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HIGH-ENERGY BEAM TRANSPORT IN THE HANFORD FMIT LINEAR ACCELERATOR*

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Abstract

The High-Energy Beam Transport (HEBT) for the Hanford Fusion Materials Irradiation Test (FMIT) Facility's Linear Accelerator must transport a large emittance, high-current, high-power continuous duty deuteron beam with a large energy spread. Both periodic and nonperiodic systems have been designed to transport and shape the beam as required by the liquid lithium target. An energy spreader system distributes the Bragg Peak within the lithium. A beam spreader and a beam stop have been provided for tune-up purposes. Characterizing the beam will require extensions of beam diagnostics techniques and non-interceptive sensors. Provisions are being made in the facility for suspending the transport system from overhead supports.

Introduction

The Hanford FMIT Linear Accelerator will produce a 3.5-MW, 100-mA continuous duty deuteron beam at 20 and 35 MeV. The beam transport system has a Y-shape to transport the beam to either of two lithium targets. The total possible geometric emittance of the linac is 68.5π cm-mrad unnormalized; the transport is designed to transport this emittance through the two bends of the Y to the last quadrupole doublet before the target. The liquid lithium target design requires both a ±500-KeV energy spread in the beam and a 1 x 3 cm FWHM Gaussian spot size incident on the target. Both periodic and nonperiodic transport systems have been designed to deliver the required beam to the target.

The Beam Transport Systems

The quadrupole apertures in the periodic system are minimized by extending the periodic quadrupole structure of the accelerator up to a quadrupole system that matches the periodic quadrupole array of the machine to the bending system (see Fig. 1). The periodic bend system consists of four identical bending magnets with the angle of bend for the second and fourth magnets reversed. A mirror image of this system provides the transport to the other test cell. Vertical focusing is provided by the downstream edge angle of each magnet such that the phase shift of the cell is 90° in both planes with equal cell lengths in both planes. The transformation matrix across the four cells is, therefore, unity and the system is achromatic.

This system can transport the full geometric emittance of the machine with reasonable apertures and should require little tuning if the beam is well matched in the linac. If the beam is not matched in the linac, the matching section in front of the bends can be readjusted. However, once the field strengths are adjusted on the quadrupoles, the system will transport any beam without being re-tuned because it has been designed for the full geometric emittance of the linac.

While the periodic system allows for a calculated, well-defined transport of a matched beam from the linac (Fig. 2), a nonperiodic system (Fig. 3) provides a reasonable but variable transport system. The first section of the nonperiodic system consists of a pair of triplets to transport the beam from the end of the linac to the switching magnet. The achromatic translation system consists of two bending magnets and five quadrupoles.[1] The first bend is 30° with the quadrupoles transporting the beam to a reverse 30° bend. The achromatic translation is symmetric about its center element.

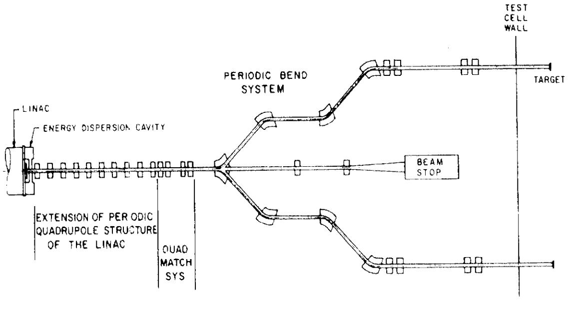

Fig. 1. Periodic transport system.

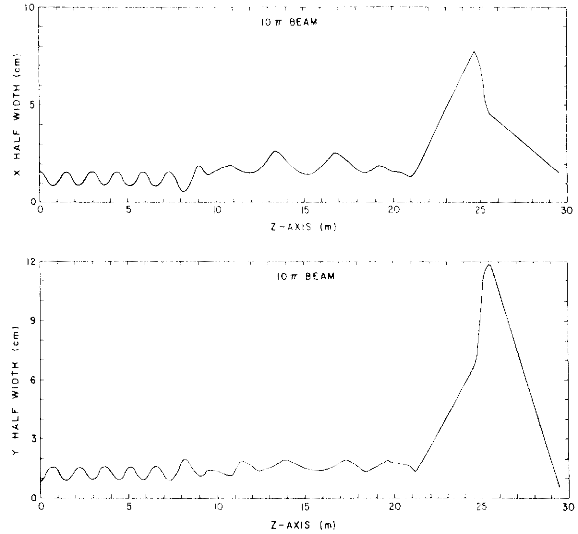

Fig. 2. Beam envelopes for periodic transport system.

