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ELECTRICAL INSULATION SYSTEM FOR THE SHELL-VACUUM VESSEL AND POLOIDAL FIELD GAP IN THE ZTH MACHINE[1]

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ABSTRACT

The electrical insulation systems for the ZTH machine have many unusual design problems. The poloidal field gap insulation must be capable of conforming to poloidal and toroidal contours, provide a 25 kV hold off, and sufficiently adhere to the epoxy back fill between the overlapping conductors. The shell-vacuum vessel system will use stretchable and flexible insulation along with protective hats, boots, and sleeves. The shell-vacuum vessel system must be able to withstand a 12.5 kV pulse with provisions for thermal insulation to limit the effects of the 300°C vacuum vessel during operation and bakeout. Methodology required to provide the electrical protection along with testing data and material characteristics will be presented.

INTRODUCTION

The electrical insulation stress levels in the ZTH machine are based on plasma termination during plasma current rise, with maximum stored energy in the ohmic heating coils. If this worst case condition is assumed with reasonable plasma current decay times, induced voltage levels at 4 MA operation are:

- Shell/Vacuum vessel: ±12.5 kV
- Poloidal Field Gap: 25 kV
- Poloidal Gap: 500 V

To further complicate the insulation design, there are possibilities of field enhancement caused by the many penetrations through the flux conserving shell by pump and diagnostic ports connected directly to the Inconel vacuum vessel (liner). These may be seen by examining Fig. 1, an orthographic view of the ZTH Front-end, the shell, interspace, and vacuum vessel assembly. Diagnostic cabling is also of concern; it must properly be maintained at the relative vacuum vessel potential. The hard wired diagnostics must be insulated from each other, as well as from the dc grounded shell.

The poloidal field gap can be pictured as a large tongue and groove assembly (Fig. 2) which convolutes with toroidal and poloidal geometries. This type of design also gives ample opportunity for dielectric failures. The inside and outside conductors are common to each other, and must be insulated from the center conductor section.

The shell and vacuum vessel dielectric system major concerns are: 300°C temperature of the vacuum vessel, mechanical rubbing that could potentially wear the insulation, and possible chemical contamination from cleaning solvents and oils. The poloidal field gap major concern is cracking of a rigid insulating material between the conductors from large impulse tensile "hoop" loads. There is sufficient uncertainty about various parameters and environmental conditions, so a conservative design must be utilized to ensure the 50,000 shot lifetime (10,000 @ 4MA). Although ZTH is scheduled for initial 1.7MA operation, the extra thickness and edge creep margins required for 4MA operation will have no significant cost impact.

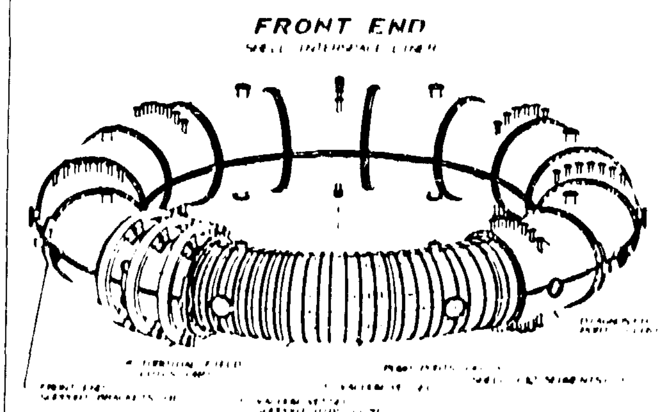


FIG 1

POLOIDAL FIELD TAPERED GAP

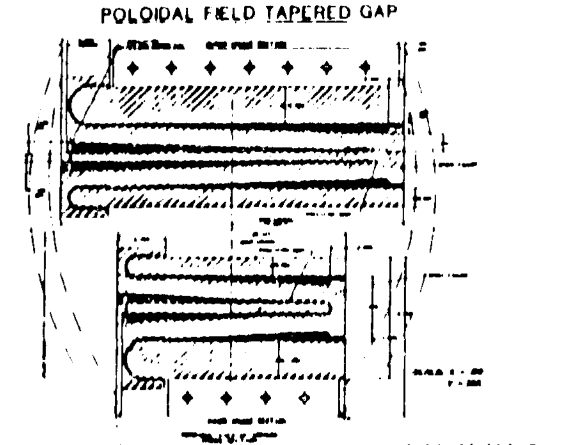


FIG 2

METHODOLOGY

Although the concept of the electrical insulation seems relatively simple, careful consideration of materials is required along with detailed examination of all surrounding structures. In general, insulation will by provided by bonding stretchable and abrasion resistant material on the metallic surfaces. At seams, "lay ups" will be provided with sufficient tracking lengths. At edges and feed throughs, insulation will be provided by "hats, sleeves, or boots." Materials for a particular application are also selected on the basis of required temperature rating, ease of manufacture, and stretchability (tolerance build up).

