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UPGRADING THE ARGONNE 4-MV DYNAMITRON*

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Summary

Recently a new type of accelerator tube,[1] made entirely of ceramic and metal and containing no organic material, was installed in the Argonne 4-MV Dynamitron.[2] Instead of being cantilevered from the base of the accelerator as was the old tube, the new tube is suspended from the main frame by a set of compact springs of unique design. Consequently, the main frame had to be strengthened against sidewise sway. The new structural members also markedly increased the shear strength of the frame.

Previously ion-source assemblies were mounted directly on and their weight supported by the accelerator tube. Now the weight of each source is carried by the terminal frame, and provisions have been made for aligning each source to the tube. To provide space for a new source assembly which incorporates mass analysis, various electronic circuits within the terminal were relocated and the terminal wiring was rerouted. The accelerator has performed well since the modifications.

Introduction

Since its installation in 1968, the 4-MV Dynamitron has been developed into a reliable accelerator that supports a wide variety of research. One important area of research is the investigation of radiation damage induced by energetic heavy ions. Several particle microamperes of ions with masses in the range $50 < A < 65$ are used in these studies. Under such use accelerator tubes supplied by the vendor of the Dynamitron have had disappointingly short lifetimes. The original tube supplied with the accelerator was so badly damaged after about 6000 h (250 days) of running time that the maximum terminal voltage was limited to less than 3.5 MV. A second tube lasted only 1500 h to 62.5 days. Because of a shortage of operating funds, the two best sections of the second tube were salvaged and combined with four new sections to form a third tube. After its installation, however, terminal voltages were still limited to values generally below 3.0 MV. Such performance forced a reduction of the scope of our experimental program for some time.

During this period a new type of accelerator tube[1] became commercially available. The new tube is so different from all others on the market that it forms a class by itself. Its properties seemed so unique and appealing that, even though no extensive experience with accelerating large currents of heavy ions existed, we decided to install such a tube in the Dynamitron. The vendor agreed to build us a tube to fit the Dynamitron and to incorporate some features not previously built into its tubes. The tube was installed during the spring of 1974.

The Accelerator Tube

A. Description

The accelerator tube consists of twelve modular accelerating sections and thirteen decoupling sections. Figure 1 is a schematic representation of one accelerating section and two decoupling sections. Each accelerating section is made of a stack of concentric alumina rings and thin hollow titanium discs bonded together between two end flanges by a proprietary technique that uses no organic glues. Reentrant titanium electrodes snap onto the flat discs and can be easily removed. Thus the interior surfaces of the ceramic insulating sections can be visually inspected and cleaned by any of several techniques if necessary. The inside diameter of each electrode is 8.25 cm.

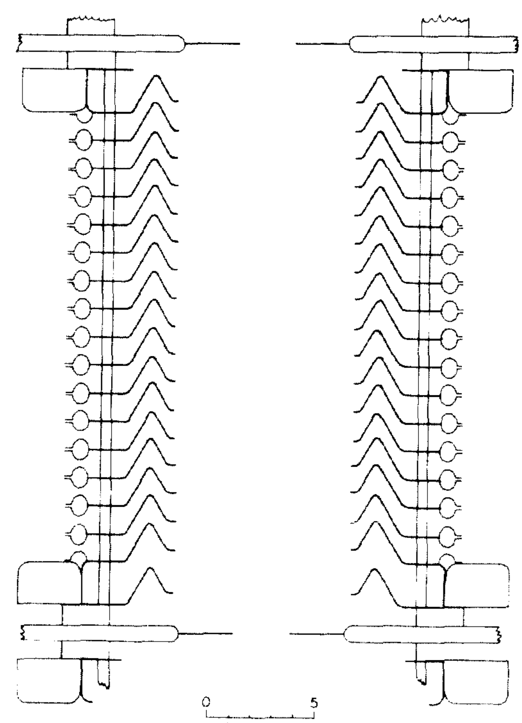

Fig. 1. A schematic cross section of a section of the accelerator tube and two decoupling sections.

