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MECHANICAL ENGINEERING AND DESIGN CRITERIA FOR THE MAGNETICALLY INSULATED TRANSMISSION EXPERIMENT ACCELERATOR

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ABSTRACT

At the request of Pulsed Power Research Division 5245, a single-unit electron beam accelerator has been designed, fabricated, and assembled in Sandia's Technical Area V to conduct magnetically insulated transmission experiments. Results of these experiments will be utilized in the future design of larger, more complex accelerators. This design makes optimum use of existing facilities and equipment. When designing new components, possible future applications were considered as well as compatibility with existing facilities and hardware.

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MECHANICAL ENGINEERING AND DESIGN CRITERIA FOR THE MAGNETICALLY INSULATED TRANSMISSION EXPERIMENT ACCELERATOR

I. INTRODUCTION

The Magnetically Insulated Transmission Experiment (MITE) Accelerator was conceived in December 1976 as a full-scale, single line of the Electron Beam Fusion Accelerator (EBFA) on which to conduct power flow research. Pulsed Power Research Division 5245 requested that Electron Beam Fusion Division 5243 assume project responsibility for the mechanical engineering and design of this system. Division 5243 then requested Project Design Definition Division II 9652 to provide the drafting and design support required to design and fabricate this accelerator. Close contact with the physicists, scientists, and technicians in Division 5245 was maintained to insure that the mechanical design was compatible with physical and electrical requirements of the experiments. Since data from experiments using this accelerator would influence the design of EBFA, and since the design of EBFA was eminent, it was necessary to consider the time element in all phases of design. Building 6595 in Tech Area V was chosen to house the accelerator, and an existing experiment, MADNESS, located in the same building, was modified to accommodate the new accelerator. New equipment and components were designed not only to be compatible with the building and with the MADNESS experiment hardware, but also to be applicable to future designs. Plant Engineering Building and Facilities Design Division II 9743 was requested to make necessary modifications to Bldg. 6595 for installation and operation of this accelerator.

II. PURPOSE

The purpose of this report is to describe the mechanical design procedures and basic philosophy utilized in the design of this accelerator and to document the unique design features that were incorporated into the various components.

III. DESIGN DESCRIPTIONS AND PROCEDURES

Initial discussions with Division 5245 resulted in the selection of Bldg. 6595 in Tech Area V in which to locate the MITE Accelerator. It was also decided that portions of the existing MADNESS experiment, located in the same building could be used by making major modifications to the equipment. The MADNESS experiment, shown in Figure 1, was designed and purchased in 1973; it was used for various high voltage pulsed power experiments. The Marx generator, aluminum water tank, oil tank assembly, and overhead crane were modified for the MITE Accelerator. The original MADNESS oil tank assembly (T27453) consisted of four 7-ft sections, removable doors on each end of the tank assembly, and a walkway on the north, east, and south sides. The removable door on the west end of the tank assembly was modified with a cutout to permit installation of the aluminum water tank as shown in Figure 2. The two west sections of tank were removed, braced, and placed in storage. The remaining two sections, with Marx generator in place, were relocated 9 feet east of their original position to provide room at the west end for the MITE experiment. After the tank sections were relocated, the transformer oil supply manifold was modified and rerouted and the modified west door was reinstalled on the west end of the tank sections. The aluminum water tank, with a modified support frame, was installed in the cutout provided in the door. The walkways were then reconfigured to provide access to the aluminum water tank as well as to the remaining two MADNESS tank sections. New support structures and 9-ft extensions for the overhead crane were designed, fabricated and installed to provide crane coverage over the entire new experiment work area.

T. N. Simmons, Health Physic Division 3312, working with Division 5245 operating personnel provided the radiation shielding requirements for the MITE Accelerator. A shielding layout drawing (T47231) was prepared and approved by Divisions 3312 and 5245. A request was then submitted to Plant Engineering to install the radiation shielding. Plant Engineering requested that Division 5243 furnish the necessary concrete shield blocks. Drawings were prepared (T47940 and T47941) and concrete blocks purchased. Plant Engineering was also requested to provide additional water, air, and electricity needed for the MITE Accelerator. These modifications to Bldg. 6595 were made simultaneously with the shielding installation.

