VARIABLE ENERGY CYCLOTRON

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Summary

The Texas A&M Variable Energy Cyclotron (TAMVEC) is presently under construction at Texas A&M University in College Station, Texas. Bechtel Corporation is responsible for engineering, procurement, and construction of the machine. Machine engineering has been completed and construction is 80% complete.

The TAMVEC, although based on a proven design and similar in basic physics and layout to the 88-inch cyclotron at Lawrence Radiation Laboratory in Berkeley, California, nevertheless has many unique features.

The mechanical design has been changed in a number of areas, resulting in improved vacuum system and simplified RF panel and trimmer capacitor drive systems.

The electrical system has been broken down into independent functional subsystems. Each subsystem is self-contained and utilizes standard off-shelf components, separate inputs, and separate interlock systems.

A centralized control system enables the operator to set and control the machine from the main control console.

The following sections describe the machine in general.

Performance Specifications

The particle energies for various ions and the machine physical specifications are given below.

General	
Proton Energy	6 - 60 MeV
Deuteron Energy	12 - 65 MeV
Alpha Energy	25 - 130 MeV
Internal Current	1 milliampere
Extraction Efficiency	40%
Extraction Radius	99 cm

Magnet	
Pole Diameter	224 cm
Gap	19 cm min.
Sectors	3
Spiral Angle	55°
AVF Coils	5 pairs/sector
Circular Trim Coils	17 pairs
Av. Field at r maximum	17.1 kG
Magnet Power	
Main	490 kW
AVF	27 kW
Trim	433 kW

RF System	
Dees	1
Width	180 degrees
Aperture	3.8 cm
Frequency Range	5.5 to 16.5 MHz
Dee Voltage	70 kV max.
Frequency Tuning by	Movable panels
Energy Gain	140 keV/turn max.
Oscillator Power Supply Output	400 kW max.

Ion Source	
Filament Current	500 amperes max.
Arc Current	0 - 5 amperes
Arc Voltage	10 - 600 volts

Vacuum System	
Pressure	10^{-6} Torr

Magnet System

The overall dimensions of the assembled magnet core are 240 x 114 x 88 inches. The total weight is approximately 275 tons, including poles, pole tips, and the dee tank. The magnet core assembly permits installation of the ion source from the bottom or top of the structure through the magnet yoke and dee tank cover.

The poles and pole tips are fabricated from magnetic steel that has been upset forged so that the axis of the pole piece coincides with the axis of the original ingot. This increases azimuthal symmetry. The pole face is welded to the dee tank cover, creating a vacuum-tight joint. Provisions have been made for the future addition of an axial injector and a polarized ion source.

The pole tip assembly consists of three flat spiral pole tips equally spaced about the pole center.

The main magnet coil pancakes have an inside diameter of 89.70 inches, a maximum outside diameter of 113.50 inches, and a maximum height of 12.00 inches. The conductor is copper with a cross-section 1.125 inches square. A 0.666-inch diameter hole is provided in the center of the conductor for water cooling. The coils produce 5.6×10^5 ampere-turns at 2,800 amperes.

There are 17 separate pairs of concentric circular trim coils. Each coil is capable of conducting 2,500 amperes. Each of the 17 pairs of coils is connected to an individual power supply. The coils are fabricated from hollow, mineral-insulated (MI) cable. The outside sheath diameter is 0.699 inch and the inner conductor has a cross section of 156,000 circular mils.

Each of the three valleys contains five coil pairs. The coils are connected in a wye arrangement. A switching system allows rotation of the coil magnetic field azimuthally in 10-degree increments for coils 1 through 4 and 3-degree increments for coil 5. The coil current capacity is 2,000 amperes. The coils are fabricated from hollow mineral-insulated (MI) cable. The high current-carrying capacity enables the future introduction of flutter. The cable has a 0.560-inch outside diameter and the inner conductor has a cross section of 133,000 circular mils.

Resonant System

The resonant system consists of the dee assembly, RF panels, panel drive system, trimmer capacitor and drive, resonator tank, and transmission lines.

The frequency is determined by the electric line length of the dee stem, which is varied by changing the capacitance between the movable panels and the dee stem.