Both the inside and outside surfaces of the ceramic insulators are shielded from radial electrical fields. The inside surface is protected by the reentrant electrodes. In addition, stray or scattered ions are greatly deterred from reaching the interior walls of the insulators. Toroidally-shaped spark gaps located around the tube provide the radial shielding to the outside surfaces.

Decoupling sections are placed between modular sections of the accelerator tube and at each end. The basic feature of a decoupling section is a diaphram which has an internal diameter of 2.54 cm. The diaphram helps prevent stray ions from striking the tube electrodes. Gas is pumped around these diaphrams as well as through the 2.54 cm apertures. The diaphrams are easily removed; hence, if for any reason the diameter of the apertures need be changed, it can be done. It would require disassembling the tube however.

B. Assembly

Figure 2 shows the accelerator tube being assembled. The manufacturer advised that in assembly the tube be aligned straight to an accuracy of ± 1.5 mm. The tube was stacked vertically on a heavy metallic plate that was rigidly fastened to the floor and carefully leveled with the aid of a precision bubble level. The required precision of the alignment of the diaphrams in the decoupling sections was accomplished with the use of a micro-alignment telescope and a right-angle prism mounted to look down through the tube, a plumb line to adjust the sighting to true vertical, and the precision bubble level to insure the diaphrams were square with the axis of the assembly. As the tube was stacked, the previously assembled portion was kept under compression by tension rods on opposite sides of the tube. The device for transferring the compressive load from section to section can be seen near the top of the tube in Fig. 2. The compressive load was 364 kg, not too much less than the force that would be exerted on the evacuated tube by the SF_6 gas in the Dynamitron. Soft aluminum gaskets were used between tube sections.

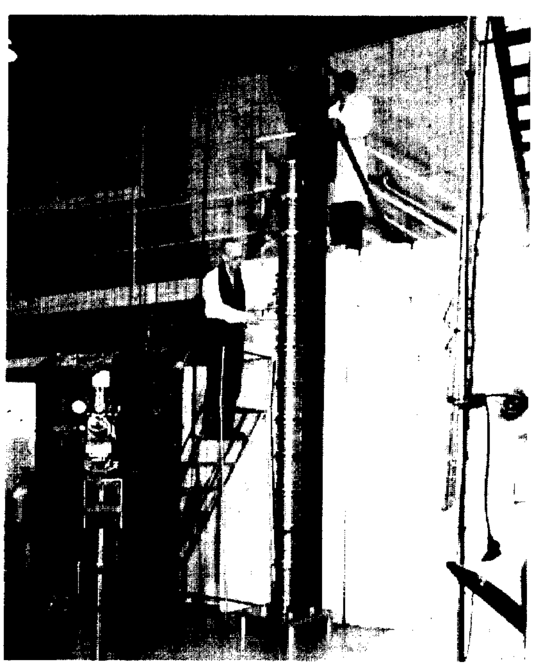

Fig. 2. The accelerator tube being assembled.

The assembled tube consists of twelve modular sections and thirteen decoupling sections. A modular section is 27.8 cm long and a decoupling section is 2.7 cm thick. The assembled tube is 3.68 m long.

C. The Voltage Divider

After assembly a wooden cradle was lashed to the accelerator tube; it was laid down horizontally and the voltage divider attached directly to the tube. Figure 3 shows a section of the tube with the divider in place. The new divider incorporates features that were developed by the supplier[2] of the Dynamitron, though it looks entirely different from their system. The divider is assembled from 2W, 10-MΩ carbon resistors. Eight such resistors are connected in series between each pair of electrodes, and six between an end flange and the adjacent electrode. Phosphor bronze resistor mounts are attached directly to the toroidal spark gaps and keep the resistor sub-assemblies under tension. The sub-assemblies are staggered to increase the insulating gap between adjacent units.