The MADNESS aluminum water tank was installed in the modified tank door at a specified height to insure that an overflow of oil from the MADNESS tank assembly would not contaminate the deionized water in the aluminum tank. This height resulted in the centerline of the aluminum tank and, thereby, the centerline of the MITE accelerator being located approximately seven feet above the building floor (Figure 3). A work platform (T47938) was then designed to provide a work surface 41 inches above the existing concrete floor with sufficent area to permit convenient installation and maintenance of MITE hardware and with adequate space to conduct necessary associated experiments.

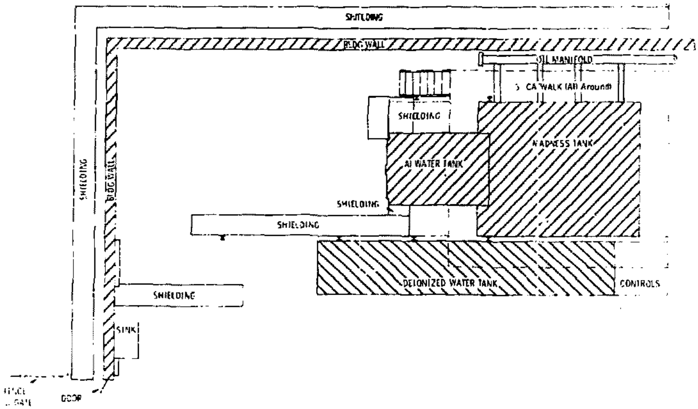


Figure 1. Madness Experiment - Top View - (Ref. Dwg T10716)

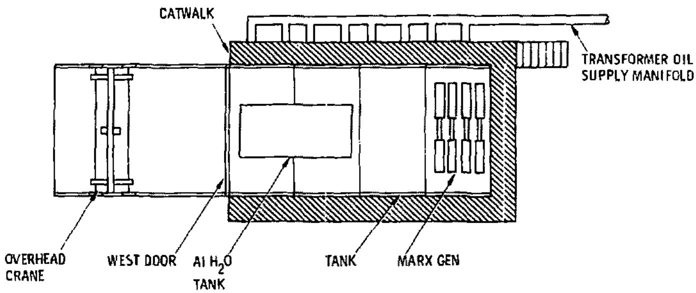


Figure 2. Modified Madness Equipment (Ref. Dwg T4723)

This platform was designed in modular sections to simplify installation and to permit its use in other applications upon the completion of the MITE experiments. The steps and an adjacent section of platform were designed for quick removal when the overhead crane is required to lift equipment on and off the work platform. Direct access from the work platform to the tank walkways was also provided. The decking for the work platform was specified to be open/non-skid type to insure safe footing in the event of oil spills.

A section of the MITE Accelerator must be evacuated of air during operation (Figure 3, Item 20). The specified vacuum was to be approximately 1×10^{-4} torr and was to be attained in less than 15 minutes. To make the best use of available equipment, two 6-in diffusion pumps with mechanical backing pumps were selected (Figure 3, Items 61 and 36). Purchased were the vacuum system roughing pumps, a 331 CFM Roots blower and a 65 CFM mechanical pump. After all the vacuum equipment had been specified, a system layout was prepared to define the location of the components and any additional required equipment. The pumps were positioned to provide the most efficient pumping, taking into consideration the anticipated gas loads while providing the best mechanical stability.

Support stands with adjustment features (Figure 3, Item 16) were designed to hold the vacuum chamber. These stands permit longitudinal movement of the chamber parallel to its centerline during operation of the accelerator while maintaining correct location in all other directions. The final detail drawings were prepared and all remaining equipment and hardware purchased. Final assembly was done by Division 5245.

