MODULAR DESIGN ASPECTS OF THE FMIT DRIFT TUBE LINAC*

D. J. Liska, R. G. Schamaun, W. Fox, J. A. Frank,† W. Coops,† C. Potter,†
T. Cole, D. Greenwood, H. Norman,† P. Giles, K. Creek,† and D. Clark
Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

Summary

The Fusion Materials Irradiation Test (FMIT) Facility drift tube linac may be subject to high levels of activation because of distributed spill of the deuteron beam. The drift tube suspension system will use a modular design to allow repairs and alignment to be made without manned entry into the tanks. Design details are presented that show the resulting high degree of flexibility. Because the accelerator will be installed at the Hanford Engineering Development Laboratory (HEDL) at Richland, Washington, it is desirable that large prefabricated tank assemblies (15 m and 18 m long by 2.5 m diameter) be delivered to the construction site. Stress studies and vacuum sealing tests have influenced the design and these results are given. The rf power dissipation in the tank walls is 1.5 MW and requires a high-capacity cooling system. Finally, rf tuning of the tanks is complicated by the presence of girder slots and open vacuum ports.

Introduction

The FMIT Facility includes one of the world's most powerful linacs, under design by the Accelerator Technology Division of the Los Alamos Scientific Laboratory (LASL). This machine is required to deliver a 3.5-MW continuous-duty deuteron beam onto a lithium target. Neither the machine energy (35 MeV) nor the 100-mA current is unique; however, the combination of the two at continuous duty and with a deuteron beam, represents a major step forward in high-powered, low energy linacs. Other papers in this conference[1,2] deal with special systems requirements and critical beam dynamics considerations involved in working with a potentially activating beam at this power level. Some of the mechanical design aspects of the linac itself that make it especially adaptable to the project needs of high availability and reliability over an operational lifetime of 20 years, will be discussed.

Modular Design Features of FMIT

A major lesson that was learned from the Clinton P. Anderson Meson Physics Facility, (LAMPF) is the advantage of a modular design. This permits not only effective maintenance to be undertaken because of smaller and more manageable units to be handled, but also a significantly higher level of duplication of components. With a modular system an attempt is made to isolate each module from the others in a functional sense even though the operational relationship between all modules is maintained. The net result is higher reliability and less disastrous consequences in the event of major breakdowns. In LAMPF the 805-MHz linac and the rf systems are highly modularized and are classic examples of high reliability and trouble-free operation.

The FMIT is a relatively small facility and its modular design makes it very manageable through the organization of the rf system, the drift tube linac, and the beam transport line. The rf power system consists of 15 identical high-power amplifiers, each of which is broken down into several components that, using air pallets, can be quickly removed for maintenance. Spare units can be moved into position as quickly.[3] The linac drift tubes are supported on 11 separate strongback girders that can be quickly disconnected from the electrical and water services and lifted out of the linac tanks.[4] A similar technique is utilized in the High-Energy Beam Transport (HEBT) lines to the target cells. Here the magnets and associated equipment are mounted on modular carriages that can be unhooked from the overhead supporting structure and can be transported to a maintenance area.[5]

The entire linac girder system and the HEBT clusters form a very suitable arrangement for precision alignment of components. Each module can be aligned in a tooling dock with optical and magnetic-center surveying methods. When installed in the system, each module must then be aligned relative to all others by using the facility alignment monument system. Calibrated positioning guides are used to support the drift tubes on the girders. This feature will allow in situ alignment of the drift tubes, a feature that may prove crucial if precision steering of the deuteron beam becomes necessary.

The final feature of mechanical modular design that is critical to FMIT is the manner in which it provides an option to hands-on maintenance. Modular design certainly makes the system more easily serviced than other construction techniques; however, if the activation levels are as high as some sources predict, no person will be allowed to enter the tanks to service the drift tubes.[6] The modular design is adaptable to remote maintenance procedures, a

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†Westinghouse/Hanford Engineering Development Laboratory employee working at the Los Alamos Scientific Laboratory.

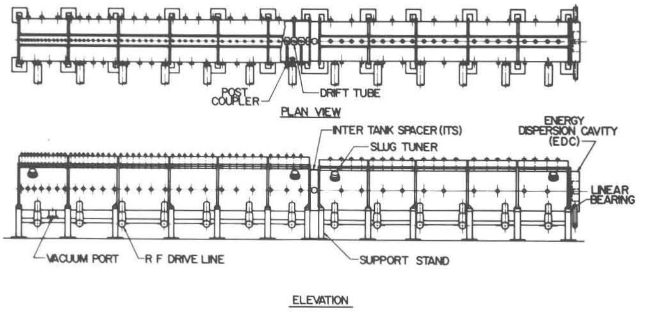

Fig. 1 The FMIT drift-tube linac.

