MODULAR ACCELERATOR DESIGN

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Summary

A modular approach to the design of accelerators is presented. A 30-inch AVF cyclotron has been built on this approach where all major assemblies are self-contained modules. Each unit, such as the magnet, RF system, vacuum system, ion source, and extraction system, was independently assembled, operated, and tested. Such an approach enabled the accelerator to be so flexible that systems of different designs, such as two-dee or single-dee acceleration, could be interchanged without modifying other parts of the machine. The features which permitted this approach on the now operational 30-inch cyclotron are presented, along with suggestions on how a modular design concept might well be used on larger accelerators.

Introduction

The Cyclotron Corporation started the design of a low-energy, multiparticle AVF cyclotron in November 1965. This cyclotron can be used for a variety of applications in the fields of nuclear medicine, physics research, and activation analysis. Because of the numerous applications the cyclotron can serve, a design of sufficient flexibility was required to meet the various anticipated requirements. To meet these objectives, the cyclotron was designed using a modular concept based on five main functional systems which form the basic modules of the cyclotron. Each cyclotron module was fabricated and tested within 10 months from start of design. The modules were assembled together in a matter of days. An internal beam was obtained from the modular-designed cyclotron at full extraction radius in early October 1966. Modules for a second and third cyclotron are now being fabricated with modifications within some modules without affecting other modules of the cyclotron. Although some additional packaging is required in a modular design, a very compact design is still possible on the 30-inch cyclotron. Figures 1 and 2 are photographs of the modular-designed cyclotron.

Design Concept

During the preliminary design phase of the AVF cyclotron, several major design parameters could not be immediately resolved. Such parameters revolved around basic considerations such as whether to have a single- or two-dee accelerating system, three- or four-fold symmetry magnet field, first- or higher-order harmonic RF frequency, axial or radial injection source, plus a multitude of component design decisions. In order not to delay the completion of the cyclotron, a modular concept was used which breaks the cyclotron down into major functional systems to permit the start of fabrication of those systems in which a design had been finalized. The cyclotron was divided into five major systems consisting of the magnet, the RF accelerating system, the vacuum system, the injection system, and the extraction system. Each system was designed to be a self-contained module with a minimum of external equipment required for its operation. All necessary monitoring instruments, gauges, electrical wiring, mechanical structure, and cooling manifolds were designed into each system to allow independent operation and testing. Each system terminated with standardized electrical, control, and cooling water connectors for mating to adjacent systems of the cyclotron.

Some of the advantages of a modular-designed accelerator are: Fewer items are on a critical path scheduling; design changes and product improvements can be incorporated in subsequent cyclotrons; an obsoleted or failed system can be more easily replaced with a minimum of down time. In our particular case, there is the additional advantage that, should a catastrophe occur to one system in a cyclotron installation, it is possible to exchange the system from another cyclotron not in operation. When the modules are brought together to complete the cyclotron assembly, there are relatively few mechanical and electrical connections to make.

Figure 3 depicts the components of the cyclotron. The magnet and its support stand serve as the physical base for the other systems. A central water supply and return manifold are located on one end of the magnet stand, and a central power distribution and control wire panel are located on the opposite end. Leads from the anode and magnet power supplies and all wires from the control console are routed to the central power distribution and control wire panel. Each system's power, control, and cooling water connections are made to these central supplies on the cyclotron stand. Thus, a system can be removed and reinstalled on the cyclotron with simple consolidated connections and without complicated routing to various connections.

Magnet

The magnet, being the heaviest and largest item of the cyclotron, serves as the core of the cyclotron, and all other systems are attached to it. The magnet yoke has a central hole through the upper and lower poles, making it possible to use an axial ion source. The magnet is energized by a pair of aluminum foil coils around each pole base. The aluminum foil, with anodized insulation surfaces, is wound around a mandrel and then cast in a high-impact-resistant epoxy to form a rigid pancake assembly. Each pair of coils is edge-cooled by a ½-inch-thick water manifold which is sandwiched between the two coils. Mica is used to electrically insulate the coils from the water manifold, and a heat sink compound is used to provide good thermal conductivity between surfaces. This coil design yielded a conductor space factor in excess of 80 per cent, as opposed to water-cooled hollow conductors which have a conductor space factor of less than 60 per cent. It was found that up to 5 watts of heat per square inch could be dissipated by edge-cooling. The pancakes and cooling manifold are separable units and can easily be replaced should either fail in service.

