approximately four hundred feet. Inside the vacuum chamber are placed special magnet pole pieces which are used to shape and correctly distribute the vertical magnetic field. Figure 4 shows a cross section of magnet, coils, and tank. The four straight sections of the magnet contain the vacuum manifold and vacuum pumps. It is also at these positions that the injector, the accelerating electrode, and the beam exit are located.

The injector consists of (a) an ion source for generating ions by means of an electric arc discharge in a gas; (b) a Cockcroft-Walton accelerator, which accelerates the ions to 500,000 electron volts; and (c) a linear accelerator that increases the energy of the ion beam to 10 Mev (million electron volts). The beam is then injected into the main Bevatron beam orbit for its final acceleration. See Fig. 5.

The accelerating electrode is a varying-frequency oscillator whose output varies from 0.16 megacycles to 2.2 Mc. This variation must be in strict accordance with the rate of acceleration of the atomic particles and with the rate of increase in the magnetic field.

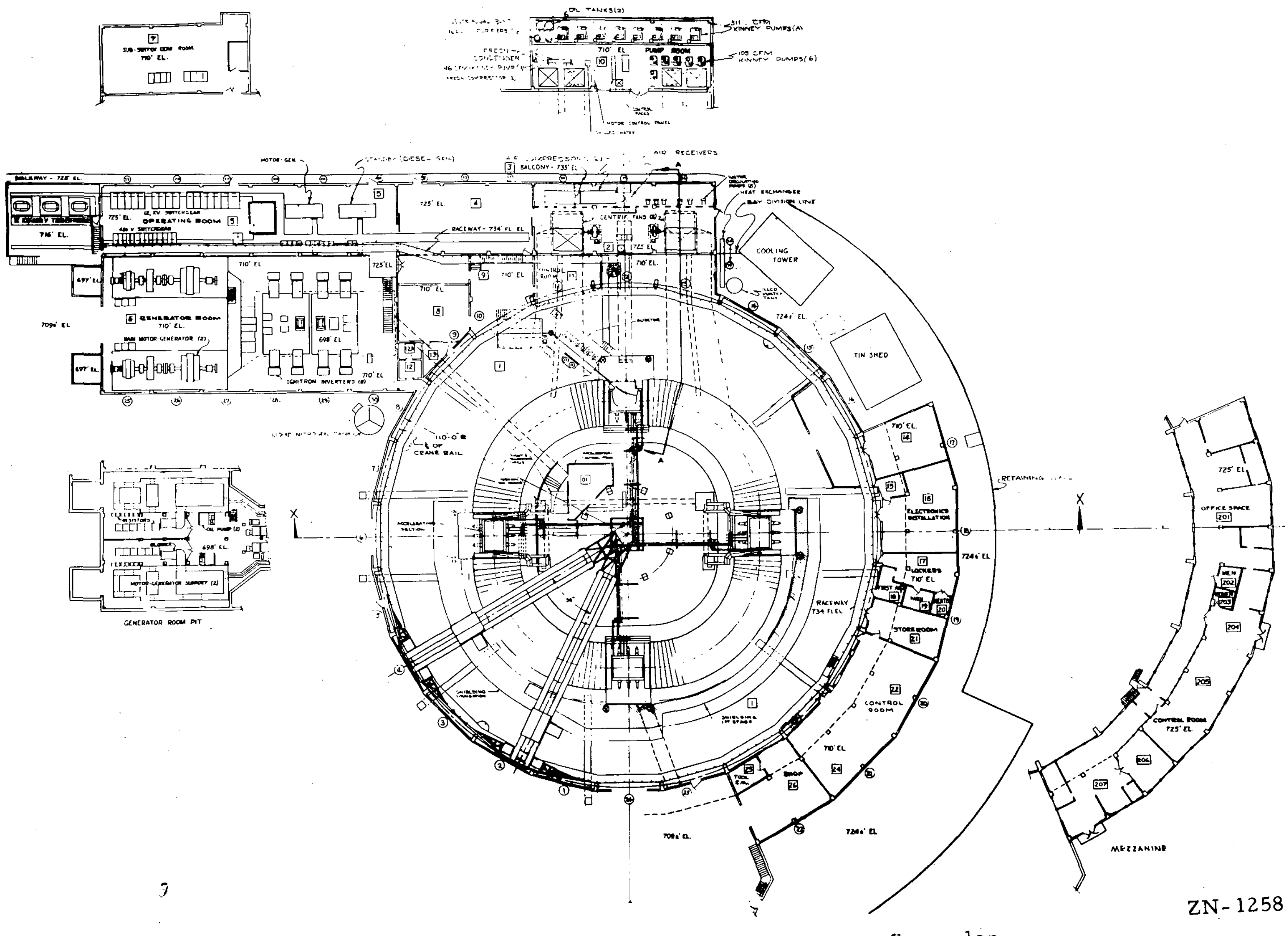

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Fig. 1 Bevatron floor plan

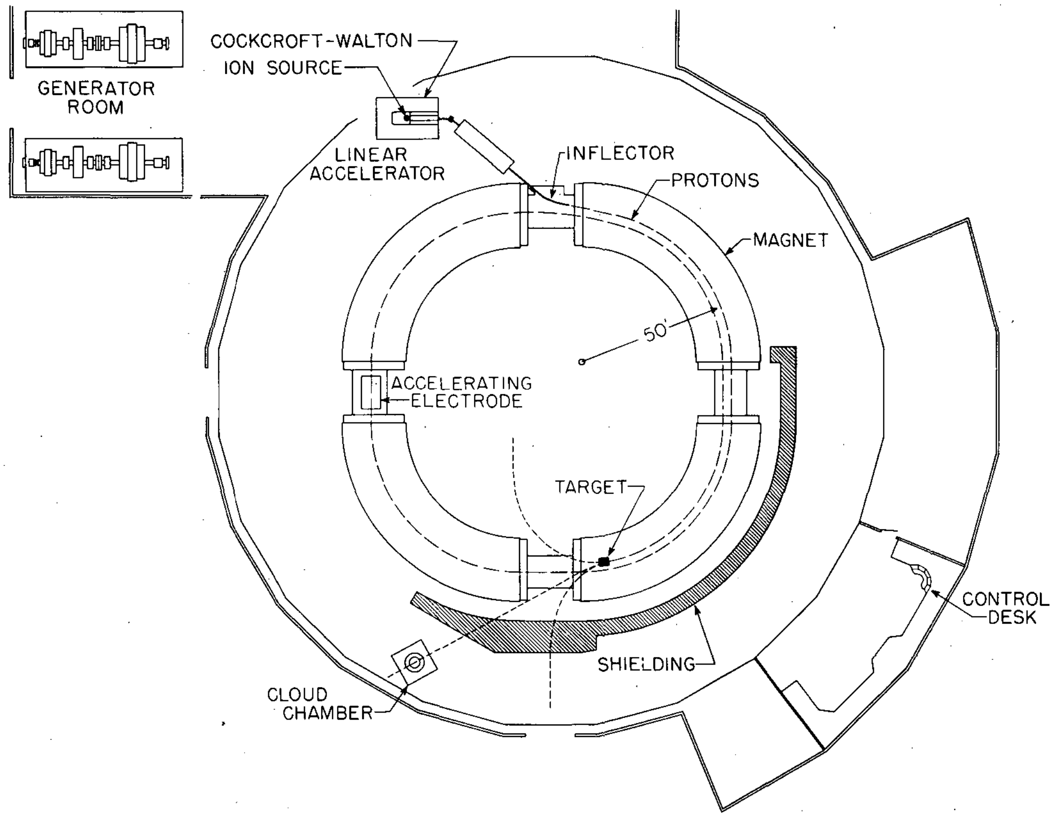

Fig. 2 Outline of Bevatron illustrating the four major elements. Note the proton beam orbit striking a target causing a nuclear event; also the shielding, composed of a concrete wall ten feet thick, which is a necessary protection against radiation. The generator room contains the magnet power supply.

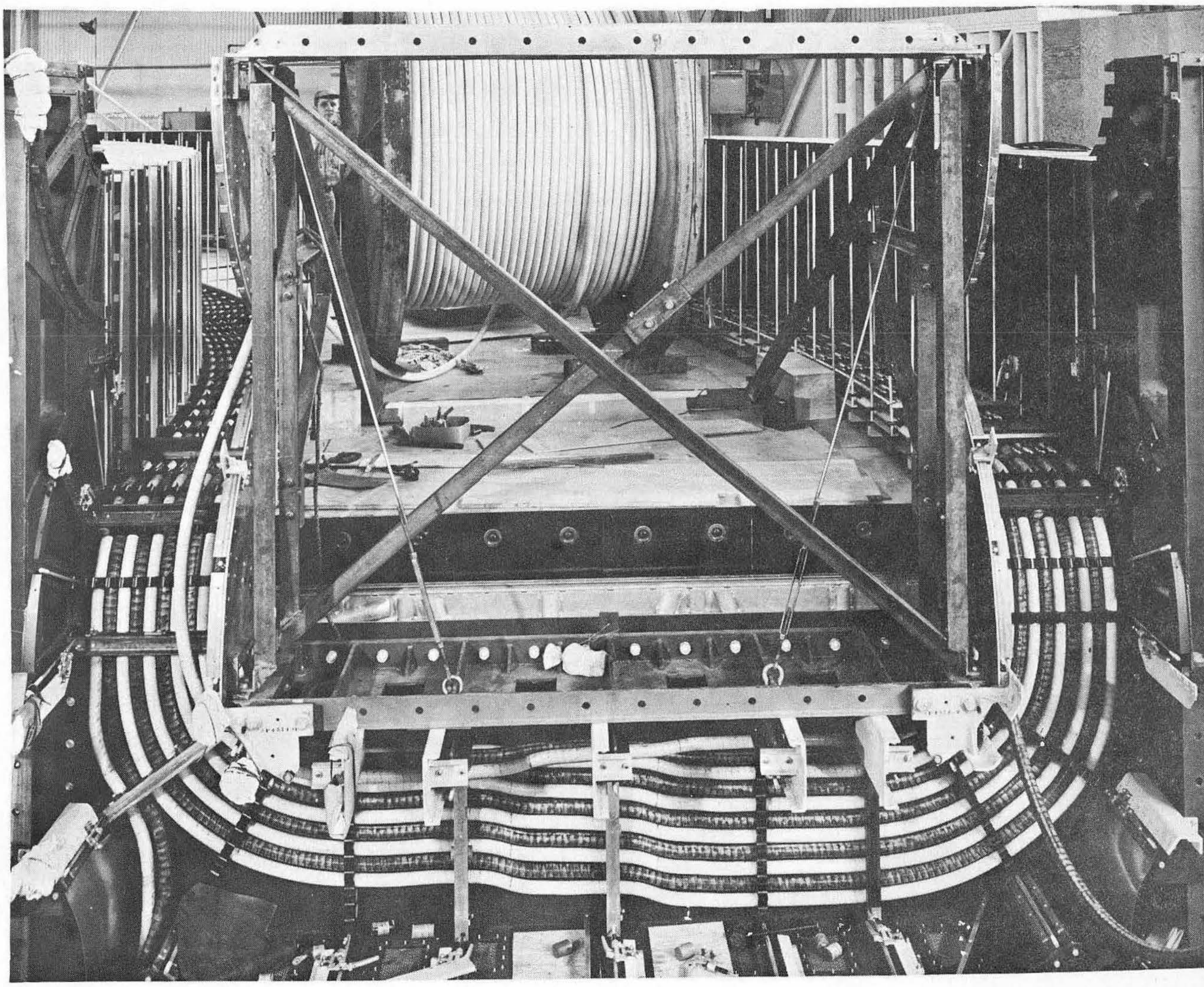

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Fig. 3 View showing the end winding of one of the magnet quadrant coils. Note size of cable reel and the black and white covered cables. These two colored cables form parallel paths for the magnet current.

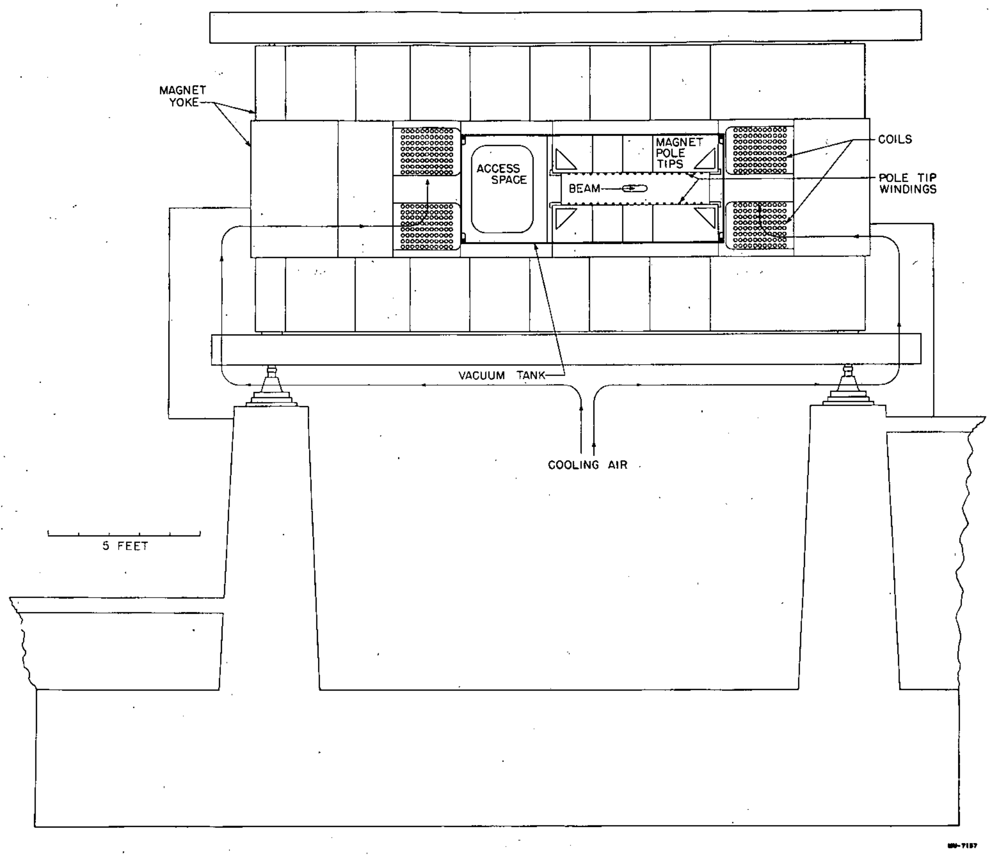

Fig. 4 A cross-sectional view of the magnet, illustrating all the elements that make up the magnet. Note the circulation of cooling air, which is supplied by two 250-hp fans.

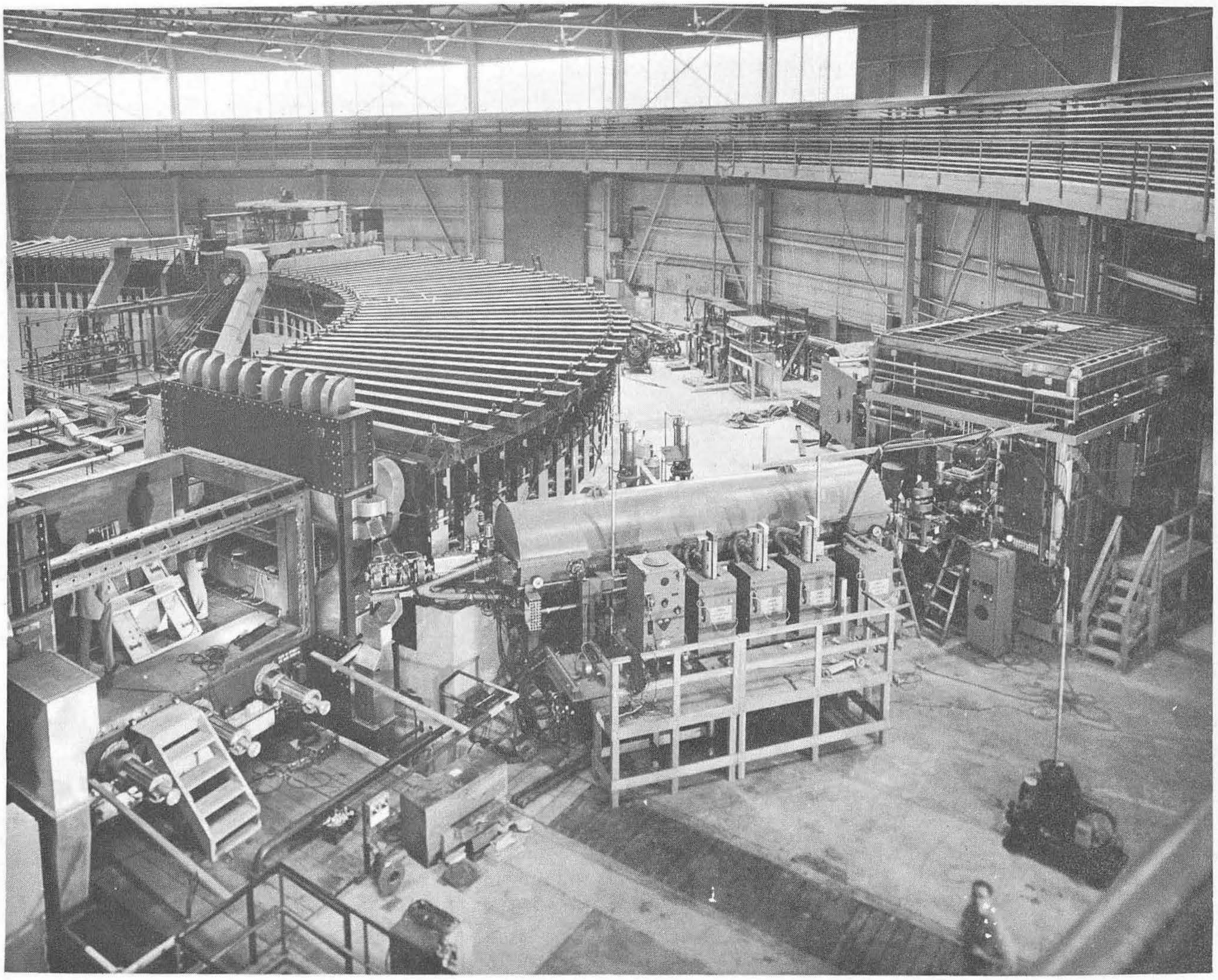

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Fig. 5 Magnet room showing the injector. The Cockcroft-Walton machine and ion source are to the extreme right, then the linear accelerator in the middle, and on the left the magnet, with the sides removed from the tangent tank.

The magnet power supply consists of two large flywheel-motor-generator sets whose output supplies electrical energy to the magnet coils via ignitron power converters. The energy is supplied in the form of direct-current pulses (Fig. 6).

C. General Design Requirements for Bevatron

The design and the operation of the Bevatron were based on three main factors[1]: (1) the maximum magnetic field to be practically maintained over a sizable air gap, which is 16,000 gauss; (2) the law of Einstein (Equation: $E = mc^2$), which explains the effect of energy and velocity on ions; (3) the principle of phase stability in atomic accelerators. The last principle provides for the geometry of the Bevatron by making it possible for a ring electromagnet to contain an accelerating beam orbit at the center of its vacuum chamber. In order to position the orbit on an equilibrium circle, it is necessary to vary both the strength of the magnetic field and the frequency of the accelerating electrode in proper proportions with respect to each other. There are two requirements as the beam of atomic particles is accelerated. The magnetic field must increase to compensate for increased centrifugal force. At the same time, the pulses of the accelerating electrode must be timed to keep pace with the increasing velocity of the particles. This means that the frequency of the impulses on the accelerating electrode must increase rapidly at first, then less rapidly as the velocity of the particles approaches the speed of light and their mass increases correspondingly (according to the relativistic equation, $E = mc^2$). To achieve the correct balance between these two accelerator elements a "tracking device" was used. The purpose of the device is to regulate the discrete increments in the frequency of the accelerating electrode; and it keeps pace by deriving its excitation from the magnet current. A general description of the operational cycle of a single magnet pulse will aid in clarifying the function of each Bevatron component. The ignitron power converters are triggered so they begin supplying energy to the magnet. The magnetic field starts to build up in the magnet. The particles to be accelerated are injected into the accelerating orbit at an instant of time that is controlled by the start of the build-up of magnetic field. (An injector must be used, as the Bevatron cannot accelerate atomic particles from rest or even from low energies;

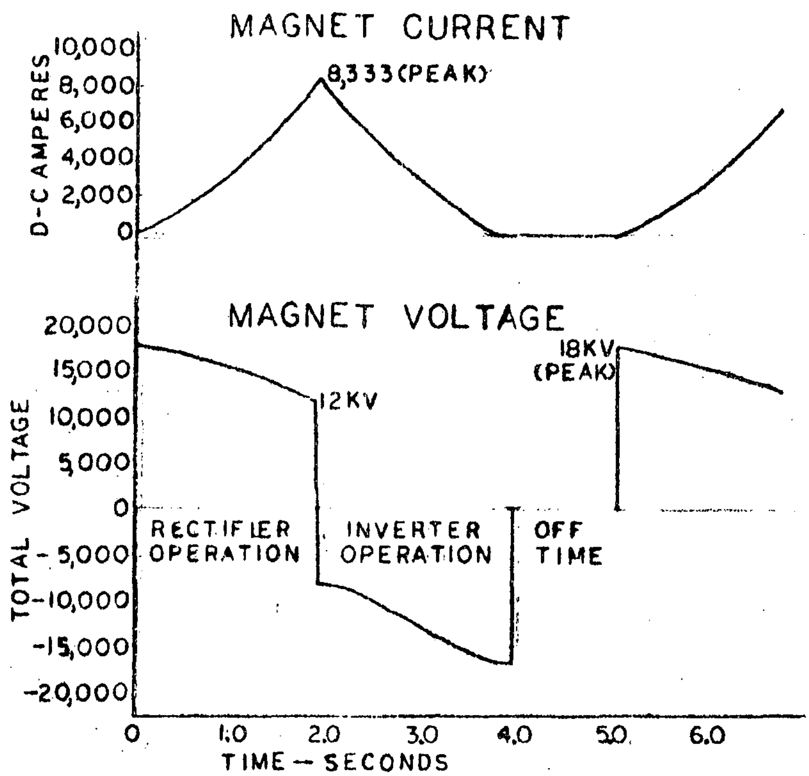

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Fig. 6 Pulse Curves.

therefore, the particles are inflected from the injector into the beam orbit with an initial energy of 10 Mev.) The accelerating voltage of the accelerating electrode then increases its frequency from 0.36 Mc at injection time to 2.5 Mc in approximately 1.85 seconds, the time required for the magnet to attain a maximum field of 16,000 gauss (Fig. 6). The magnet current at this point has increased to 8,333 amperes and the voltage across the magnet coils has decreased from an initial value of 16 kv dc to 12 kv at peak current. At the end of this accelerating period of 1.85 seconds the beam energy has increased to approximately 6.21 Bev (6.21 billion electron volts), and at this time the beam is permitted to bombard an appropiate target, thereby initiating nuclear events. In acquiring such an energy the beam has completed approximately 4,000,000 revolutions of the orbit path and has traveled more than 300,000 miles with a final velocity approaching 99 percent the speed of light.