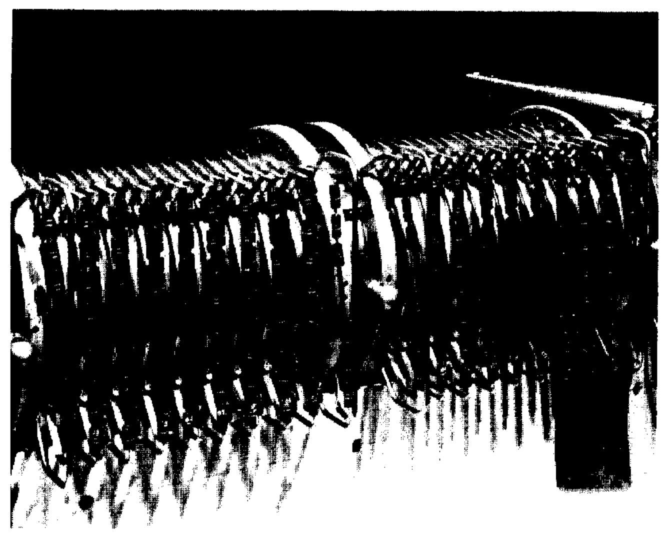

Fig. 3. A section of the voltage divider as it is attached to the accelerator tube.

The resistor units are protected from stray electrical fields by stainless steel tubular shields which are fastened to each electrode and to the end flanges and surround the resistor assemblies. Four of the shields are visible in Fig. 3 near the ends of the accelerator tube sections. The resistor divider used with the old tubes was similarly protected. In the six years that the Dynamitron has been used, not a single resistor has failed. We believe that this reliability can in large measure be directly attributed to the use of such shields.

Installation of the Tube

A. Preliminary Considerations

The Dynamitron is a horizontal machine with its main frame cantilevered from the base plate of the accelerator. The frame was constructed of acrylic (Plexiglas) sheets mounted in a vertical plane. It consisted of two parallel members 3.96 m long and 50 cm apart and connected near their top and bottom edges by two rows of tie rods made from aluminum tubes and spaced 7.6 cm apart. The frame was adequately strong and rigid in the vertical direction, but was surprisingly flexible in the horizontal direction. The old accelerator tubes were also cantilevered from the base of the accelerator and were mounted almost independently of the main frame. Ion sources were mounted directly on the high-voltage end of the accelerator tube.

For some time we had wanted to stiffen the main frame in the horizontal direction. It was so weak that cooling fans blowing the high-pressure SF_6 gas caused the high-voltage terminal to sway at times and thus modulate the accelerator voltage. In addition, the design of the new tube made suspending it from the main frame desirable. To do so, however, would require a stiff frame. For these reasons, and since the installation of the new tube presented an opportune time, we decided to modify the frame.

B. Modifications of the Main Frame

Figure 4 is an end view of the modified Dynamitron frame. The original vertical members carrying all of the original mounting hardware were retained. Two additional acrylic plates, added top and bottom, convert the frame into a box girder. They are attached to a new set of cross bars formed from stainless steel sheet 3.2 mm thick and spaced 30.5 cm apart. The new cross bars are visible in Fig. 4 at the top of the frame and through the new plate at the bottom of the frame. The large washers that can be seen at the point where the acrylic plate is fastened to the cross bars protect it from electrical breakdown and have been found to be absolutely essential. The large holes visible along the center line of the lower plate are 17.8 cm in diameter and allow access to the interior of the frame. An identical set of holes are provided in the upper plate.

A new heavy aluminum ground plane, 2.5 cm thick, was installed at the base of the main frame. The upper plate is rigidly attached to the ground plane which also serves as a thrust plate for the lower acrylic plate. The new structural members have increased the horizontal strength of the frame by several orders of magnitude and, in addition, have markedly increased its vertical-shear strength.

