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THE FMIT EXPERIMENTAL DRIFT TUBE*

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Summary

An experimental drift tube (EDT) is being developed for use in the prototype Fusion Materials Irradiation Test (FMIT) Facility. The EDT is being used as a developmental test bed for evaluation of drift-tube design and fabrication. Standard features, typical of the FMIT drift tubes, such as copper-plated stainless-steel construction, channelized-flow face cooling, beam steering coils, water-cooled quadrupole magnets, and water-cooled bore tubes, will be incorporated into the EDT. The EDT also will serve as a diagnostic tool containing a beam-position monitor, (BPM) as well as instrumentation to provide engineering data relating to vibrations, heating because of beam spill, and normal operating quadrupole and drift-tube skin temperatures. The EDT program is currently in the design and developmental fabrication stages, and the proposed completion date is April 1981, with installation into the prototype FMIT accelerator in June 1982.

Introduction

The EDT program was initiated to determine the feasibility of the drift-tube design to be used in FMIT. The mechanical design was complex enough to raise doubts as to the overall manufactureability and cost of building 100 (including spares) drift tubes. To relieve these doubts, and the associated risk, a program was proposed to build a prototype drift tube that would be a substitute for the #1 FMIT drift tube. The program had three goals:

1. to evaluate mechanical design and fabrication techniques for the FMIT drift tubes,
2. to test and evaluate their operational characteristics, and
3. to provide, if possible, an on-line diagnostics tool.

The EDT program has been structured to satisfy these goals, and in doing so reduces the risk associated with building the drift tubes.

General Design Requirements

The complexity of the mechanical design of the drift tubes arises primarily from the general criteria for the FMIT linac. The deuteron linac is a 100%-duty machine designed for a 20-year operating life. Over this life span the drift tubes will be subject to beam spill and the radiation damage associated with it. This criteria demands

1. a stringent cooling criteria that requires all RF surfaces to be directly cooled to maintain strict dimensional control, and
2. that drift tubes must be fabricated from a radiation-hard material.

The cooling of the drift tubes is a difficult problem. The average RF power dissipated in the drift tubes is 3 kW/m^2, with a 10-kW/m^2 peak power dissipation. To maintain strict dimensional control, a precise and predictable cooling technique will be required. A counter-current, channelized-flow configuration will be used to control the skin-temperature rise to 5.6°C ± 1.1°C. The drift tubes will be fabricated to very precise tolerances: their length will be held to ± 50 µm, diameter to ± 125 µm, and profile to ± 175 µm. These tolerances are required to maximize machine efficiency and minimize beam spill. Temperature distribution and fluctuation have a serious impact on these tolerances; therefore, a strict temperature-control criteria is being imposed. Inlet cooling-water temperature will be controlled to ± 0.28°C. The heat load, from beam spill in the bore tubes at the low energy end of the linac, will hit peaks of 16 kW/m^2, requiring water-cooled bore tubes.

The requirement for a radiation-hard material for drift-tube fabrication stems primarily from the beam-spill exposure criteria. Beam spill over the machine life span may produce exposures of 1.0 x 10^{16} D/cm^2, at energies varying from 2 to 35 MeV in the drift-tube bore. At this maximum exposure level, swelling and creep from radiation damage becomes a consideration, particularly in regard to precise operating tolerances.

The drift-tube design has to incorporate various other criteria to accommodate the RF and physics requirements. Several different drift-tube configurations are required. Face angles, bore diameters, and outside diameters vary (see Table I) down the length of the linac. The drift-tube design has to incorporate these various parameters, as well as provide excellent cooling and precise dimensional control.

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TABLE I - DRIFT TUBE PARAMETERS

Drift Tube						Quadrupole		
No.	Model	Face Angle -degrees	Bore -cm.	O.D. -cm.	Length cm.	Model	Gradient Gauss/cm	Current amps.
1-4	I	4	5	42	14.2-15.5	A2	2950	950
5-15	I	4	5	42	15.9-20.8	A1	2750	810
16-25	II	8	6	38	22.3-27.6	B	1885	830
26-37	III	12	6	38	28.5-34.6	B	1885	830
38-51	IV	15	6	38	35.7-42.1	B	1885	830
53-73	V	15	8	38	44.7-54.5	C	990	750

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Beam focusing will be achieved by water-cooled, quadropole electromagnets located inside each drift tube. The quad will use a demountable coil design to facilitate fabrication and assembly. A potting development program has been initiated to satisfy the requirement for the rad-hard ceramic potting used in the FMIT quads. Four models of magnets (Table 1) satisfy the beam-focusing requirements for the entire linac.