The peak power of the magnet at maximum beam energy is 100,000 kva, and the stored energy in the magnet is 82,500 kilowatt-seconds. This energy at maximum magnetic field must be disposed of, and the magnetic field returned to zero, so the pulse sequence can be repeated. This disposal is achieved by returning the energy "stored" in the magnet to the magnet power-supply system. The ignitron power converters are the means by which the energy flow is reversed. At the peak current they are changed from rectifiers to inverters, thus causing the generators to change into motors. Working as motors, the generators than help the motor-generator sets regain their initial speed, with the result that the energy is stored in the flywheels until the magnetic field must be built up again. Application of this reverse energy-flow cycle means that the only energy consumed by the magnet and its power supply is what is actually lost (as heat or through friction).

D. Research with the Bevatron

The Bevatron is operated as a research tool to study the generation of nuclear particles by the bombardment of various elements with a beam of protons. The research program should lead to the identification of nuclear mechanisms and also aid in the nuclear-chemical investigation of atomic structures, which can be studied only by means of very high-energy nuclear reactions. A family of particles, called mesons, that are created by such high-energy reactions will be given special attention. Mesons were first discovered in cosmic rays and have a very short life span. They are found only when very-high-energy particles interact with nuclei, causing transmutation or atomic disintegration; the theoretical speculation is that mesons are intimately involved with the powerful forces which must exist to hold a nucleus together. If this is true, then mesons are a fundamental factor determining the ultimate form and order of the physical universe. The Bevatron, possessing such high energy, makes possible the study under laboratory conditions of intermediate and heavy mesons. The high-energy beam should lead to "pair production", i.e., the splitting of a nucleus into new nuclei; the barrier of actually creating matter may be crossed by the phenomenon of pair production. The theoretical threshold of energy for pair production is 5 Bev.[2]

II. MECHANICAL INSTALLATION OF FLYWHEEL-MOTOR-GENERATOR SETS

A. Special Problems

The large flywheel-motor-generator sets are unique in their actual physical dimensions because of the unusual application, in which they supply pulsating energy to the largest electromagnet in existence. Figure 7 illustrates the size and weight of each of the components combined in the 3-unit, 5-bearing machine. The driving unit is a 12-kv, 3-phase, 60-cycle self-ventilated wound-rotor motor rated at 3,600 horsepower. The energy-supplying unit is a 46,000-kva 12-phase synchronous generator of 95% power factor, force-ventilated by two auxiliary exhaust fans. The energy-storing unit is a 67-ton flywheel made from solid steel. (Figs. 8, 9.)

The foundation problems involved in supporting such a heavy motor-generator set were intricate and critical because of the pulsating energy cycle and the enormous rotating inertias. The machine foundations were made of poured reinforced concrete as shown on Fig. 10. They were constructed to be individually self-supporting, not fastened rigidly to any other object or building structure. This separation of individual units of the machine foundations was required so as to isolate the vibrations set up as a result of the magnet-pulsing cycle. The self-supporting aspect was made feasible by making the total weight of the reinforced concrete foundation greater than the total weight of a flywheel-motor-generator set. This foundation-weight requirement was made more difficult because the machine foundation had to contain sufficient openings for cooling-air ventilation, lubrication-oil piping, and electrical-wiring rights of way. The necessity for these openings resulted in much greater foundation dimensions, so to allow for adequate quantities of concrete and reinforcing steel.

B. The Installation Process

The installation of the motor-generator sets, which was performed in accordance with the contract specification in Appendix I, was begun by placing upon the foundation walls the steel bedplates or sole plates (Figs. 11, 12). All the machine components would be fastened to these plates by means of bolts and dowels. The plates are held securely to

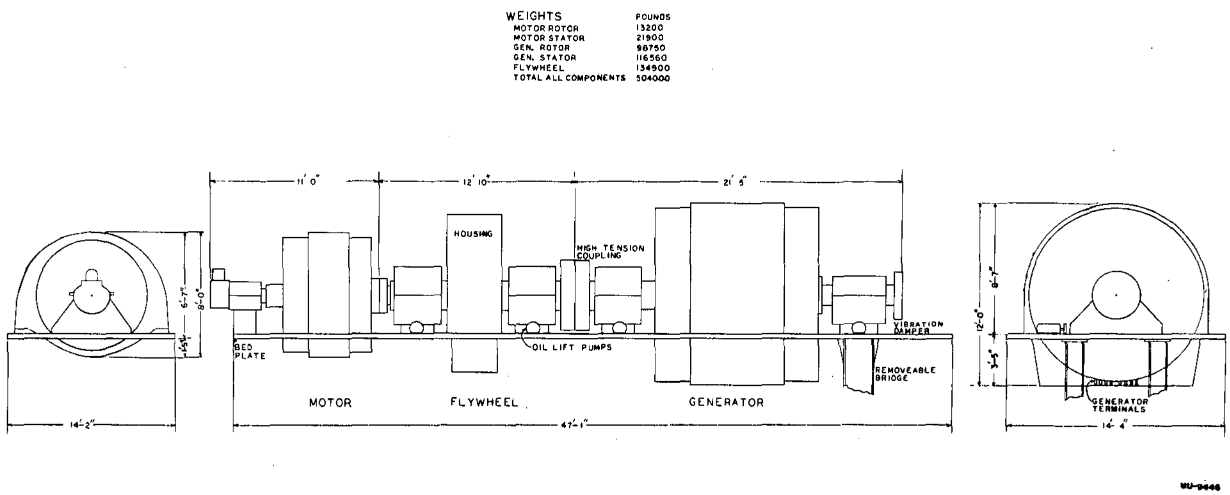

Fig. 7 Entire motor-generator set, showing weights and reactions due to inertias and dimensions.

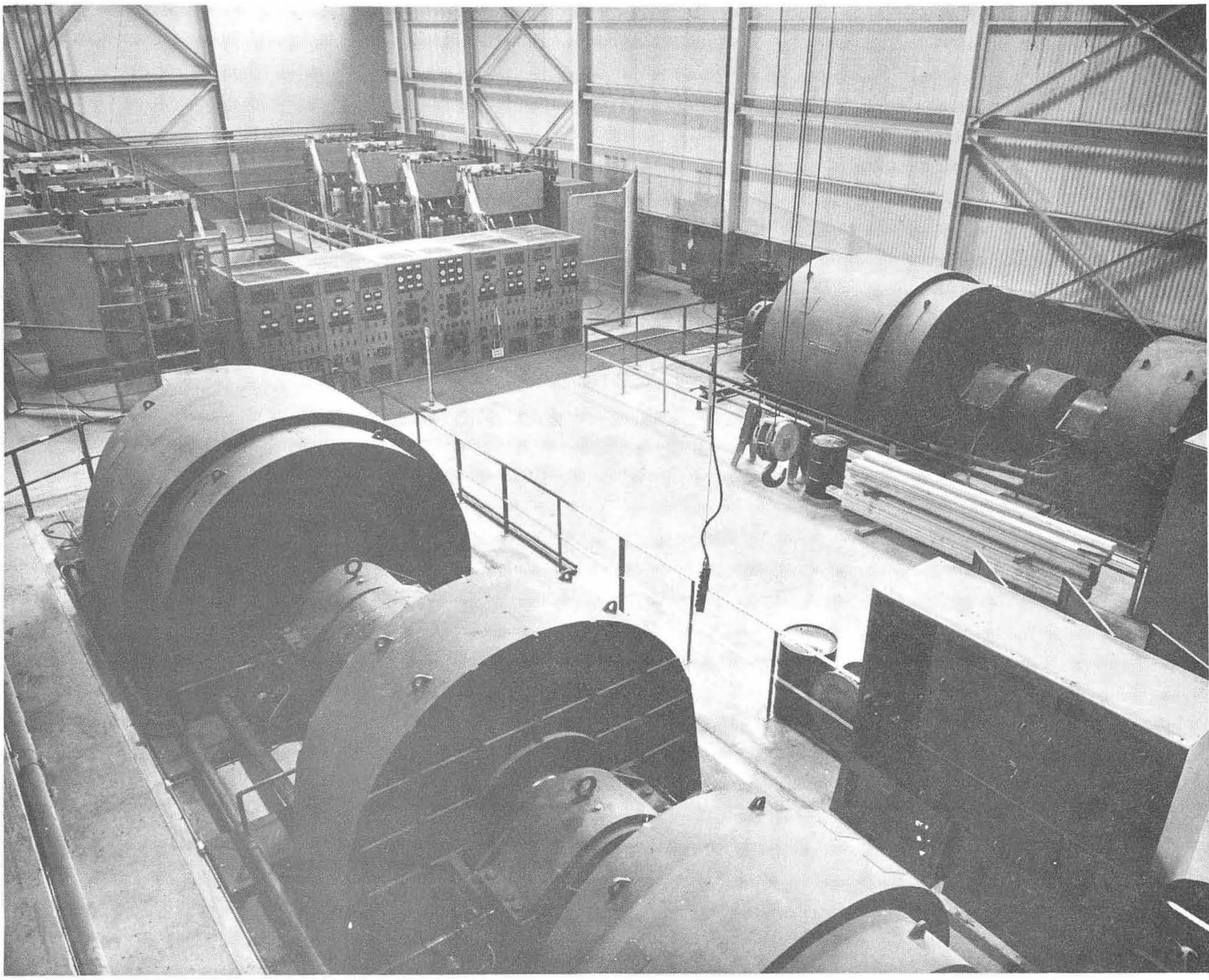

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Fig. 8 Installed flywheel-motor-generator sets. Generator at middle left, flywheel with its cover, center bottom, motor at right bottom. (Note motor-control cubicle adjacent to motor.) Nearer set is east machine, right west machine at upper right.

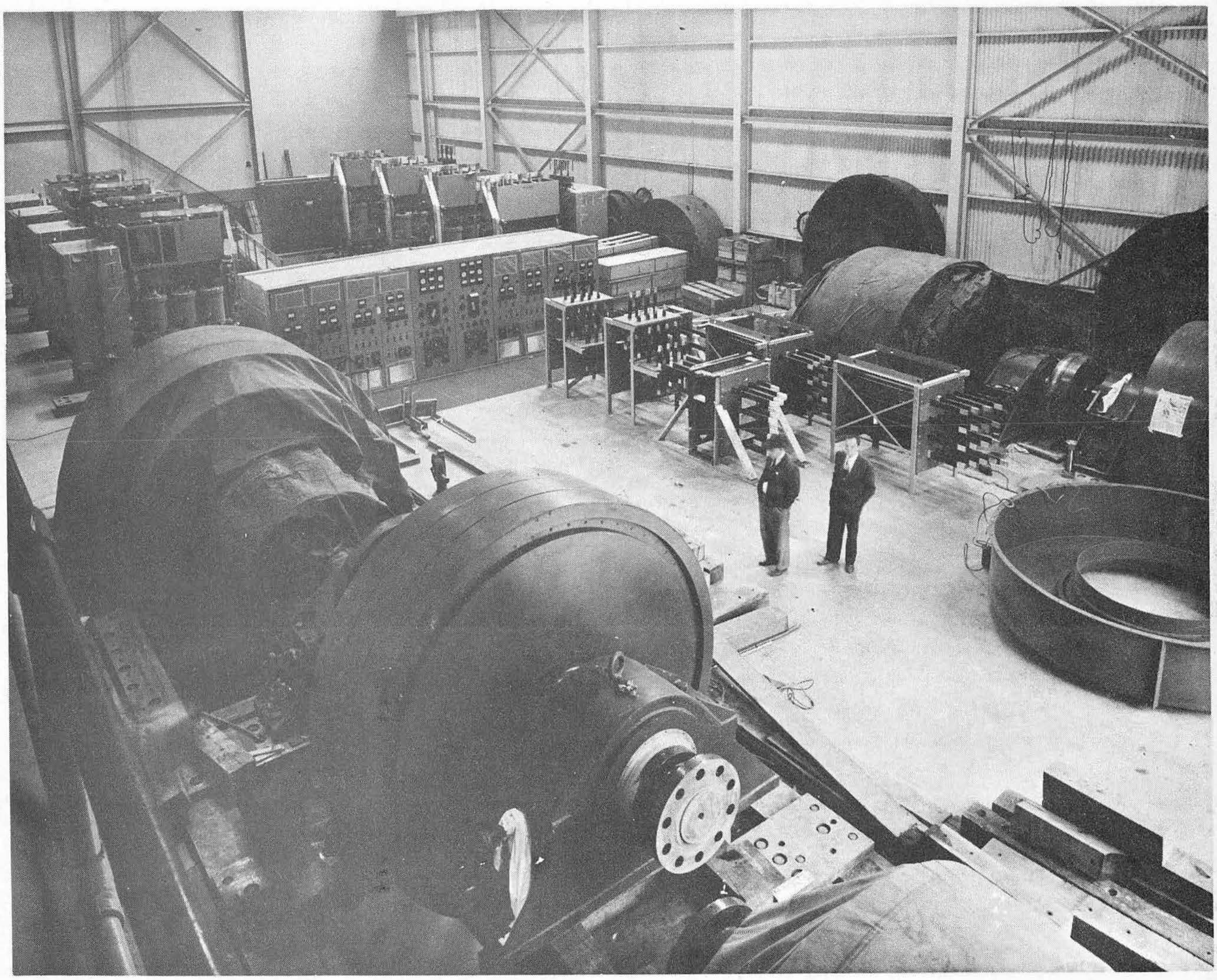

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Fig. 9 View showing flywheel being lowered into place between motor and generator. Note solid composition of flywheel and pedestal bearing on flywheel shaft, with motor end coupling face. A generator end-bell is lying on the floor on the right. In background, on floor, are sections of insulated bus array described in Section III.

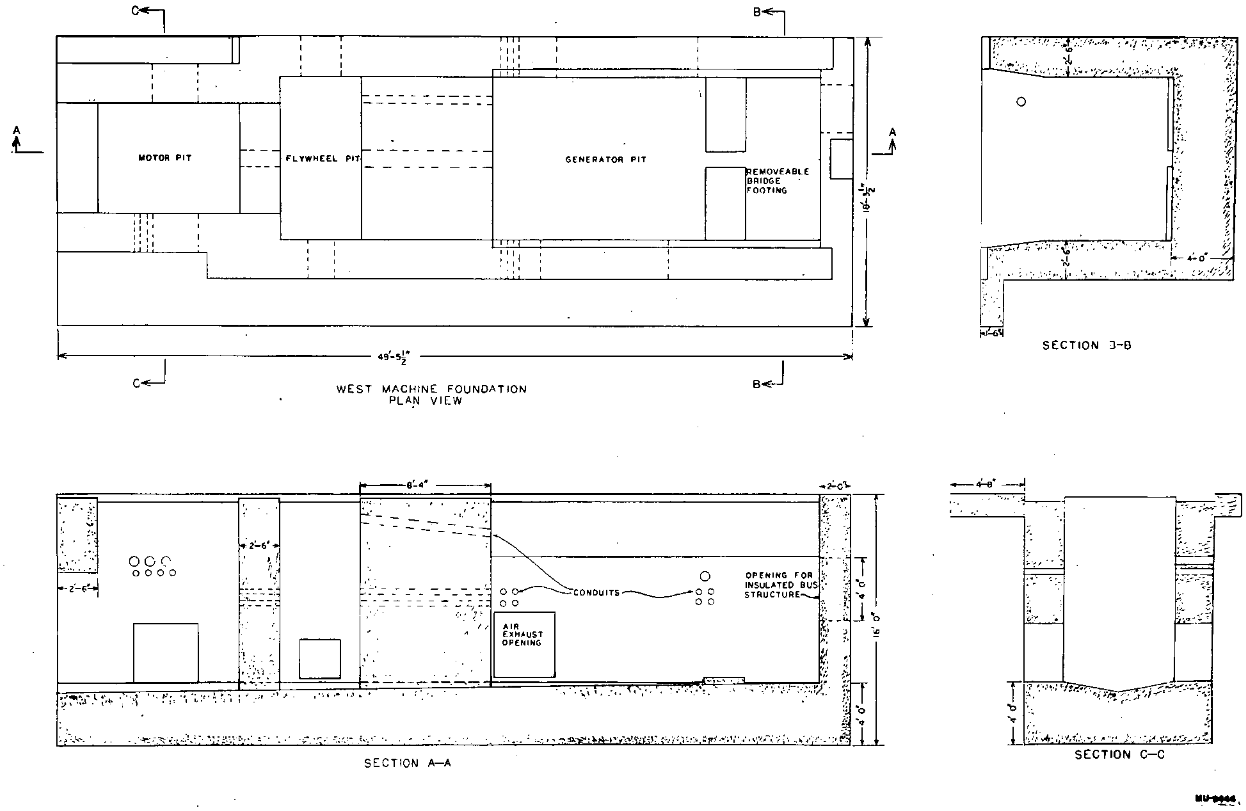

Fig. 10 Motor-Generator Concrete Foundations.

the foundation by large hold-down bolts. These bolts were accurately positioned in the foundation walls when they were poured (Fig. 13). Each bedplate required 54 hold-down bolts, two inches in diameter and four feet long; the bolts were made of high-tensile-strength steel. For the removable bridge at the generator end of the foundation there were 8 hold-down bolts, two inches in diameter and 18 inches long. To obtain the desired accuracy in placing each of the 62 bolts in its proper location, surveying methods were resorted to, employing a transit. Such a high degree of precision alignment was mandatory throughout the entire installation of the motor-generator sets, because of the large rotating inertias and the severe stresses generated by the pulsating magnet current and possible short circuits in the generator phases (Fig. 7). Another precision setting was the leveling and alignment of the bedplates, by means of small steel leveling plates grouted into place on each side of the hold-down bolts (Fig. 14). Section 11.d. of Appendix I describes the bedplate installation in detail.

Once the bedplates were in place the components of the machine were assembled on this base. The individual components of the motor-generator sets were so heavy they exceeded the design value of unit floor loading for the generator room. To take care of this difficulty the entire floor between the machine foundations was covered with wood planks and shored from underneath. The machine components were then brought into the generator room and put into place by industrial rigging methods. The motor stator was the first component to be positioned on the bedplate. Grooves had been machined into the bedplates to match grooves in the stator superstructures of the motor and the generator. These grooves formed tracks in which ball-bearing steel rollers were placed, making it possible for the stators to be rolled back and forth for machine assembly and alignment. The sequential grouping of the components upon the bedplate was such as to work toward the center component, namely the flywheel. On completion of the grouping, all the pedestal bearings were then accurately aligned to their working positions.

The final operation in the machine assembly was the bolting of the large generator coupling. This coupled the flywheel shaft to the generator rotor shaft (Fig. 15). The coupling bolts were 4.5 inches

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Fig. 11 View from motor end of bed plates upon foundation walls of west machine. Note groove in bed plate for motor stator and generator stator rollers. Planking and shoring of generator room floor was necessary to protect from overloading by heavy machine components.

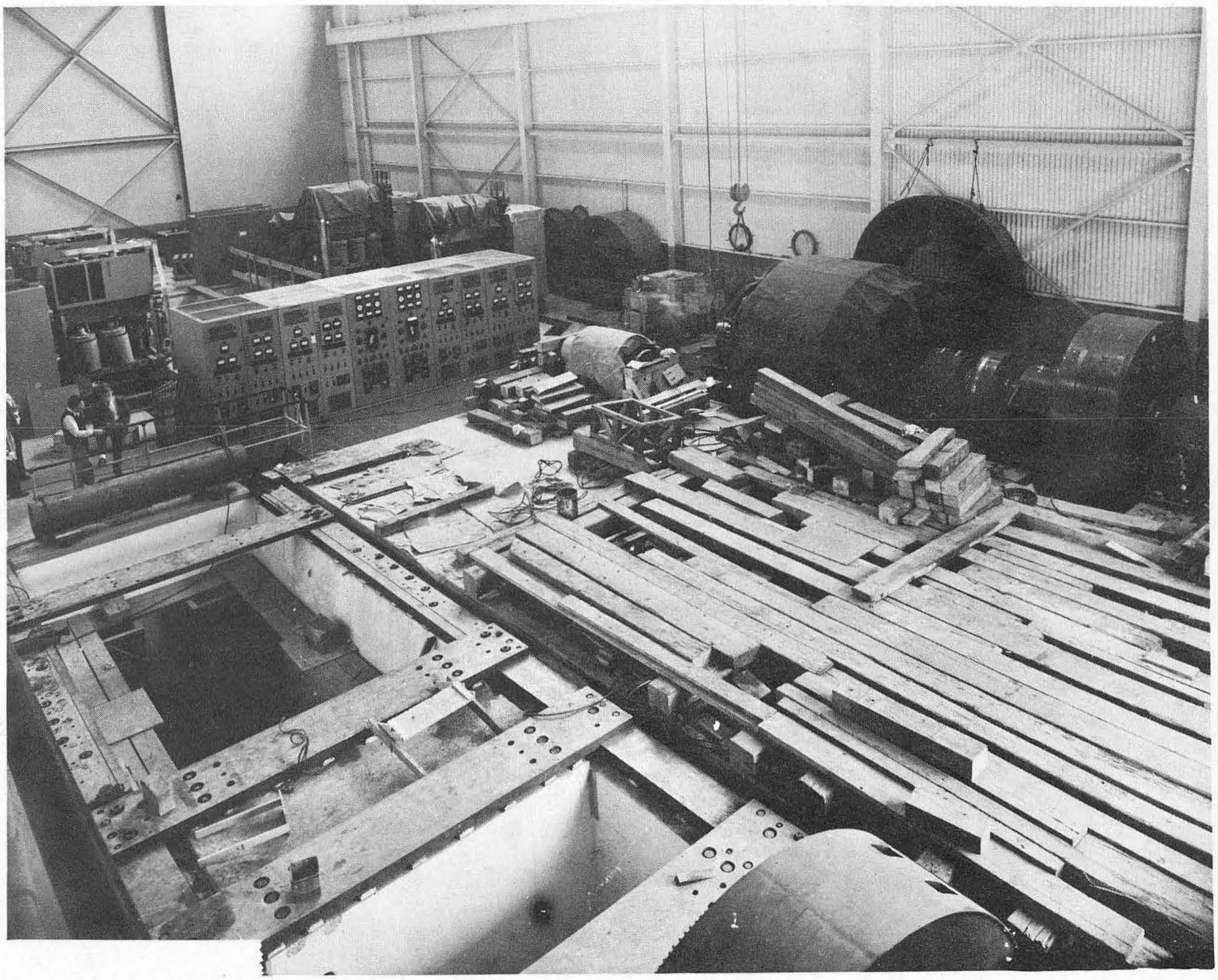

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Fig. 12 Looking down on bedplate of east machine from the motor end. Note the nuts of the hold-down bolts, set flush. At generator end can be seen the removable bridge. West machine has been assembled in back ground.