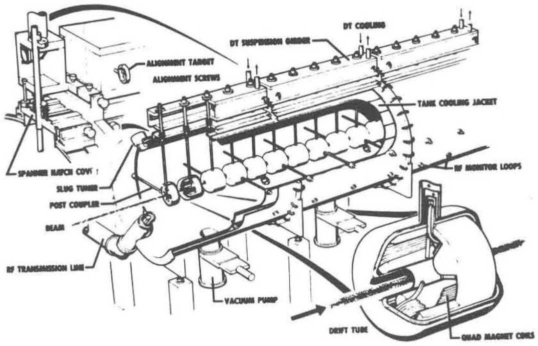

Fig. 2 Modular drift-tube suspension.

factor that will become more crucial if the allowable limits on personnel radiation exposure are dropped from 5 R/yr to 500 mR/yr.

Mechanical Design Details

Linac tanks

The drift tube linac shown in Fig. 1 consists of two tanks that will be installed as prefabricated assemblies. Tank 1 is 248 cm in diameter and 18 m long; it raises the beam energy from 2 to 20 MeV. Tank 2 is 240 cm in diameter and 15 m long and raises the beam energy to 35 MeV. Drift tube loading of these shells results in an operating frequency of 80 MHz. A cutaway section of a typical tank is shown in Fig. 2. The tank is provided with girder slots that are strengthened by means of forgings that encircle the slots. The drift tube girder assembly is lowered through the slot and the spanner hatch overspans the gap, adds strength, and completes the vacuum seal. Heavy stiffening rings, located every three meters, support the weight of the girders. The tank material is 2.5-cm-thick copper-clad steel and it is important that the stiffening rings do not deflect excessively when the tanks are evacuated. Calculations show that the maximum compressive stresses are under 3000 psi and that the deflection of the stiffening rings is less than 0.1 mm. This assures accurate alignment support for the girder kinematic mounts.

The vacuum ports are open pipes 46 cm in diameter and 46 cm deep. As waveguides-beyond-cutoff, attenuation of the TE_{11} mode at 46 cm is about -31 dB, so only the lightest duty rf grills are provided at the base of the ports to protect the ion pumps against stray fields. Other tank openings are required for the multiple rf drive loops, the post couplers that provide rf stability, and the tuning slugs.

The welded and proof-tested tanks will be installed at HEDL. Transport from the fabricator and installation of tank sections up to 18 m in length is feasible, allowing a significant reduction in on-site assembly work. The tanks, mounted on their supporting structure, will be slipped into the injector end of the building and rolled into position. To prevent damage from overhead work, this installation will be done after the facility roof is in place.

Drift tube girders

The use of modules is developed to a high degree in the girder concept for supporting the drift tubes. This technique has been applied by CERN but differs in one major respect from FMIT. The drift tube stems have been isolated from the linac tank by the bellows seen in Fig. 2. Protection of the bellows from the rf fields is by a choke joint and a rf seal, which are presently under development. Use of the bellows prevents distortions of the tanks from disturbing drift tube alignment and this further eliminates the need for precision machining of drift tube mounting sockets in the tank. The girders are supported on kinematic mounts that allow relocation to precise positions following removal for maintenance. All services for the girder are connected to a convenient panel and distributed through the girder by electrical and water manifolds.

An important feature of the alignment system is the provision of calibrated positioning guides on each drift tube stem, which can be accurately postioned with lead screws. Reproducible alignment adjustments can be made to the drift tubes under conditions of operating vacuum and temperature in direct response to beam position error measurements. Of the six degrees of freedom, x, y, z and yaw can be controlled in this way. The remaining degrees of freedom, pitch and roll, are constrained during installation of the quad in the drift-tube housing.

