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TITLE: HIGH-RADIATION-ZONE DESIGN OF THE FMIT HIGH-ENERGY BEAM TRANSPORT

MASTER

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HIGH RADIATION ZONE DESIGN OF THE FMIT HIGH-ENERGY BEAM TRANSPORT*

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Summary

The Fusion Materials Irradiation Test (FMIT) deuteron linac, operating at 35 MeV and 100 mA continuous duty, is expected to spill 3 μA/m and to lose 10 μA at specific bending-magnet positions. The major impact of this spill will be felt in the High-Energy Beam Transport (HEBT), where many beamline components must be maintained. A modular design concept, that uses segmented termination panels remotely located from the modules, is being employed. Radiation-hardened quadrupoles can be opened, clamshell fashion, to release the water-cooled beam tube r replacement if there is beam damage or lithium contamination from the target. Termination panels contain electrical, water, and instrumentation fit- tings to service the module, and are positioned to allow room for neutron-absorbing shielding between the beamline and the panel. The modular construction allows laboratory prealignment and check-out of all components on a structural carriage and is adaptable to supporting gamma shields. Proper choice of beam tube materials is essential for controlling activation caused by beam spill.

Beam Spill in the FMIT Facility

The average power contained in the full-current, maximum-energy FMIT beam is 3.5 MW. Transport of this beam from the linac to the lithium target is accomplished with the transport line[1] shown in Fig. 1. Either of two targets can be supplied with beam, or the beam can be directed at low duty factor into a beam stop. The beamline is designed to accommodate the full geometric emittance of the downstream drift tubes of the linac (68.5 π cm-mr), which implies very low losses for a beam of normal total emittance (10π cm-mr). However, uncertaintainties in halo content, as well as anticipated losses at the bending magnets, have led us to assume, for design purposes, a loss model of 3 μA/m and 10 μA at the bend points. These losses are comparable to estimates made by other researchers.[2] We feel that this beam-loss model is a safe upper limit because of the conservative nature of the FMIT design: the radio-frequency quadrupole (RFQ) low-beta linac reduces the component of off-energy particles; precision alignment is a design criteria; large bores exist to transport the beam; abundant diagnostics are being provided; the machine operates CW, rather than pulsed; a periodic quad and bend system is used in the HEBT; and finally, strict administrative control will be exercised over the operation of FMIT to guarantee personnel and machine safety.

Nevertheless, a 3 μA/m-loss criteria requires special attention to maintenance procedures, and an awareness of the frequency with which maintenance operations may take place. For the FMIT HEBT, maintenance operations have been categorized as shown in Table I. In addition, it is anticipated that all contact with the beamline itself may require remote-handling techniques and all components directly surrounding the line must be radiation-hardened. This is especially important in the downstream legs of the HEBT that are exposed, not only to direct beam losses, but also to intense backstreaminng of neutrons from the lithium target.

Table I

FMIT HEBT MAINTENANCE CATEGORIES

CATEGORY	FREQUENCY	TYPE
I	Weeks - Months	Vac pumps Diagnostics
II	1 - 5 years	Water fittings Electrical fittings Insulators Instrumentation Connectors Vac seals Realignment
III	Rarely	Cluster failure/removal
IV	Often	Move shielding