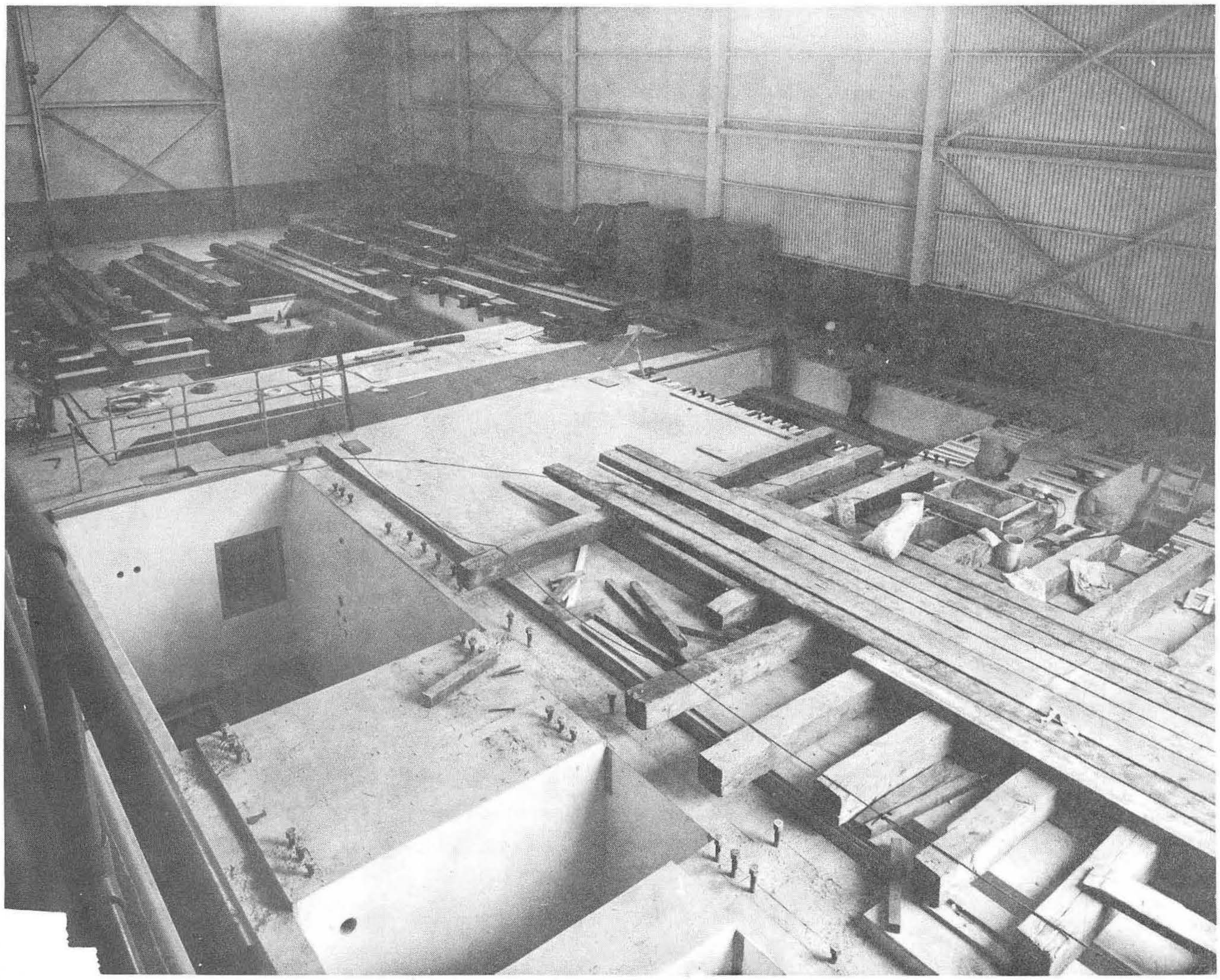

Fig. 13 Looking down on foundation of east machine, showing hold-down bolts. Opening in generator-pit end wall is for the insulated bus array.

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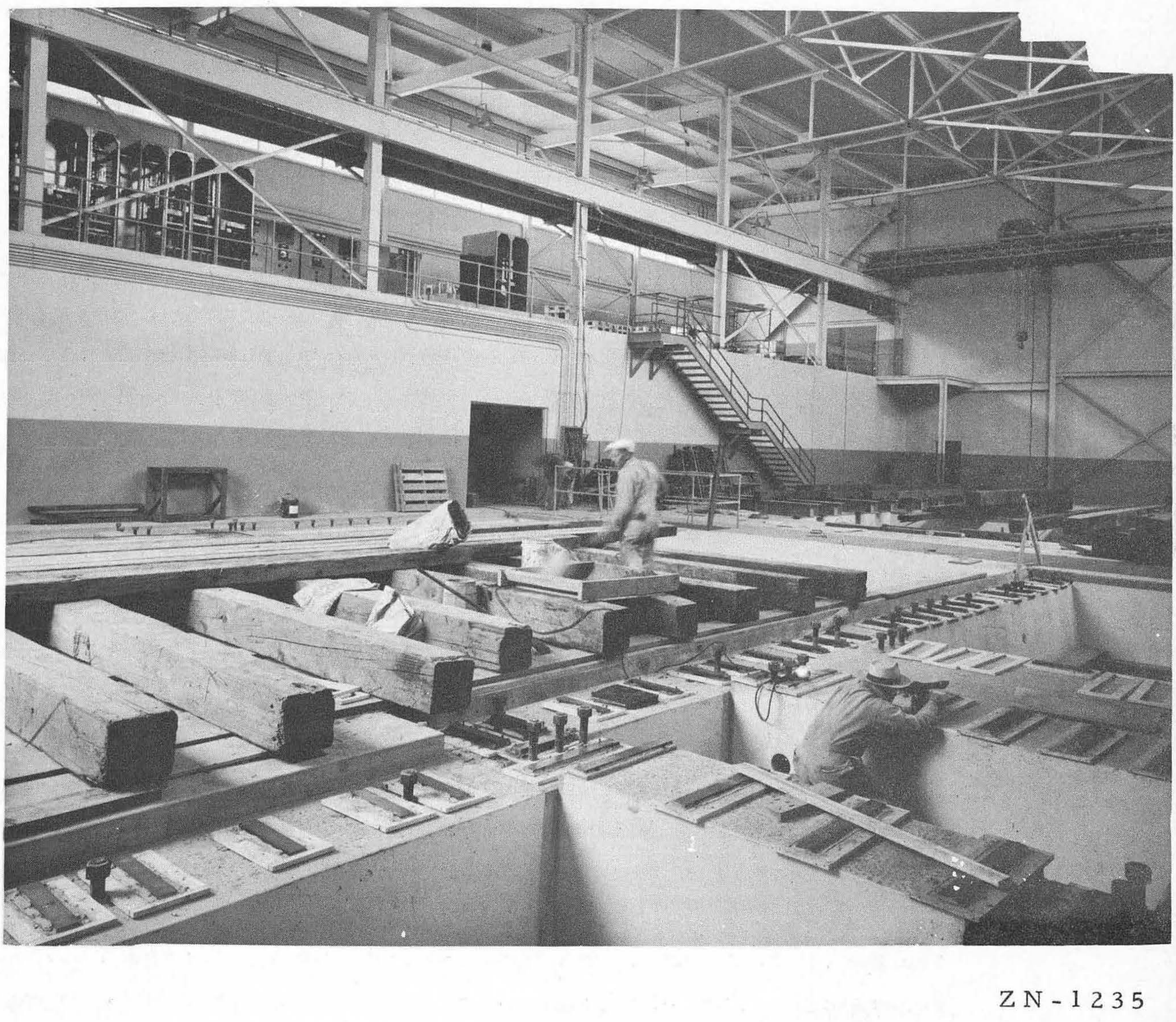

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Fig. 14 West machine foundation, showing leveling plates in position.

in diameter and had a 0.75-inch-diameter hole through the center of the bolt. They were polished and fitted into the coupling with a close machine tolerance. Into the hole through the coupling bolt was placed a portable long thin electrical heating element exactly as long as the bolt. These elements were used to heat the bolts, evenly over their lengths, in place in the coupling. The bolts were heated until they had elongated a prescribed number of thousandths of an inch. At this time the nuts on each end of the coupling bolts were tightened, and then the heating elements were removed to allow the bolt to cool, thus achieving a high-tension connection. Three bolts at a time, equally spaced about the coupling, were thus taken up, and the process was repeated until all sixteen bolts were tightened.

The generator end of the machine was designed so the final outboard pedestal bearing was supported on a removable bridge. By the use of a portable extension shaft the generator rotor shaft could be extended. The generator rotor could then be supported in place from the back generator foundation wall, thereby making it possible to remove the pedestal bearing and the removable bridge. This will then permit the generator stator to be rolled back on its steel rollers off the rotor, making the stator windings accessible for repair or maintenance without disassembling the entire machine. The removable bridge is made up of structural steel members that are easily unbolted.

After the entire machine was assembled and properly aligned, a vibration damper was mounted upon the end of the generator rotor shaft. This damper consists of two concentric toruses rotating in a special hydraulic fluid. Its purpose is to damp any oscillations set up in the shafts. Critical oscillations can be generated from the magnet-pulsing cycle and from the changes in the generator flux due to the inversion cycle of the magnet stored energy.

The two main auxiliaries to the flywheel-motor-generator sets are the oil lubrication system and the air cooling for the motors and generators. The oil lubrication system is composed of (a) a main oil reservoir with a circulating pump, located adjacent to the generator end of the machine foundation; (b) four high-pressure bearing lift pumps; and (c) the necessary piping and controls. The main reservoir contains an oil-to-water heat exchanger to cool the lubricating oil in order to insure its proper viscosity as the entire lubricating system

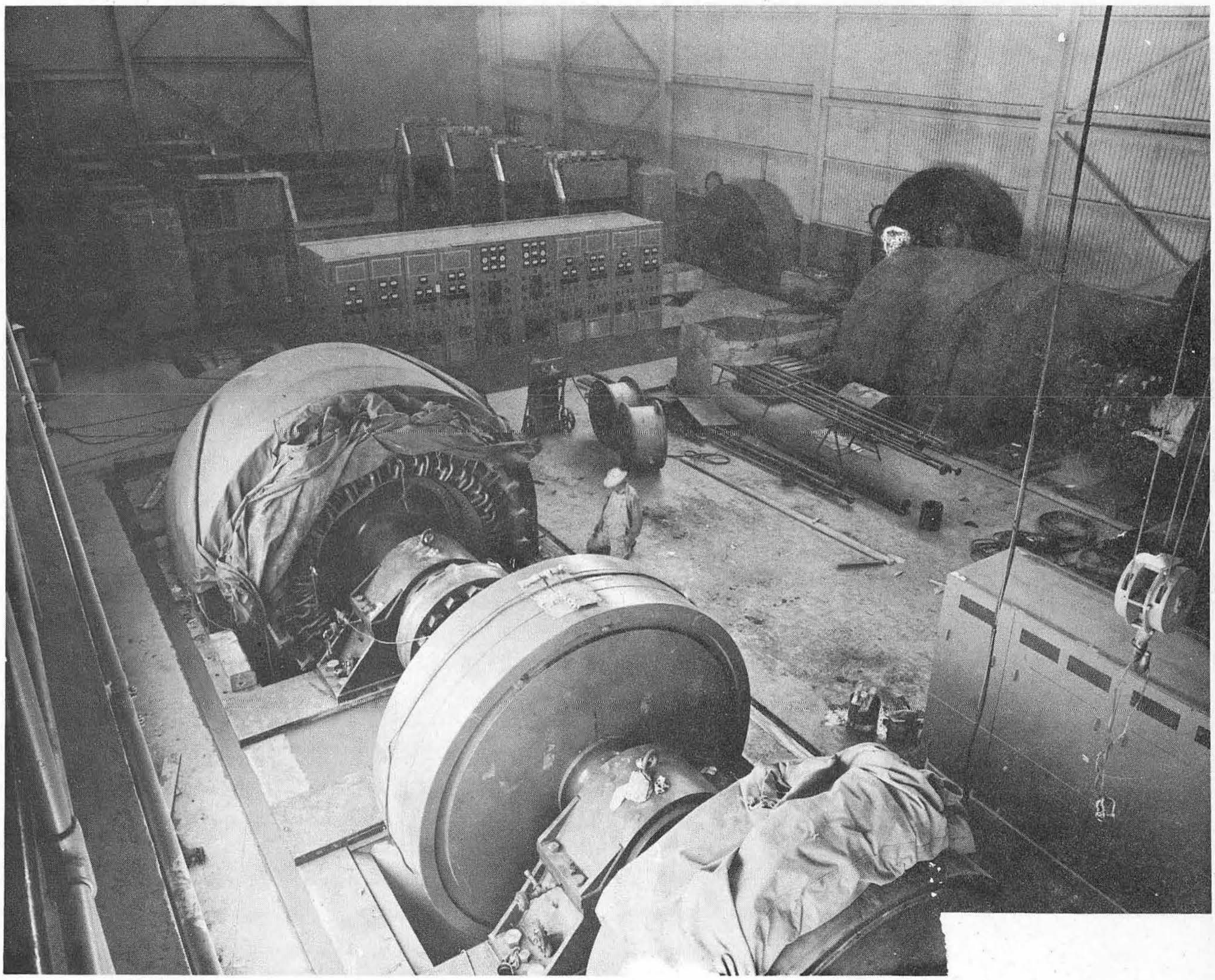

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Fig. 15 Looking down on east machine. Note generator couplings between the pedestal bearings and the large nuts of the coupling bolts.

is continuously circulated. Each pedestal bearing, however, contains a residual oil reservoir to provide lubrication in case of emergencies. The four high-pressure lift pumps are used only when the machine is being started and do not function when the machine is running. These pumps are actually used to lift the shafts up off the bearings upon a thin film of oil. Starting the motor-generator sets is thus made much easier; also the thin film of oil eliminates the possibility of any damage to the babbit-metal bearing linings because of the unusual concentrated weights of the machine components.

The 3,600-hp motors are air cooled by self-ventilation from built-in fans mounted on the rotor shaft, and each motor exhausts 18,000 cubic feet of air per minute. The generators are air cooled by forced ventilation. Each generator has two 40-hp axial-flow exhaust fans that exhaust a total of 85,000 cubic feet of air per minute. These two fans are located on each side of the machine foundation at the generator end. An air-exhaust duct was built as a part of the generator wing of the Bevatron Building, adjacent to the motor end of the machine foundations, to receive and exhaust the cooling air. (Fig. 22).

III. ELECTRICAL INSTALLATION OF BEVATRON POWER SUPPLY

A. Over-All Electrical Operation

The power supply that pulses the magnet and operates the controls is indicated diagramatically in Fig. 16. The entire Bevatron building, including the accelerator, derives all its electrical energy from an 18,750-kva bus supplied by a 12-kv line from an electric utility company. This 12-kv bus supplies the following loads: (a) three 1,500-kv transformers whose 480-volt secondary busses supply electrical energy to all the Bevatron building utilities, which also includes the accelerator vacuum pumps, the magnet-cooling fans, and the electrical equipment of the control rooms; (b) the accelerator auxiliary components, which are the injector and the accelerating electrode; (c) the experimental equipment used in conjunction with the accelerator, such as cloud chambers and analyzing magnets; (d) the two 12-kv 3,600-hp motors; and (e) a 750-kva transformer whose 480-volt secondary bus supplies energy to all the magnet power supply auxiliaries. (See Fig. 17.)

The two 3,600-hp motors that drive the flywheel-motor-generator sets are eight pole-wound rotor motors with grid resistors in the wound-rotor circuit to limit the starting currents and the sudden pulse currents to a practical level. The synchronous generators are eight-pole, twelve-phase machines rated at 46,000 kva. The twelve-phase generator winding is actually four three-phase windings displaced 30° from one another, and they are all "wye" connected. (See Fig. 16.) The rating for each wye winding is 11,500 kva with 3,200 volts from line to neutral. Each of the three-phase windings is connected via an insulated bus structure to a six-tank ignitron power converter continuously vacuum pumped. This six-tube power converter acts as a single three-phase wye-connected unit with two ignitron tubes connected in parallel through an anode balance coil to each phase of the wye. (Fig. 18).

The four three-phase windings of each generator are connected with respect to one another in the pattern shown in Figs. 16 and 19.[3] Such a pattern results in an over-all 12-phase operation because of the 30° displacement in the windings. Because of this 12-phase opera-

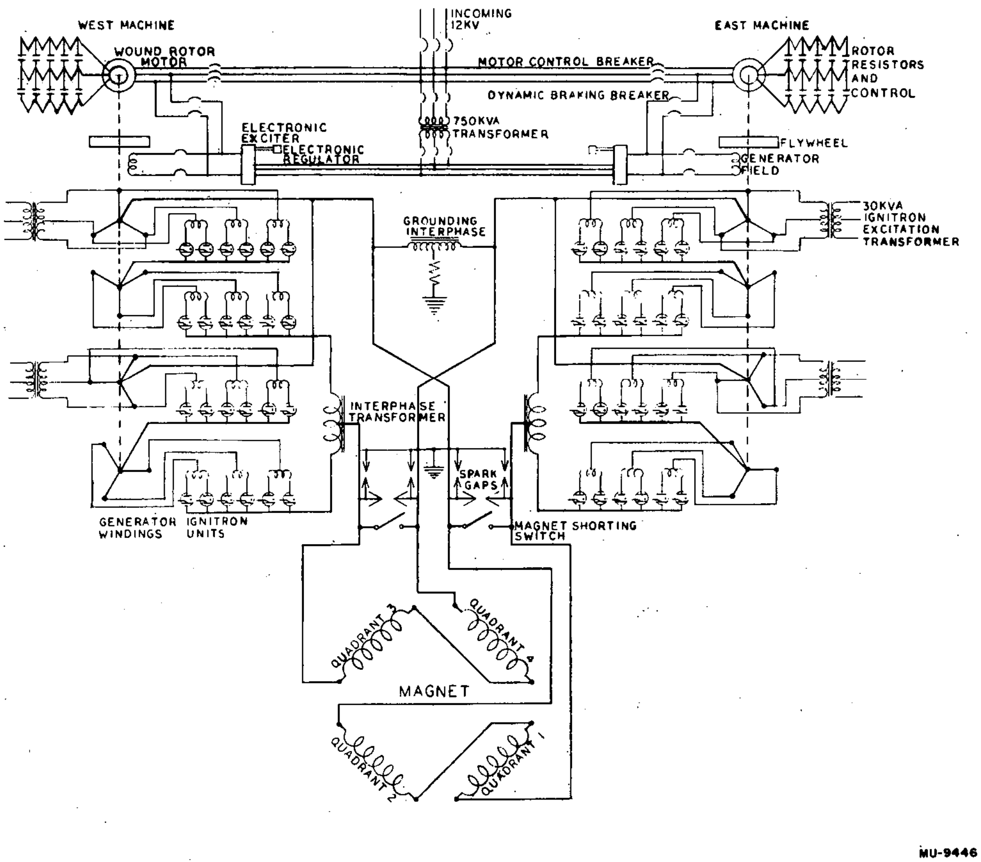

Fig. 16 Complete line diagram of Bevatron power supply.

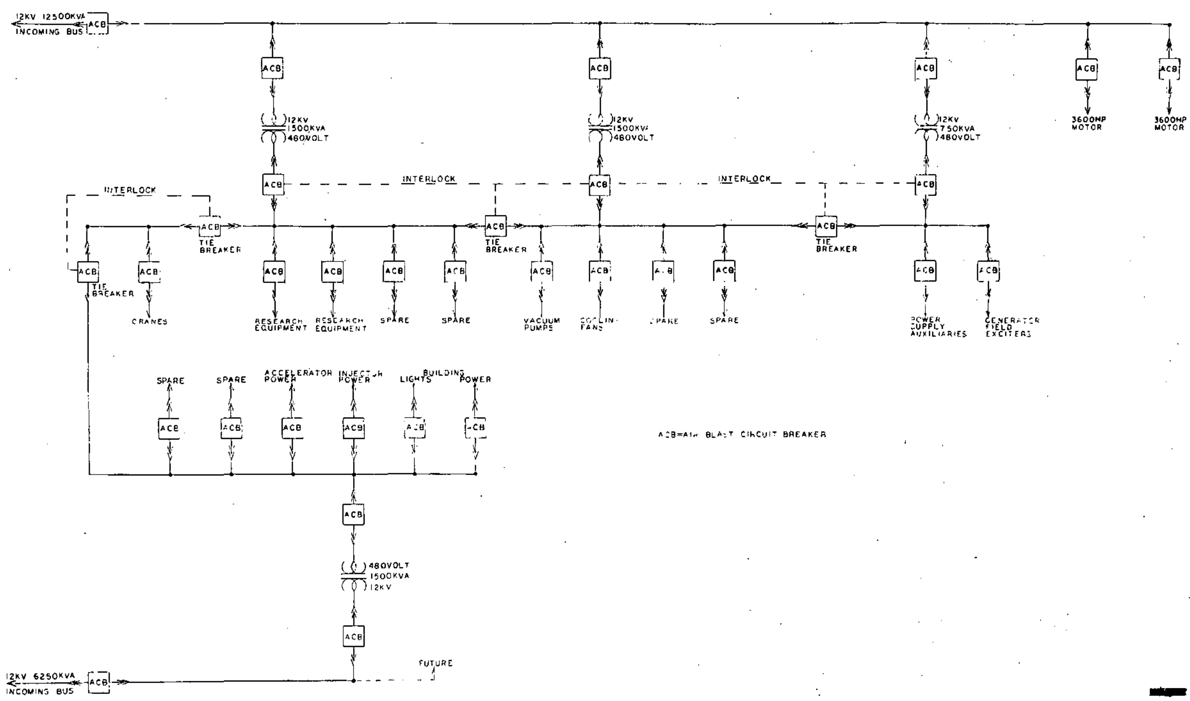

Fig. 17 One-line diagram of the electrical distribution system for the Bevatron.

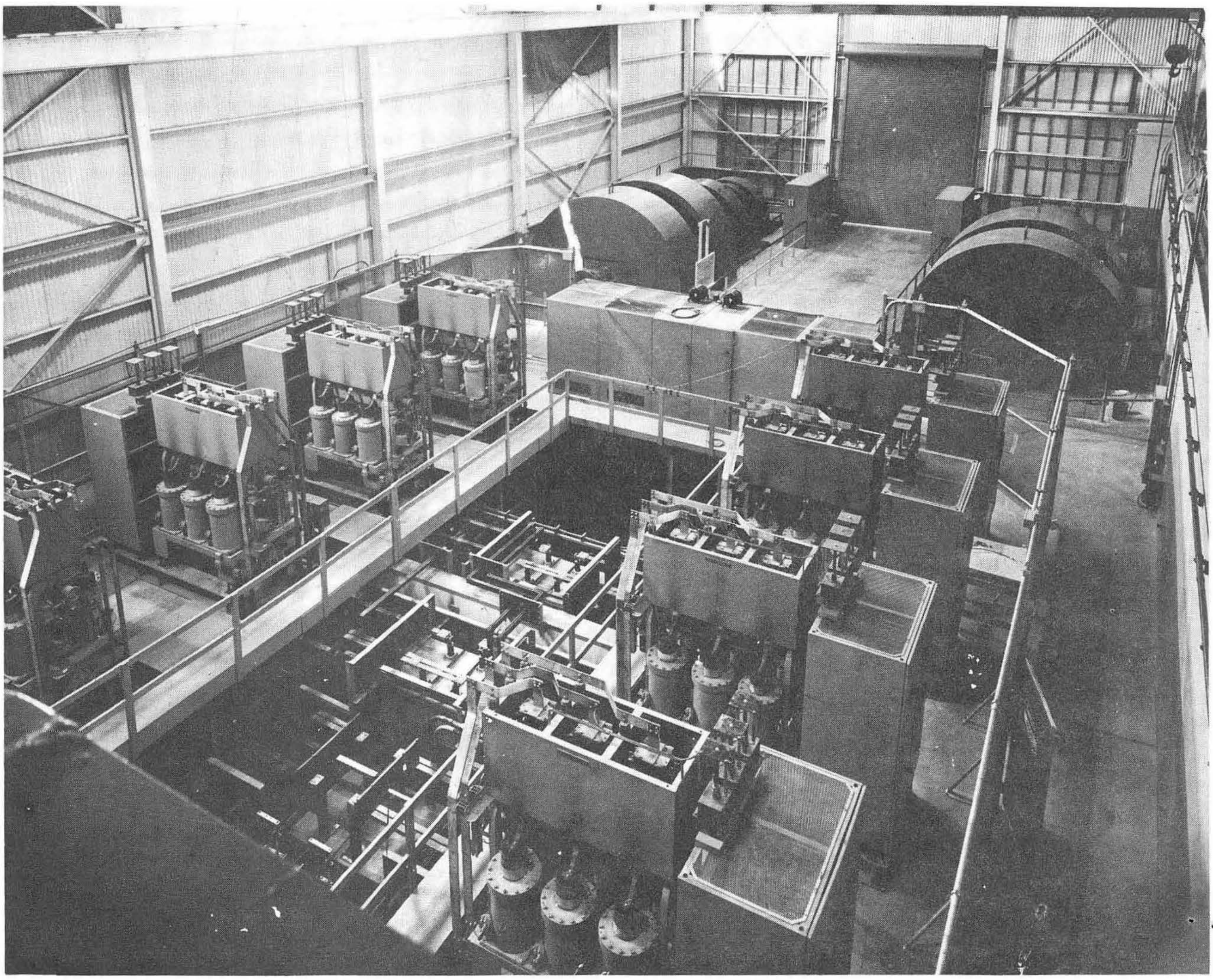

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Fig. 18 Looking down on ignitron units. Bare bus rises from ignitron pit to connect generator phases to ignitron anode balance coils located above ignitron tubes. High-voltage control cubicles are mounted on outboard end of ignitron units.

