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UNIQUE FEATURES OF THE TEXAS A & M VARIABLE ENERGY CYCLOTRON

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Abstract

This paper describes some of the design, engineering, construction and procurement details of the Texas A & M University Variable Energy Cyclotron (TAMVEC). All major engineering has been completed, and system components are presently under construction at various vendor plants throughout the country. Assembly and installation of the machine will begin in the latter part of June 1966. It is anticipated that construction and check out of the machine will require only 9 months.

The TAMVEC machine is funded by the United States Atomic Energy Commission. Engineering, procurement, and construction of the machine is being performed by the Bechtel Corporation.

TAMVEC is a variable-energy cyclotron basically similar in physics and arrangement to the 88-inch variable energy, spiral-ridge cyclotron(1) installed at Lawrence Radiation Laboratory (LRL) in Berkeley, California. However, as a result of LRL, Texas A & M University, and Bechtel staff experience and recommendations, the TAMVEC machine has several improved design features incorporated in it. These are discussed in the following paragraphs.

Machine General Arrangement

Although the machine general arrangement is similar to the LRL 88-inch cyclotron, several features of construction are different from those in the LRL machine. These are shown in Figure 1. For example, the dee tank cover is welded directly to the pole face, which has been increased in thickness. Also, the pole face is a single piece, while, in the LRL 88-inch machine, it is composed of a ring and a center section. This arrangement eliminates the need for the copper seal between pole face ring and pole piece, a major source of sealing difficulty in the LRL cyclotron.

The ion source vacuum seal is made between the bottom of the ion source sleeve and the pole face, using an O-ring. This reduces the surface area exposed to the vacuum chamber. All carbon steel surfaces exposed to the vacuum, such as the pole face, pole tips and rose shims, and the respective mating surfaces, are electrolysis nickel plated.

The dee tank is constructed to permit complete removal of the side plates and corner posts. The double metal seals and the Permatex impregnation system used at LRL have been replaced by a continuous Butyl O-ring. The O-ring is made by vulcanizing a molded corner gasket (Figure 2) to extruded Butyl rod. The use of the resilient seal will eliminate leakage due to permanent deformation, a weakness of the metal seal system. Details of the dee tank corner seals are also shown on Figure 2.

Valley and Trim Coils

Valley Coils

The TAMVEC is a three-sector machine, with each of the three valleys containing five coils. The coils are connected in a wye arrangement similar to the LRL 88-inch machine. A relay, controlled from the control console, varies the phase angle in 10-degree increments for coils 1 through 4 and 3-degree increments for coil 5. The coil current capacity has been increased from 250 amperes for LRL to a maximum of 2000 amperes for TAMVEC. The power supplies are rated at 350 amperes. This increased capacity is accomplished by using a water-cooled mineral-insulated cable of a larger overall dimension that that used in the LRL machine. The increased cable size is permitted by slight rearrangement of coil configuration and by maintaining a tighter overall stacking tolerance. The increased current carrying capacity permits correction of larger first harmonics and also enables the future introduction of flutter. The cable used was produced by General Cable Corporation and has a 0.560-inch outside diameter. The inner conductor has an 0.385-inch outside diameter and an 0.186-inch inside diameter. This provides a cross section of 133,000 circular mills.

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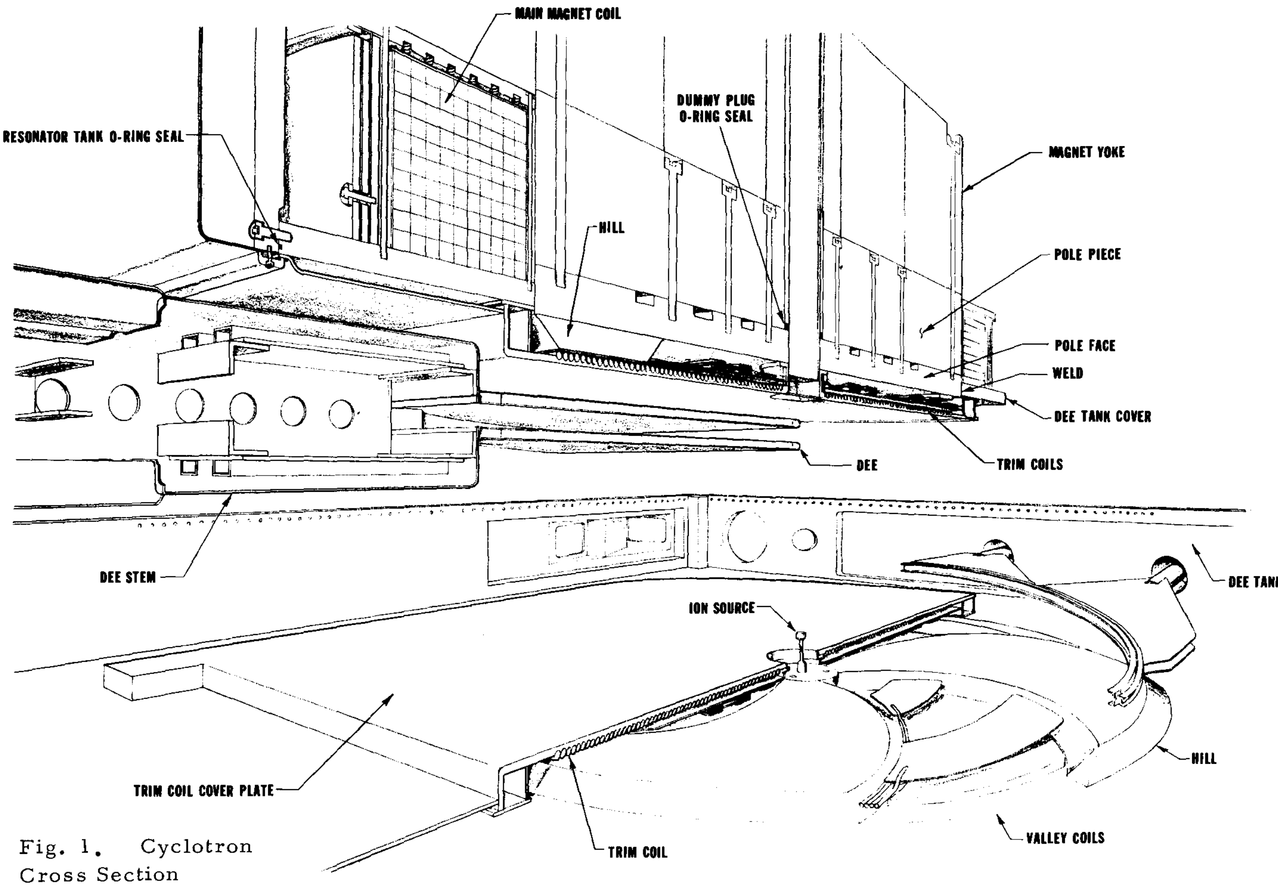