At the low-energy end, the requirements for large-aperture, high field-gradient, dipole steering coils, and very limited space inside the drift-tube body all combine to yield a difficult packaging-design problem (See Fig. 1). The quad requires a maximum operating field gradient of 2950 G/cm (15 200 A turns/pole) with 10% excess capacity. This is achieved by using a 1010 mild-steel yoke with high permeability, vanadium Permendur poles. Current density in the water-cooled conductor is calculated to be 3100 A/cm^2.

Material Selection

The choice of materials for the drift-tube shell was dictated by the following criteria:

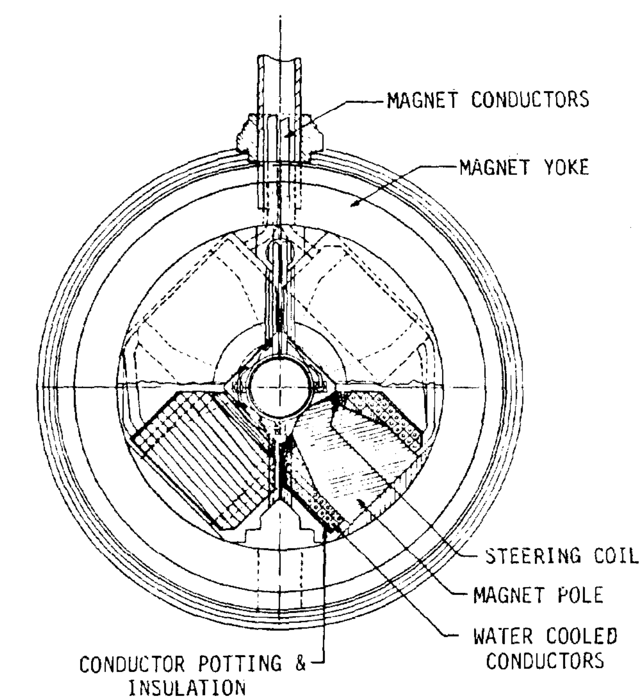
1. structural stability,
2. minimal magnetic permeability,
3. good electrical conductivity,
4. ease of fabrication, and
5. vacuum compatibility.

Copper-plated Type 316L stainless steel was selected as the best candidate to satisfy the criteria. The structural stability of stainless steels is well recognized, particularly in irradiated environments. Type 316L is an excellent compromise between magnetic permeability and ease of fabrication. Copper plating will be used to satisfy the requirements for the electrical conductivity. A plating thickness of 175 μm ± 50 μm OFHC copper will be electrodeposited on the stainless steel drift-tube shell using an acid copper bath containing organic brighteners. Plating thickness was chosen on a wear-and-tear criteria. Activation criteria requires approximately 25 μm of gold to be plated on the inside surface of all FMIT bore tubes, above 10 MeV.

EDT Fabrication Program

The drift-tube cooling criteria required that the back side of all RF surfaces be wetted to minimize temperature excursions. This is provided by a two-piece shell design that incorporates flow-directing ribs (Fig. 1.). The fabrication complexities of a two-piece drift-tube shell, with flow-directing ribs and strict dimensional tolerances, initiated the EDT program. The aim of the program was to evaluate fabrication techniques in terms of practicality, cost, and dimensional control. Several parallel programs were initiated to evaluate machinability, weldability, and weld distortion.

Part of the EDT programs was initiated to evaluate the possibility of forming blanks for both outer shells and inner liners, precisely machining these blanks, welding them together, then machining the welded asembly (Fig. 1). First, the blanks were hot-formed into a dishpan shape by using a combination of matching dies and draw rings. These dishpan-shaped blanks were formed with a 3-mm machining allowance on all surfaces. After hot-forming, the blanks were fully annealed, taking care to minimize material sensitization. A numerically controled (NC) lathe was used to machine both outer shell and inner liner. NC machining was chosen to simplify this procedure, because of the sequences involved in the manufacturing process. These two