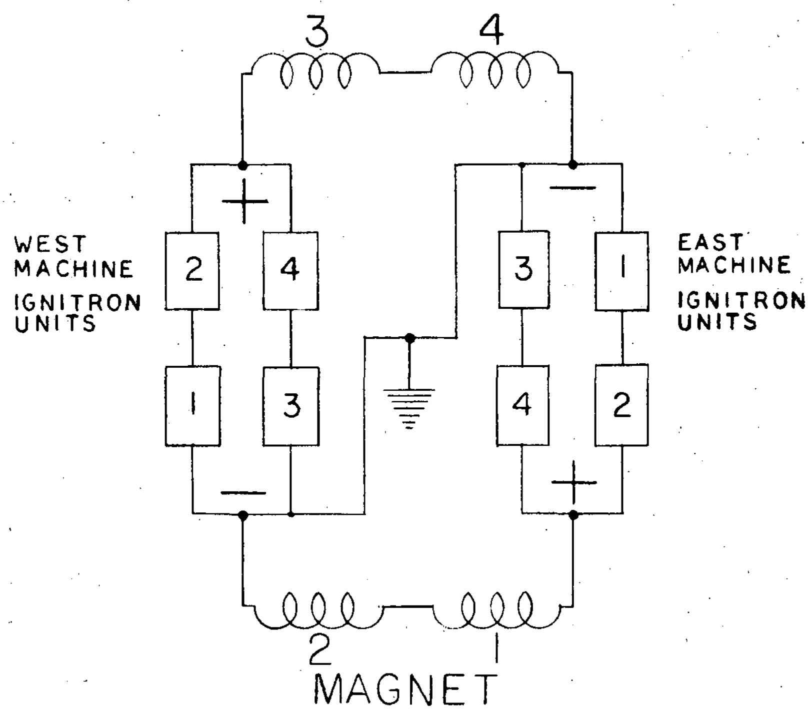

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Fig. 19 Block diagram of magnet power connections.

tion an interphase transformer is placed in the paralleling connection of each generator to aid in load-division stability and synchronization of ignitron loads. A third interphase transformer is connected between two halves of the magnet-coil connections to establish a ground point for the power supply.

The direct-current circuit of each of the ignitron power converter units is rated with a maximum of 4,500 volts to ground, and with two of these units in series the potential varies from plus 9,000 volts to minus 9,000 volts. As the total direct-current circuit is connected across the magnet coils, the total potential across the magnet is 18,000 volts at the beginning of each magnet pulse. The pulse is initiated by applying an external positive bias to the grid circuits of the ignitrons, causing them to act as rectifiers. The current builds up in the magnet as shown on Fig. 6 to a peak of 8,333 amperes. It is at the instant of peak current that the ignitrons are changed into inverter operation, permitting the energy now stored in the magnet to flow in a reverse direction into the motor-generator set and aid in restoring the no-load speed. At the beginning of the magnet pulse the motor-generator was running at approximately 97% synchronous speed. The 97% synchronous speed is acquired by having a set of permanent slip resistors in the rotor circuit of the 3,600-hp motors. With this speed the total inertia of the rotating parts of each motor-generator set is 1,819,000 lb-ft^2 and the stored energy is 251,000,000 foot-pounds.[3] For maximum peak current the stored energy given up by the motor-generator sets is approximately 90,000 kv sec, and at this time the rotation of the motor-generator set has been reduced to 91% of synchronous speed. During the decay time of the magnet pulse the stored energy in the magnet drives the generators, which act as motors, thereby increasing the speed of the motor-generator sets. The result of this action is to restore inertia to the motor-generator rotating components, therefore, because of the reverse cycle, the only energy consumed by pulsing the magnet from the incoming 12-kv line is for all the losses in the power-supply system. The quantity of pulsing energy taken from the incoming power line at any one instant, however, was limited by the serving utility company to a total of 3,000 kva or

1,500 kva per motor-generator set. The above limiting requirement was fulfilled by controlling the amount of resistance in the wound-rotor motor circuit, thereby limiting the quantity of current consumed by the 3,600-hp motor. Control of the resistance is achieved by a set of sequential cycling contactors, which are regulated by timing mechanisms. (Fig. 20.)

As shown on Fig. 20, the duration of the magnet pulse is approximately 3.75 seconds and the "off" time is 1.25 sec, giving a 75% duty cycle. The off time is to allow the motor to return the machine to 97% synchronous speed. At the instant this speed is attained, another pulse is started. The pulsing-control circuits have been designed to produce a variable pulse rate, varying from one random pulse to a maximum of approximately 12 pulses per minute.

In order to insure the above proper operation, it was necessary to build into the magnet power-supply system many emergency and protective mechanisms. These electromechanical appliances had to be of a critical self-supervising type capable of handling the large surging blocks of pulsing electrical energy and the powerful inertias of the motor-generators' rotating masses. The protective facilities are divided into two main groups, with the first group interacting with the second group in case of a hazardous emergency. The first group of these mechanisms reacts to create what is named a "partial shutdown". Any of a variety of minor fault occurrences, such as misfires, arc-throughs, or arc-back in the ignitron units will produce this shutdown. These faults energize control relays so they will trip the magnet short-circuiting switch, open the generator field-excitation circuit breaker, and short-circuit the firing elements of the ignitron units. The above three events comprise the partial shutdown. The magnet short-circuiting switch places a direct short circuit on the magnet coils, thus compelling the stored energy to be dissipated as heat in the magnet. This heat is carried off by the forced air cooling of the magnet coils. Injurious transient conditions may develop in the magnet when short circuiting occurs. To limit and dissipate these potential surges, spark gaps and resistor-capacitor damping circuits to ground were included in conjunction with the short-circuiting switch. The generator-field

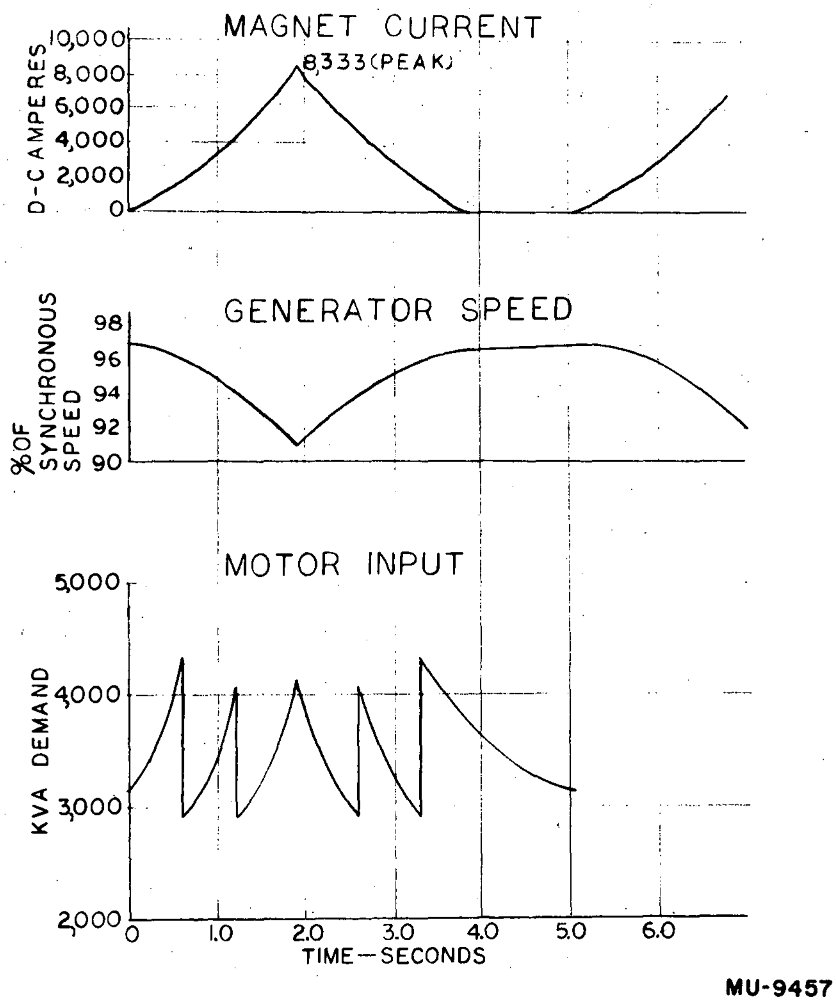

Fig. 20 Energy and speed curves

circuit breaker interrupts the generator-field circuit, thus reducing the phase voltage to zero, and relieves the ignitron power converters of their energy. A further device short-circuits the ignitron firing elements, thereby causing the ignitron conduction to cease.

The second group reacts to effect what is called a "complete shutdown." Emergency faults which produce this shutdown cause the motor-generator sets to be stopped by dynamic braking in addition to the events that occur with partial shutdown. Dynamic braking of the motor-generator sets is necessary because such huge energies are stored in the rotating masses that they would require several hours to coast to a stop. Such a long coasting period would greatly hamper operations and could--under certain conditions--destroy the pedestal bearings of the machine. Dynamic braking is applied automatically by control relays activated by any of several different emergency events, for example, a hot bearing of a motor-generator set. The sequential events involved in dynamic braking are as follows: the 12-kv motor circuit breakers are opened and the dynamic braking circuit breakers close, allowing the direct-current voltage of the generator field exciters to be impressed across two of the phases of the stators of the 3,600-hp motors, thus electrically blocking the motor rotors. All the energy stored in the rotating parts of the motor-generator sets will then be dissipated in the rotor resistors of the wound-rotor motors as heat. (See Fig. 16).

B. Electrical Installation

Although many of the electrical equipment components that make up the Bevatron power supply were physically installed and wiring connections were accomplished concurrently, the following explanation of the electrical installation is presented from the viewpoint of the electrical energy flow from the 12-kv incoming supply to the magnet-coil terminals. One portion of this work that is only mentioned here is the tremendous quantity of control wiring and electric-power cabling that was required to complete this installation. (See Fig. 21.) Numerous drawings and wiring diagrams were prepared for the contract drawings to illustrate all these electrical connections.

The generator room of the Bevatron Building, where the entire electrical installation was executed, contained three floor levels. The highest floor level was built to hold the 12-kv switchgear and the 480-volt switchgear. The middle floor level has the same elevation as the magnet room and is called the main Bevatron floor level. On this elevation were placed the flywheel-motor-generator sets, the control cubicles, the ignitron units, and a room under the switchgear used for a wiring vault and also housing the generator field exciters. The lower floor elevation was divided into two areas, the generator basement and the ignitron pit. On this elevation were placed the insulated bus array, the interphase transformers, the magnet short-circuiting switch, the spark gaps of the generator cooling fans, the machine-oil lubrication reservoir circulating pump, and the motor-rotor grid resistors, (Fig. 22).

The incoming 12-kv power lines are terminated in a line of 12-kv switchgear to produce a total bus capacity of 18,750 kva. This switchgear serves as the high-voltage distribution equipment. The switchgear is composed of three-phase, three-pole air-blast circuit breakers of the 15-kv class with an interrupting capacity of 500,000 kva. The distribution is as shown on Fig. 17. Two of the air circuit breakers served as the motor-starting controlling contactors for the 3,600-hp motors. It is on the two 12-kv feeders that the pulsing and starting current peaks are limited to a definite level by controlling the quantity of rotor resistance. The rotor control cubicles are placed on the main floor level adjacent to each motor, and they contain timing contactors which short out sections of the rotor resistance according to a definite time sequence. During the motor-starting cycle all these contactors are used, and during the magnet-pulsing cycle only three of the contactors are used if the pulsing rate is maximum at maximum magnet current. These timing controls must be altered within specified limits for different pulsing rates and for different values of magnet peak current. Another control imposed by these contactors is during the dynamic-braking cycle, when all the rotor resistance must be used to dissipate, as heat, the stored energy of the machine. To simplify the electrical connections between this control cubicle, the motor rotor, and the grid resistors, the resistors were assembled and mounted directly below the rotor control cubicle on the generator basement

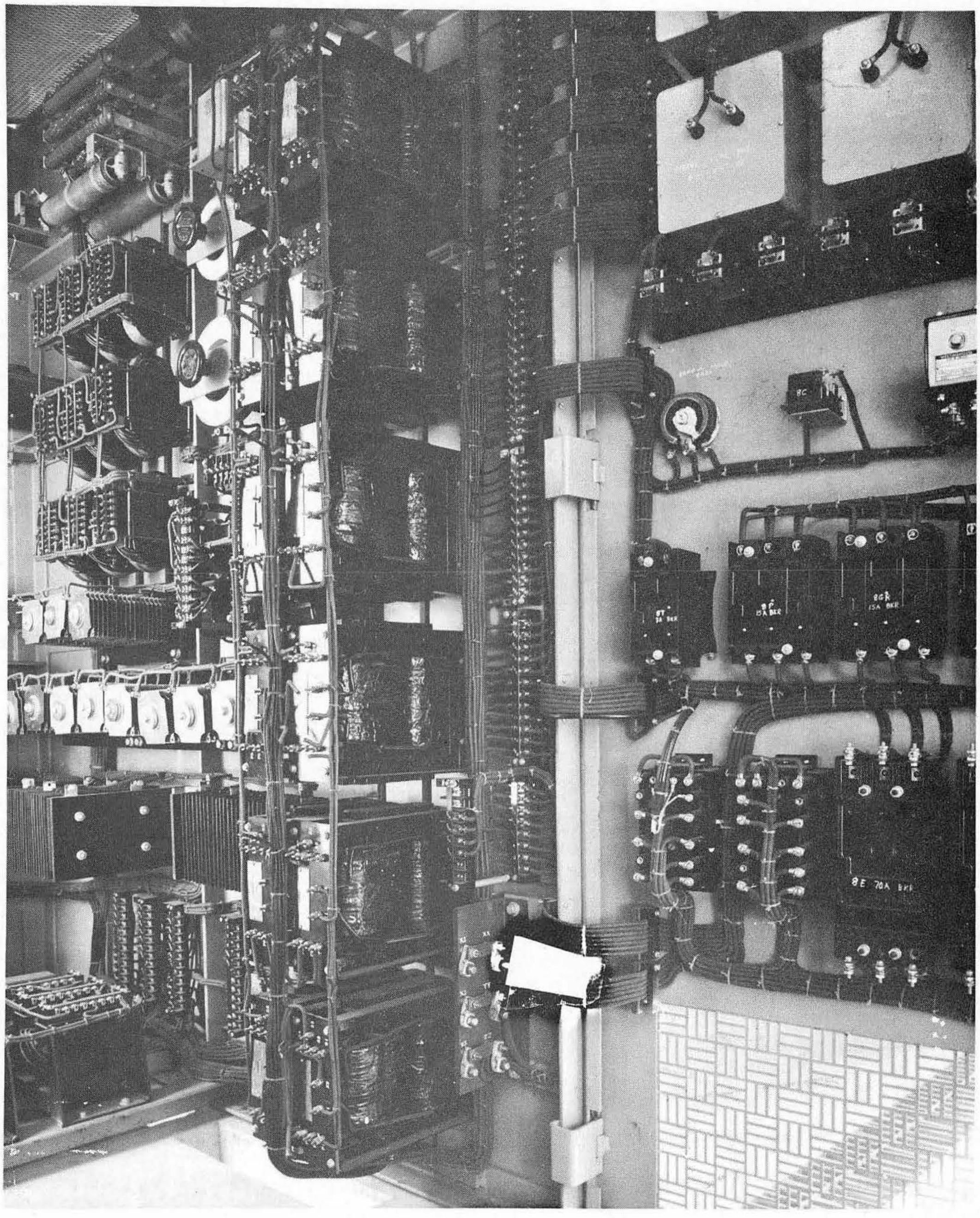

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Fig. 21. Single ignitron low-voltage control cubicle, showing type and quantity of control wiring.

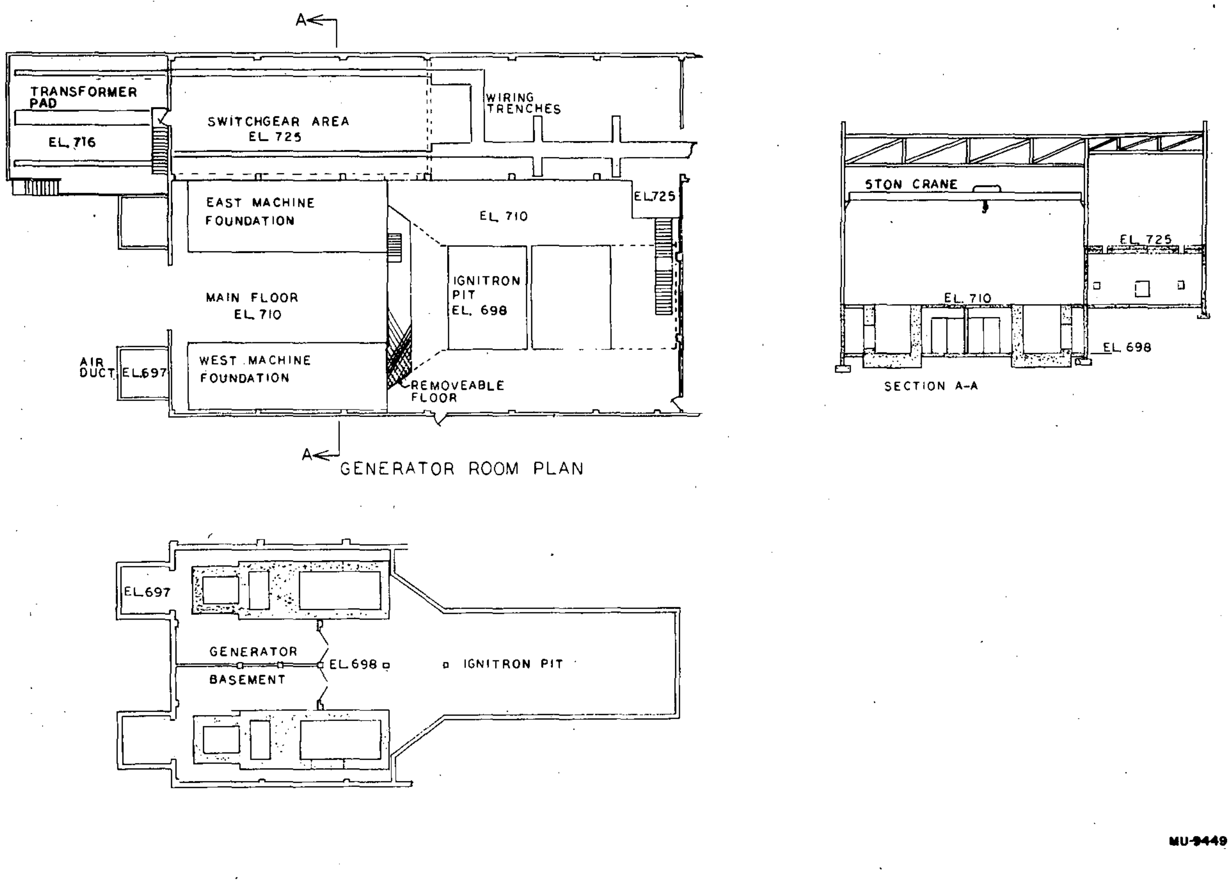

Fig. 22 Floor plan and section of generator room, showing locations and elevations of different floors.

floor adjacent to the motor end of the machine foundation. With the resistors placed in this location all the heat generated during dynamic braking is carried to the outside by the cooling-air exhaust from the generator ventilating fans (Fig. 23).

Next to each of the 12-kv motor controllers is placed a cubicle which contains the dynamic-braking controlling contactor. This is a 2-pole air-blast circuit breaker of the 15-kv class. When the main motor controller opens, this contactor closes, placing the 250-volt direct current of the generator field exciter across two-phases of the motor stator, thus starting the dynamic-braking cycle. The final piece of equipment in the 12-kv switchgear is an indoor air-cooled 750-kva transformer, whose secondary potential of 480 volts supplies energy to all the magnet power supply auxiliaries, such as the oil lubricating systems of the two machines, the generator-cooling fans, the generator field exciters, the ignitron components, and the charging rectifier for the emergency-station battery.

Except for the two 3,600 -hp motors all the electrical power for the entire Bevatron building, the magnet power supply, and the accelerator auxiliaries is distributed at 480 volts. This low voltage was selected because the ease of handling it resulted in the most flexible and practical power-distribution system. The 480-volt distribution network is controlled by a line of 480-volt switchgear (see Fig. 24). The feeding buses of this switchgear were arranged to give the most flexible type of distribution network. Circuit breakers were placed between the feeding buses to act as ties to connect the different sectional buses together, so that any one of the 1,500-kva transformers could feed 480-volt power into all or any one of the sections of the switchgear (Figs. 16, 25).