Fig. 1. Cyclotron Cross Section

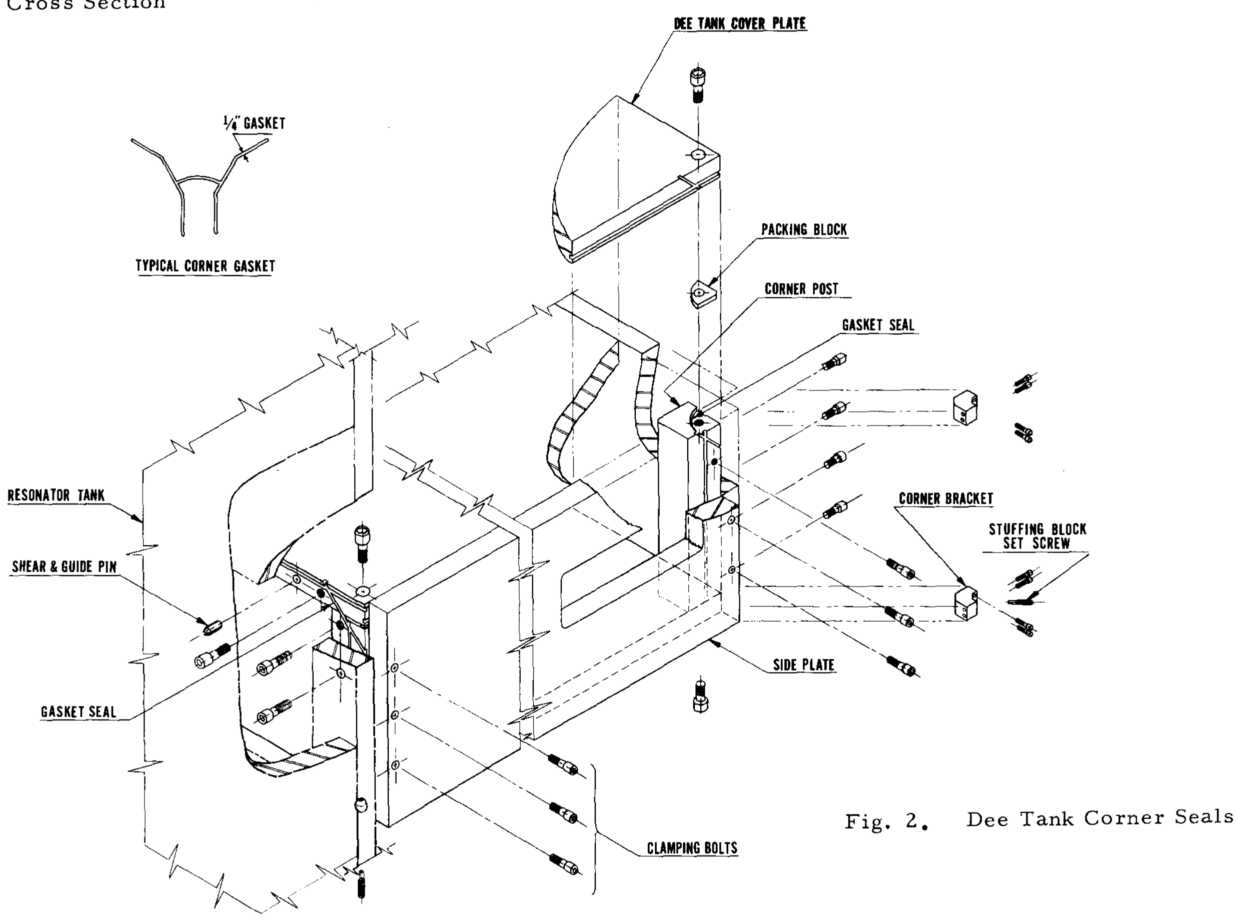

Fig. 2. Dee Tank Corner Seals

Trim Coils

The circular trim coils in the TAMVEC machine are water cooled as they are in the LRL machine. The outside diameter of the coils (0.699 inches) remains the same; however, the conductor cross-section has been increased to 156,000 circular mills, thus reducing the power requirements and permitting an increase in current capacity.

Vacuum Penetrations and Cable Terminations

The vacuum penetration and cable termination arrangement used in the LRL machine has been modified to reduce fabrication difficulties, improve vacuum properties, and reduce the possibility of moisture degradation of the mineral insulation at the cable terminal points. The coil external connections and vacuum penetrations are shown in Figure 3.