The electro-mechanical requirements for the vacuum insulator (Figure 3, Item 2) were then specified. A design layout was prepared and approved by Division 5245. Due to the calculated weight of the insulator (~495 lb), lifting features were required for handling. A bracket enables the assembly to be lifted and moved with an overhead crane; the insulator remains in a vertical position during movement. The hook height of the overhead crane in Bldg. 6595 is not sufficient to lift the insulator in and out of the aluminum water tank as required for preferred assembly and disassembly. Therefore an additional hoist system (Figure 3, Item 17) was designed and installed. With this hoist and the lifting fixture (T48359) the insulator can be lifted by the two trunnions (T48866) attached to the assembly. The lifting fixture permits 360° rotation thus providing a means for rotating the insulator as required for insertion into the aluminum water tank and installation into the bulkhead. Mounting features were also provided on the insulator to install varied specified diagnostic hardware. The final assembly (T46877) and detail drawings were prepared and the insulator fabricated. Installation and checkout was done by Division 5245.

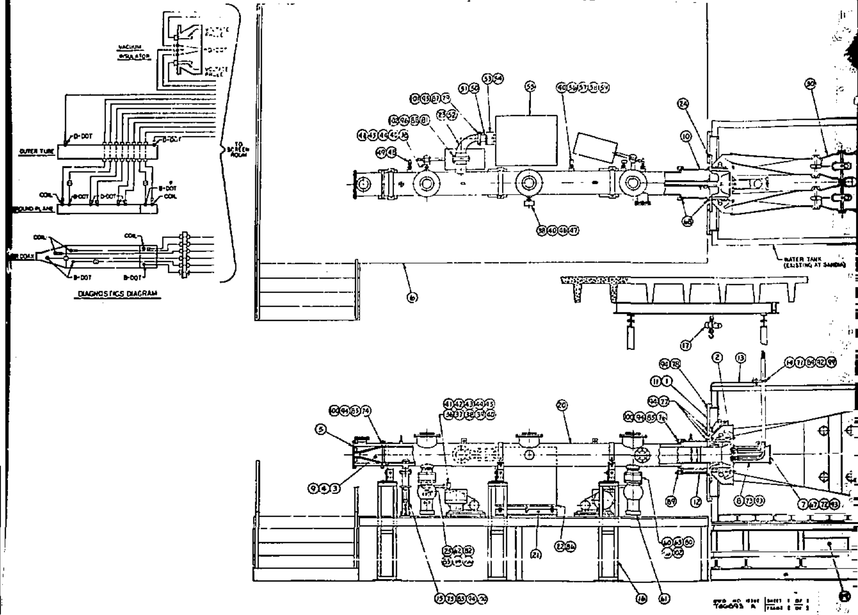
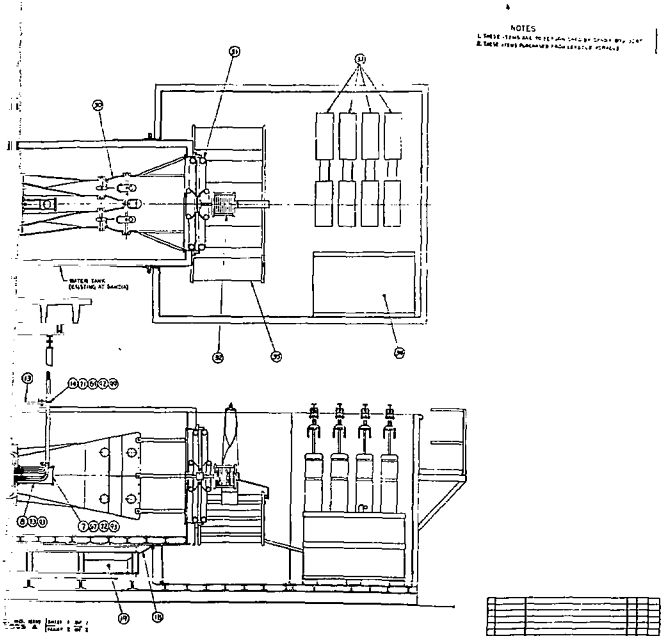
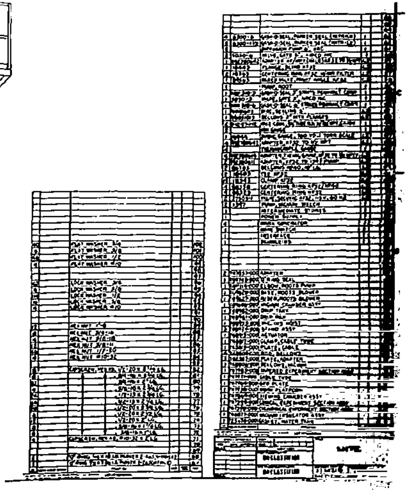


