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AN IMPROVED DESIGN FOR THE FERMILAB SEPTA

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Summary

Thin electrostatic septa are the most critical elements of the main ring extraction system and the beam splitting stations at Fermilab.[1,2] Operating experience since the first extracted beam in 1972 has indicated several improvements needed over the original septa for both extraction (single cathode) and beam splitting (double cathode). A second generation of septa, now being implemented, is described here.

Original Fermilab Septa

These consist of several modules (4 for beam splitter and 5 for extractor) placed in line to give the required 10-foot length. The modules are accurately aligned inside an aluminum box with a thin stainless steel vacuum skin. It was eventually learned that the alignment is degraded when the vacuum skin is welded on. A typical effective thickness is .030" although the alignment before welding is accurate to .001".[1] The resulting extraction efficiency for slow spill is limited to about 90%.

The wire plane consists of .002" tungsten wires with a .050" spacing. The wires are tensioned on an accurately machined aluminum frame. Each wire is hard-soldered to a coil spring on both ends and tensions are individually set at 300 grams. Since one 10-foot septum contains 2400 wires, the assembly is very tedious.

Both failure at the solder joints and beam-induced wire breakage have been serious problems, resulting in shorted septa. The welded vacuum skin makes disassembly for repair inefficient.

Second Generation Septa

The septa now being implemented at Fermilab are characterized by:

1. A one-piece wire support frame, 10 feet long.
2. A simplified wire fastening technique.
3. Improved wire material.
4. Retracting springs to automatically extract broken wires from the high field region.
5. One-piece hollow titanium cathodes, 10 feet long.
6. Decoupling of the frame from the vacuum box to preserve straightness.

Frame

The wire support frame is machined from a single piece of type 300 cast aluminum tooling plate. Flatness of the wire plane is held to better than .002" over the 10-foot length.

The cross-section for beam splitting septa is such that a significant bow in the frame results from the wire tension. This is due to longitudinal coupling of Poisson forces in the back section of the frame and results in a bow of .007". Fortunately the wire plane is horizontal and two support points can be chosen to straighten the frame with gravity loading (the frame weighs 150 pounds).

Because of a more favorable geometry the bow caused in the extraction septa by wire tension is only about .002". Since the wire plane is vertical we cannot compensate by gravity loading and have not yet solved this problem.

Fastening the Wires

Wire is wound on the frame in a lathe. Uniform tension is achieved by a dynamic tensioning device employing a magnetic brake. The wires are captured in soft aluminum strips (type 1100) attached to the sides of the frame. The operation proceeds as follows: small slits of .050" spacing are cut in the soft aluminum by a sharp wheel. Wire is wound into these slits as a swaging tool follows a few turns behind, making it captive. See Figure 1. This technique results in uniform tension and spacing and is characterized by speed and economy as compared to the earlier technique.

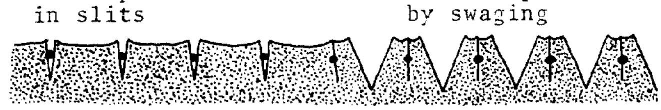

Fig. 1-Magnified view of septum wires captured in soft aluminum

Wire Material

The factors involved in optimizing wire material and size are not fully understood. Great demands are placed on the mechanical properties. Tensile stress of about 2×10^5 lb/in^2 is necessary to minimize the bow caused by electrostatic loading. Increase in effective septum thickness due to electrostatic loading results through different mechanisms for the single and double cathode geometries.

Wire bow is calculated to be about .001" at 80 kV for the single cathode extraction septum. To first order, this can add to effective thickness only through variations in wire tension.

Diverging fields at the wire plane of the double cathode septum give an unstable equilibrium which can result in a bistable condition. If wires pull towards either cathode with equal probability, two wire planes with a small separation result. Fortunately this is a small effect dependent on