*Work performed under the auspices of the US Department of Energy.
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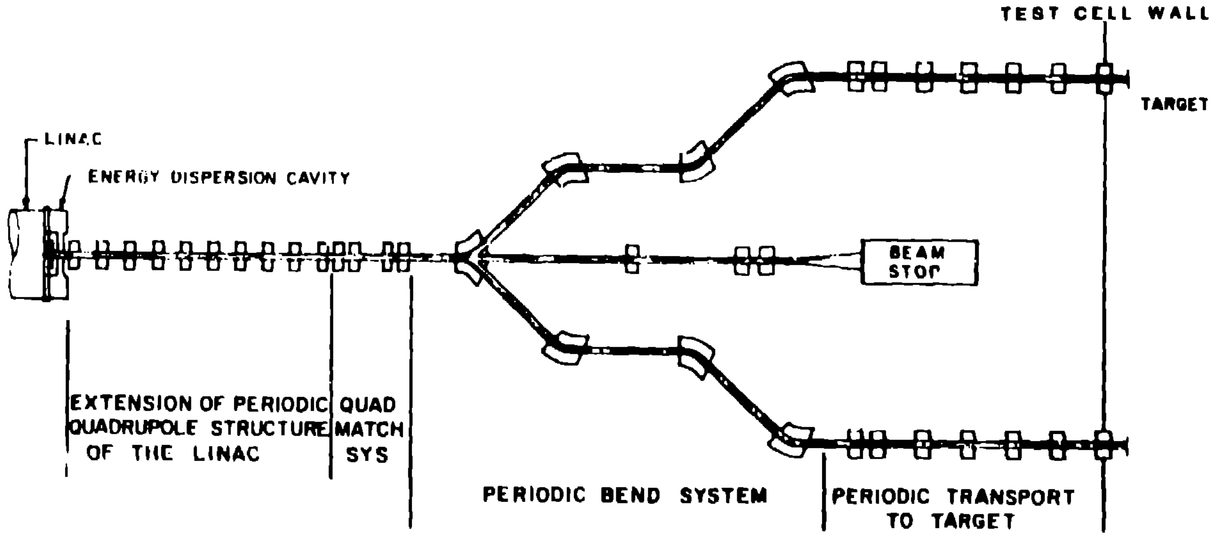

Fig. 1. The FMIT High Energy Beam Transport

HEBT Modularization

The solution to a great many of the maintenance problems listed in Table I is accomplished through modularization. In applying this technique, the HEBT is broken down into sections approximately 3 m long, within which all the beamline components are mounted on a structural-steel carriage, supported from the facility floor, independent of the neighboring carriages. An artist's conception of a typical module assembly is shown in Fig. 2. The assembly breaks down into three subassemblies: the top-yoke halves of the quadrupoles; the beam tube and all connected components; and the bottom-yoke halves and carriage. Each of these subassemblies is connected to a termination panel on which is mounted all the water fittings, dc power contacts, water-distribution manifolding, and protective interlock circuitry. The termination panels are cantilevered 2 m out from the beam centerline, which allows 1 m for neutron-absorbing shielding. With this technique we intend that many of the Category II maintenance items not only will be readily accessible for inspection, but that hands-on maintenance of these items will be possible over the lifetime of the facility.

Another advantage of modularization is alignment. The modules will be assembled in a laboratory, where sufficient care can be exercised in making all terminations, and both water and electrical circuits can be thoroughly tested. During this assembly, the carriage will be supported in the same way, as in the HEBT; that is, by kinematic mounts. Therefore, all static loadings of the carriage structure will be accounted for and accurate alignment of each component, principally the quadrupoles, can be made. The bore line of the module will be set to a reference line established on the exterior of the carriage by twin alignment targets. When the module is inserted in the HEBT, this reference line will be used to align each module relative to its neighbors.

The most critical maintenance items fall into Category I. Vacuum pumps will be mounted remotely from the beam tube and shielded so that a direct approach to these pumps will be possible. Where possible, diagnostic equipment will be mounted in service tubes which allows the vacuum seals to be made outside the shielding. Diagnostic equipment that cannot fit into a service tube will have to be handled with remote-maintenance equipment, or the entire beam tube will have to be removed and replaced.

The water-cooled beam tube is attached to its neighbors by remote maintenance-rated flanges. The vacuum seals are soft-metal plated K-seals. Because of the dense packaging of components required in each module to accommodate the periodic optics system, the beam tube assembly will be all-welded, with flanges used only at each end. All components that insert into beam boxes will be replaceable externally, but should a flange or weld fail on the tube itself, replacement of an entire beam-tube assembly is possible by opening the quad halves and removing the failed unit. As a final back-up, extensive damage can also be repaired by replacing the entire module. This feature also accommodates maintenance Category III.