Figure 3. MITE Assembly (Re





: Assembly (Ref. Dwg T46893)

The power flow line section of this accelerator consists of the vacuum chamber, the vacuum coax, and the ground plane plates (Figure 3, Item 20). A cross-section in the shape of race track was requested for the vacuum coax and the material selected was aluminum. After a supplier survey, a fabricator was found who would extrude this shape to our specifications. The high cost of fabricating an extrusion die was justified because we anticipated possible future applications for this item. A detail drawing of the racetrack-shaped extrusion (T49629) was prepared and the units purchased. The vacuum coax is supported by the vacuum insulator and extends approximately 16.5 feet from the insulator as a cantilevered beam. To provide additional support to the vacuum coax, a pneumatically operated actuator system (Figure 3, Item 15) was designed and fabricated. Division 5245 specified that, except at the vacuum insulator, the vacuum coax must be completely free of mechanical support during operation of the accelerator. To be clear of the vacuum coax at the time the accelerator fires, while at the same time permitting the coax to fall no more than a specified 0.04 inch, the actuator must travel 2.0 inches in 14.5 ms. Prior to installation on the power flow lines the actuator was tested using various drive pressures and valve settings (Figure 4). An optional scheme of allowing the vacuum coax to assume its deflected cantilevered position and of adjusting the vacuum chamber for proper symmetry from the coax was carried out. This was accomplished by providing sufficient movement in the vacuum chamber support stands (Figure 3, Item 16) and incorporating a bellows section (Figure 3, Item 10). This permitted motion between the vacuum chamber and the aluminum water tank. Prior to evacuation, the vacuum chamber can be aligned relative to the coax. After this adjustment, the bellows position can be secured by four threaded rods (Figure 3, Item 12) to maintain a rigid union between the vacuum chamber and the aluminum water tank when the chamber is evacuated. A special clamping joint was designed to secure the vacuum coax to the vacuum insulator. This joint had to maintain the straightness of the vacuum coax and had to have sufficient strength to support the cantilevered beam. Ease of assembly and disassembly was also considered during design. Various design layouts were prepared and a modified Marmon clamp (T49606) was selected. Clamping is accomplished with two U-shape tapered clamps (T48818) that are secured to the vacuum coax and vacuum insulator with screws. The clamp is of stainless steel to provide the required strength as well as to be compatible with the vacuum environment. The aluminum ground plane plates (T49608 thru T49611) are mounted parallel to the sides of the vacuum coax, (Figure 5). Spacing between the plates and the vacuum coax was specified to be adjustable for .5, 1.0, and 2.0 cm. An adjustment assembly (T49612) was designed to provide this movement. This assembly also permits tilt adjustment so as to maintain parallelism between the plates and the vacuum coax. All adjustments are made through three ports in the vacuum chamber, prior to evacuating the system. The adjustment port covers have a lucite window to provide visual inspection of the vacuum coax and ground plane plates under vacuum conditions. These windows are also used for optical diagnostics during operation of the accelerator. In addition to the plate adjustment ports, the vacuum chamber also has various other ports to install vacuum monitoring instrumentation. A cable port was provided on the vacuum chamber, with electrical feed-through connectors, so that electronic diagnostics inside the vacuum chamber could be connected to equipment in the control room.

The extreme western end of the power-flow lines contains the anode/cathode experiment section (Figure 3, Items 3, 4, and 8). This section consists of a viewing chamber (T47868) and three interchangeable experiment configurations (T47398, T47399, T47983). The viewing chamber has mounting features for the ground plane plates end adjustment mechanism. This mechanism supports and provides adjustment capabilities for the terminal end of the ground plane plates. The chamber also has a Lucite port for optical diagnostics near the terminal end of the accelerator. The chamber end plate (T47353) contains a copper plate (T47354) which serves as the accelerator anode. Electrical continuity between the ground plane plates and the end plate is maintained with adjustable copper spring contacts (T47801).