The lead assembly plate is fabricated from stainless steel and copper. Prior to assembly to the coil leads, the plate is furnace-brazed with a copper gold alloy. The leads are vacuum sealed by furnace brazing using a copper-silver alloy. Simultaneously, ceramic-to-metal cable terminations are also brazed to the leads. The cable terminations provide an absolute hermetic seal to protect the mineral insulation. The seal between the lead plate and the dee tank cover is accomplished with an O-ring. This O-ring is confined by two concentric rings which also establish maximum gasket compression. The O-ring seal assembly is used in lieu of the metal seals used on the LRL machine.

Trim Coil Power Connection

On TAMVEC, the connections between the power supplies and the trim coils are made with hollow, water-cooled, rigid conductors 0.718 by 0.718 inches in cross section. Flexible solid conductors are used on the LRL machine. The conductors used on TAMVEC reduce the power loss and increase power carrying capacity. The water is introduced at the center junction of the upper and lower coils and is removed at the power supplies. Temperature is monitored on each water outlet.

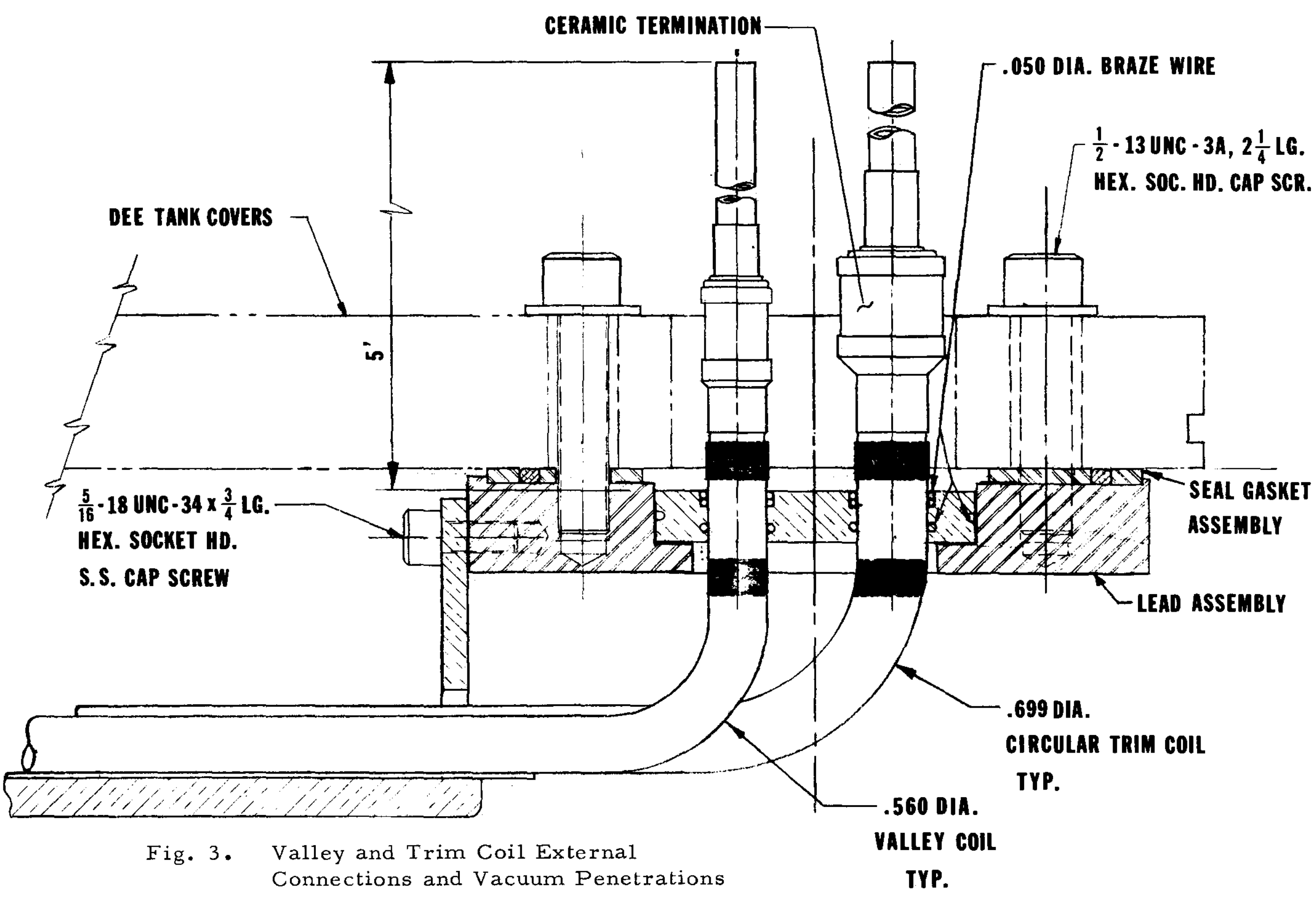

Fig. 3. Valley and Trim Coil External Connections and Vacuum Penetrations

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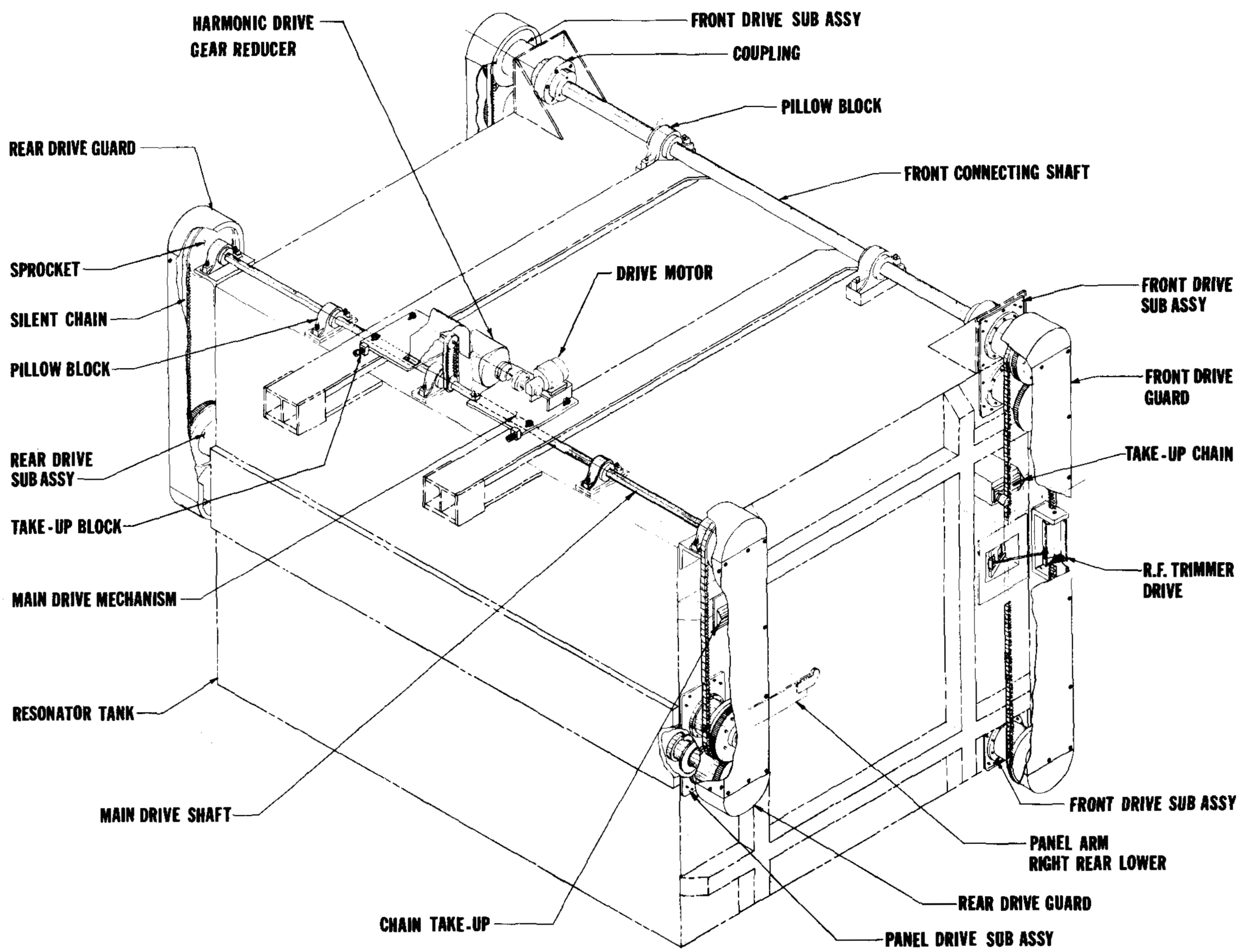

Fig. 4. Resonator Panel Positioning System

Resonator Panel Positioning System

The purpose of the panel positioning system is to accurately locate the upper and lower panel assemblies about the dee stem to establish the cyclotron resonant frequency. An isometric drawing of the system configuration is shown in Figure 4. The panels are driven through the rear panel arms. The upper and lower panel assemblies are coupled together through a low backlash gear train to provide a counter-balanced system. The front drive systems are floating. However, the panel assemblies are coupled to provide tracking and counter-balancing of the upper and lower panels.

The main drive is a dc motor. A harmonic drive speed reducer is used between the drive motor and the horizontal drive shaft. Silent chains are used to couple the drive shafts and the panel drive subassemblies. A rotary spring-loaded O-ring provides the panel shaft vacuum seal. The system is constructed from commercially available components and is used in lieu of the hydraulic system in the LRL machine.

Ion Source Positioning and Gas Systems

The TAMVEC ion source is installed in the lower yoke of the cyclotron, instead of in the upper yoke as it is in the LRL machine. In addition, the overall length of the ion source positioning mechanism is reduced to permit mounting it entirely above floor level. The general arrangement for the ion source positioning system is shown in Figure 5. Through the use of two eccentrically nested cylinders, the ion source may be positioned to within 0.005-inches repeatedly over an extended 90-degree quadrant.