The frequency is variable from 5.5 to 16.5 MHz. A step-motor driven trimmer capacitor, controlled by a digital feedback system, maintains the frequency stability to 1 part in 100,000.

The dee stem is a box structure fabricated from type 304 stainless steel covered with a water cooled OFHC corrugated copper skin. The dee stem is supported from external structural members through a bellows-type vacuum seal. The dee stem and dee may be removed by a cart provided for that purpose. Stress rods are incorporated in the structure to provide for proper camber. The dee is fabricated using a box structure and water-cooled sandwich plates, top and bottom. The dee is easily removable from the dee stem.

The RF panel assembly consists of two sets of three movable corrugated water-cooled panels hinged together and operated symmetrically. Each panel is fastened to a stainless steel frame. The skin is water-cooled OFHC copper. The three panels forming the top or bottom assembly are hinged together with structural stainless steel arms and ceramic bushings coated with navy dry-film lubricant. The RF continuity between panels is provided by thin copper foil.

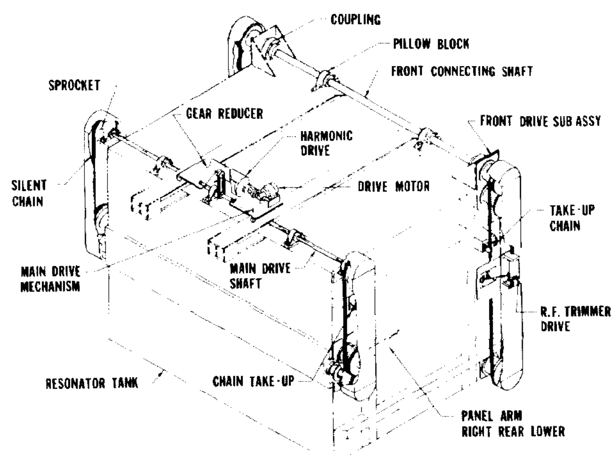

Fig. 1 Resonator Panel Positioning System

An isometric drawing of the panel drive system is shown in Figure 1. The panel assemblies are driven by a single variable speed dc motor. A Harmonic Drive speed reducer is used between the drive motor and the horizontal drive. Silent chains are used to couple the drive shafts connected to the rear of each panel assembly. A separate pair of silent chains is used to connect the front panel drive shafts together. Rotary vacuum seals are made using O-rings.

The fine frequency adjustment is accomplished by a trimmer capacitor formed by a movable panel attached to the resonator tank wall and a stator attached to the dee stem. The movable panel is supported by a shaft which penetrates the resonator tank. The movable panel is positioned by a ball-screw mechanism located external to the vacuum.

The resonator tank is fabricated from 1.5-inch carbon steel plate with external structural carbon steel stiffeners. The side and rear tank plates are copper-clad steel. Two large aluminum doors are provided for easy access, one on each side.

Ion Source Positioning and Gas Systems

The general arrangement for the ion source positioning system is shown in Figure 2.

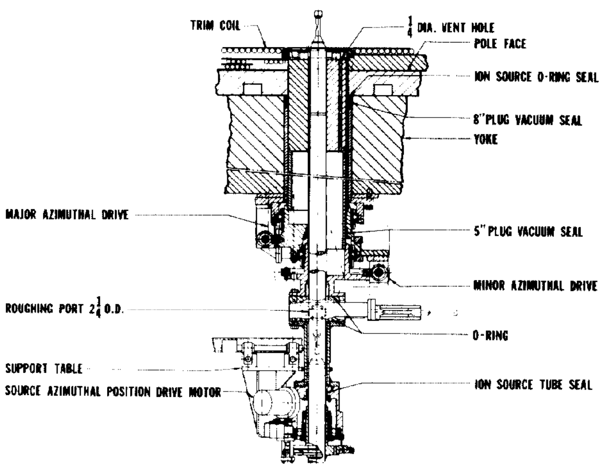

Fig. 2 Ion Source Positioning System

The ion source is positioned by three ac drive motors (major and minor azimuthal, and ion source slit angular rotation) to within 0.005 inches over an extended 90-degree quadrant. The major azimuthal drive moves the ion source tube at a constant radius. To move the ion source in a radial direction, the major and minor azimuthal drives are electrically actuated simultaneously in opposite directions. The ion source slit angular orientation is controlled independently from movement of the ion source position. The positioning mechanism is surrounded by a safety cage and service stand. The service stand includes a motorized hoist to raise and lower the ion source tube and positioning mechanism for maintenance.