All the 12-kv and 480-volt switchgear has a control and operating direct-current potential of 125 volts that is supplied direct-current energy from a station battery located in the subswitchgear room. The station battery is equipped with a continuously floating rectifier charger to keep it fully charged. This equipment insures an emergency power supply, for all the opening and closing mechanisms of the switchgear would be ready to operate in case of a complete power failure. Connected also to this supply are the controlling and operating relays of the magnet short-circulating switch and the generator-field circuit breaker, so

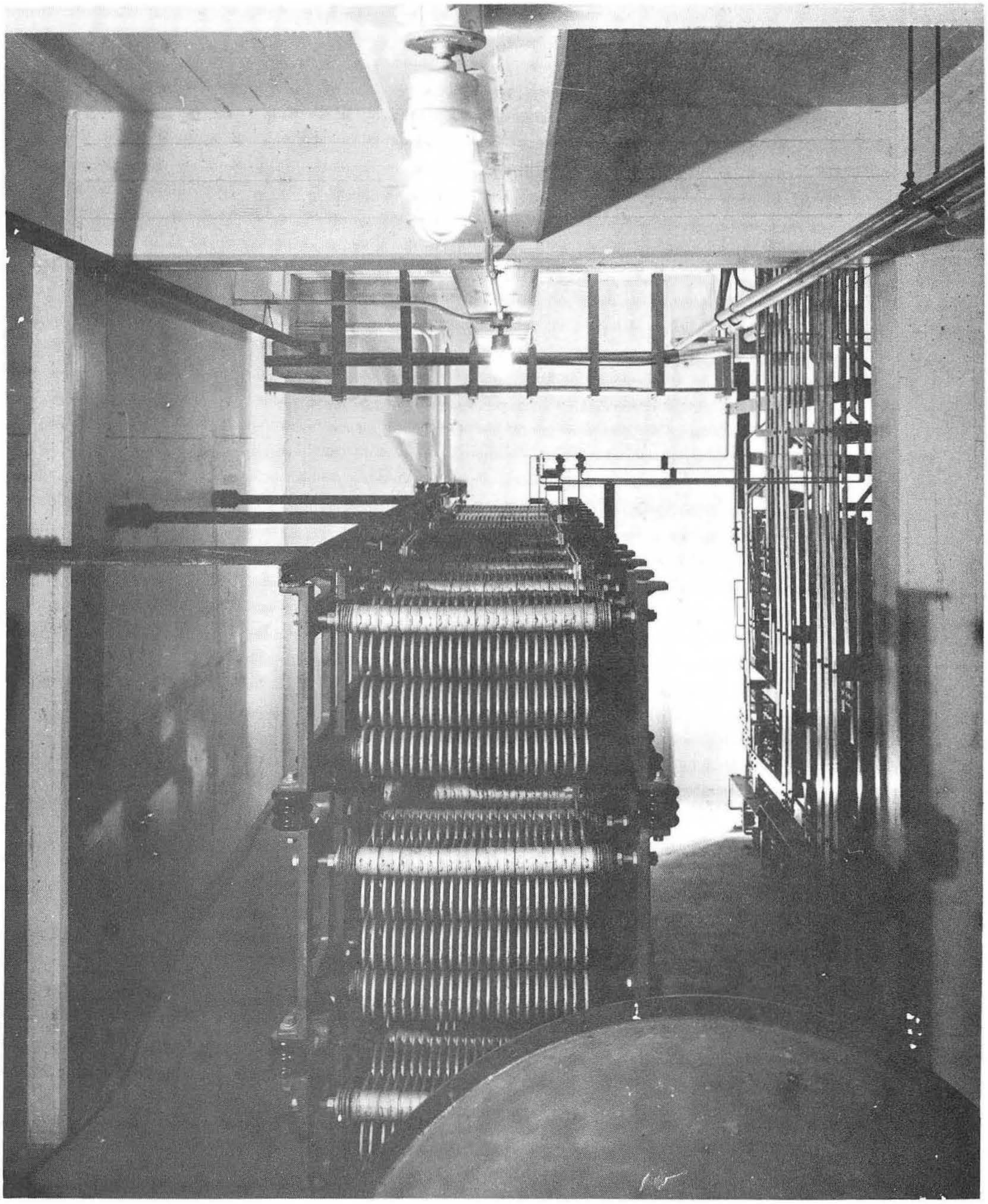

Fig. 23 Looking from generator end toward outside air-exhaust duct along the side at east machine foundation, showing the rotor grid resistors. End manifold of one of the generator exhaust ventilating fans is at bottom right. Note all the bare bus-bar electrical connections that rise vertically to the control cubicle. Resistors had to be mounted on insulators and all the bus bars were mounted on "ebony asbestos" insulating blocks.

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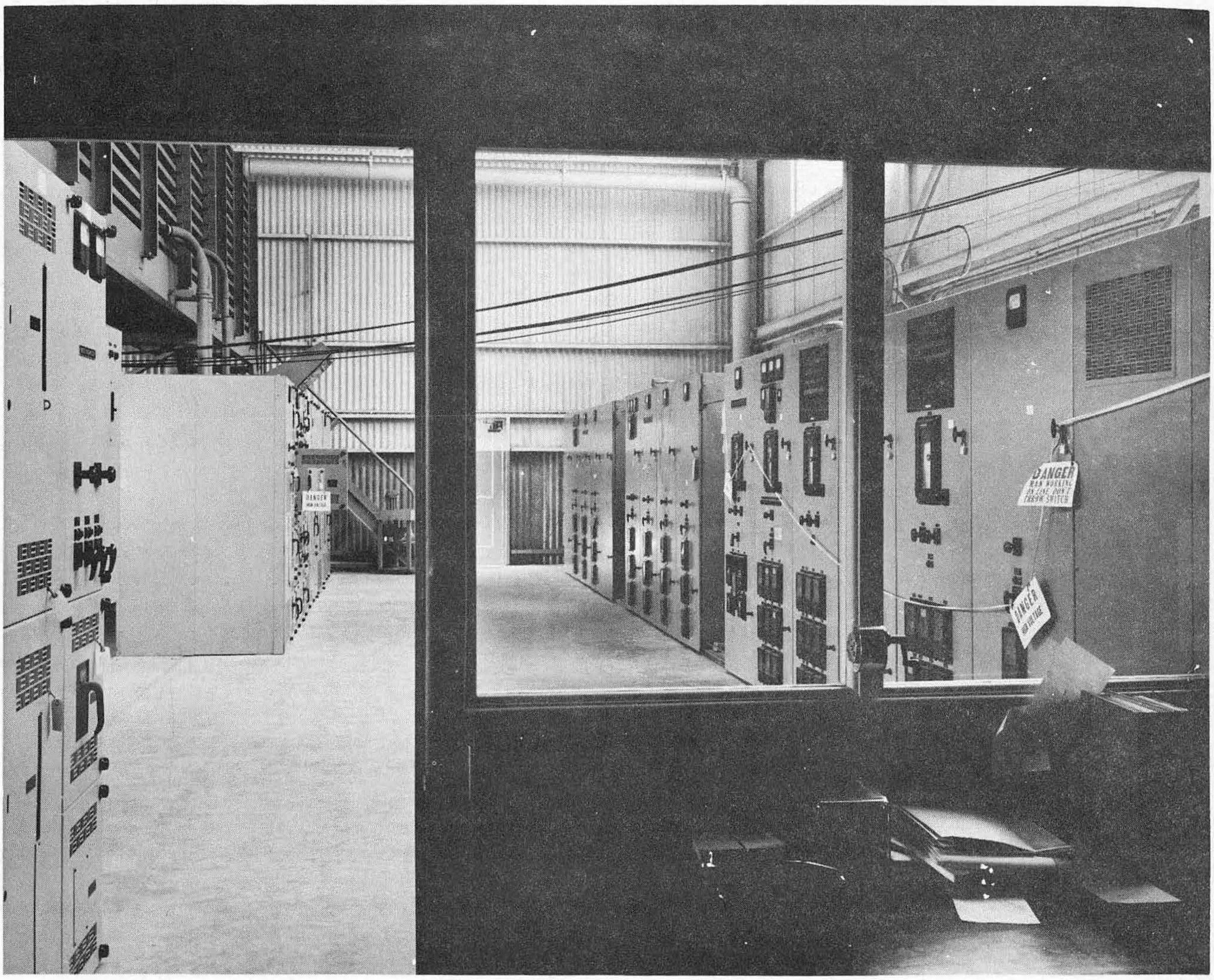

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Fig. 24 View on switchgear level looking toward the transformer yard. On left is the 480-volt switchgear and on the right is the 12-kv switchgear. Note the 750-kva transformer at right-hand edge and its associated 480-volt switchgear on left-hand edge.

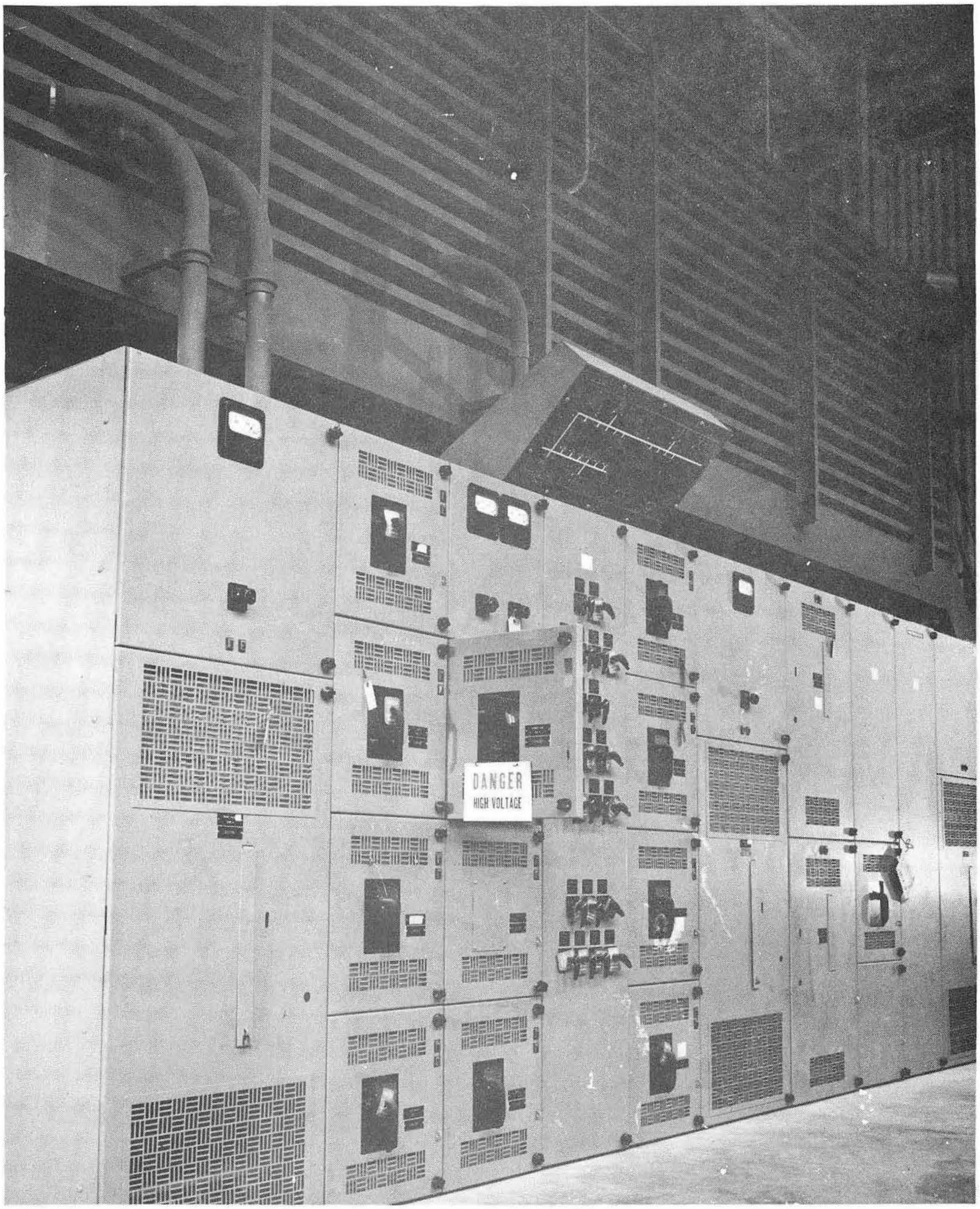

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Fig. 25 Two sections of 480-volt switchgear. Note central control panel for all circuit breakers. Above control panel is a map with colored lights to give an indication of open or closed position for each circuit breaker.

they will act in the event of an emergency.

The next equipment along the line of energy flow is the generator, with its accompanying control cubicles and the field electronic exciter. The electronic exciter is of a mercury-arc type rated at 900 amperes at 225 volts direct current. The direct-current energy is obtained from six vacuum-sealed, water-cooled ignitrons which are energized from a 480-volt double-wye-winding transformer. The output voltage of the field exciter is controlled by an electronic voltage regulator located in the generator control cubicle (Fig. 26). This regulator produces field forcing during the magnet-pulsing cycle, and insures the proper output voltage of the four three-phase windings at the starting of each pulse. The energy from the field exciter is cabled to the generator field via a high-speed circuit breaker, also located in the control cubicle. This circuit breaker is rated for one-cycle operation on a 60-cycle basis, and this fast rating is necessary so the breaker can be used as an emergency protective device in the event of partial or complete shutdowns. The remaining equipment in the generator-control cubicle includes all the controlling relays for the generator performance, the controlling contactors for the generator ventilating system, and the machine oil lubrication system.

The output of the four three-phase generator windings is connected to the four ignitron power converters by means of a high-voltage insulated copper bus structure (Fig. 27). The terminals of the four three-phase windings are located underneath the generator, so the bus structure runs from this point through the entire ignitron pit area, making all the power connections and terminating at the magnet-coil feeder cables (Fig. 28). This bus array carries both the generator power-output circuits and the direct-current magnet-power circuit. Certain sections of the bus structure run vertically upward to connect to the ignitron units, which are cantilevered on structural steel beams a short distance out over the ignitron pit to make this a simple connection, (Fig. 29). The ignitron units are mounted on insulators, as the power converters float 4,500 volts direct current above ground. Associated with and mounted adjacent to each ignitron unit is a high-voltage control cubicle, and associated with each of two ignitron units is a low-voltage control cubicle (Fig. 30). The high-voltage cubicles contain isolating

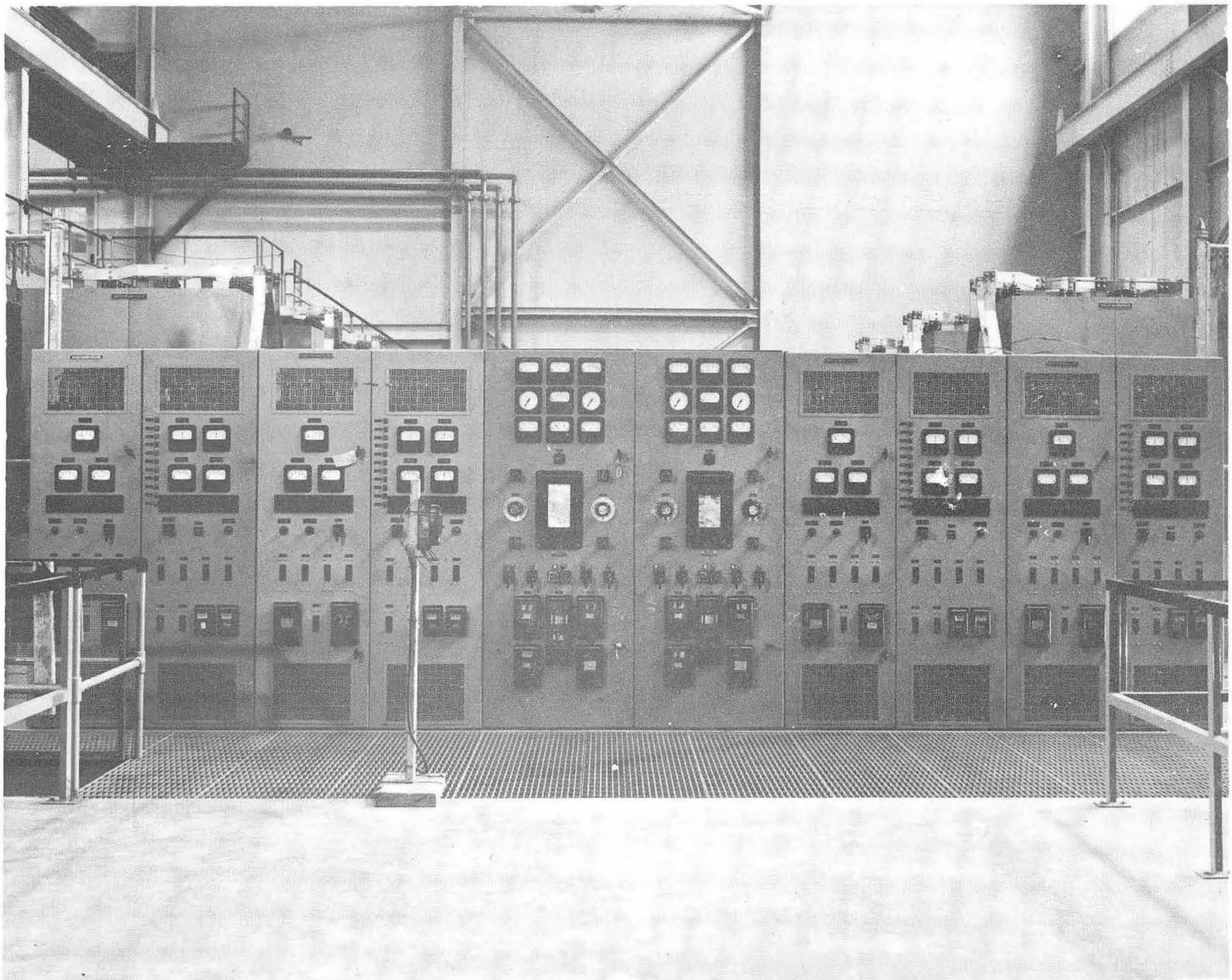

Fig. 26 View on main generator room floor looking at the two generator control cubicles and the four low-voltage ignitron control cubicles. The two generator cubicles are located in the middle. Note the control relays and meters for the generator performance, mounted in the door; also, in the center of the cubicle door, the electronic voltage regulator with its adjusting mechanisms at each side.

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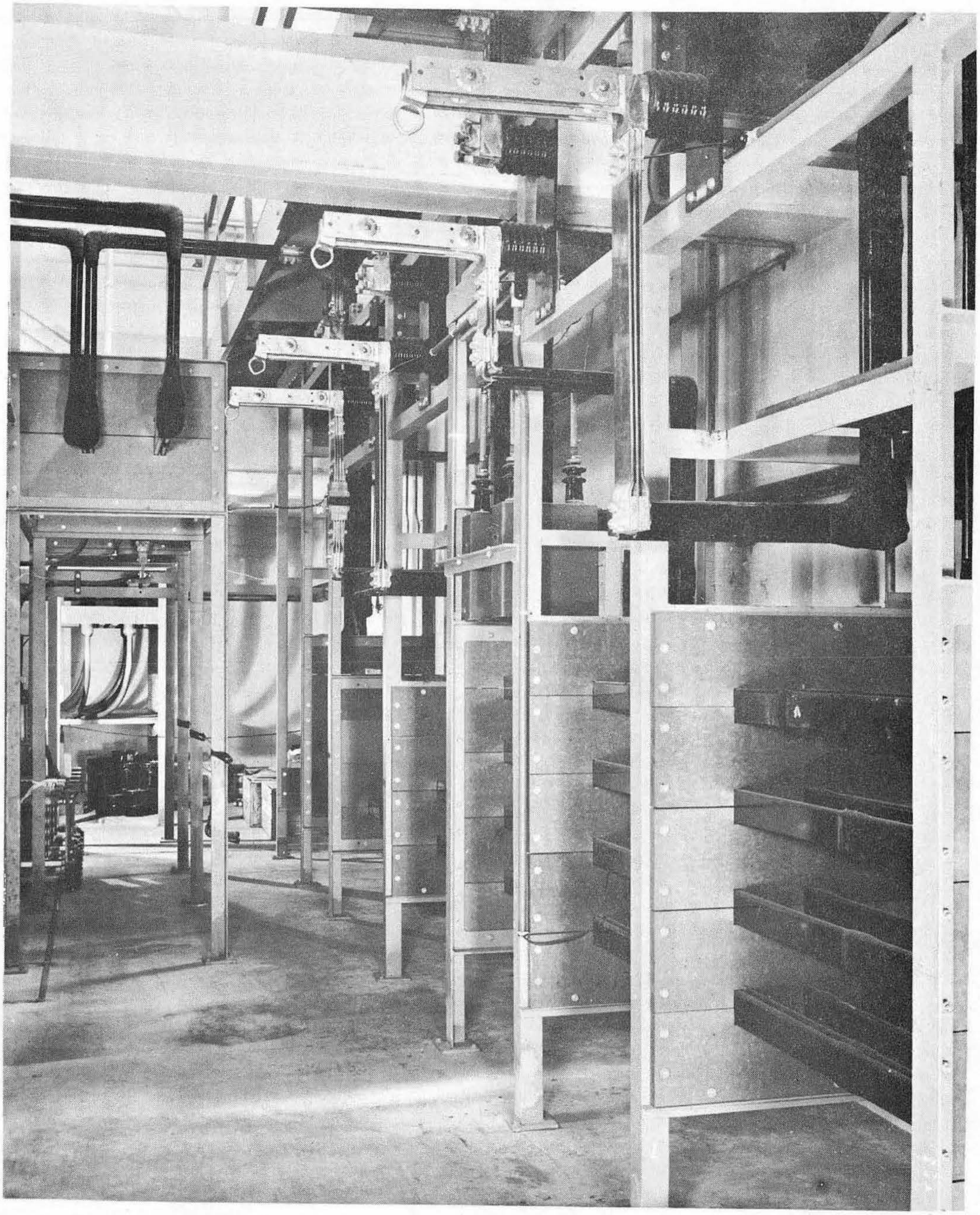

Fig. 27 Looking from generator area through ignitron pit toward the magnet feeder cable terminals. On right are bus feeders from the west generator windings. The disconnect switches are placed in the neutral circuit so as to isolate any one of the ignitron units. At top left are the connections over to the interphase transformers, and at the back middle left one can see the magnet feeder cables.

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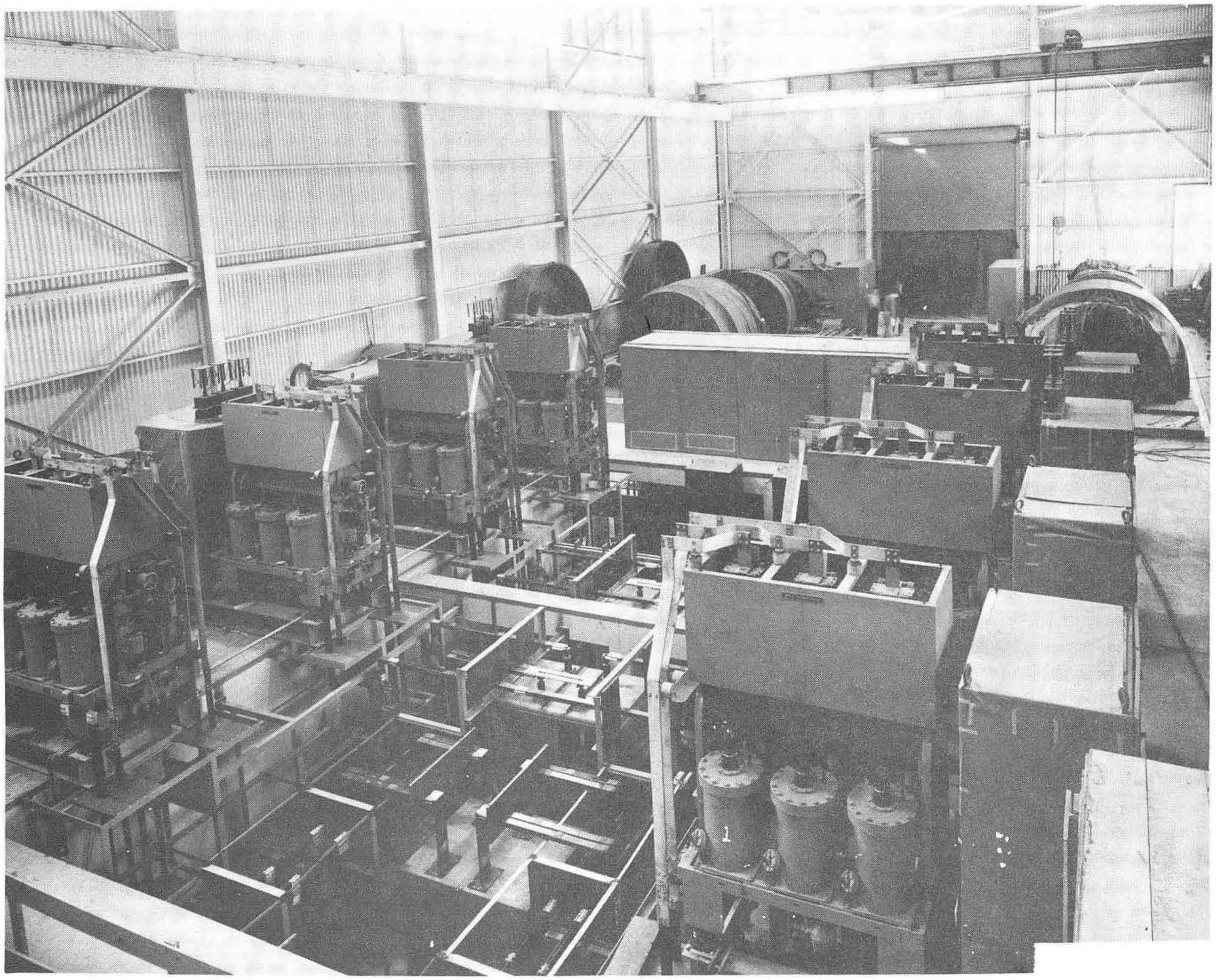

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Fig. 28 Looking down on ignitron units and into ignitron pit. Note how bus structure connects all the electrical equipment together by vertical risers to the ignitron units and horizontal runners in the pit to the interphase transformers and the short-circuiting switch.