Alignment system

The FMIT alignment system is shown in Fig. 3. Again, this is similar to the CERN concept except that it is carried through from the injector to the target. Alignment of each girder relative to the others is made with an alignment scope mounted on any of a number of

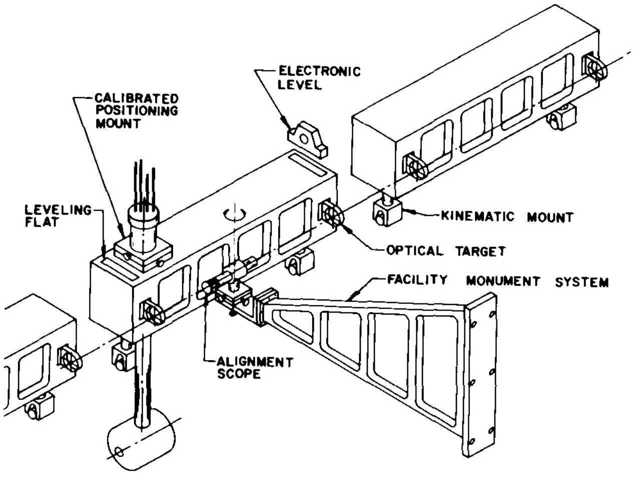

Fig. 3 The FMIT alignment system.

facility-surveyed monument fixtures sighting through transparent targets on each adjustable module. Theodolite stations are provided in the HEBT to turn the line of sight through precise angles. The system shown in Fig. 3 can deal with x, y, pitch, yaw, and roll errors. Roll is measured by an electronic level and z by digital tape. General alignment tolerances in FMIT are ±0.25 mm and ±1 mrad, although low-loss beam transport through the linac may require considerably tighter translational adjustments.

Drift tubes and quads

There are 72 free-standing drift tubes in FMIT and 4 captive in the end walls. All free-standing drift tubes are mounted on the 11 girders and the end-wall quads are all supported by separate, small girder fixtures. Each drift tube carries a quadrupole magnet. Each magnet is wound with a split winding that allows a dipole field component to be generated in the vertical plane by differential excitation of the field coils. This method of horizontal steering produces sextupole field distortion and can only be used in small amounts; another reason that calibrated positioning of the drift tubes has been adopted. Vertical steering at specific quads has been provided by trim coils.

The quads are mounted in cast stainless steel housings (Fig. 4). Castings are used because of the need for complex cooling courses and mechanical stiffness. Firm positioning and support for the quad is provided by the girth ring casting. The tapered drift tube shells are derived from SUPERFISH optimization studies and result in high rf power efficiency. Type 316L stainless steel was used because it is resistant to permeability changes during fabrication and because it has good weldability. After the shells are fabricated, they are copper plated before they are installed and aligned in the girders. The PARMILA beam dynamics studies have shown that a "constant-length, constant strength" concept can be used to reduce the number of quads and drift tubes that are required. Three quads and five shell models can be used to equip the FMIT girders. Those combinations are listed in Table I.

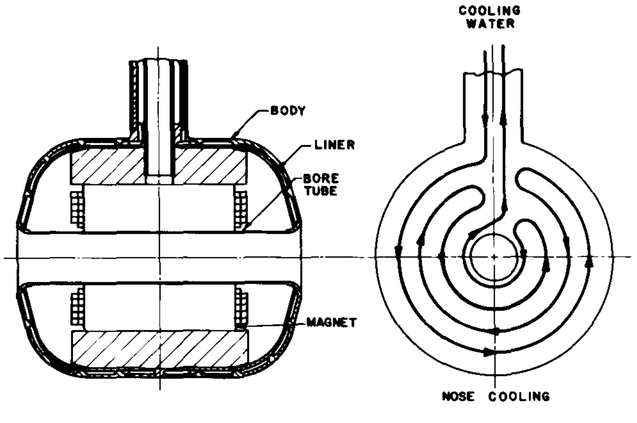

Fig. 4 Quad support and drift-tube shell cooling.

Essential linac peripherals

The peripheral attachments to the drift tube linac tanks include the post couplers, slug tuners, rf drive loops, intertank spacer, and energy dispersion cavity (Figs. 1 and 2). It will be noted that rf domes are absent; instead flat-plane rf windows were located at the 1/8 wavelength position from the loop (47 cm) so that the window will be exposed to high but not maximum fields during transients to better cope with multipactoring.

The intertank spacer provides a one-cell drift space for diagnostic purposes at the 20-MeV point. The quads in the drift space are supported by a yoke, which in turn is attached to an externally mounted small girder. This allows the modular external alignment system to be carried from Tank 1 to Tank 2 as well as to permit effective maintenance without tank disassembly and entry. The energy dispersion cavity (EDC) is attached to the downstream end of Tank 2. It exposes the 35-MeV beam to a sinusoidally varying voltage of ±500 kV at a beat frequency of a few megaHertz. This effectively disperses the energy of the micropulses by 1 MeV to ease the thermal stresses applied to the lithium target. In addition to its effect on beam dynamics, the EDC also provides the downstream pressure bulkhead for Tank 2.