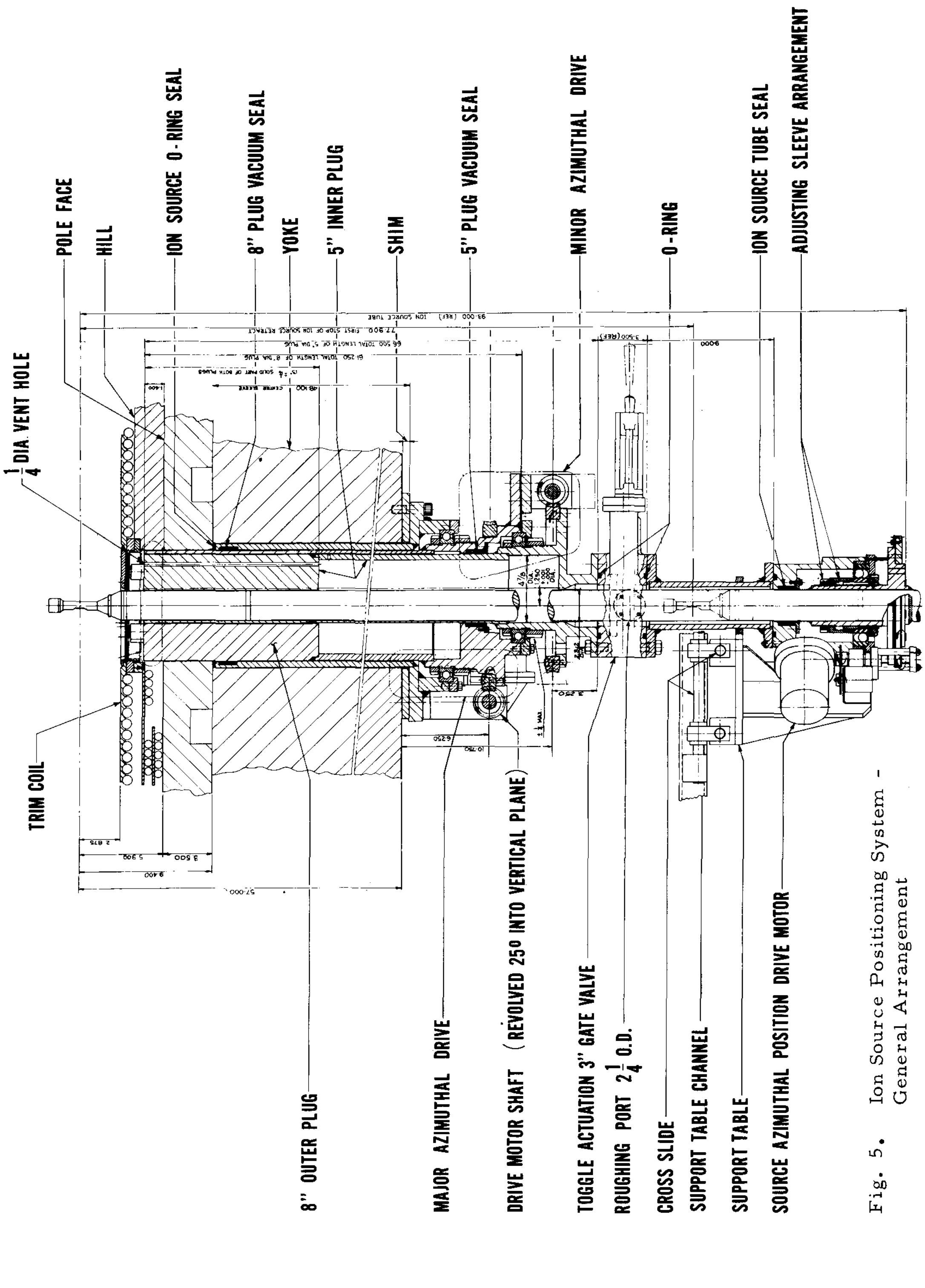

Fig. 5. Ion Source Positioning System - General Arrangement

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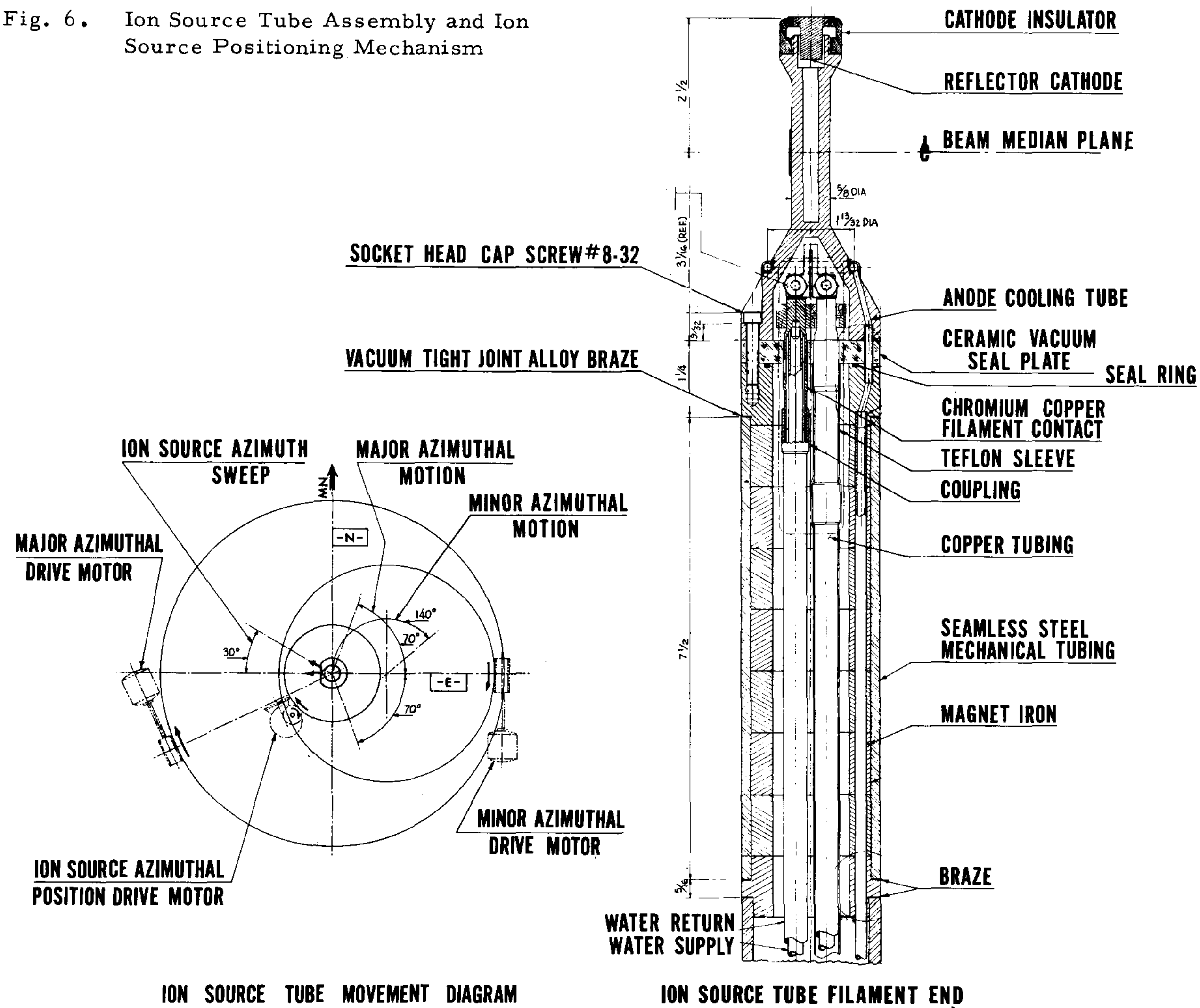
Fig. 6. Ion Source Tube Assembly and Ion Source Positioning Mechanism