The ion source gas supply system is mounted on the safety cage. The flexible utility and gas connections are terminated at the safety cage. The gas supply system allows rapid changing of up to six different gases. The gas flow control is adjusted by a precision gas leak valve. The gas flow is automatically regulated by a feedback circuit.

Vacuum System

The high speed vacuum pumping system uses a 35-inch diffusion pump rated at 50,000 liters/second for nitrogen and 75,000 liters/second for hydrogen. It is backed by a 1,000 liters/second Roots mechanical booster pump and 135 liters/second mechanical pump. A second 65 liters/second mechanical pump provides backing for the diffusion pump during standby operation. 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 is shown in Figure 3.

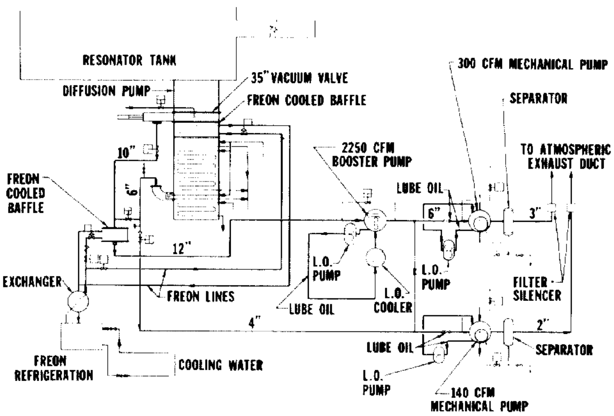

Fig. 3 Vacuum System Schematic

A freon-cooled, anti-migration, optically dense, chevron baffle is located between the diffusion pump and the main vacuum valve. A mixed isometric, five-ring polyphenyl ether is used as the diffusion pump fluid. The diffusion pump fluid was selected because of its low vapor pressure and because it can be safely exposed to an oxygen-rich environment at operating temperature.

Control System

A centralized control system, with all the machine control functions performed from the main console, is used. The control functions can be divided into the following groups:

ON-OFF CONTROLS accomplished by momentarily actuating the ON or OFF push button switches;

CURRENT, VOLTAGE and FREQUENCY CONTROLS accomplished by setting 10-turn potentiometers; and

POSITIONING CONTROLS accomplished by actuating the positioning push button switches.

In addition, each system has a local control panel from which it can be operated for testing and trouble-shooting purposes.

Each individual system is fully interlocked and the interlock status is displayed on the local panel. The summation series interlock status for each system is displayed on an annunciator on the main control panel.

Power Supplies

Wherever possible, solid-state circuits are used to provide maximum reliability and compact design. Regulators, interlock controls, and current metering are contained within individual supplies.

The 24-volt dc 350-ampere power supply is provided to power all systems' indicating lights, interlock circuits, and ON-OFF circuits.

The main magnet power supply is current regulated and is designed to deliver 3,000 amperes dc at up to 175 volts. The phase-angle silicon-controlled-rectifier regulator provides 0.01 percent regulation at 3,000 amperes. The output is filtered to provide less than 1 percent ripple at 12 times the input frequency.

Three different output ratings are provided by the trim coil power supplies.

1. Eleven 750-ampere supplies are used to power the eleven inner-most coils.
2. Four 2,000-ampere supplies are used to power number 12 through number 15 coils.
3. Two 2,500-ampere supplies are used to power the two outer-most coils - numbers 16 and 17.

All power supplies employ solid state components and have emitter-follower transistor bank series regulators. A regulation of 0.01 percent has been obtained at the maximum current rating of each power supply. The 750-ampere power supplies are contained in a single cabinet and the 2,000- and 2,500-ampere power supplies are contained in another cabinet.

Each group of three wye-connected valley coils is powered from a separate power supply. Each power supply delivers 350 amperes at 15 volts dc. The power supplies are unregulated. The current setting is accomplished by motor driven variacs in the power supplies. All five power supplies are contained in a single cabinet.