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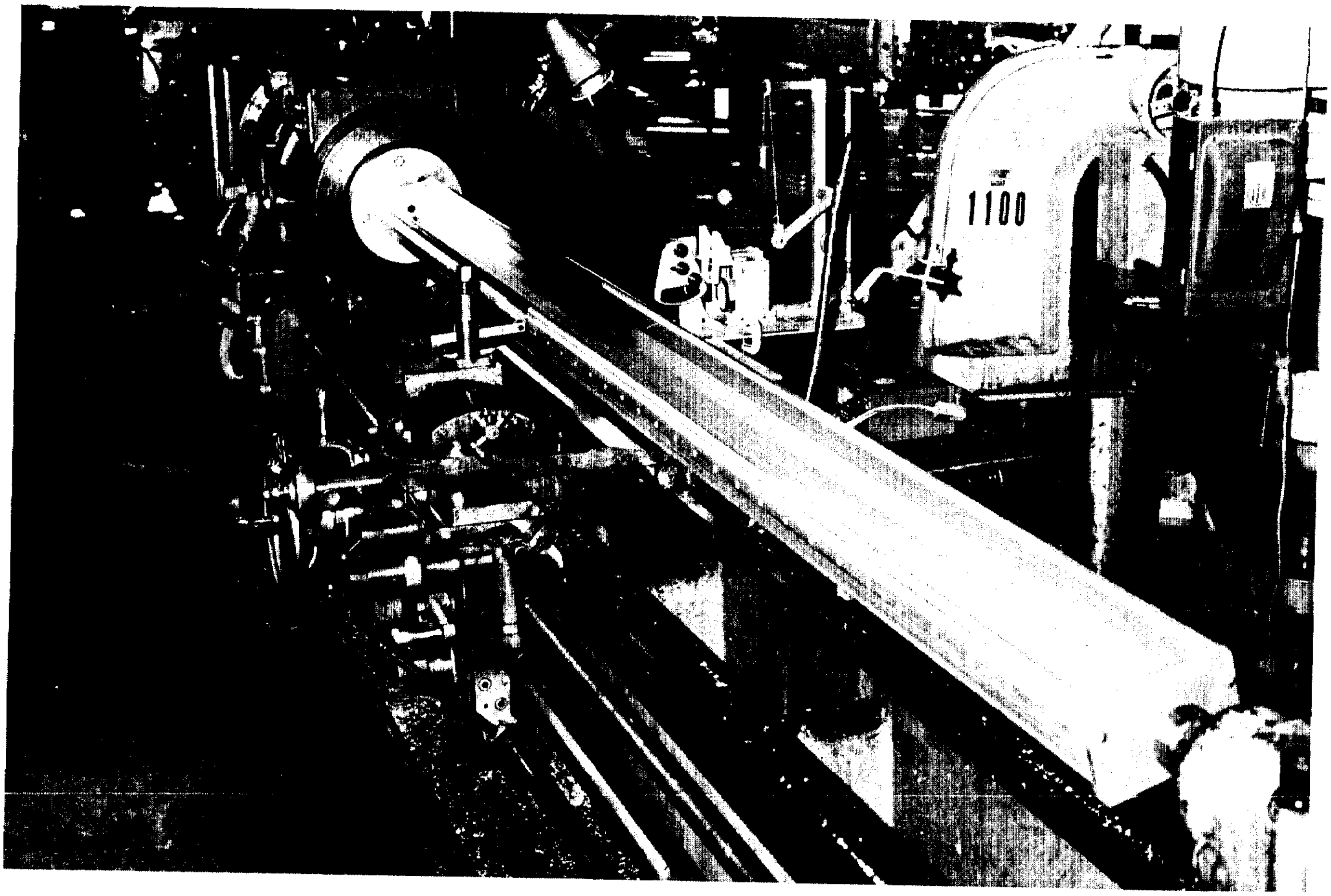