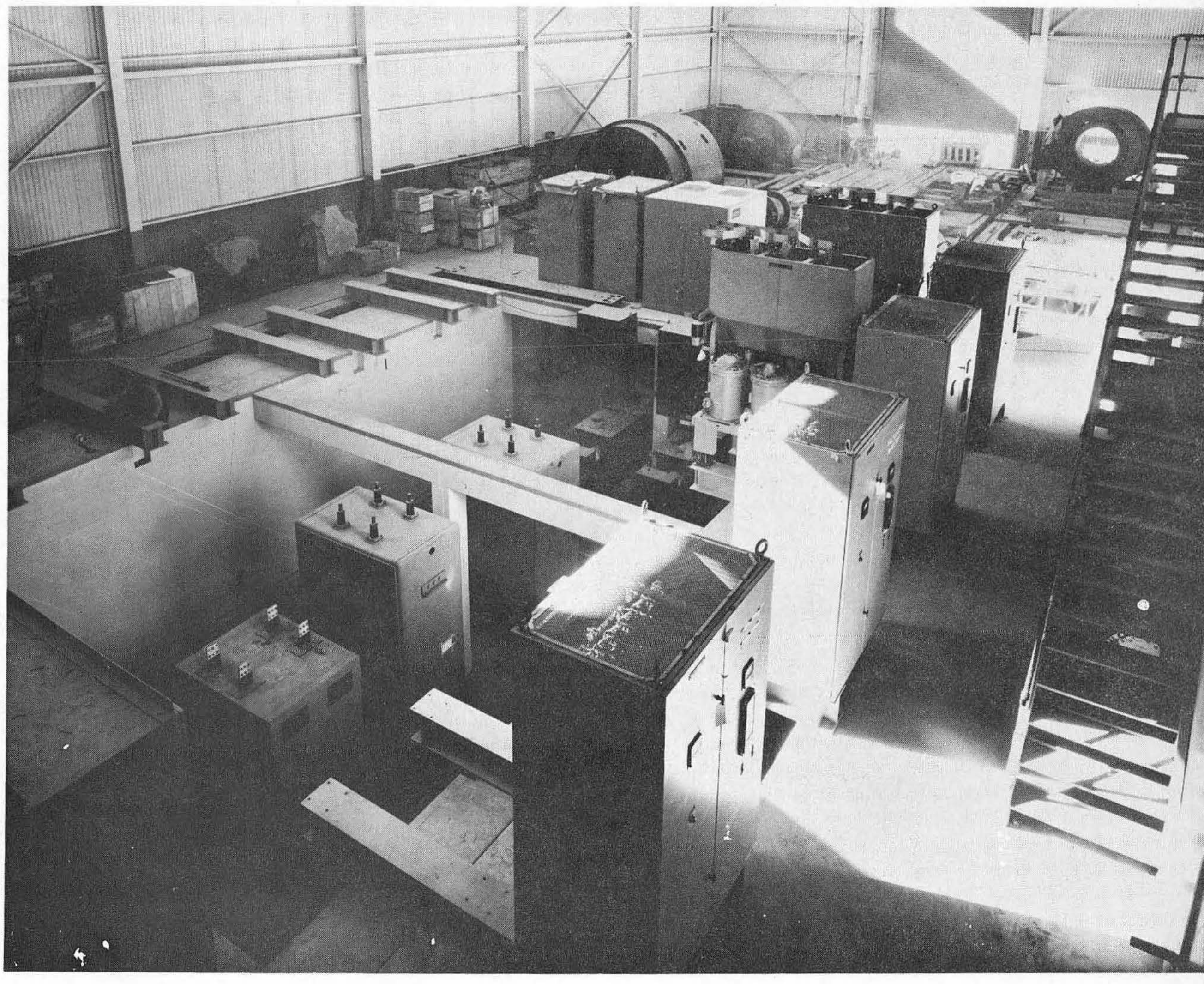

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Fig. 29 Looking down into ignitron pit, showing ignitron unit mounting beams with high-voltage control cubicles in place on the right. In the ignitron pit, from left to right, are short circuiting switch; two interphase transformers, and ignitron excitation transformers with motor-operated disconnect switches mounted above.

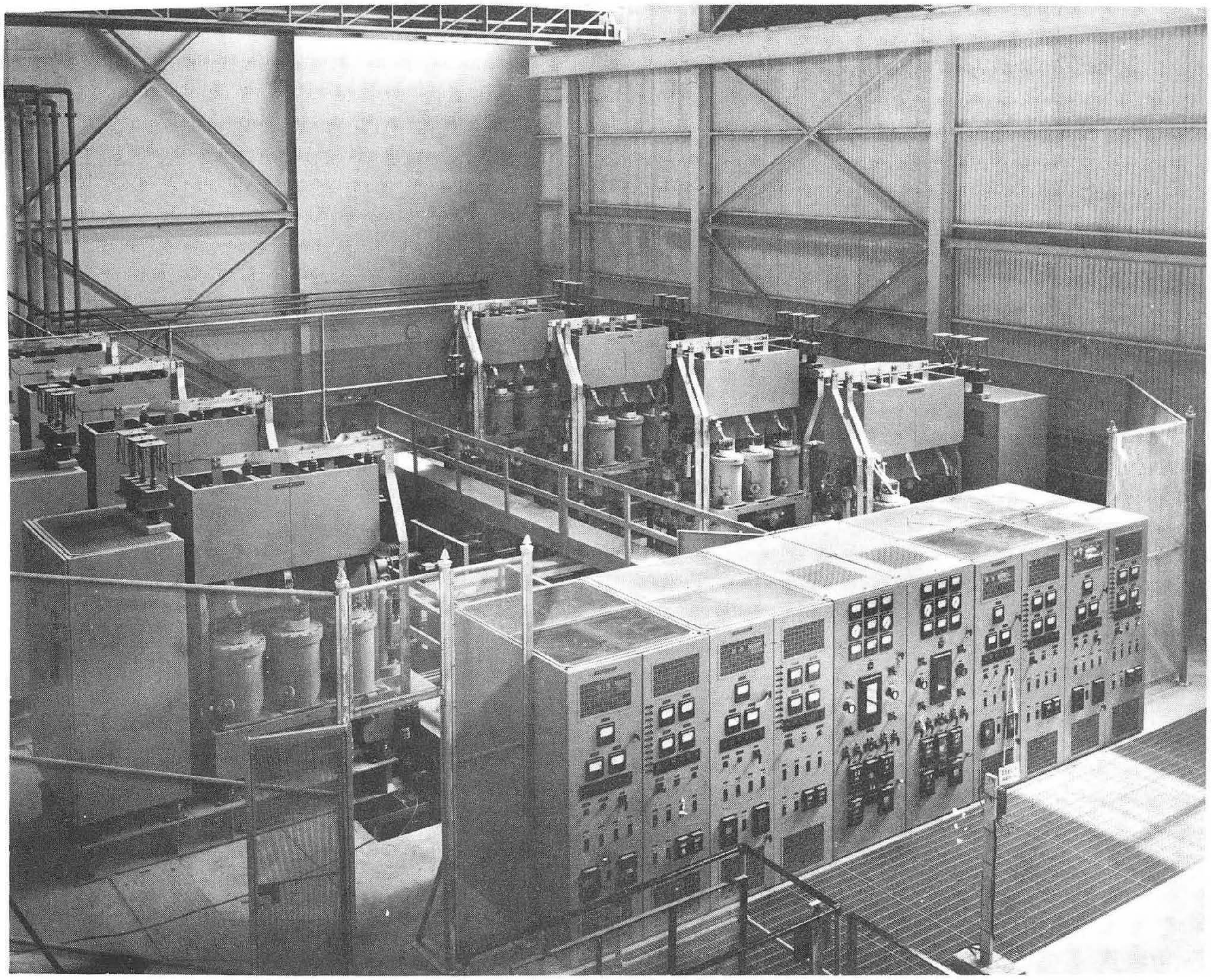

Fig. 30 Looking down on ignitron area, showing relationship of high-voltage and low-voltage control cubicles.

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transformers and control actuating circuits for the power converters and their auxiliaries, such as the vacuum pumps and the cooling-water circulating pump. All these circuits are in turn fed from the low-voltage cubicles, making it possible to make adjustments for proper performance and to maintain these circuits when the high voltage is on the ignitron units. The control and actuating circuits are energized by four 30-kva excitation transformers, one for each low-voltage control cubicle. These transformers are fed from two of the four 3-phase windings of the synchronous generator (Fig. 16). In the primary side of each of the excitation transformers is placed a motor-operated disconnect, so that any two of the ignitron units can be de-energized.

The direct-current circuit of the bus structure ties together the remaining electrical components of the power supply, namely, two large interphase transformers, a small grounding interphase transformer (Fig. 31), the magnet short-circuiting switch, the surge-protective spark gaps with their current-limiting resistor and capacitor damping circuits, and lastly, the terminals for the magnet-coil power cable feeders. Of this equipment certainly the most remarkable is the short-circuiting switch. This huge switch is rated to operate within three cycles on a 60-cycle basis, and must be able to effect a short circuit on the magnet at maximum peak stored energy. This peak quantity of stored energy is 80 megajoules. The two large copper knives that make up the switch are opened by means of a pneumatic cylinder, and, on opening, these blades are latched against a powerful mechanical steel spring, placing this spring in compression. When the switch is tripped by the control relays the spring drives the knives downward into their contacts. The contacts are connected via the bus structure across the magnet-power feeder cables.

Placed on the end of the insulated bus structure are rows of potheads and into these potheads connect the magnet-power feeder cables, (Fig. 32). These cables, of 1,250,000 circular mils, are lead-covered, paper-insulated, and rated for 23-kv service. These cables run through an underground duct network which connects the four quadrants of the magnet to the direct-current power bus. The installation of these power cables was determined to be the most economical method of distributing the large blocks of pulsating power. The cables are air-cooled,

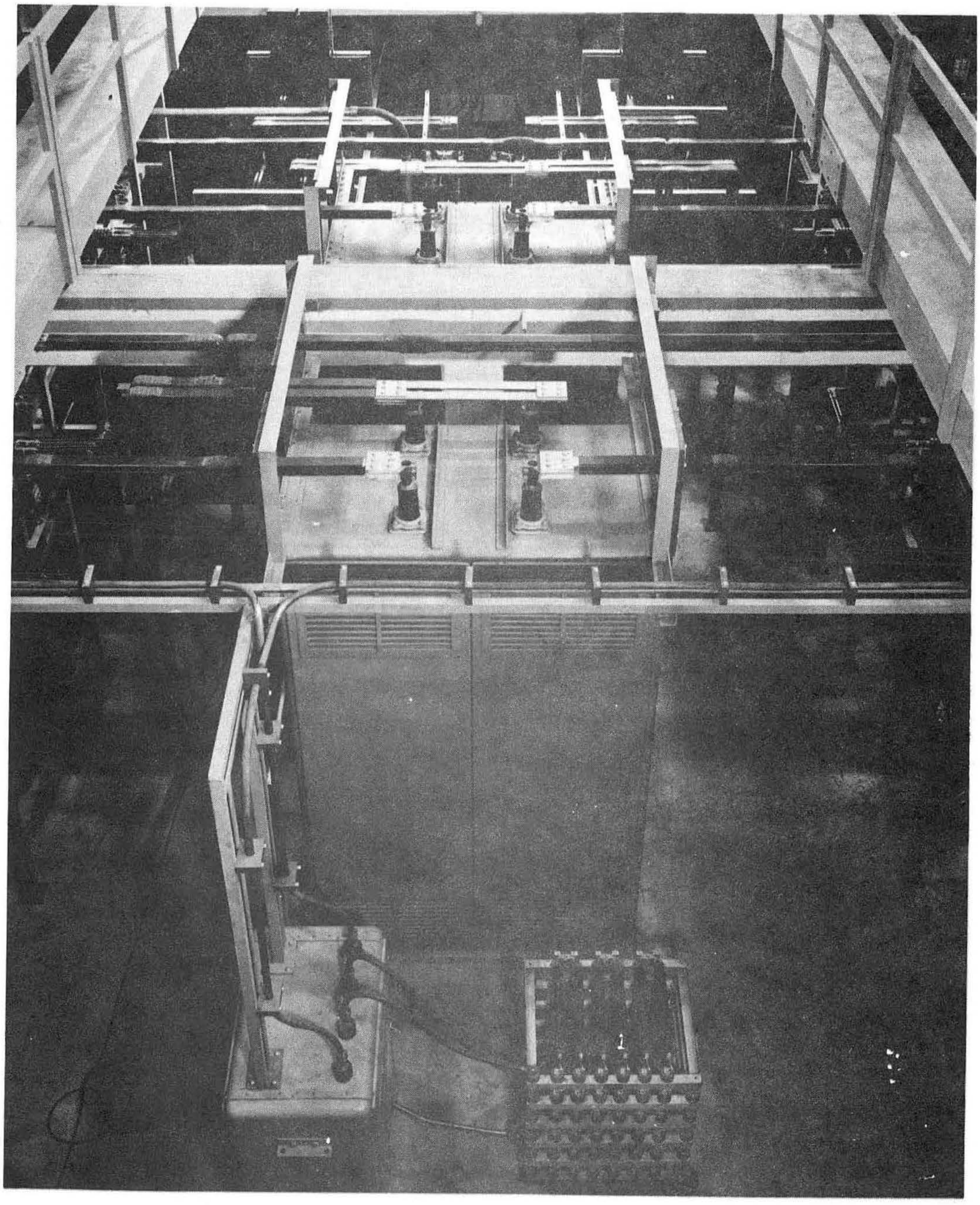

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Fig. 31 Looking down into ignitron pit on the interphase transformers. At bottom is the grounding interphase transformer with the ground current-limiting resistors to the left.

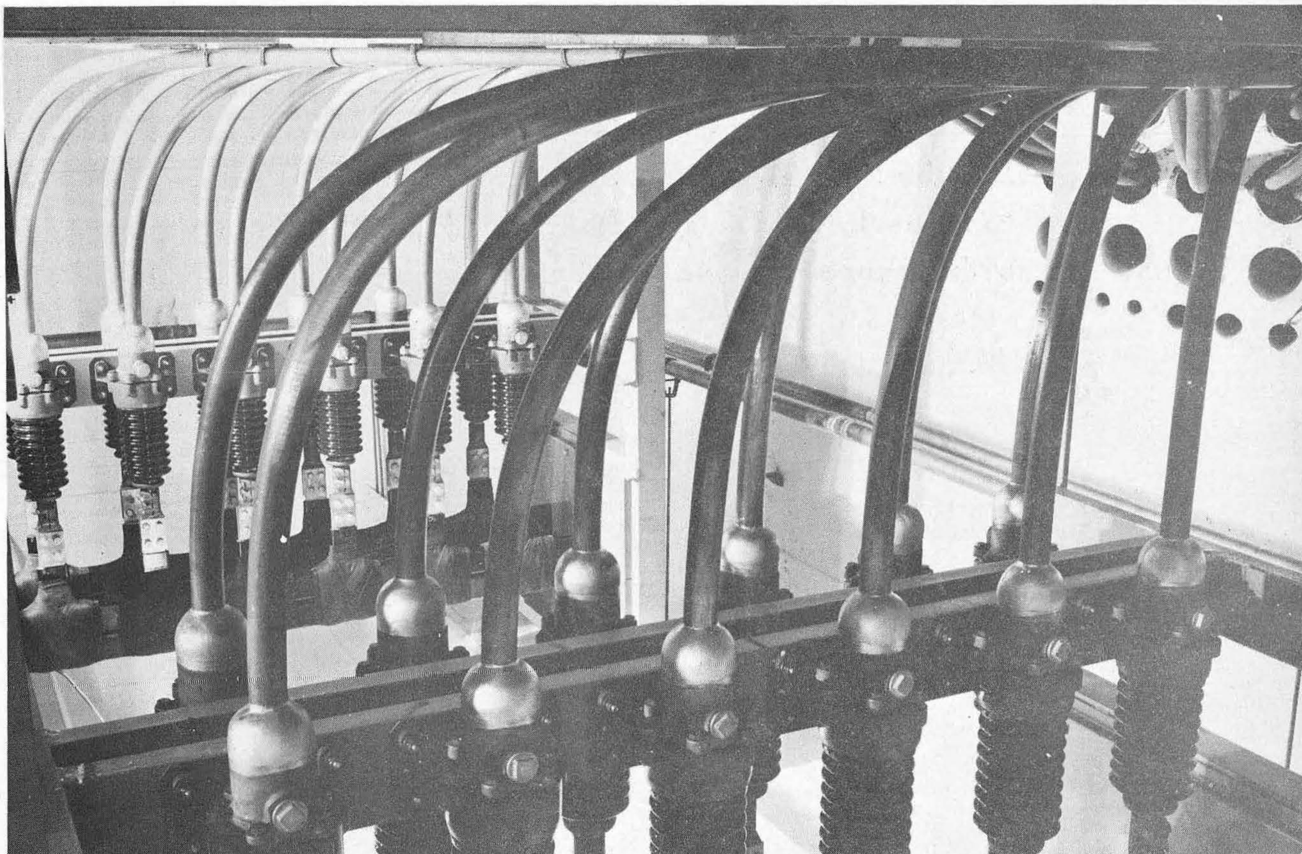

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Fig. 32 Magnet power cable feeders terminating into the bus structure. Note underground duct network in background.

and receive their cooling air from the ventilating fans of the magnet.

The final procedure in the installation of the magnet power supply was the testing and adjustment period. All the myriads of control, protective, and power electrical circuits had to be carefully tested and traced through for any inaccuracies. An example of this was the setting of the sequential timing mechanisms of the relays, which control the 3,600-hp motor-rotor resistor contactors. Each flywheel-motor-generator set had to be completely dried out by an artificial means because of the high voltagesinvolved. For the ignitron power converter units, each unit had to be properly degassed to insure that sufficient vacuum could be maintained in the tubes. This operation was done by means of a portable degassing transformer, which placed an artificial load on the ignitron tubes and caused them to outgas. The last test to be performed was to determine if all the protective devices could accurately supervise any fault that may occur and, also, if these devices would transmit the correct intelligence so as to give the correct alarm signal to the operators.

It was a great thrill the first time the proper control switch was turned and the unusual flywheel-motor-generator sets sprang into motion.

ACKNOWLEDGMENTS

The author wishes to express his deepest appreciation to the various research groups and the Engineering Departments of the University of California Radiation Laboratory for the aid and teachings that made it possible to prepare this document.

This work was done under the auspices of the U.S. Atomic Energy Commission

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Appendix I

SPECIFICATIONS

FOR

INSTALLATION OF TWO FLYWHEEL MOTOR GENERATOR SETS

OF THE

BEVATRON POWER SUPPLY EQUIPMENT

UNIVERSITY OF CALIFORNIA

Berkeley, California

Radiation Laboratory

April 1950

INSTALLATION OF TWO FLYWHEEL MOTOR GENERATOR SETS

SECTION I

GENERAL REQUIREMENTS

1. LOCATION

The work is to be performed in the Bevatron Building located in the Wilson tract north of the 184-inch Cyclotron on the Berkeley Campus, University of California, Berkeley, California.

2. LIMITS OF WORK

The Subcontractor shall confine his operations to the building and a portion of the building site as directed. Access to this site will be via the access road starting at the head of Hearst Avenue in Berkeley.

All materials for the erection operation shall be brought in and the work so conducted as to avoid any interference with others working on the site.

3. VISIT TO SITE

The bidder shall visit the site and completely inspect the entire premises of the construction area. The University will not allow any extras to the Subcontractor that arise from lack of knowledge of the conditions of the construction area.

4. PERMITS

The Subcontractor shall obtain all permits and licenses that are required for the performance and completion of the work under this subcontract.

5. CODES

The entire installation shall comply with the latest applicable orders of the Industrial Accident Commission of the State of California, the American Standards Association, and all other State and Federal rules and regulations applicable to this work. However, when the Specifications call for materials or construction of a better quality or a larger size than required by the aforementioned codes, the provisions of the Specifications shall govern the installation.

6. TITLES AND HEADINGS

Titles and headings to divisions and paragraphs in these documents are introduced merely for the convenience and shall not be taken as a part of the Specifications and, furthermore, shall not be taken as a correct or complete segregation of the service units of materials and labor. No responsibility, either expressed or implied, will be assumed by the University for omissions or duplications by the Subcontractor due to real or alleged error in arrangement of matters in the Subcontract documents.

7. INTERPRETATION OF TERMS

Certain common expressions hereinafter used shall be interpreted as having the following significances:

"Or equal": shall mean "or equal in the opinion of the Engineer."
"Approved": shall mean "approved in writing by the Engineer."
"If, when or as directed": shall mean "if, when or as directed by the Engineer."
"If, when or as required": shall mean "if, when or as required by the best building practice."
"A.S.T.M.": shall mean "American Society for Testing Materials."

In the General Conditions where reference is made to Architect or Architects, it shall be understood to mean Engineer or Engineers of the University of California, Radiation Laboratory.

8. JOB OFFICE

The Subcontractor shall provide and maintain on the premises, where directed, until completion of the installation, a temporary office. The structure shall be made watertight and shall be provided with locks.

9. TOILET FACILITIES

Toilet facilities on the job site are maintained by the General Construction Contractor. Arrangements may be made with the General Contractor for use of these facilities until such time as his work is completed; thereafter the Subcontractor shall provide a temporary house for toilet facilities in a location approved by the Engineer and shall connect it to utilities (water and sewer). The Subcontractor will be responsible for keeping these facilities clean and sanitary and shall maintain the equipment in a workable condition.

10. WATER AND POWER

Water and power services are available at the construction site and are billed to the General Construction Contractor for the Bevatron Building at the rates of fifteen (15) cents per hundred (100) cubic feet and two (2) cents per kilowatt hour, respectively. Arrangements may be made with the General Contractor for the use of these services.

11. TELEPHONE

The Subcontractor shall provide and maintain for the duration of the installation public telephone service in the temporary office.