Design layouts were prepared and, after approval by Division 5245, the experiment configurations were drawn, fabricated and assembled. Spacing between the anode plate and the end of the experiments is adjustable from 0.2 inch to 1.0 inch in 0.1-inch increments (Figure 6). This adjustment is accomplished by removing or adding 0.1-inch thick spacing rings (T47804) as required to obtain the desired spacing.

Another unique feature of this section of the accelerator is the ground feed plates. These plates are located above and below the experiment coax (Figure 6) in contact with the ground plane plates. Spacing between the ground feed plates and the experiment coax (Transition sections) is adjustable for 0.5, 1.0 and 2.0 cm to be compatible with the ground plane adjustments. Final assembly and installation was done by Division 5245.

Diagnostic requirements for the accelerator were specified by Division 5245. Various design layouts were prepared to define the location and size of hardware needed. Electronic components were supplied by Division 5245 and drawings of housings, brackets, etc., were prepared, and parts fabricated. Eight signal cables exit the vacuum chamber through the cable port bulkhead. Six signal cables, located inside the vacuum coax (Figure 5) exit the feed-through connectors on the vacuum insulator. All signal cables, including seven already outside the vacuum chamber and insulator, are routed to the control room to appropriate instrumentation (Figure 3).

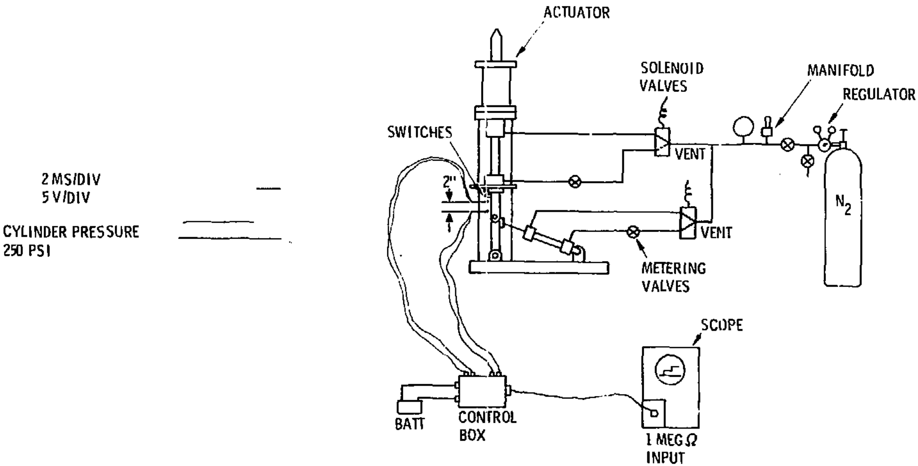


Figure 4. Actuator Test Setup and Scope Picture of Tests

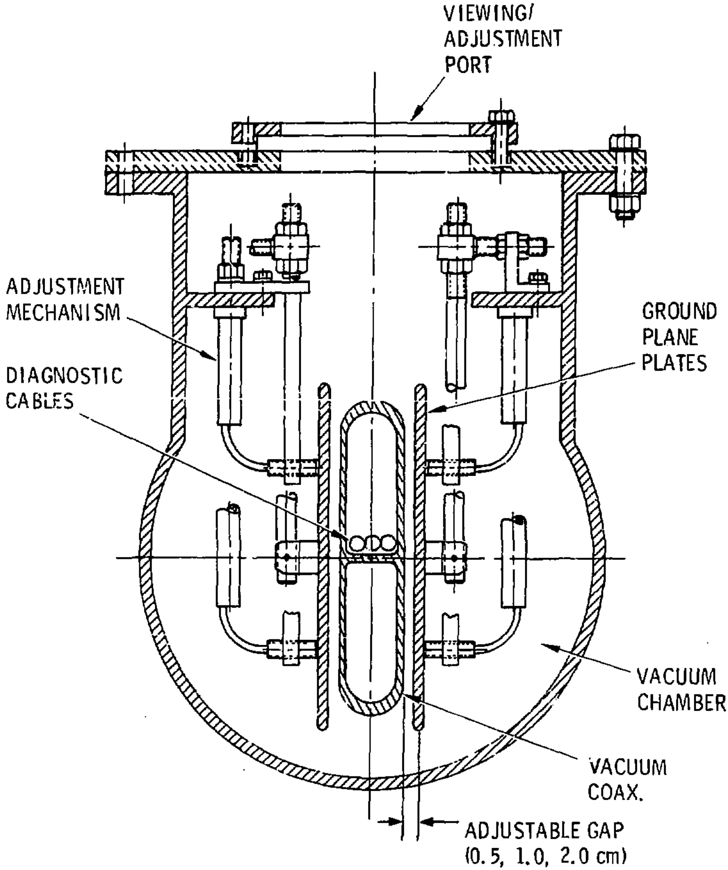