Vacuum and cooling

Most vacuum seals on FMIT are conventional aluminum wire. The spanner hatch seals however are 7 m long and in addition they are exposed to thermal as well as rolling stresses caused by spanner deflection under vacuum. Preliminary

TABLE I

SUMMARY OF FMIT DRIFT TUBE AND QUADRUPOLE MAGNET PARAMETERS

	Drift Tube					Quadrupole Magnet	
Drift Tube Number	Bore Diam (cm)	Outside Diam (cm)	Face Angle (degrees)	Length min/max (cm)	Type	Gradient (G/cm)	Approx. Power (kW)
1-15	5.0	42.0	4	14.24/20.77	A	2750	6.6
16-25	6.0	38.0	8	22.35/27.60	B	1885	7.7
26-37	6.0	38.0	12	28.48/34.53	B	1885	7.7
38-51	6.0	38.0	15	35.69/42.12	B	1885	7.7
53-73	8.0	38.0	15	44.72/53.46	C	990	9.4

model tests on all important seals, including the spanner hatch, have been completed and full scale testing of the spanner hatch seal is continuing.

The tanks and drift tubes are temperature controlled to dissipate about 5 kW/m^2 at $31^{\circ}\pm0.3^{\circ}$C, by a servo-controlled cooling system that mixes 85% mainstream water from a heat exchanger with 15% water from heaters and chillers. This system has been simulated and it readily controls the major transient resulting from loss of 1.5 MW of rf in the copper. A time constant of about one minute results from thermal lag in the tanks and the response of the heat exchanger. The tanks are longitudinally channel cooled by counterflowing the coolant over channel lengths as great as 18 m in Tank 1. A 3°C temperature rise in the channel is allowed with full rf power dissipation.

Radio-frequency tuning

The drift tube linac tanks must resonate at 80 MHz when fully loaded with the drift-tube clusters. The presence of the girder slots and the open vacuum ports lowers the resonant frequency by about 250 kHz. The post couplers and centered tuning slugs raise the frequency by about 25 kHz. It is essential that the tanks be fabricated low in frequency. A tuning bar area of 50-70 cm^2 is required to tune the tanks. These must be cut by trial and error with the tanks under partial vacuum. Once tuned, the resonance control system and slug tuners will only be able to control the frequency by ±6 kHz. The required fine balance of mechanical adjustments will be verified by the construction and test of reduced-scale rf models.

Conclusions

The FMIT drift tube linac is moving from conception into preliminary design. To solve the problems with maintenance of potentially activated components, as well as to provide for precision alignment, a modular design system has been adopted. Alignment can be checked externally because all components are mounted on girders or carriages outside the vacuum and rf envelopes. Calibrated positioning fixtures on the drift tube stems allow reproducible adjustments of individual drift tubes in response to beam dynamics measurements. In principle, it may be possible to steer a low-loss beam through FMIT without the use of steering magnets in the drift tube linac portion. This is a decided advantage, because packaging restrictions prevent the use of discrete steering elements and only allow minor steering, using trim coils or differential excitation of the quadrupole field windings with undesirable sextupole side effects. Unusual fabrication techniques are required in this accelerator because the design is being done by LASL for HEDL, fabrication is by U. S. industry, and installation will be by HEDL personnel at Richland, Washington.

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Discussion

Grand, BNL: What is the maximum energy spread you expect to have with the energy dispersion cavity, and what does it do to the transport line?

Liska: We expect to swing the cavity plus or minus 750 kilovolts.

Grand: And you have to add to that the energy spread in the beam due to the linac. So you end up having 1 MeV spread. What does that do to the transport in the bends?

Liska: Yes, that's right. But the transport system is quite achromatic - it has been designed to handle this sort of a spread - actually 1.5 MeV spread has been designed into the HEBT. The spread of the beam is very important, as Jameson has shown. If it is not taken into account properly, then very strong bimodal shaping of the dispersion can take place, which can do more harm to the target than no dispersion. But if the linac energy spread is properly taken into account, then quite good flattening of that energy spread can be achieved.

Miller, SLAC: Do you anticipate wobbling individual quadrupole excitations in order to check the alignment of each quad with the beam?

Liska: Yes, I expect that one technique we will use to check alignment will be individual operation of the quads to check the steering effects that this might cause. I didn't point it out, but we do have on our girders what amounts to a panel in which all the utilities are delivered, including in effect, a huge Burndy connector on each quad, which would allow us to individually excite it to check this sort of thing.