12. TEMPORARY CONSTRUCTION

a. The Subcontractor shall provide, maintain and remove upon completion of work all temporary rigging, shoring, scaffolding, hoisting equipment, barricades around openings, and ladders between floors that are required for all work hereunder.

12. TEMPORARY CONSTRUCTION (Cont'd)

b. The temporary work shall conform to all requirements in regard to operation, safety and fire hazard of State and local authorities and underwriters. The Subcontractor shall furnish and complete all items necessary for such complete installation and for conformity with such requirements whether called for under the separate sections of the Specifications or not.

13. CLEANING

At completion of the work the Subcontractor shall remove all his tools, appliances, materials, debris and/or rubbish, from the building and the premises and shall sweep and clean the installation areas thoroughly.

14. USE OF CRANE

There will be installed in the building a five (5) ton electrically operated crane which may be used by the Subcontractor in aiding him in the erection of the two motor generator sets.

15. GUARANTEE

When required by the Specifications guarantees shall be in the form of the following Guarantee on the Subcontractor's own letterhead:

GUARANTEE FOR ______________________

We hereby guarantee that the ___________________________ which we have performed in the Bevatron Building, Building 51, University of California, Berkeley, California, has been done in accordance with the Drawings and Specifications and that the work as installed will fulfill the requirements of the guarantee included in the Specifications. We agree to repair or replace any or all of the work together with any other adjacent work which may be displaced by so doing, that may prove to be defective in its workmanship or material within a period of _______________ years from date of acceptance of the above-named structure by The Regents of the University of California, ordinary wear and tear and unusual abuse or neglect excepted.

In the event of our failure to comply with the above-mentioned conditions within sixty (60) days after being notified in writing by The Regents of the University of California, we, collectively or separately, do hereby authorize The Regents of the University of California to proceed to have said defects repaired and made good at our expense, and we will honor and pay the costs and charges therefor upon demand.

Signed ___________________________________
(Subcontractor)

SECTION II
INSTALLATION OF TWO FLYWHEEL MOTOR GENERATOR SETS

1. IN GENERAL

This work is subject to the General Requirements. The Subcontractor, having read them and being familiar with their contents, shall be responsible for and governed by all requirements thereunder.

2. WORK INCLUDED

The Subcontractor shall furnish all labor, equipment, appliances and materials necessary for performing all operations in connection with the draying, rigging, erecting, assembling, securing and aligning the two flywheel motor generator sets and their respective oil lubrication systems. The work shall be done in strict accordance with the Specifications and applicable Drawings.

3. WORK NOT INCLUDED

The following items of work are not included as part of this Specification:

a. Electrical connections to the two motor generator sets and its associated equipment.

b. The two exhaust blowers for each motor generator set will be installed by others.

4. DRAWINGS

Although dimensions are indicated on the accompanying Drawings, it will be the responsibility of the Subcontractor to check the dimensions of the equipment before installation.

5. MATERIALS

All materials shall be new, of the best quality for the purpose intended, and shall conform to the requirements of all the codes prescribed. The University reserves the right to reject any material not in accordance with this specification either before or after installation.

a. Structural steel shall conform to the "Standard Specifications for Structural Steel for Bridges and Buildings" (Serial Designation A.S.T.M. A7-46).

b. Grout

1. Cement shall conform to the requirements for type 1 of "Tentative Specifications for Portland Cement" (Serial Designation C150-40T) of the A.S.T.M.

2. Sand for grout shall be clean, hard, durable, and free from injurious amounts of lumps of soft particles, alkali, organic matter, clay,

loam, or other deleterious substances; and shall be of such sized particles or grain to be easily and effectively used in grouting either the leveling plates or sole plates.

3. The relative proportions of cement and sand for the grout shall be one part of cement to two parts of sand. The mixing of each batch shall be done in an approved mechanical batch mixer which will insure a uniform distribution of the ingredients. The amount of clear water added to the batch shall make the grout of a consistency which will give a reasonably dry pack. The entire batch shall be discharged from the mixer before recharging. The mixer shall be cleaned at frequent intervals.

c. Oil Piping

1. All oil pipe shall be black wrought seamless steel and shall conform to the Codes for Pressure Piping ASA-B31.1 and A.S.T.M. A-106 or A-53 and shall be Crane Co. or equal as called for on the Drawings.

2. All fittings for oil piping shall meet the requirements of the Code for Pressure Piping and shall be Crane Co. or equal as called for on the drawings.

d. Lubrication oil shall be a high quality refined oil containing oxidation inhibiting, anti-rusting, and foam suppressing additives which shall be added to the oil at the refinery plant. Each motor generator unit will require five hundred thirty (530) gallons of lubrication oil. The lubrication oil shall be supplied under the following specifications:

CHARACTERISTICS	SPECIFICATIONS	AVERAGE TEST DATA
Gravity - degrees A.P.I.	Min. 25	
Color A.S.T.M.	Max. 1-1/2	
Pour point - degrees F.	Max. - 15	
Flash, Cleve. O.C. - degrees F.	Min. 360	
Fire - degrees F.	Min. 400	
Viscosity, Seconds S.U. @ 100 deg. F	225-245	
S.U. @ 130 deg. F		113
S.U. @ 210 deg. F	44-48	
Viscosity, Index	Min. 50	
Carbon residue, % b.w. (Conradson)	Max. 0.10	
Acid No. (tan-C)	Max. 0.10	
Water, % b.w.	Nil	
Steam Emulsion	Max. 120	
Corrosion @ 212 deg. F (F.S.B.530.31)	Neg.	
Rusting test	OK	

Shell Turbo oil T-29 or equal

e. Water piping shall conform to the A.S.T.M. Standards No. A120-40 and shall be as called for on the Drawings Crane Co., or equal.

6. SHOP DRAWINGS

The Subcontractor shall promptly submit to the University five (5) copies of all shop drawings, schedules or material lists required. All data submitted shall include sufficient information for checking as to dimensions and quality. Specific reference to supplier and manufacturer shall be included for each item submitted. The Subcontractor shall make any changes required by the University and resubmit to him five (5) corrected copies. The University's approval for such lists, schedules or drawings shall not relieve the Subcontractor from responsibility for deviation from drawings or specifications unless he has, in writing, called the University's attention to such deviations at the time of submission and has obtained approval in writing from said University, nor shall it relieve him from responsibility for errors in shop drawings. Information shall be submitted for approval on the following items:

a. A complete list of materials as called for on the Drawings and Specifications.

b. Drawings and description of shoring and cribbing of building floors.

c. Miscellaneous drawings or lists as required by the University.

7. SUBSTITUTIONS

Substitutions of sections, or modifications of details, or both, shall be made only after the written approval of the University has been given.

8. INSPECTIONS AND TESTS

It will be the responsibility of the Subcontractor to notify the University in advance before making any tests as called for in the Specifications.

Material to be furnished under the Specifications shall be subject to inspection and tests. Inspection and tests shall be observed by a qualified person or agent of the University. Inspections shall not relieve the Subcontractor of his responsibility to furnish satisfactory materials, labor and workmanship and the right is reserved to reject any material, labor or workmanship at any time before final acceptance of the work when in the opinion of the University the materials and workmanship do not conform to the Specification requirements.

9. SUPERVISION

The entire installation of the two flywheel motor generator sets will be under the supervision of the Westinghouse Service Supervising Engineers who represent the manufacturer of the equipment involved.

10. DESCRIPTION

Each of the flywheel motor generator sets consists of a 3600 h.p. wound rotor motor, a 67 ton flywheel, a 12-phase 39,000 kva generator, vibration dampener, 5 bearings, steel sole plate slabs, a removable bridge and support columns and an oil lubrication system.

11. WORKMANSHIP AND DETAILS

a. Workmanship shall conform to the current rules and practices set forth in the National Code for Standard Practices of the A.S.A.

b. Draying and rigging: The two flywheel motor generator sets will arrive at a railroad destination siding mounted on skids and disassembled. The Subcontractor will be responsible to remove equipment from the railroad cars and transport the equipment to the Bevatron Building site, assemble the two flywheel motor generator sets in the required sequence on the existing concrete foundations as presently provided by the University.

c. Shoring and cribbing: The Subcontractor shall be responsible for supplying and installing sufficient shoring and cribbing in the motor generator room so as to insure against exceeding the safe load limit on any concrete floors (maximum of 500 lbs per square foot). The Subcontractor will not be allowed to use any of the building structural steel for rigging. There have been placed in the concrete at four different positions anchors to be used for rigging.

d. Sole plate installation: The sole plates for both motor generator sets are identical and are shown on Westinghouse drawing 30A6541. The foundations are shown on the building architect's drawings and installation drawings SFA-29300 to SFA-29305. Prior to the setting of the sole plates on the foundation, the Subcontractor shall set pregrouted leveling plates ((one hundred twenty-four (124) leveling plates per motor generator set; i.e., forty-five (45) leveling plates per side plus eight (8) each at bearings one (1), two (2), and three (3); four (4) each at bearing four (4); and six (6) each at bearing five (5)) on the motor generator foundation to assist in leveling the sole plates, and there shall be enough of these leveling plates installed so that the concrete shall not be overloaded in weight per unit area (maximum weight per unit area will be 130 pounds per square inch on the leveling plates). The size and spacing of these plates shall be approved by the University before installation. These plates shall be approximately three inches wide, one inch thick, and long enough to reach from side to side of the sole plate. They shall be located on each side of a holddown bolt at each point where there is a concentrated load, and, in general, at a spacing not to exceed three feet. The Subcontractor shall furnish leveling shims so as to insure the correct elevation of the sole plate as called for on the Drawings.

Suitable forms shall be made and placed in position to hold the grout while the leveling plates are being installed and setting. The grout shall be placed in the forms and the leveling plate placed on the grout. The plates shall be depressed into the grout so that the top of the plate shall be at an elevation which will permit the sole plates to be shimmed to elevation. Each leveling plate shall be leveled in both directions by the use of a machinist's precision level. The forms shall be left in position until the grout has set. There shall be no grout above the top of the leveling plates to interfere with the leveling of the sole plates.

The sole plates shall be thoroughly cleaned, placed on the leveling plates, shimmed to elevation as called for on the Drawings, according to accepted practice and tolerances for equipment of this size. The five bearings shall be set on the bearing pads after all surfaces have been cleaned, and they shall be checked for proper horizontal and vertical alignment. After the sole plates are satisfactorily leveled, they shall be grouted in to make a presentable appearance with the main floor. The grout shall be allowed to set for four (4) days until it is thoroughly hardened before the weight of the equipment is placed on the sole plates. The leveling plates are not to be installed on the foundations as long as there is any possibility of damage caused by the building construction. The pull on the nuts of the existing installed sole plate hold-down bolts will be 15,000 lbs. unless otherwise specified by the supervising Westinghouse Service engineers.

e. The setting of rotating machines: It will be the responsibility of the Subcontractor to assemble the two flywheel motor generator sets in their proper sequence and to do all work of checking proper leveling and alignment in strict accordance with the tolerances prescribed by the representatives of the manufacturer of this equipment. The manufacturer will furnish alignment charts whereon coupling openings will be shown to compensate for shaft sag. These coupling openings will be given in thousandths of an inch and the Subcontractor will be required to install pedestal bearings as necessary to obtain the coupling openings as designated. They must be set so that the coupling faces in the vertical and horizontal positions are within one thousandth of an inch of the values given on the alignment chart. This may be determined by feeler gages. There will be some preliminary operations required by the Subcontractor when aligning and making up the couplings and they will consist of checking all coupling rims and coupling faces for "truth" by use of dial-indicators and rotating the shaft from zero degrees to 180 degrees, taking readings at each of these two (2) points. The average of any outage thus found on any coupling half must be added to the one thousandth of an inch limit of alignment tolerance in the couplings. All bearing surfaces on the sole plates, bearing housings, and stator frame feet shall be thoroughly cleaned before the equipment is set on the sole plates.

f. Oil lubrication system: The oil lubrication system consists of four (4) oil lift pumps located at the bearings and an oil sump tank with oil circulating pump and oil to water heat exchanger which is located in the generator room basement. The oil circulating feed and return lines shall be furnished and installed as indicated on the Drawings and must be done in such manner that will provide smooth inside joints in the piping in order to eliminate all possible restriction to oil flow in the gravity return to the sump tank. The entire oil lubrication piping system must meet the code requirements of Section 3 of the Code for Pressure Piping A.S.A.-B31.1 and shall stand the hydrostatic tests as called for in above code.

There are two existing water pipes installed to be used to cool the lubricating oil and it will be the responsibility of the Subcontractor to install the water piping as indicated on the Drawing.

g. Lubricating oil: The Subcontractor shall furnish the lubricating oil as previously defined. It shall be his responsibility to clean, swab and completely flush the entire oil system with a very light oil so as to insure that all the oil pipes and bearing oil reservoirs are completely cleaned of all sediment.

INSTALLATION OF TWO FLYWHEEL MOTOR GENERATOR SETS

SCHEDULE OF DRAWINGS

Drawing No.	Title
SF-A-29300	East F.W.M.G. Set Foundation Sole Plate and Hold-down bolts.
SF-A-29301	West F.W.M.G. Set Foundation Sole Plate and Hold-down bolts
SF-A-29302	East F.W.M.G. Set Foundation Plan and Section Views
SF-A-29303	East F.W.M.G. Set Foundation Section Views
SF-A-29304	West F.W.M.G. Set Foundation Plan and Section Views
SF-A-29305	West F.W.M.G. Set Foundation Section Views
SF-A-29318	Cooling water piping - Electronic Exciter and M.G. Set Lub Oil
SF-A-29319	East M.G. Set Lub. Oil Return Piping Diagram
SF-A-29320	West M.G. Set Lub. Oil Return Piping Diagram
SF-A-29321	M.G. Sets Lub. Unit, Feed and Return Lines
SF-A-29322	Generator Floor Sleeves for M.G. Sets Lub. Oil Lines
SF-A-29323	East M.G. Set Lub. Oil Feed Piping Diagram
SF-A-29324	West M.G. Set Lub.Oil Feed Piping Diagram
SF-A-29328	Lub. Unit and Electronic Exciter Cooling Water Piping
55-J-580	Motor Generator Set Outline
30A6541	M.G. Set Bedplate
4Y-1682	M.G. Set Assembly Outline
4Y1691	M.G. Set Motor Unit Outline
4Y1701	M.G. Set Flywheel Unit Outline
4Y1711	M.G. Set Generator Unit Outline
X-7	Revisions in Gen. Foundation Conduit Runs, etc.
S-3	Floor Framing plans

Appendix II

SPECIFICATIONS

FOR THE

INSTALLATION OF

BEVATRON POWER SUPPLY EQUIPMENT

UNIVERSITY OF CALIFORNIA
Berkeley, California

Radiation Laboratory

April 1950

INSTALLATION OF BEVATRON POWER SUPPLY EQUIPMENT

SECTION I

GENERAL REQUIREMENTS

1. LOCATION

The work is to be performed in the Bevatron Building located in the Wilson tract north of the 184-inch Cyclotron on the Berkeley Campus, University of California, Berkeley, California.

2. LIMITS OF WORK

The Subcontractor shall confine his operations to the building and a portion of the building site as directed. Access to this site will be via the access road starting at the head of Hearst Avenue in Berkeley.

All materials for the erection operation shall be brought in and the work so conducted as to avoid any interference with others working on the site.

3. VISIT TO SITE

The bidder shall visit the site and completely inspect the entire premises of the construction area. The University will not allow any extras to the Subcontractor that arise from lack of knowledge of the conditions of the construction area.

4. PERMITS

The Subcontractor shall obtain all permits and licenses that are required for the performance and completion of the work under this subcontract.

5. INTERPRETATION OF TERMS

Certain common expressions hereinafter used shall be interpreted as having the following significances:

"Or equal": shall mean "or equal in the opinion of the Engineer".
"Approved": shall mean "approved in writing by the Engineer".
"If, when or as directed": shall mean "if, when or as directed by the Engineer".
"A.S.A.": shall mean "American Standards Association".
"A.S.T.M.": shall mean "American Society for Testing Materials".
"A.I.S.C.": shall mean "American Institute of Steel Construction".
"A.I.E.E.": shall mean "American Institute of Electrical Engineers".
"N.E.M.A.": shall mean "National Electrical Manufacturers' Association".
"I.P.C.E.A.": shall mean "International Power Cable Engineers' Association".
"A.S.H.V.E.": shall mean "American Society of Heating & Ventilating Engineers".

"N.E.C.": shall mean "National Electric Code".

In the General Conditions where reference is made to Architect or Architects, it shall be understood to mean Engineer or Engineers of the University of California, Radiation Laboratory.

6. TITLES AND HEADINGS

Titles and headings to divisions and paragraphs in these documents are introduced merely for the convenience and shall not be taken as a part of the Specifications and, furthermore, shall not be taken as a correct or complete segregation of the service units of materials and labor. No responsibility, either expressed or implied, will be assumed by the University for omissions or duplications by the Subcontractor due to real or alleged error in arrangement of matters in the Subcontract documents.

7. CODES

a. The materials and workmanship involving cables, wires, ducts, cable racks, supports, fittings, conduits, wiring devices, and the installation of such materials shall be in accordance with the requirements of the National Electric Code, California Safety orders, A.I.E.E., N.E.M.A., I.P.C.E.A. or Standard Federal specifications, as revised to date, wherever applicable to this particular installation. All materials shall be of the best quality available and the workmanship shall follow the best accepted practices of the industry. All materials and equipment shall be installed with the manufacturer's recommendations. Whenever these specifications call for or describe work of better quality or larger size than required by the aforementioned codes, the provisions of these specifications shall govern the installation.

b. The electrical system layouts as indicated on the drawings and wire and cable schedules are generally diagrammatic; however, the exact routing of the cable and wiring shall be governed by the structural conditions and obstructions and also governed by the trench and duct systems presently provided by the University.

c. The Subcontractor shall cooperate and coordinate his work with all other subcontractors on the site and shall arrange and prosecute his work in such a manner as required for the satisfactory and efficient installation of the Bevatron power supply by all trades concerned.

8. JOB OFFICE

The Subcontractor shall provide and maintain on the premises, where directed, until completion of the installation, a temporary office. The structure shall be made watertight, and shall be provided with electric lights and locks.

9. TOILET FACILITIES

Toilet facilities on the job site are maintained by the General Construction Contractor. Arrangements may be made with the General Contractor for use of these facilities until such time as his work is completed; thereafter the Subcontractor shall provide a temporary house for toilet facilities in a location approved by the Engineer and shall connect it to utilities (water and sewer). The Subcontractor will be responsible for keeping these facilities clean and sanitary and shall maintain the equipment in a workable condition.

10. WATER AND POWER

Water and power services are available at the construction site and are billed to the General Construction Contractor for the Bevatron Building at the rates of fifteen (15) cents per hundred (100) cubic feet and two (2) cents per kilowatt hour, respectively. Arrangements may be made with the General Contractor for the use of these services. After completion of the building by the General Construction Contractor arrangements may be made with the University for water and power.

11. TELEPHONE

The Subcontractor shall provide and maintain for the duration of the installation public telephone service in the temporary office.

12. TEMPORARY CONSTRUCTION

a. The Subcontractor shall provide, maintain and remove upon completion of work all temporary rigging, shoring, scaffolding, hoisting equipment, barricades around openings, and ladders between floors that are required for all work hereunder.

b. The temporary work shall conform to all requirements in regard to operation, safety and fire hazard of State and local authorities and underwriters. The Subcontractor shall furnish and complete all items necessary for such complete installation and for conformity with such requirements whether called for under the separate sections of the Specifications or not.

13. CHANGED CONDITIONS

Should the Subcontractor encounter or the University discover during the progress of the work conditions materially differing from those shown on the Drawings or indicated in the Specifications, or unknown conditions of an unusual nature differing materially from those ordinarily encountered and generally recognized as inherent in work of the character described in these Drawings and Specifications, the attention of the University shall be called immediately to such conditions. The University will thereupon promptly investigate the conditions and if he finds that they do so materially differ, this order will be modified to provide for any increase or decrease of cost and for difference in time resulting from such conditions.

14. DELIVERY OF EQUIPMENT

Switch gear and magnet excitation equipment will be made available to the Subcontractor at the job site in time for installation in the building.

15. USE OF CRANE

There will be installed in the building a five (5) ton electrically operated crane which may be used by the Subcontractor in aiding him in the erection of the magnet excitation equipment.

16. INSULATED BUS STRUCTURE MODEL

There will be available for inspection by the Subcontractor a model of the insulated bus structure, illustrating that portion of the bus structure that will be installed beneath the two generators.

17. CLEANING

At completion of the work the Subcontractor shall remove all his tools, appliances, materials, debris and/or rubbish, from the building and the premises and shall sweep and clean the installation areas thoroughly.

18. GUARANTEE

When required by the Specifications guarantees shall be in the form of the following Guarantee on the Subcontractor's own letterhead:

GUARANTEE FOR ______________________

We hereby guarantee that the ______________________ which we have performed in the Bevatron Building, Building 51, University of California, Berkeley, California, has been done in accordance with the Drawings and Specifications and that the work as installed will fulfill the requirements of the guarantee included in the Specifications. We agree to repair or replace any or all of the work together with any other adjacent work which may be displaced by so doing, that may prove to be defective in its workmanship or material within a period of ______________ years from date of acceptance of the above-named structure by The Regents of the University of California, ordinary wear and tear and unusual abuse or neglect excepted.

In the event of our failure to comply with the above-mentioned conditions within sixty (60) days after being notified in writing by The Regents of the University of California, we, collectively or separately, do hereby authorize The Regents of the University of California to proceed to have said defects repaired and made good at our expense, and we will honor and pay the costs and charges therefor upon demand.

Signed ______________________
(Subcontractor)

INSTALLATION OF BEVATRON POWER SUPPLY EQUIPMENT

SECTION II

INSULATED BUS STRUCTURE

1. GENERAL

This work is subject to the General Conditions and General Requirements and the Subcontractor shall be responsible for and governed by all requirements thereunder.

2. WORK INCLUDED

The work covered by this Specification shall consist in furnishing all plant labor, equipment, supplies and materials, and in performing all operations in connection with the fabrication and furnishing approximately four thousand five hundred (4500) lineal feet of insulated copper bus, its various supports and associated equipment in strict accordance with this Specification and applicable Drawings.

3. INTENT AND RESPONSIBILITY

a. Intent: It is the intent of these Specifications and Drawings forming a part thereof, to indicate as clearly as possible where the equipment to be connected is to be placed and how it is to be connected by the bus structure, and how the bus structure is to be supported.

b. Responsibility: It will be the responsibility of the Subcontractor to build the entire bus structure including supporting and insulating members to the dimensions as shown on the Drawings.

4. DESCRIPTION

The bus structure to be furnished under these Specifications will be used to interconnect the main power units of the Bevatron Magent Power Supply Equipment and magnet feeder circuits. The bus structure to be furnished under these Specifications interconnects the flywheel motor-generators, rectifiers, disconnect switches, interphase transformers, short-circuiting switch, shunts, transductors, and magnet feeder potheads, and is supported by various steel structures as shown on the installation Drawings. The location of the bus is indicated on the Drawings, as well as the points where the various taps or changes in direction are to be made.

5. EQUIPMENT TO BE FURNISHED

a. Steel structures to hold current transformers and potheads at D-C bus terminal point will be a part of this Specification.

b. All tapes, varnishes and fillers called for on Drawing #SFA-29354 will not be furnished under this Specification; however, compound boxes and other materials called for on the above Drawing will be furnished under these Specifications.

c. All bolts and anchors to secure bus supports to concrete as called for on the Drawings will not be furnished under this Specification.