As is shown in Figure 6, the ion source positioning mechanism is driven by three ac motors (major and minor azimuthal and ion source angular rotation) operated from the control console. The major azimuthal drive moves the source tube at a constant radius. To move the ion source in a radial direction the major and minor azimuthal drives are operated simultaneously in opposite directions. The ion source tube angular orientation is controlled independently from movement of source position. The ion source position is presented in x-y coordinates at the control console.

The positioning system is designed to provide easy servicing and to reduce surface area exposed to the vacuum. It is surrounded by a safety cage and service stand. The service stand provides a hoist to raise and lower the ion source tube. The safety cage provides a convenient junction point for utility connections and the ion source gas system.

The ion source gas system provides the machine operation with six different gases. The gas flow rate is regulated from the control console. The control is provided by monitoring gas pressure across an orifice in the source tube with a capacitor manometer, and by providing a feedback signal which automatically adjusts a precision gas leak valve. The system was manufactured by Granville Phillips Corporation.

The ion source tube differs from the LRL configuration in that it has been modified to reduce the volume and area exposed to vacuum and to provide for the use of ceramic vacuum seal plate. The vacuum seal plate provides the vacuum barrier between the cyclotron and the atmosphere. The filament is accurately supported from the seal plate. The plate is easily removed and replaced. The ion source tube assembly also is shown in Figure 6.

Vacuum System

The high speed vacuum system consists of a single 35-inch diffusion pump rated at 50,000 liters/second for nitrogen and 75,000 liters/second for hydrogen. It is backed by a 2250-CFM Roots mechanical booster pump and a 300-CFM mechanical pump. A second 140-CFM mechanical pump provides backing for the diffusion pump during standby operation. The vacuum system will evacuate the cyclotron to operating range -- less than 1×10^{-5} Torr -- in less than one hour. The net pumping speed at the resonator tank is 13,000 liters/second for nitrogen and 34,000 liters/second for hydrogen.

A flow schematic of the system and predicted system performance are shown in Figure 7. A freon-cooled, anti-migration, optically dense, chevron baffle is located between the diffusion pump and the main vacuum valve. The lower flange of the baffle is coated with teflon on the inner surface to act as an anti-migration barrier. A mixed isomeric, five-ring, polyphenyl ether is used as the diffusion pump fluid. The diffusion pump fluid was selected because of its low vapor pressure (1×10^{-11} Torr at a chevron baffle operating temperature of 0 degrees F) and because it can be safely exposed to an oxygen-rich environment at operating temperature.

Control System

Control Philosophy

The LRL cyclotron uses a single central control system philosophy. The control of all systems on the TAMVEC machine is also accomplished from a central control console. However, each system has a local control panel from which it can be controlled for testing and trouble-shooting purposes. Each system also is fully interlocked. The individual interlock status is displayed on the local panel, and the total series interlock status is displayed on an annunciator panel in the control room. The control system is point-to-point wired using multiconductor cables.

Power Supplies

The power supplies are constructed with all solid-state circuits to provide maximum reliability and compact design. Regulators, interlock controls, and current metering for each major subsystem are contained within the source supply cabinets. The control and regulation philosophy is shown in Figure 8, the block diagram for the main magnet power supply.

Main Magnet Power Supply. The high-current dc main magnet power supply is regulated by a phase-angle silicon-controlled-rectifier regulator system. The current stability of the supply is 0.01 percent at 3,000 amperes, with a 1 percent voltage ripple at 720 cycles per second. The supply was manufactured by Ling Electronics.

Main Oscillator Power Supply. The main oscillator power supply consists of an adjustable, precisely regulated, high voltage dc power supply for the anode; a regulated grid bias supply; and a current-limited filament power supply. The main oscillator power supply provides all necessary interlocks and controls for the oscillator system. The anode output voltage is adjustable from 500 volts to 20 kilovolts at an output current of 20 amperes at 8 to 20 kilovolts. The voltage stability is 0.1 percent. Silicon diodes are used as rectifiers and water-cooled vacuum tubes are used as series-pass regulators. Load protection is provided by a fast-acting (1 microsecond) crobar circuit. This supply also was manufactured by Ling Electronics.