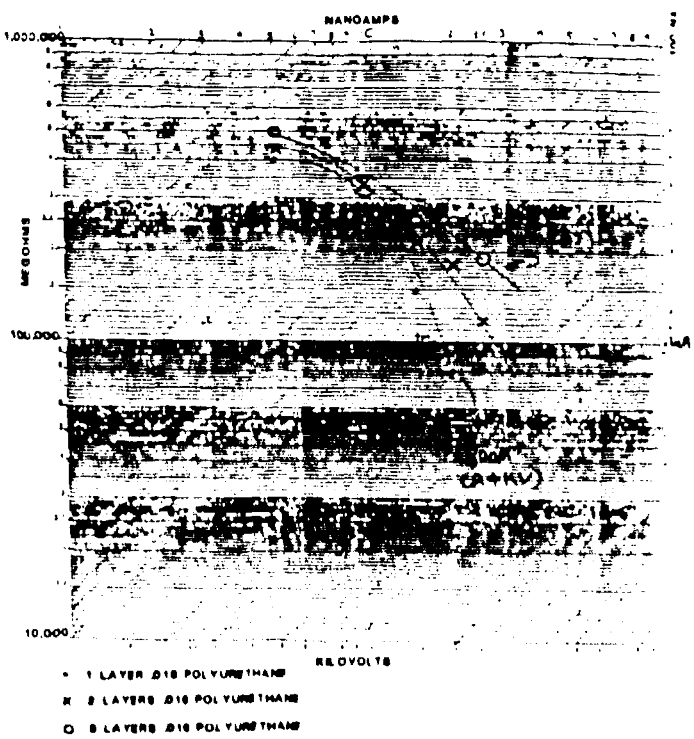
[1] Work performed under the auspices of the US DOE

MATERIALS

To provide electrical insulation for the shell segments, 3M type 8663 self-adhesive polyurethane film was chosen. This material of .016" thickness can stretch 500% without breaking. Available in 4' wide by 100' spools, single pieces may be cut and when installed on the shell segments, provide a seamless and wrinkle free insulating layer. Polyurethane film is typically used as an abrasion resistant layer to protect aircraft radomes and helicopter blade leading edges. It also has good electrical properties. Considerable electrical testing has been performed to ensure meeting the machines required lifetime. Tests have included 3 axis log plots of leakage characteristics, environmental stress tests, and pulse life tests. Figures 3 and 4 show three axis log plots with small area test electrodes and large shell sized pieces, respectively.

POLYURETHANE HIPOT TEST

FIG. 3



Precision equipment of Los Alamos design was necessary to obtain the nano-ampere resolution (at 25kV levels) for insulation testing with the small area electrodes. A nearly vertical plot at high voltage is obtained with one layer of insulation, and failed rather abrubtly at 24 kV. With three layers, the large area (12 sq. ft.) test of insulation was easily characterized. Testing discrepancies along with the statistical information gained during assembly can be used to isolate defective components. We should obtain curves similar to Fig. 4, which indicates no inflection points or "knee's," with a leakage resistance of better than 500 MΩ. A leakage current of 100 μA at 25kV may be cause for component rejection. Faulty insulation layers can be repaired by replacing the polyurethane film.