The main oscillator power supply provides the anode, grid, and filament power for the RCA 6949 power oscillator tube located in a separate cabinet mounted on the resonator tank. This cabinet also contains the necessary RF circuitry and filament transformer. The anode voltage is adjustable from 500 volts to 20 kilovolts dc maximum. Current is 20 amperes from 8 to 20 kilovolts dc. The grid voltage is adjustable from -50 to -500 volts dc. The voltage into the filament transformer is adjustable from 0-800 volts ac. The anode and grid voltage stability is 0.1 percent. Silicon diodes are used as rectifiers and water-cooled vacuum tubes are used as series-pass regulators. The overload protection is provided by current overload relays and by a fast-acting crowbar circuit.

Multipactoring phenomena sometimes occur in the resonator system at isolated frequencies. A pre-exciter is provided to drive the resonator system through the voltages where the phenomena occur. The pre-exciter system is packaged in two separate cabinets: the pre-exciter oscillator cabinet and the power supply cabinet. The pre-exciter oscillator cabinet contains the oscillator and the power amplifier with all associated electronic equipment. The power supply cabinet contains all power supplies and the interlock circuits. The amplifier anode voltage is adjustable from 0 to 10 kilovolts dc. The amplifier screen voltage is adjustable from 0 to 1,000 volts dc, and the grid bias voltage is adjustable from 0 to 500 volts dc. All pre-exciter power supplies are unregulated and voltages are remotely controlled from the main console.

The ion source arc and filament power supplies are regulated. The arc power supply is current regulated. The arc voltage is regulated by controlling 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 feedback signal if the filament current reaches a set limit. 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 at 15 volts.

An electrostatic deflector is used for beam extraction from the cyclotron. A very low energy storage electrical system supplies from 0 to 120 kilovolts dc to the deflector plates. The deflector power supply system consists of a common dc supply providing plate voltages of 2,500 to 3,500 volts dc, adjustable by transformer taps, to two 100 kHz oscillators. The output of each oscillator is then fed into Cockcroft-Walton rectifiers. The output of each rectifier is connected to one of the two deflector plates. Each power supply output is protected by a fast-acting crowbar circuit.

RF Frequency Regulating System

Frequency regulation is accomplished with a closed loop digital servo system. A frequency sensor, coupled to the grid line of the resonator tank circuit, transmits a signal to 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. The output signal of the comparator is fed to a pulse shaping network and amplifier. The output pulse of the network is trapezoidal and is used to drive a printed circuit motor. The motor drive time per correction is 10 to 15 milliseconds. This provides a correction frequency response rate of 20 Hz for the control loop. The control system can track and adjust for frequency shifts up to 4 kHz.

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. The longer measurement time eliminates false movements of the capacitor due to the limitations of the frequency measuring device.

The trimmer position can be manually controlled from the main console by application of a dc voltage to the printed circuit motor. The motor speed in the manual mode is adjustable, but has been initially set at a nominal rate of 5 kHz.

Positioning Systems

The following cyclotron items are positioned with dc or ac motors:

1. Ion source - 3 ac motors.
2. RF panels - 1 dc motor.
3. Grid line capacitor - 1 ac motor.
4. Deflector - 7 ac motors.
5. Probes - 4 ac motors.

All positioning control equipment, including the power supply for the position indicating system, is contained in one cabinet. All positioning motors, except the RF panel drive motor, are fractional horsepower and are operated from 120 volts ac. Limit switches are included in all positioning systems for protection.

Vacuum Control System

A vacuum control system cabinet contains all pump and valve actuating relays and related equipment. A semi-automatic sequential controller provides simple and reliable operation.

Instrumentation

The control instrumentation is used for emergency shut-down purposes. During the cyclotron opera-operation, two systems can be considered critical: the cooling water system and the vacuum system. The loss of either or both of these can cause excessive damage to the machine. Therefore, both systems are heavily instrumented to monitor the system status and to shut off the machine in case of system failure.

The indicating instrumentation is used for informing the operator of the status of various systems. These instruments are located on the control console and on the control panel just a few feet in front of the main control console. The parameters such as coil currents and voltages, RF voltages, and frequency are considered critical for monitoring the performance of the machine.

Acknowledgment

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