RF Accelerating System

The RF accelerating system was designed as a completely independent system mounted on casters. The entire RF system can be rolled up to the cyclotron with the dees protruding into the vacuum tank. When the RF system is in position, the dee cover plate is bolted down to provide a vacuum-tight seal. Leads to the anode power supply, cyclotron console, and cooling water connections are all made between a central connector on the RF system and a power and water distribution system on the cyclotron stand. These connections can all be made in less than 30 minutes. Voltage and current meters, water flow, and temperature interlocks are built into the RF system. Therefore, the RF system can be operated before installation without separate instrumentation, test, or bypass connections. Although a two-dee accelerating system was built and installed, the cyclotron was designed at the outset to also accept a single-dee accelerating system. This was accomplished by designing a standard vacuum insulator to support the dees. The vacuum insulator design, as shown in Fig. 4, can be used in either a single- or two-dee accelerating system. The insulators have been tested up to 30 kV at 25 Mc/s with a vacuum of less than 1×10^{-6} torr inside the insulator. The RF system was fabricated as three subassemblies consisting of the oscillator, resonator, and accelerating dees. The oscillator fastens to a hinged panel of the resonator, as shown in Fig. 5. The accelerating frequency for the different particles is changed by opening the hinged panel and replacing the resonator strap. The vacuum insulator is also accessible through the resonator and can be quickly replaced should it fail. The RF system was designed such that the accelerating dees form a single assembly which mounts between the resonator and vacuum tank and is separable from either the resonator or vacuum tank. This design permits the cyclotron vacuum to be maintained should the oscillator and resonator be removed from the cyclotron.

Vacuum System

Vacuum for the cyclotron is provided by a packaged, high-vacuum pumping station which is housed in a portable enclosure. All vacuum components are contained in the enclosure, including interlocks which close the high-vacuum valve to isolate the vacuum system from the cyclotron chamber should either the foreline or cyclotron tank pressure rise above a preset value. Electrical power, cooling water, and air supply connections are made from sources on the magnet stand to a central connector panel in the vacuum system. The vacuum system can easily be removed from the cyclotron for servicing and performance testing. Before installation onto the cyclotron, the vacuum system was used to provide the vacuum on a test tank for RF system testing.

The cyclotron vacuum chamber consists of a pair of vacuum plates around the pole base and a ring enclosure which sandwiches between the vacuum plates. The vacuum ring contains a series of ports for installation of the RF accelerating dees, a radial ion source, beam probe, beam exit valve, and pressure gauge. Additional ports are provided on the vacuum ring for viewing and leak checking. The vacuum plates are used to hold the coils in place around the pole base, and access to the cyclotron vacuum chamber is made by lifting the upper portion of the magnet from the vacuum ring, as shown in Fig. 6. The vacuum chamber is leak checked by installing a helium-sensitive mass spectrometer head directly to one of the ports on the vacuum ring. This method of leak checking does not require a separate vacuum system and offers faster response time and cleanout time from a helium leak. Although this method has a lower sensitivity, leaks in the order of 10^{-6} atm cm^3/s are detectable.

Ion Source

Two ion sources have been designed for use with the cyclotron. They are an external ion source for generating negative hydrogen ions and an internal ion source for generating multi-particle ions. The external ion source was designed for axial injection into the cyclotron through a central hole in the upper magnet yoke. The internal source was designed as a radial source which fits through and mounts onto a port on the vacuum ring. Both sources were developed and tested independent of the cyclotron. The external ion source contains its own vacuum pump and magnet, whereas a test magnet and vacuum enclosure were required for testing the internal ion source. Like the other systems of the cyclotron, either ion source can be installed onto the cyclotron with a minimum of mechanical assembly. Simple electrical power and cooling water connections between the ion source and the central supplies on the magnet stand are all that are needed.

Extraction System

The final extraction system was developed after the cyclotron had been in operation. The extractor and septum are assembled on a common mounting plate which bolts directly onto one of the cyclotron poles. The extractor power supply and high voltage transmission line are contained in a separate enclosure which connects onto the lower vacuum plate. Electrical and cooling water feed-through connections are mounted on the lower vacuum plate, and connections to the high voltage extractor are made in the vacuum region of the cyclotron. An earlier version of the extractor contained two motor-driven positioning drives mounted on a vacuum cover plate. The entire extractor plugged into the vacuum ring, and electrical connection was made as the extractor was plugged into position. The cyclotron can still accept either extractor module and, hopefully, other extractor designs which may develop.