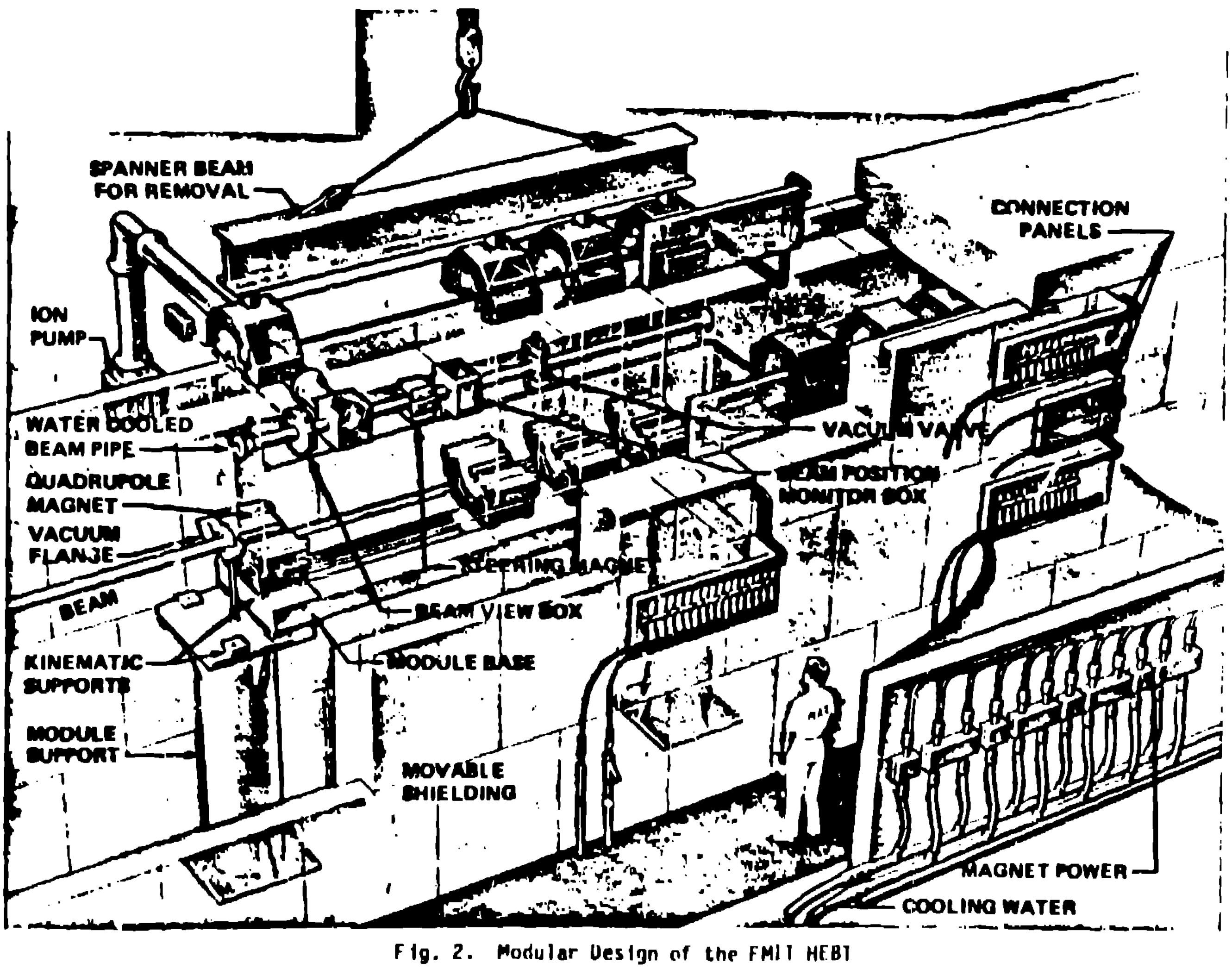

Fig. 2. Modular Design of the FMIT HEBT

Quadrupole Design

To accomplish the disassembly procedure outlined above, the quadrupoles must be designed to open clam-shell fashion. This is achieved by building them in quadrants, as shown in Fig. 3. Each quadrant is a single block of low-carbon steel, with yoke and pole tip machined as a unit and the quadrants fastened together by means of dowel pins and edge-mounted tabs. A pair of these quadrants then makes up the top or bottom quad half. Each quadrant carries a coil, wound from a continuous length of solid-core, mineral-insulated conductor. Four such coils, consisting of individual conductors, are terminated, four conductors on the top and four on the bottom termination panels, where series electrical and parallel water connections are made. To break the quadrupoles apart, stripper bolts are removed from the tabs and the quad halves are removed with the associated termination panel. On modules with several quadrupoles, all must be opened simultaneously. The process is reversed in reassembly.

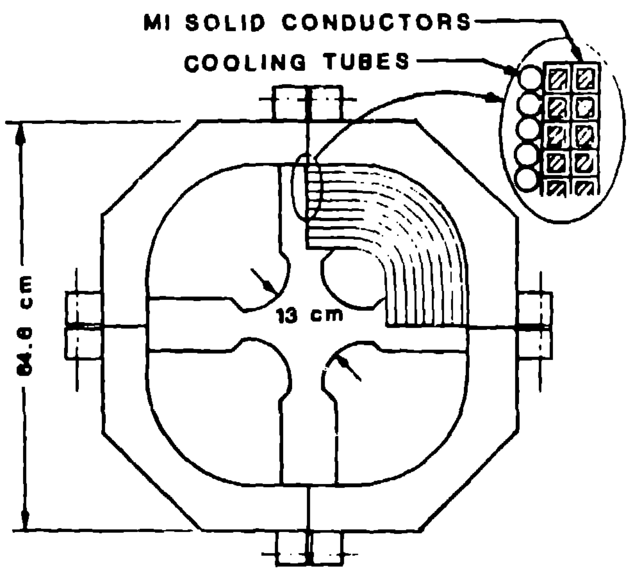

Fig. 3. Mineral-insulated, solder-potted, indirectly cooled HEBT 30-cm quadrupole.

Extremely high neutron fluxes exist in the beam tube of the downstream leg of the HEBT caused by back-streaming from the target. These fluxes range from almost 10^{11} n/s-cm^2 down to 10^9 n/s-cm^2. Because of the attendant disassociation of the conductor cooling water, directly cooled copper conductors are not used in the design of the field coils. Instead, solder-impregnated, solid-core, mineral-insulated conductors are used, which are indirectly cooled by stainless-steel tubing imbedded in the solder along with the conductors.

Each magnet is designed with flat faces, to which slabs of lead can be attached for gamma shielding. The weight tolerance of each module for additional lead shielding is about 5 tons. This means that a thick sheath of lead can be applied over all accessible surfaces, without exceeding the capacity of the bridge crane that services the HEBT. All lead shielding is applied in the tooling dock before the precision alignment is done.

Material Choices

The FMIT HEBT beam tube is exposed to activation from direct beam spill, neutron backstreaming near the target, and Be^7 carried back by diffusing lithium. In addition, chemical action from lithium occurs at seals in the beam tube near the target, and can attack the beam-tube wall itself. Activation studies have shown that aluminum is a preferred beam-tube material, because of its rapid cool-down rate. Near the target, the beam tube will have to be 304 SS, which is highly resistant to chemical action by lithium. In the upstream HEBT vacuum flanges, lead-coated K-seals can be used, but near the target, another type of sealing plate will have to be found.

There are many details to be solved in the HEBT design, but the concepts described in this paper have been developed with a single purpose: that sophisticated conceptual design may reduce or avoid sophistication in maintenance procedures later--rather than the other way around.

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