Figure 5. Power Flow Line, Vacuum Coax (Section View)

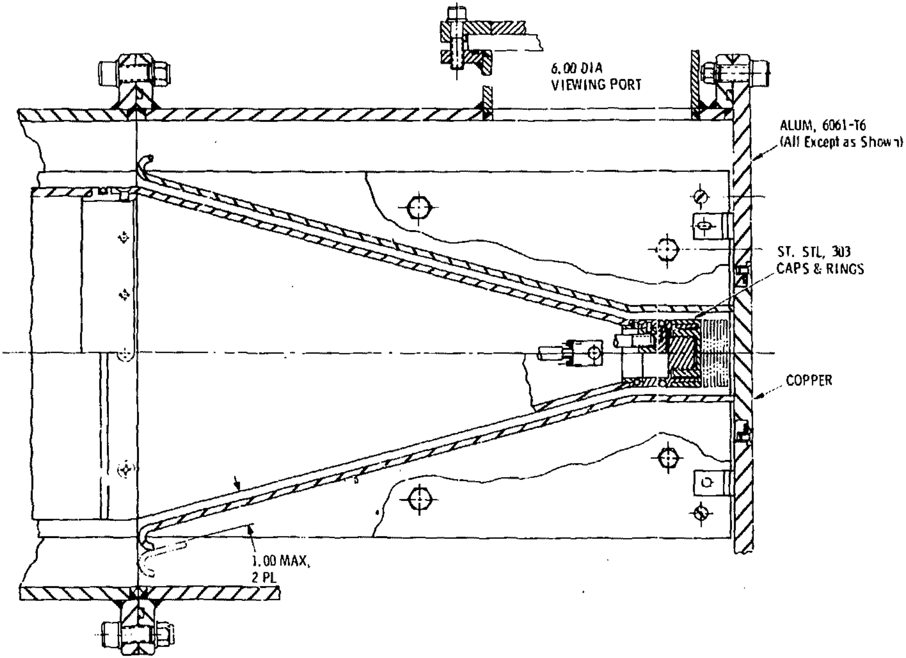


Figure 6. Experiment Adj. (Ref. Dwg T47269)

IV. CALCULATIONS

Preliminary engineering calculations were made for various components of the MITE accelerator. These calculations were based on estimated maximum loads, assumed shapes, probable worst conditions, etc., and were used only to determine the feasibility of building the proposed accelerator.

As the design became finalized, calculations were made on critical components to determine actual stress, deflection, etc. Critical components were those items that would be subject to high stress during routine operation of the accelerator. Because of the complexity of some calculations, requests were made with Applied Mechanics Division III 1284 to provide additional and concurring analysis on certain items. One calculation by Division 1284 was to determine the best cross-section design for the racetrack-shaped vacuum coax. Four proposed cross sections were investigated to determine which one would have the least deflection at the tip if it were a cantilevered beam. Results of these calculations were used in selecting the cross section and are documented in a memo from C. R. Adams, 1284, to Division 5243, dated March 7, 1977.

Another analysis by Division 1284 determined the strength of the joint which secures the vacuum coax to the vacuum insulator. Results indicated that the stress at the joint and at the securing clamps was low and that the design was satisfactory. The above analysis is documented in a memo from C. R. Adams, 1284, to Division 5243, dated June 14, 1977.