C. Hanging the Tube

At its ground end the accelerator tube is anchored to a gimbal-ring support and is connected to the drift tube through a flexible metal bellows. The weight of the tube is transported to the main frame by six pairs of hangers fastened to every other upper cross bar. Each hanger consists of a spring-loaded delrin rod, a spring housing, and a spring of unique design[3] which exerts a constant force independent of extension. Our springs were designed to carry a constant load of 11.8 kg over a range of motion of 2.5 cm. The tube hangers can also be seen in Fig. 4. One of the tube supports is attached to the first pair of hangers in the figure.

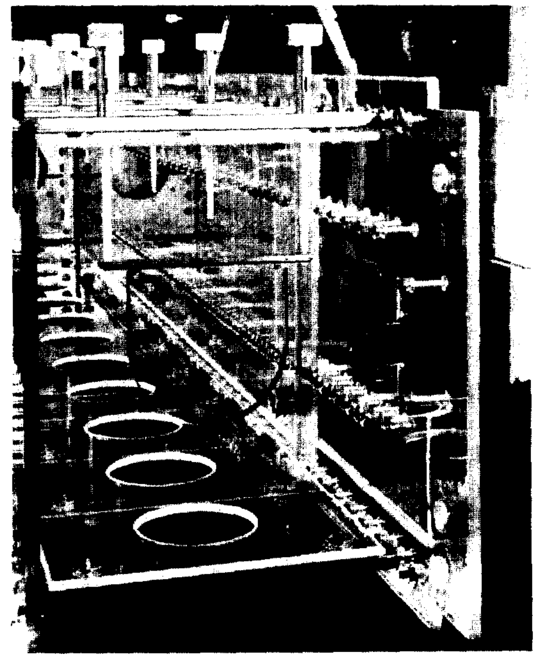

Fig. 4. The main support frame of the Dynamitron.

Figure 5 shows the tube in position in the main frame before the terminal frame was attached. With the tube alone in place, the hangers just exactly carry its weight. Within the dynamic range of the springs, the tube will remain in any position at which it is placed. The additional weight of the gate valve attached to the high-voltage end of the tube was sufficient to extend the springs to their limit. Hence the lab jack visible in the picture was temporarily used to hold up the end of the tube.

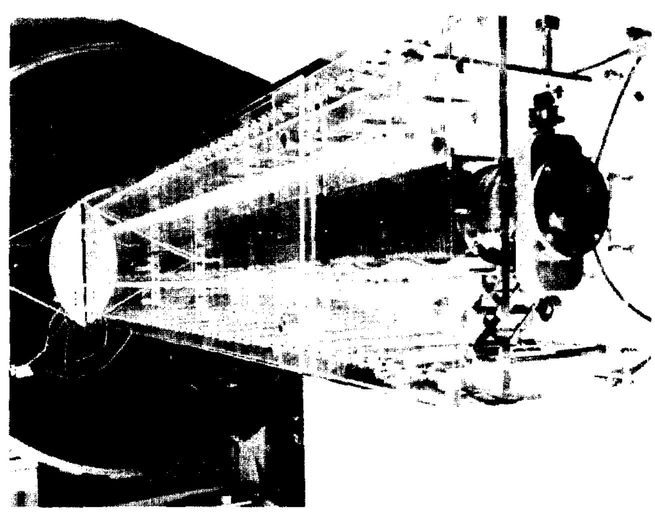

Fig. 5. The accelerator tube in position in the main frame. The tubular shields that protect the voltage divider from stray electric fields are visible on the left-hand side of the tube.

In use, the high-voltage end of the accelerator tube is located by the ion source assembly. Ion sources are now suspended from the terminal frame. Adjustable supports were developed so that the individual ion source systems can be positioned and attached to the accelerator tube without introducing any strains. The gate valve allows ion source systems to be exchanged without admitting air into the accelerator tube.