Fig. 2 - Beam splitter frame being wound

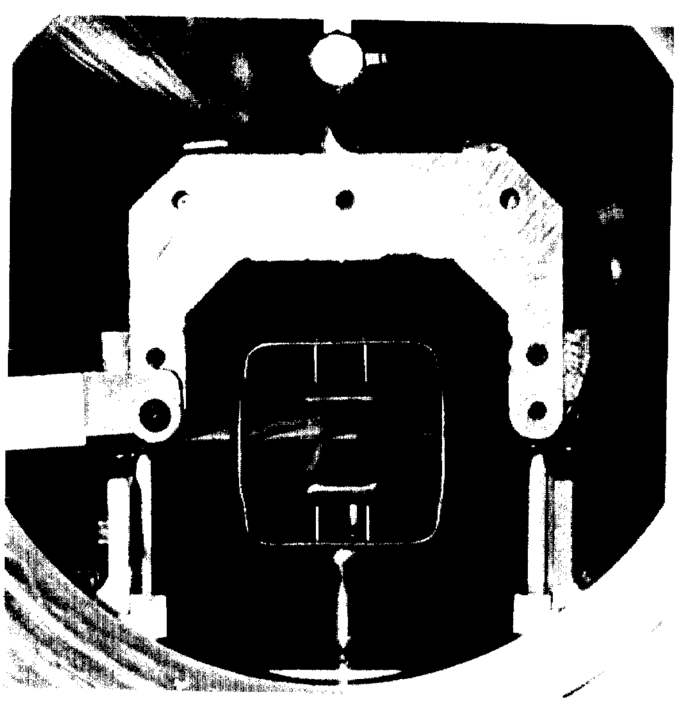

Fig. 3 - End view of beam splitting septum

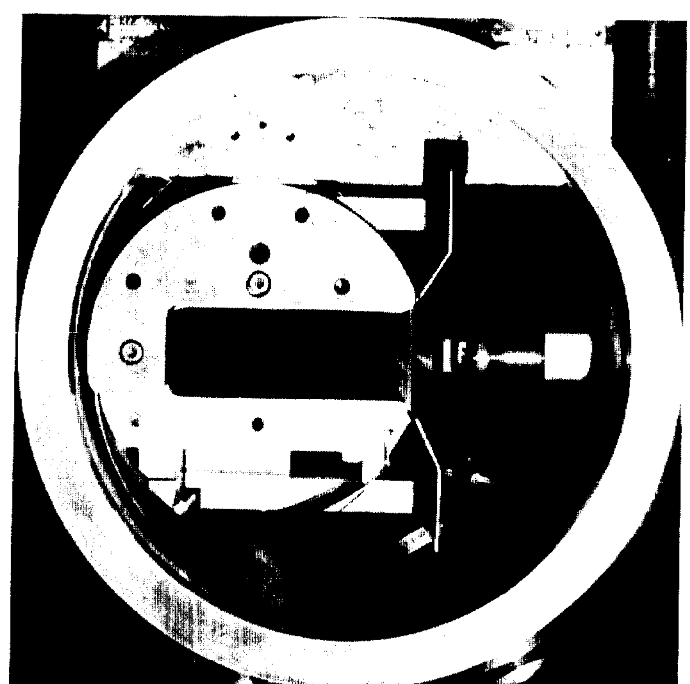

Fig. 4 - End view of extraction septum

the difference between cathode to wire plane distances for the two sides. Resulting separations are less than .001" for reasonable cathode alignment.

Monte-Carlo calculations show that of the beam incident on the septum, most is multiple-scattered out in the first few feet.[6] The trade-off is between choosing a high-Z material to increase the ratio of coulomb scattering to nuclear interactions and low Z to reduce heating of the wires. Thermal heating from short duration high losses is believed to be a major cause of wire failure.[1,3,4] Good high temperature strength and high specific heat are therefore indicated. Reasonable ductility is necessary to allow handling and fabrication.

The original septa used .002" pure tungsten wire. Since then, several refractory wire materials have been evaluated for high-temperature strength at Fermilab. These include pure tungsten, various tungsten-rhenium alloys, tungsten-thorium alloy, tantalum, molybdenum, molbdenum-rhenium alloy and nickel alloys. Tests were made by heating a tensioned wire by electric current in a helium atmosphere. The criterion used is time before failure versus wire temperature, as measured with an optical pyrometer. The alloy 75% tungsten - 25% rhenium rated highest in these tests, giving a significant improvement over pure tungsten along with increased ductility. Operating results to date confirm that this alloy is superior to pure tungsten as a septum wire material. Of six operational septa having 75% W - 25% Re wire (two extraction septa and four beam-splitter septa) there has been one failure, apparently caused by high-voltage breakdown.

We plan to further investigate lower Z materials by constructing an extraction septum with nickel alloy wire.

Wire Retractors

Because of machine downtime and radiation exposure to personnel resulting from septum failures, it was decided to attempt a mechanism for automatically retracting any broken wire from the high-field region. An appropriate scheme had already been proposed at CERN, i.e., that each wire be fitted with retracting springs. Such springs are now employed on all septa built at Fermilab.

The spring is a straight length of .016" music wire fastened at one end to the back of the septum frame, the other end hooked to the septum wire. Once a broken wire is pulled clear, a baffle prevents its re-entry into the high-field region.

Cathodes

Titanium was chosen as the cathode material.[2,5] The 10' cathode length was made up of modules in the original design. This was mainly for ease of fabrication, since the cathodes were machined from solid titanium. Operating experience with this configuration showed high-voltage breakdown problems at the module boundaries. The second generation septa employ a one-piece hollow titanium cathode drawn from .030" wall titanium tubing. These are both economical and minimize activation as compared to solid cathodes.

Cathodes of several different cross-sections to accommodate various aperture requirements were drawn at Fermilab. A standard draw bench was used and good results were achieved only after considerable experience. The more complex cross-sections require several steps in drawing (2 or 3 successive dies). After drawing, the cathodes are annealed at 500°C by passage of electric current, stretched to remove bow, and straightened under tension to eliminate twist. Smooth ends are produced by welding in titanium plugs and polishing.

Vacuum Box

The frame is supported on bearings to decouple any distortions of the vacuum box. Easy disassembly is provided by 11" diameter quick-disconnect vacuum seals at both ends. The boxes are of all aluminum welded construction to minimize activation. Radiation hardened vacuum seals are effected with commercially available indium coated c-rings.

Conclusion

At this time, second generation septa have been implemented in main-ring extraction (2 septa) and two beam splitting stations (2 septa per station). The extraction efficiency for slow spill has reached 98½% with the new thinner septa, about a factor of 10 improvement. Beam-splitting losses are reduced by at least a factor of 3. Operating voltages of 90kV/cm have been attained. The plan is to eventually replace all septa at Fermilab with those of the new design.

References

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