Modular Design of Large Accelerators

A modular design concept has proven useful on an operating 30-inch AVF cyclotron and has enabled valuable savings in time and effort during the removal and reinstallation of components for design modification, servicing, and testing. The modular-designed cyclotron is also less susceptible to obsolescence. It is conceivable that the efficiency of the ion source on the cyclotron may be improved in the future to a point where the gas load becomes greatly reduced. Accordingly, it would be quite easy to install smaller capacity vacuum pumping systems on existing and subsequently manufactured cyclotrons.

A modular design concept could well be extended to larger accelerators. By judiciously separating the functions of the numerous subsystems on an accelerator, it is possible to design various components into independent modules. The vacuum for a large accelerator may require a large number of vacuum pumps, each requiring mechanical backing pumps, electrical power, control instrumentation, and water-cooling. By combining all the components for each vacuum pump into independent modules, the vacuum for a large accelerator could be designed to accept a series of identical modular vacuum systems with a spare system to serve as a standby replacement should one system fail, or rotated among the other systems on a periodic replacement schedule for servicing or oil changing in the case of diffusion and mechanically pumped systems. Radio-frequency components could be modularized in a like manner. Feasible places where RF components could be separated are at inductive or capacitive coupling portions of a circuit or at a vacuum feed-through connection. In many instances, large accelerator components are made in several mechanical sections to facilitate handling. By selecting the place of sectioning on a functional basis, it may be possible to make the mechanical sections into independent modules where the control, electrical, water, air, and vacuum interconnections between sections are minimized and localized. The great ease with which modular components can be assembled and replaced on an accelerator is most advantageous on large accelerators as components can be quickly removed from radioactive areas of the accelerator and serviced in a safer area.

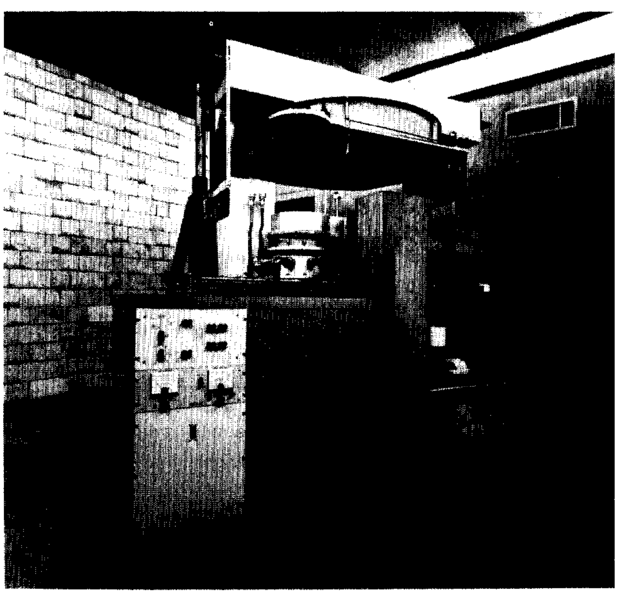

Fig. 1. View of the vacuum system and RF system (with the oscillator panel removed) on the modular-designed 30-inch AVF cyclotron.

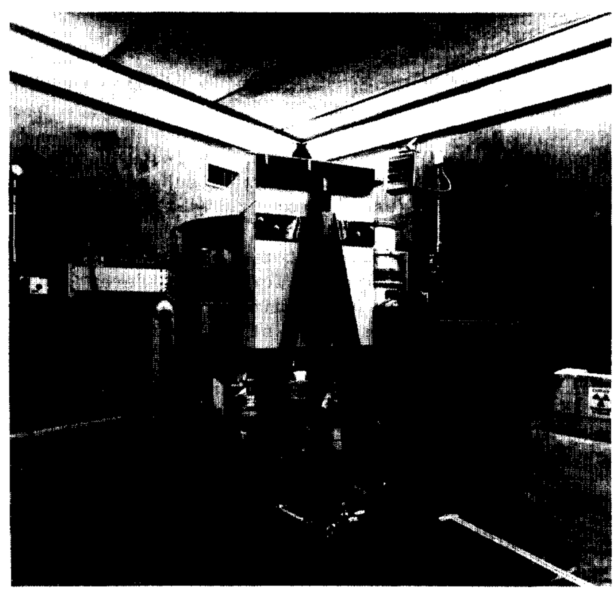

Fig. 2. A modular-designed 30-inch AVF cyclotron.