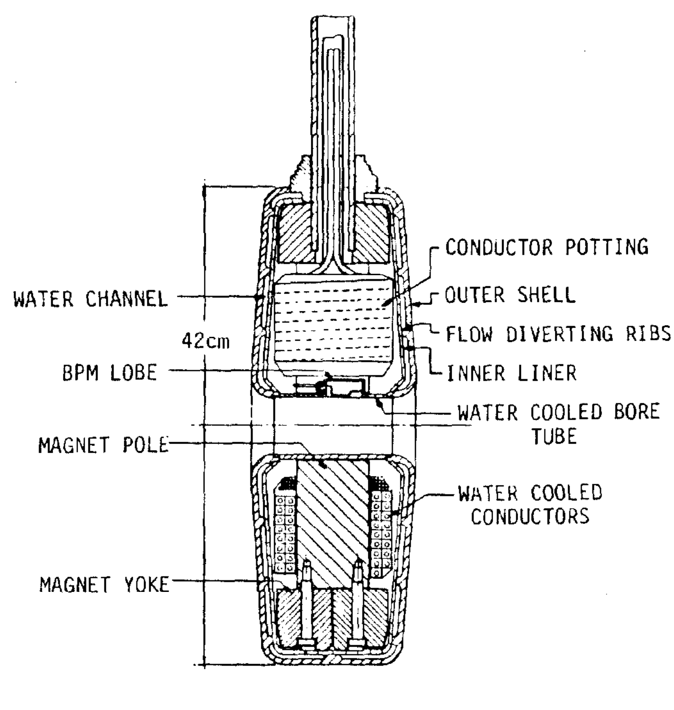


Fig. 1. Experimental drift tube (EDT).

parts then were welded together to form a drift-tube half (with cooling water passages) and finish machined.

A second program was initiated to evaluate the welding of the machined liner to the shell. A blind electron-beam (EB) welding technique was chosen. The weld is a fusion weld made through the backside of the liner (Fig. 1). A thorough evaluation of the weld technique incorporating weld distortion measurements, destructive testing, and weld metallurgy yielded very positive results that indicated minimal distortion and weld strengths of approximately twice the parent material.

A third program involving the fabrication of the bore tubes also was initiated. A BPM is located in the bore tube of some of the drift tubes. The BPM takes the form of four small lobes attached to the bore tube, located at 90° to each other, with a shorted wire loop in each lobe (Fig. 1). Each lobe has a radiation-hard coaxial cable welded to it that carries the signal out of the drift tube and up the stem to the receiver. The fabrication sequence dictates that the lobes be welded to the bore tube after the cable is welded to the lobe, thereby resulting in an awkward assembly that is difficult to machine. Because of the stringent alignment-concentricity requirement, it is necessary to make these lobe/tube welds with minimum distortion. After several attempts a weld technique, using a tungsten inert gas (TIG) welder and incorporating an aluminum mandrel (chill block), was used and was shown to eliminate any measurable weld distortion.

EDT Testing

After the construction phase of the EDT is completed, a series of test programs will begin, to evaluate its operational characteristics. Cooling is a predominant consideration; hence, flow vs pressure curves will be generated for various cooling loops (quad, shell, and bore tube). A dimensional inspection, both static and dynamic, will be used to evaluate drift-tube shell stability.

The quad will undergo a rigorous evaluation to determine the mechanical-axis/magnetic-axis relationship, the steering-coil axis displacement parameters, operating temperature, and other operating data.

The EDT: A Diagnostic Tool

The true evaluation of the EDT lies in its performance under operating conditions. The EDT will be installed in the prototype linac, to be used as a diagnostic tool that will provide on-line engineering and beam-dynamics information. Multiple thermocouples incorporated in the EDT will monitor RF heating and temperature control, quad temperature, bore-tube temperature, and beam spill. The EDT also will monitor drift-tube vibration by a 2-axis accelerometer placed in the quad potting. Direct readout of displacement, velocity, and acceleration of the EDT will be available. Finally, the water-cooled EDT bore tube will incorporate a BPM and will provide information regarding drift-tube alignment and beam spill.

Conclusion

The EDT has been, and will continue to be, an excellent tool for evaluating mechanical design and fabrication techniques. It also will provide on-line information useful for accelerator start up. The EDT program will conclude in April 1981, and the EDT will be installed in the prototype accelerator for start up in June 1982.

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