Additional calculations were made using formulas and techniques from J. Roark and W. Young, Formulas for Stress and Strain, 5th Edition and from the Machinery's Handbook, 20th Edition. The structural integrity of the vacuum chamber was analyzed as if it were a pressure vessel. The chamber was modeled as a closed-ends cylinder under uniform external pressure. A computer program was written for the NOS system to calculate the external pressure at which elastic buckling would occur. Results indicate that a minimum external pressure of 193 lb/in^2 would be required to buckle the vacuum chamber. The maximum stress on the vacuum chamber, under vacuum load, was calculated to be 280 lb/in^2. The external collapsing pressure calculated for the vacuum chamber, when a yield strength of the chamber materials is assumed to be 18,000 lb/in^2, was 275 lb/in^2. The minimum factor of safety for the vacuum chamber was calculated to be 12.9. However, since the chamber was assumed to be a cylinder when, in fact, it has various ports through the walls, advice was obtained from Division 1284 on the affect these ports would have on our calculations. It was felt that the ports would not adversely influence the analysis and, since our design was conservative, the vacuum chamber was considered satisfactory. Advice was also obtained from C. H. Maack, Metal Application Systems Division 5832, on the selection of the aluminum alloy used for this chamber. The chose of alloy, temper and welding procedures was in accordance with the recommendations of Division 5832.

Stress and deflection due to the vacuum was calculated for the 6-in diameter Lucite viewing port, the viewing chamber end plate, and the copper anode plate. Results indicated a minimum safety factor of 4 due to stress and a maximum deflection of .028 inch.

The four bellows-retaining rods were analyzed as columns to determine their load carrying capabilities under vacuum conditions. The total load on each rod due to the vacuum was 625 lbs. A safety factor of 46.5 was calculated for each rod when used as a column as it is in our design.

The maximum stress in the vacuum coax under dynamic conditions was determined to be 2675 lb/in^2 and the maximum deflection at the tip was .616 inch, when analyzed as a cantilevered beam. The maximum stress on the aluminum adapter plate which was used to secure the vacuum insulator assembly to the aluminum water tank was calculated to be 648 lb/in^2. Shear stress on the bolts which secured the above plate to the aluminum water tank and fastened the vacuum insulator to the plate was 2646 lb/in^2 maximum.

Stress on the Lucite ring stack was calculated by modeling the Lucite stack as if it were a cantilevered Lucite tube. Combining the compressive stress due to the clamping force of the bolts, the stress due to the bending moment caused by the cantilevered vacuum coax, and the bending stresses due to the weight of the various components resulted in a maximum stress of 1302 lb/in^2.

Stress on the nylon bolts used to clamp the vacuum insulator assembly was 5339 lb/in^2. This stress was calculated by assuming that only one bolt would carry the bending stress exerted by the vacuum coax. Conservatively, however, one could expect half the 18 bolts to share the load.

A minimum safety factor of 4 was used to calculate modifications to support members and to hardware used to mount the 1000-lb capacity vacuum insulator hoist to the existing overhead crane structure. A minimum safety factor of 4 was also used to calculate the design criteria for the lifting bracket, lifting trunnion, and lifting fixture used to handle the vacuum insulator assembly. After fabrication, proof tests were conducted on these lifting fixtures to verify their design strength prior to actually handling the vacuum insulator assembly. Conservative methods and estimates were used for all preceding structural analysis.

V. CONCLUSIONS

The design, fabrication, and assembly of this accelerator has been accomplished on a limited time schedule through the utilization of, and cooperation among, various Sandia organizations. The completed machine has been assembled by Division 5245. The mechanical design features were checked out and, with minor adjustments, judged to be satisfactory. The Operations and results of experimentation using this accelerator will be documented by Division 5245.

VI. ACKNOWLEDGMENTS

We, the authors, wish to acknowledge the technical assistance of G. E. Hiett, 5243, for the design, fabrication, assembly, and testing of the actuator system used with this accelerator. We also wish to thank R. Anderson, F. Long, M. Roach, D. Shead, C. Tucker, B. Tafoya, and C. Wimmer, all 8652, for their technical assistance in the preparation of design layout, assembly, and detail definition drawings used for the design and fabrication of this accelerator.