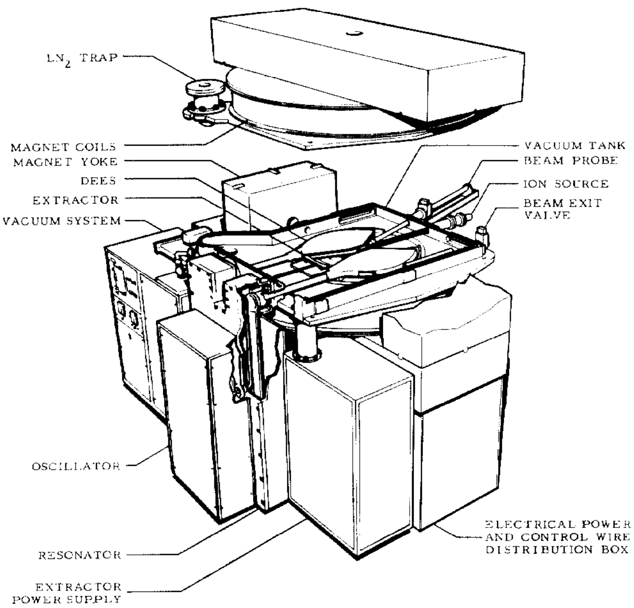

Fig. 3. Modular components on the 30-inch AVF cyclotron.

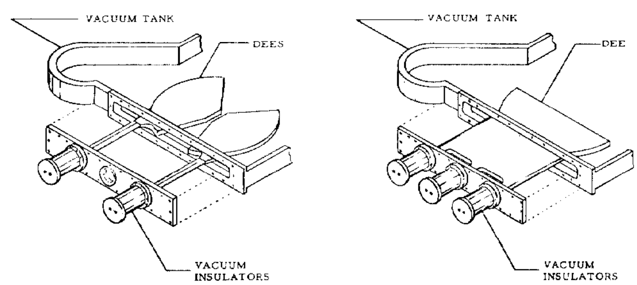

Fig. 4. Interchangeable single-dee or two-dee accelerator design.

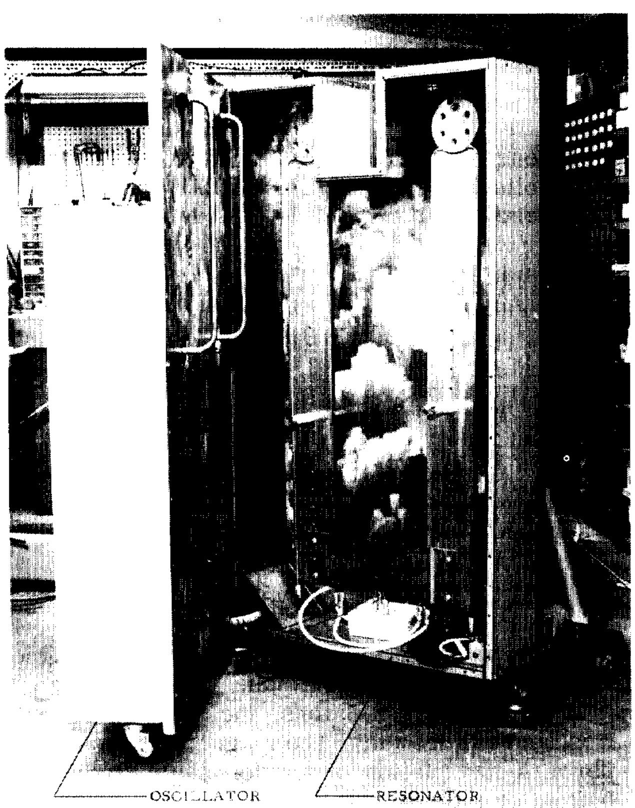

Fig. 5. Hinged resonator panel opened for access to resonator straps and vacuum insulators. Oscillator is fastened to the hinged panel with the oscillator coupling loops extending through the panel.

Fig. 6. Upper magnet pole raised for access to vacuum chamber.