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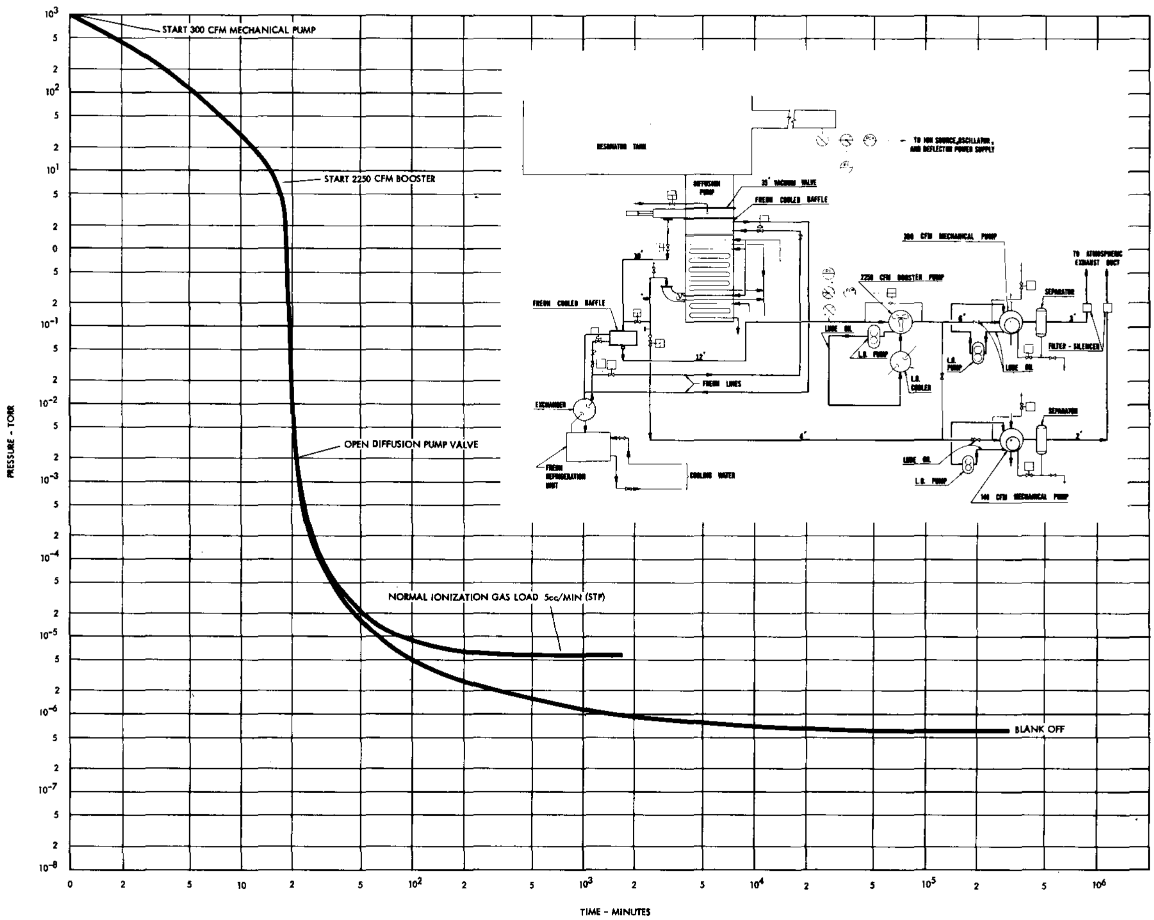

Fig. 7. Vacuum System Characteristic Curve and Vacuum System Schematic

Trim Coil Power Supplies. The 17 trim coil power supplies employ solid state circuitry. A transistor bank acts as an emitter-follower-regulator with the result that the emitter potential "follows" the base potential. The base potential is regulated by a wide band amplifier. The transistor bank also allows a response speed considerably faster than 0.1 second, which would be the limit for a silicon controlled rectifier or magnetic amplifier system.

The output metering is accomplished by use of a transductor, which has an output voltage of 10 volts at design current. By using this method, the high voltage signal is less subject to the noise pickup problems usually encountered with shunt monitoring systems. The power supplies are manufactured by Temescal Metallurgical Corporation.

Ion Source Power Supply. The ion-source arc and filament power supplies are regulated. The arc power supply is current regulated. The arc voltage is regulated by varying the emission of the filament. This is done by regulating the filament current with a feed-back signal proportional to the arc voltage. The filament power supply has an adjustable current limiting circuit which overrides the arc voltage feed-back signal as soon as the filament current reaches its limit. Transient current limiting in the arc supply is achieved by an inductor in the output, after the ripple filter. The arc current and arc voltage are regulated to 0.1 percent of maximum rating.

The arc power supply is rated at 600 volts and 5 amperes. The filament supply is rated at 500 amperes. All interlocks, regu-