Other Modifications

A. Terminal

The experimental program conducted at the Dynamitron uses several separate ion-source systems with several variations of each possible. Recently a new system, that momentum analyzes the ion beam before it enters the accelerator tube, was acquired. To provide space for this system, several of the power supplies had to be rebuilt into more compact units, and several of the electronic units had to be repositioned within the terminal. All of the interconnecting wiring was rerouted. The new system now fits comfortably into the machine.

B. Elimination of the Second Voltage Divider

In addition to the voltage divider that distributed the voltage along the accelerator tube, a second identical resistor divider had been mounted in parallel with the first between terminal and ground. It was used to measure the terminal voltage and provide an electrical input to the voltage-regulating system for the machine.

Over a period of several years we have found that a generating voltmeter is a satisfactory substitute for the second voltage divider. It is equally reliable, more precise, and its response is linear with terminal voltage. The second divider had gradually become a back-up system. When the new tube was installed a decision was made to eliminate the second divider entirely. To date we have not felt a need for this spare system. Its elimination does remove a possible source for triggering sparks down the column.

Operational Experience

A. Vacuum

The new tube is an all metal and ceramic system. However, all of our ion source systems use rubber O rings for vacuum gaskets and certain parts are bonded together with organic glues. The drift region beyond the accelerator tube and all beam-line systems are conventional vacuum systems that use O-ring gaskets. The tube is pumped by a 650 ℓ/sec turbo-molecular pump backed by a 10.2 cm oil-diffusion pump and a mechanical pump. After the tube was installed, a vacuum of 4×10^{-8} Torr just outside the pressure vessel was obtained after a few days of pumping. The tube was then outgassed by running a set of internal heaters until the temperature of the outer surface of the tube reached 60°C. While the tube was being baked, the base pressure rose to 8×10^{-8} Torr and then fell back to 4.8×10^{-8} Torr after a few hours. After cooling the pressure stabilized at 3.5×10^{-8} Torr.

B. Performance

Experience with the new tube has been generally favorable. Since the initial tests were completed in June, 1974, the Dynamitron has been used regularly 24 hours per day, 5 days per week. It easily reaches the design voltage of 4 MV and has run up to 4.5 MV. At this level the terminal voltage is limited by the RF drive power and not by the accelerator tube. We believe the tube will run up to at least 5 MV.

To date there is no overt evidence of damage to the tube either internally or externally by electric arcs or sparks. Spontaneous loading currents and X-ray production is much less in the new tube than in the old. It "conditions" rapidly as one raises the terminal voltage. When the machine sparks, gas bursts in the vacuum system are much less severe than previously. After six months use, an attempt to outgas the tube produced only a fractional rise in base pressure during the process.

The ion beam optical characteristics are good. It is easy to focus a beam to a spot size ≤ 5 mm in diameter. From day to day the beam emerges from the machine in the same way and along the same path, though it does appear to emerge from the tube about 1.5 cm off axis.

The only problem we have encountered to date is that the maximum beam current available is about half what could be obtained previously. Even so, we have used more than 250 μA of helium ions on target. Attempts to accelerate very large ion beams create a spontaneous loading condition in the tube that causes the terminal voltage to collapse, and interlocks shut our accelerator down. Below the threshold for this effect, however, the machine runs well. The cause for this effect is not understood. A possible source is the small, 2.5 cm, apertures in the decoupling sections. The design of the tube, however, does allow them to be changed.

With the exception of the maximum current limitation, experience has been good. No adverse affect has been seen with heavy ions. To date we have used the tube more than 2800 h and it is still performing well.

References

[1]Manufactured by National Electrostatics Corp., Middleton, Wisconsin.

[2]Supplied by Radiation Dynamics, Inc., Westbury, L.I., New York.

[3]"Negator" constant force springs, made by Hunter Spring Co., Div. of Ametek, Hatfield, Pennsylvania.

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