LARGE AREA D.C. LEAK CHECK

3 LAYERS 8663

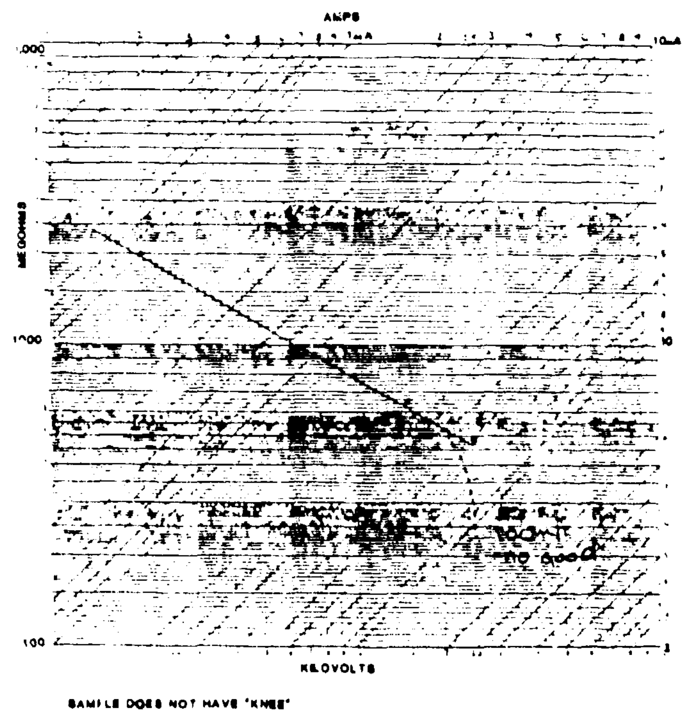


FIG. 4

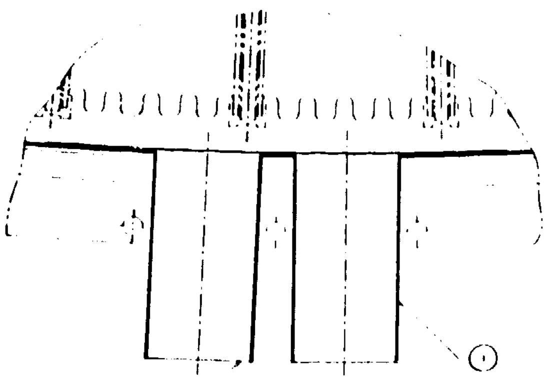
A 25kV pulse test that simulates a 4MA termination waveform was also performed and yielded failures at 20 shots with one layer, 15,789 shots with two layers, and testing was terminated at 151,500 shots with three layers. Polyurethane dielectric testing has also included simultaneous application of pressure (200 psi), temperature (100°C), and solvents. To further ensure the integrity of the 3 layer insulation system, additional abrasion resistance will be provided by Cohrlastic TC-100 strips. These strips will be placed between the vacuum vessel support ribs and the shell insulating layers. The compliant Cohrlastic strips also evenly distribute the heat flux as well as provide additional flexibility in the tolerance build up.

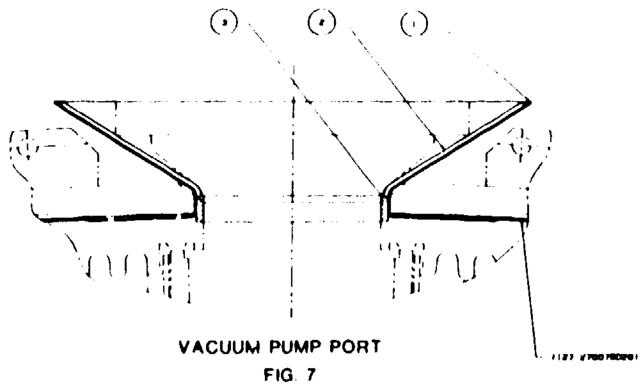
Polyester mat/polyester film composites with resin impregnate (Westinghouse Pyrolam 100) will be used to shield the shell segment joints with sufficient creep margins. This material finds significant use in the power industry, and its electrical and thermal parameters are well characterized. We intend to use two layers of Pyrolam 3103, each .016" thick. Rated at 19,800 volts, we could not punch through a single layer, but at 45kV, would surface track to the ground plane (6" path). Most of the hats, boots, or sleeves will be fabricated with .050 polyethylene, an example is shown in Fig. 5, a wire diagnostic boot. The typical methodology used to insulate all ports is shown in Fig. 6, a type "P" port with the callouts as follows:

1. Outer boot of polyethylene
2. Inner boot of polyethylene
3. Thermal insulation around port (Min K)
4. Pyrolam wrap around flange
5. PTFE Teflon tubing over Min K

POLYETHELENE WIRE DIAGNOSTIC BOOT

FIG. 5



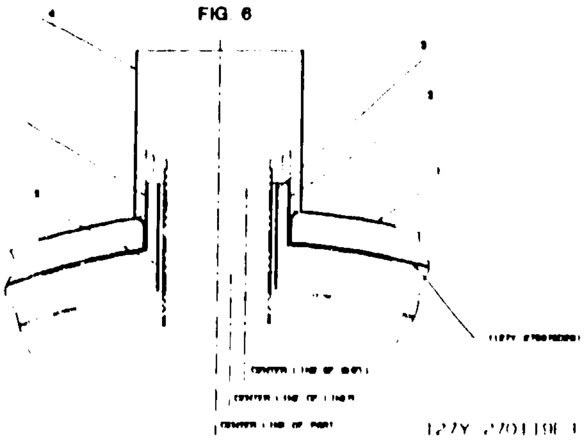


VACUUM PUMP PORT

FIG. 7

TYPE "P" DIAGNOSTIC PORT

FIG 6



The vacuum pump port (Fig. 7) presents a more difficult problem, anti-clocking rings ("3"), which maintain relative shell and vacuum vessel position, short circuit the thermal path and bear directly on the insulation ("1"). For this "boot" we may use spun Teflon or other high temperature plastic such as a polyimide. The final design will depend on flow characteristics, flexibility, and impulse resistance. Fortunately, all other ports and internal electrical insulation is protected from thermal effects with Min-K, Nomex, and other materials.

The poloidal field gap, (Fig. 2) will use 8663 polyurethane film (3 layers) on each surface. Polyethylene boots at each corner will be required. Before final epoxy impregnation, high pot testing will confirm the electrical integrity. A polyurethane epoxy (non rigid when cured) will then be pumped into the interspace between the conductors or an epoxy fiberglass pre preg layup will be utilized.

CONCLUSION

After detailed examination of the ZTH machine's shell, vacuum vessel, interspace, and environmental conditions, an electrical insulation method (with thermal protection) was developed. Careful testing of newly introduced materials permits us to fabricate completed assemblies that can be easily quality assured. Should any units fail, they may be easily repaired without any programmatic impact. Self adhesive polyurethane film will be used throughout the ZTH machine. Hats, boots, and sleeves; required to insulate feedthroughs and edges, will typically be fabricated from polyethylene.