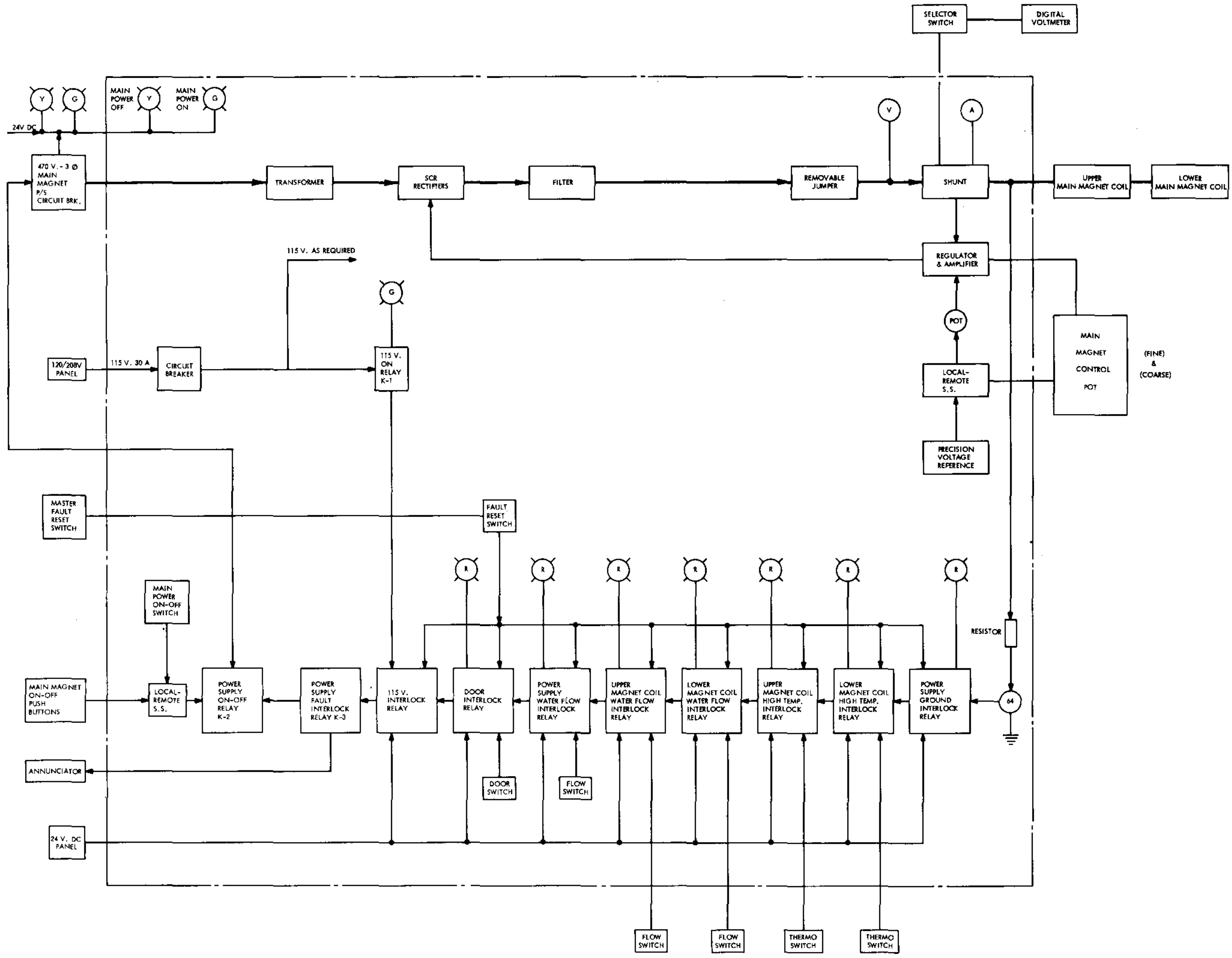

Fig. 8. Main Magnet Power Supply Block Diagram

lators, and controls for the ion source system are contained within the ion source power supply cabinet.

RF Frequency Regulating System

Frequency regulation is accomplished with a digital system. The frequency of an rf signal, coupled from the grid line of the resonator tank circuit, is measured by a digital frequency meter. The output from the digital frequency meter is compared in binary-coded-decimal form with a set point. An error signal is generated in a comparator which provides a trapezoidal-shaped pulse to control a trimmer capacitor. This is accomplished by amplifying the pulse in a wide-band power amplifier. The output pulse controls a printed circuit motor which drives the trimmer capacitor actuator.

The printed circuit motor drive time is 10 to 15 milliseconds. This provides a frequency response of the control loop of 20 cycles per second. The tracking rate of the system is 4000 cycles per second. The closed loop frequency response for TAMVEC is twice that for the LRL cyclotron.

To reduce the possibility of frequent or continuous "hunting" about the set point a SLEW/VERNIER mode of operation has been provided in the system. The SLEW mode (10 millisecond measurement time followed by the 15 millisecond drive time) is used until the set frequency is reached. When this occurs, the system automatically changes to the VERNIER mode wherein the measurement time is increased to 100 milliseconds ($\pm$ 10 cycles per second of cyclotron frequency). The longer measurement time eliminates false movements of the capacitor due to the limitations of the frequency measuring device. Removal of "hunting" characteristics from the system design is made at the expense of the control loop frequency response which is reduced to approximately 5 cycles per second in the VERNIER mode. If this response should prove to be too slow in some operational conditions, it is possible to lock-out the VERNIER mode and remain continuously in the faster SLEW mode.

The trimmer position can be manually controlled by application of a dc bias voltage. The motor speed in the manual mode is adjustable but will be initially set at a nominal 5,000 cycles per second.

Role of the Engineering-Management Firm

The Bechtel Corporation has contracted with Texas A & M University to deliver and install the cyclotron machine on a cost-plus-fixed-fee basis. Bechtel furnished the cost analysis, planning, design, liaison, procurement, etc., and awarded subcontracts to vendors for manufacturing systems and components. All efforts are being coordinated with and approved by Texas A & M University and the U.S. Atomic Energy Commission.

Unless difficulty is encountered, it is anticipated that the total time on the project, from the award of the contract to the online beam, will be only 27 months.

The manner in which the TAMVEC machine is being designed and built should be of interest to those institutions who do not have the manpower of major national laboratories, but wish to obtain first-rate research facilities on a contracted time schedule.

The machine uses fully engineered, standard components which are purchased on a specification basis. Thus vendors will provide warranties and, in the future, components can be easily replaced. The techniques outlined above, combined with the overall capabilities of a large engineering-management firm, have allowed an almost "off-the-shelf" cyclotron to be constructed for the first time.

In addition to the engineers and specialists assigned directly to the project, it has been possible to bring other specialists from the large pool available for work in other fields to assist with specific problems on TAMVEC design.

The experience gained in conducting a large yearly volume of business and in the resultant broad contact with vendors throughout the country also is a valuable assist in preparing specifications, selecting vendors, controlling costs and schedules, and advising the customer on subcontract awards. In general, this encourages a healthy competitive attitude among the vendors and results in cost savings to the customer.

References

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