6. WORKMANSHIP

The manufacture of this insulated bus structure shall conform to the best accepted practices for the manufacture of similar structures and to the standardization rules of A.I.E.E., I.P.C.E.A., and N.E.M.A., as revised to date, insofar as they are applicable to this structure. California Safety Orders will take precedence over all other codes, but where they do not apply, Standard Federal Specifications will be used.

7. MATERIALS

a. Copper bus bar: Copper bus bar shall be one-half (1/2) inches by three (3) inches with half round edges and shall be annealed electrolytic copper with guaranteed minimum conductivity of ninety-eight (98) percent. International Annealed Copper Standards shall apply.

b. Insulating sleeves and insulating supports: The insulating criterion will be a minimum of fifteen thousand (15,000) volts to ground (a-c RMS value). The insulating sleeves shall be one-fourth (1/4) inch Micarta tubing, fifteen (15) kv class with a ninety-five (95) kv impulse level, as manufactured by Westinghouse, or equivalent. Bus supports and spaces shall be made from one and one-quarter (1-1/4) #297 Micarta plate as manufactured by Westinghouse, or equivalent.

c. Steel supports: Structural steel shall conform to the "Standard Specifications for Structural Steel for Bridges and Buildings" (Serial Designation A.S.T.M. A7-46).

d. Silver plating: Silver plating shall be accomplished by the flame and torch or electrolytic method with a minimum thickness of one one-thousandth (1/1000) of an inch.

8. DIMENSIONS

The Drawings indicate location and spacing of the phases and neutral buses in the bus run. The required location of each phase and neutral bus was determined by the location of the terminals and cathode on the rectifier units and also by the positions of the interphase transformers and disconnect switches.

Attention is called to the fact that the floor underneath the generator slopes from each side to the center; therefore it will be necessary for the steel support footings to be adjusted to the floor slope.

9. METHOD

a. Joints and bus supports: In some portions of each phase and neutral bus, the length of continuous bus is such that it will require more than one length of bus. When two pieces of bus are to be joined to form a continuous piece of straight bus, the Subcontractor shall use butt-joints with one-fourth (1/4) inch splice plates on each side of joint. The use of butt-joints will keep the bus at the same centerline spacing on both sides of the joint and permit more uniformity in making the insulated bus supports. All bolted joints of bus and splice plates shall be silver plated. In the insulated bus supports, the slots for the bus shall have a snug fit to the insulated bus for both the depth and width of the slot. The insulated bus support blocks shall be drilled as indicated on the installation Drawings to permit bolting to the steel supports.

b. Equipment connections: On some of the equipment provided, the spacing for the bus connections will not permit the use of half-inch copper bus bar. The Drawings indicate the size of copper to be used in such cases and the Subcontractor shall provide this bus as required; however, it can be of the rectangular type of copper bus bar. Again, the International Annealed Copper Standard will apply. This bus bar will be furnished uninsulated as shown on the Drawings.

c. D-C Feeder: The arrangement of the bus in the d-c magnet feeder circuit will be two wide and two high, and each connection thereto will be bolted to all four pieces of bus. There is a removable link in each leg of this bus which will be uninsulated bus and it is bolted to the main insulated bus so that it may be removed.

d. Removable links at rectifier units: There is a removable link at each phase terminal of the rectifier units, and these links shall be bolted to facilitate removal. These links will be uninsulated bus.

e. Discrepancies: Due to discrepancies during construction of the building and floors, it may be necessary for the Subcontractor to leave the ends of certain pieces undrilled. These ends will have to be drilled in the field by an installation contractor; however, all of these bus joints will be silver plated as previously called for. The University's Engineers will determine which ends are to be left undrilled.

f. Drilling: The entire copper bus bar structure shall be drilled and punching of the copper bus will not be allowed.

g. Steel support structures: The Bills of Material on the Drawings indicate the various sizes of structural steel to be furnished for the bus supports. The general construction of these supports will be by welding the various pieces of each individual structure. All welding, so far as shall come in contact with the insulated bus supports, will be ground smooth. After welding, each structural piece of the support shall be sand blasted and given one coat of primer paint and two coats of gray lacquer.

The welding shall be in accordance with the current Code for Arc and Gas Welding in Building Construction of the American Welding Society, the applicable portions of which are hereby made a part of this Specification.

h. Marking: All material shall be marked by the Subcontractor to facilitate proper assembly at the building site.

10. SUBSTITUTIONS

Substitutions of sections, or modifications of details, or both, shall be made only after the written approval of the University's Engineers has been given.

11. SHOP DRAWINGS

a. Four (4) prints of the shop drawings must be submitted to the University for approval. All data submitted shall include information for checking as to dimensions and quality of materials. The Subcontractor shall make any changes required by the University, resubmit to him four (4) corrected copies. The University's approval for lists or drawings shall not relieve the Subcontractor from responsibility for deviation from Drawings or Specifications unless he has, in writing, called the University's attention to such deviations at the time of submission and has obtained approval in writing from said University, nor shall it relieve him from responsibility for errors in shop drawings.

12. INSPECTION AND TESTS

a. How made: The material to be furnished under this Specification shall be subject to inspection and test in the shop by authorized agents of the University. Tests will be made by the Subcontractor and certification of those tests will be submitted during the fabrication of the bus structure. Inspection in the shop shall not relieve the Subcontractor of his responsibility to furnish satisfactory materials and the right is reserved to reject any material at any time before final acceptance of the work when in the opinion of the University the materials and workmanship do not conform to Specification requirements. It will be the responsibility of the Subcontractor to notify the University when sufficient material is available for inspection.

SECTION III

INSTALLATION

1. GENERAL

This work is subject to the General Conditions and General Requirements and the Subcontractor shall be responsible for and governed by all requirements thereunder.

2. WORK INCLUDED

The work of this section shall include all materials, services, labor and equipment (except as specifically indicated otherwise) necessary to provide the following:

a. Complete erection, alignment, assembling and securing of all electrical equipment and insulated bus structure as indicated on the Drawings.

b. Complete wiring, cabling and connections to all electrical equipment as indicated on the cable and wiring schedules and the Drawings.

c. Complete water piping, sheet metal work, steel work, etc., as called for on the Drawings.

d. Miscellaneous items of work and materials not specifically mentioned but necessary for a complete working installation.

e. It is the intent of the Drawings and Specifications that the entire installation shall be complete, except as otherwise noted, and ready for operation.

3. WORK NOT INCLUDED

The following items of work are not included as a part of this section of this Specification:

a. The draying, rigging, erecting, assembling, securing and aligning of the two motor generator sets and the installation of their entire oil lubricating systems are not a part of this Specification.

b. The furnishing and fabrication of the entire insulated bus structure, except as otherwise noted, are not a part of this Specification.

c. The connecting of the two incoming twelve (12) kv lines to the twelve (12) kv switchgear.

d. The connecting of the load circuits to the four hundred eighty (480) volt switchgear except as otherwise noted.

e. The setting and alignment of the three fifteen hundred (1500) kva outdoor transformers.

f. The following structural steel members to secure equipment to the building proper:

(1) The I-beams to hold eight rectifier units.

(2) Steel angles to secure switchgear, generator electronic exciters, motor control cubicles, rectifier low voltage control cubicles, and the steel plates to secure the two large interphase transformers.

g. The remote control board for the electrically operated switchgear.

h. Remote controls to control the cycling and pulses of the motor generator sets.

4. SHOP DRAWINGS

The Subcontractor shall promptly submit to the University four (4) copies of all shop drawings and material lists required for approval. All data submitted shall include sufficient information for checking as to dimensions and quality. Specific reference to suppliers and manufacturers shall be included for each item submitted. The Subcontractor shall make any changes required by the University and resubmit to them four (4) corrected copies. The University approval for such lists and drawings shall not relieve the Subcontractor from responsibility for deviations from Drawings or Specifications unless he has, in writing, called the University's attention to such deviations at the time of submission and has obtained written approval from the University, nor shall it relieve him from responsibility for errors in shop drawings. Information shall be submitted for approval on the following items:

a. Wires and cables. Description of manufacturer's type.

b. Cable racks and cable trays - complete shop drawings showing the entire routing of all wiring and cables.

c. All hardware and miscellaneous steel. Description of manufacturer's type.

d. Water pipes and fittings. Description of manufacturer's type.

All information must be submitted sufficiently in advance of the date required for installation to allow the University a reasonable time for checking and for the Subcontractor to make required corrections.

5. INSPECTIONS AND SUPERVISIONS

The entire installation of the Bevatron power supply will be inspected and supervised by Westinghouse engineers, the manufacturer of all equipment (except the three 1500 kva transformers and certain remote control boards) involved. If any work performed does not meet the approval of the Westinghouse engineers or the University, it shall be the responsibility of the Subcontractor to replace any rejected work at no extra cost to the University.

Inspection in the field, however, shall not relieve the Subcontractor of his responsibility to furnish satisfactory material, and the right is reserved to reject any material at any time before final acceptance of the work when in the opinion of the University the material and workmanship do not conform to the Specification requirements.

6. TESTS

Tests shall be conducted throughout the installation as required by the University and as are required to determine conformity with the Specifications.

a. Tests shall be applied to all feeders, subfeeders, and control wiring. Such tests shall be made with a magneto generator capable of ringing through 50,000 ohms, and with an applied voltage of five hundred (500) volts.

b. The resistance between conductors and between conductors and ground shall be not less than the values stipulated in the N.E.C. and California Safety Orders.

c. After the installation is complete, voltage and ampere readings shall be taken with connected equipment turned on.

d. All tests shall be made in the presence of the University Engineer.

e. All testing equipment, material and labor shall be provided by the Subcontractor.

f. Scheduling of tests shall be subject to review and approved by the University, but in no case shall the last test be made more than one month after the installation is completed.

g. Any defects disclosed as a result of such tests shall be immediately remedied by and at the expense of the Subcontractor.

7. SUBSTITUTIONS

Substitution of materials or modification of detail or both shall be made only after the written approval of the University has been given.

8. DESCRIPTION

The two flywheel motor generator sets will furnish twelve (12) phase power to the eight (8) rectifier units which, in turn, feed d-c power to the magnet feeder circuit, via the insulated copper bus structure. The excitation for the a-c generators is furnished by two electronic exciters. The excitation for the two generators is regulated by the two excitation control cubicles. The twelve (12) kv power is available at the twelve (12) kv switchgear located in the seitchgear room and the four hundred eighty (480) switchgear is located in the same room. The twelve (12) kv/480 volt transformers are located on the concrete transformer pad outside the switchgear room. Trenches and slots and Transite ducts have been installed in the building to facilitate the installation of the cables and wiring. In various places it will be necessary to install cable racks for the power cables and wiring trays for the control wiring and where necessary to meet code requirements, steel conduits will be required.

The eight rectifier units are located over the interphase transformer pit to facilitate the interconnection of all associated equipment with the insulated copper bus structure. The Subcontractor should take proper precautions to insure all the above assembled equipment is set to exact dimensions as called for on the Drawings in order to facilitate the installation of the insulated copper bus structure.

9. MATERIALS

a. General requirements: All materials shall be new, of the best quality for the purpose intended, and shall conform to the requirements of the Underwriters' Laboratory Incorporated. The University reserves the right to reject any material not in accordance with this Specification either before or after installation.

b. Wires and cables: The wires and cables shall be of type and insulation as called for in the wiring and cable schedules. Connections and quality of all wires shall conform to the before-mentioned codes and standards.

c. Water Pipe shall be Type K hard drawn copper water tubing such as manufactured by Anaconda or Crane Co., or equal. Fittings shall be wrought copper similar or equal to Crane Co. and the joints shall be brazed with silver solder, silfos, or equal.

d. Structural steel shall conform to the "Standard Specifications for Structural Steel for Bridges and Buildings" (Serial Designation A.S.T.M. A7-46).

e. Sheet metal: In general sheet metal work will comply with the standards of the A.S.H.V.E. and with respect to the U.S. Standard Gage, and it shall be hot dipped, galvanized sheet steel.

f. Cable racks and cable wiring trays shall comply with the A.I.E.E. standards.

10. WORKMANSHIP AND DETAILS

a. Wiring: All wiring and terminations shall specifically conform with the before-mentioned codes and standards.

(1) All shielded and lead sheath cables shall be properly terminated, bonded, and grounded as called for on the Drawings.

(2) The Subcontractor shall tag all wires and groups of wires so as to properly identify all the circuits. Identification shall be in accordance with numerical numbering as called for on the Drawings.

b. Electrical equipment: It will be the responsibility of the Subcontractor to assemble parts of some of the electrical equipment that will be delivered to the site not completely assembled.

(1) Vacuum tubes placed in their sockets where called for;

(2) Large resistors to be assembled into proper groups;

(3) Miscellaneous items with control and excitation.

c. It will be the responsibility of the Subcontractor to make all the electrical connections to the two motor generator sets and also to set and connect the two exhaust blowers for each motor generator set.

(1) The Subcontractor will be responsible for furnishing and installing and fabricating the sheet metal and structural steel work for the exhaust blowers as called for on the Drawings.

d. It will be the responsibility of the Subcontractor to assemble and install the entire insulated copper bus structure, including necessary shimming.

(1) It will be necessary for the Subcontractor to furnish the necessary anchors and bolts to secure the insulated copper bus structure to the concrete floors and walls.

(2) The Subcontractor shall furnish and install the necessary tapes, varnishes and fillers as called for on the Drawings of the insulated copper bus structure.

(3) Certain members of the insulated copper bus bar will be furnished undrilled in order to facilitate assembly; therefore, the Subcontractor shall drill the insulated copper bus bar in the field; punching of copper bus bar will not be allowed.

e. It will be the responsibility of the Subcontractor to insure the proper alignment and leveling of the eight rectifier units and make all electrical and mechanical connections as called for in the Drawings.

(1) The Subcontractor shall furnish and install the water piping and fittings as called for on the Drawings for each rectifier unit and be responsible for proper tests to be made by the Subcontractor on the entire water system.

(2) The piping shall be tested at a hydrostatic pressure of two hundred fifty (250) p.s.i.g. and proven tight.

f. It will be the responsibility of the Subcontractor to install and assemble the d-c storage batteries as called for on the Drawings. This will include assembling the battery rack, painting the battery rack with the paint supplied, installing the rack in the battery room, furnishing and installing the d-c battery feeder panel and all wiring thereto.

g. The Subcontractor will be responsible for furnishing and painting the structural steel racks, supports and frames that are called for on the Drawings with one primer coat and two coats of gray lacquer. Any electrical equipment that has been marred during installation shall receive touch-up painting to match the existing finish.

h. The Subcontractor shall install all grounding connections to the existing grounding network as called for on the Drawings. All grounding shall be in strict compliance to the A.I.E.E. standards.

i. All welded connections shall be as indicated on the Drawings and shall be in accordance with the current Code for Arc and Gas Welding in Building Construction of the American Welding Society.

j. Structural steel frames and supports shall conform to the current rules and practices for the erection of structural steel for building of the A.I.S.C.

11. LIST OF ELECTRICAL EQUIPMENT TO BE INSTALLED

(1) 3 assemblies of 12 kv switchgear

(2) 2 assemblies of low-voltage indoor metalclad switchgear

(3) 750 kva - 3 phase transformer

(4) 2 generator field electronic exciter units consisting of low-voltage switchgear, transformer and rectifier cubicle

(5) 60 cell d-c battery, battery charger and feeder panel

(6) 4 - 40 hp exhaust blowers

(7) 12 special current transformers

(8) 2 motor secondary control cubicles

(9) 2 sets of motor secondary accelerating, cycling and permanent slip resistor assemblies.

(10) 2 generator field electronic exciter control cubicles

(11) 2 generator field-discharge resistors

(12) 4 - 30 KVA - 3 phase transformers with motor-operated no-load tap changers

(13) 4 - motor-operated disconnect switch assemblies consisting of 4 motor operated mechanisms and 4 'BA' fused disconnect assemblies

(14) 8 inversion arc through protection assemblies, each consisting of a potential transformer and a 2 MFD capacitor

(15) 8 surge suppressor resistor assemblies to be mounted on top of the high voltage control cubicles

(16) 4 7200/120 volt potential transformers for metering

(17) 4 low-voltage rectifier-excitation control cubicles

(18) 8 high-voltage rectifier-excitation control cubicles

(19) 8 rectifier assemblies

(20) 1 grounding interphase transformer with grounding resistor and 25 ohm - 50 M.V. shunt

(21) 2 interphase transformers

(22) 1 - 2 pole high-speed short-circuiting switch cubicle

(23) 1 grounding and overcurrent protective relay cubicle

(24) 2 - 600 amp. single pole disconnect switches

(25) 8 - 3000 amp. single pole disconnect switches

(26) 4 - 5000 amp. - 50 M.V. DC shunts

(27) 2 - 5000 amp. DC to 2.5 amp. AC transductors

(28) 2 damping units consisting of one 90 ohm resistor and a one MFD capacitor

(29) 2 resistors across the magnet feeder bus for use with the graphic recording voltmeter

(30) 2 spark gap assemblies consisting of three spark gaps and a current limiting resistor in each assembly and both assemblies connected to a 50 amp. - 50 M.V. shunt to ground

INSTALLATION OF BEVATRON POWER SUPPLY EQUIPMENT

SCHEDULE OF DRAWINGS

Drawing No.	Title
SF-A-29302	East F.W.M.G. Set Foundation Plan and Section Views.
SF-A-29303	East F.W.M.G. Set Foundation Section Views.
SF-A-29304	West F.W.M.G. Set Foundation Plan and Section Views.
SF-A-29305	West F.W.M.G. Set Foundation Section Views.
SF-A-29306	Switchgear Floor trench openings and floor steel channels.
SF-A-29307	Switchgear Floor Section views trench and floor steel channels.
SF-A-29308	Switchgear Floor Col 7 to 10 trenches and floor steel channels.
SF-A-29309	Transite conduit from trench "K" to pit near column, line 9.
SF-A-29310	Transite conduit from switchgear to F.W.M.G. site north of Col "G".
SF-A-29311	Transite conduit from switchgear to pit near Col line 7.
SF-A-29312	F.W.M.G. Set Secondary control cubicle-cable slots.
SF-A-29313	Electronic Exciter Foundation Pads and Mtg. Channels.
SF-A-29314	Ignition L.V. Exc. Cub. & Gen. Exc. Control Cub. Mtg. Channels & slots.
SF-A-29315	Ignition Rect. & H.V. Excitation Cub. mtg. beams East.
SF-A-29316	Ignition Rect. & H.V. Excitation Cub. mtg. beams West.
SF-A-29317	Interphase Transformer floor equipment location.
SF-A-29318	Cooling water piping - Electronic exciter and M.G. Set Lub Oil.
SF-A-29325	Main motor accelerating and permanent clip resistors.
SF-A-29326	Motor sec. resistor support and mtg. details.
SF-A-29327	Rectifier Cooling Piping.
SF-A-29328	Electronic Exciter Cooling Piping.
SF-A-29330	Bus connections from A-C generators to ignitions.
SF-A-29331	East Gen. Bus Arrangement Elev. Facing east.

Drawing No.	Title
SF-A-29332	East Gen. Bus Arrangement Plan view.
SF-A-29333	East Gen. Bus Arrangement Section View.
SF-A-29335	East Gen. Bus Arrangement Elev. view facing east.
SF-A-29336	East Gen. Bus Arrangement Plan view.
SF-A-29337	East Gen. Bus Arrangement Elev. view.
SF-A-29338	Gen. bus assem. details "J" to "V".
SF-A-29339	12 Phase Bus and Neutrals @ East Gen. Foundation.
SF-A-29340	Gen. Rectifier Diagonal Bus for "A" Units East Group.
SF-A-29341	Gen. Rectifier Bus for units 1A-2A & 4A East Group.
SF-A-29342	Gen. Rectifier Bus for units 3A and Sections East Group.
SF-A-29343	Gen. Rectifier Bus Units 1A to 4A East Group.
SF-A-29344	D-C Bus Run "A" Units East side.
SF-A-29345	West Generator Bus Arrangement Elev. View.
SF-A-29346	West Generator Bus Arrangement Plan View.
SF-A-29347	West Generator Bus Arrangement Sect. Elev. Views.
SF-A-29349	West Generator Bus Arrangement Elev. View.
SF-A-29350	West Generator Bus Arrangement Plan View.
SF-A-29351	West Generator Bus Arrangement Section View.
SF-A-29352	Inversion Arc Through Protection.
SF-A-29353	12 phase bus and neutrals @ West Gen. Foundation.
SF-A-29354	Gen. Rectifier Diagonal Bus for "B" Units West Group.
SF-A-29355	Gen. Rectifier Bus for units 1B-2B & 4B West Group.
SF-A-29356	Gen. Rectifier Bus for units 3B & sections West Group.
SF-A-29357	Gen. Rectifier Bus Sections Units 1B to 4B West Group.

Drawing No.	Title
SF-A-29358	D-C Bus Run "B" Units West Side.
SF-A-29359	D-C Bus Run Sections East & West Sides.
SF-A-29360	D-C Bus to Cable Potheads Mtg. details.
SF-A-29361	Spark Gaps and Associated Equipment.
SF-A-29362	Short Circuiting Switch mtg. details.
SF-A-29363	Grounding resistor and transformer connections.
SF-A-29364	Ignition Exc. Control Transformer 1A & 1B connection.
SF-A-29365	Ignition Exc. Control Transformer 2A & 2B connection.
SF-A-29366	Generator Blower Motor mtg. Details - inside.
SF-A-29367	Generator Blower Motor mtg. Details - outside.
SF-A-29368	D-C Battery, Battery Charger and D-C Feeder Panel.
SF-A-29369	Wire & Cable Cross reference Drawing.
SF-A-29370	Wire Cable & Bus Schedule Group 1 to 68.
SF-A-29371	Wire Cable & Bus Schedule Group 80 to 125.
SF-A-29372	Wire Cable & Bus Schedule Group 126 to 179.
SF-A-29373	Wire Cable & Bus Schedule Group 180 to 230.
SF-A-29374	Wire Cable & Bus Schedule Group 231 to 284.
SF-A-29375	Wire Cable & Bus Schedule Group 285 to 344.
SF-A-29376	Wire Cable & Bus Schedule Group 345 to up.
55-J-580	Motor Generator Set Outline.
31A3816	Gen. Exc. Rect. L.V. Switchgear Cub. F.B. and Sec.
15B6290	Aux. Power Transformer 750 KVA Outline.
30A5462	Motor Secondary Control Cub. Gen. Assembly.
30A6604	Ignition Rect. IPJ76 Outline.

INSTALLATION OF BEVATRON POWER SUPPLY EQUIPMENT

SCHEDULE OF DRAWINGS

Drawing No.	Title
56J550	H.V. Exc. Cubicle Gen. Assem.
15B7327	Interphase Transformer 7100 KJA Outline.
20B8365	Short Circuiting Switch Cubicle Gen. Assembly.
57-J-9	Magnet Power Supply Structure Diagram.
X-7	Revisions in Gen. Foundation Conduit Runs, etc.
S-3	Floor Framing plans.
4Y1114	U.C.R.L. One Line Diagram.
4Y1074	U.C.R.L. Grounding Network.

INSTALLATION OF BEVATRON POWER SUPPLY EQUIPMENT

June 12, 1950

ADDENDUM NO. 1

Subcontract No. 39

The insulated bus structure specified in Section II will be furnished by others but installed by this Subcontractor.