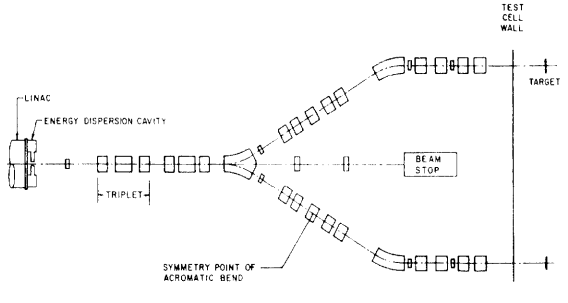

Fig. 3. Nonperiodic transport system.

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The nonperiodic system allows almost unlimited range of control over the spacing between focusing elements. This control allows greater flexibility in positioning of diagnostic equipment in particular. In cases (such as FMIT) where the beam must be well-defined, this flexibility can be very important.

However, the periodic system has several advantages overthe non periodic system. It can transport a large emittance through much smaller apertures thus lowering the power requirements for the magnets. Also, the majority of the elements have "fixed" field strengths requiring less beam tuning to transport the beam. Because the periodic system needs little tuning, it permits the beam to be transported in a more controlled, stable and predictable fashion with minimum beam spill. This predictability can be advantageous for diagnostics by possibly simplifying beam reconstruction techniques used to obtain emittance information from beam profile measurements.

After the final bending magnet in each system the two designs are basically equivalent, each requiring two quadrupole doublets to shape the beam as needed by the target. The last doublet is designed to transport a phase space of 25π cm-mrad to the 1 x 3 cm spot on target.

Other Systems

Beam Diagnostics

Monitoring the progress of the transported beam will require noninterceptive sensors such as current transformers, magnetic position monitors, inductive pick-ups, and spill detectors. The information and feedback from these sensors must be processed through the control system and then returned to beam handling elements with sufficient speed and sensitivity to correct out-of-bounds conditions with minimal spill of the deuteron beam. Providing profiles of the density distribution within the beam may be accomplished by viewing (and digitizing) the light emitted from recombination processes of ionized residual gases in the beam tube. Three such optical profiles may be converted to a two-dimensional density plot and three or four such density plots from differing transport conditions may be reconstructed to give emittance information. Alternative schemes involving ion collection or laser interaction are also being investigated.

Further requirements for the diagnostics system include measurement of longitudinal emittance, and verification of the required energy spread on target. The shape of the beam spot on target must be well defined because it is the source both of 3.5 MW of lithium target heating and of the product neutrons. These measurements must be made reliably in the presence of quite intense neutron fields.

Energy Dispersion Cavity

The creation of a ±500 keV spread in beam energy requires a special rf cavity at the end of the linac (Fig. 1). This cavity operates at a frequency varying slightly from the 80 MHz of the accelerator itself so that the energy dispersion is a "beat" of about 1 MHz. The cavity is a simple capacitively loaded TM_{010} resonator that has a gap about equal to the last gap of the drift-tube linac and a diameter equal to the last linac tank. Thus, the pressure bulkhead can be transferred to the energy dispersion cavity itself and permits a simple rf bulkhead between the linac and the cavity. Positioning the cavity at the end of the linac permits its use for either beam line branch. The energy dispersion cavity is frequency and amplitude controlled but not phase controlled.[2]

Beam Stop

A beam spreader and a beam stop have been provided for initial tune-up purposes using an H_2^+ tune-up beam in a pulsed mode or a very low current of deuterons. Because the fill time of the linac tanks is under 2 ms, 10-ms pulse widths can be used to adequately exercise the operation of the rf control system, the set points of the drift tube quads in the linac, and the HEBT up to the first bending magnet. The short pulse widths allow low duty factor operation at full peak power that greatly simplifies the design, construction, and expected lifetime of the beam stop. The beam stop will utilize the calorimeter principal and resembles the Lawrence Berkeley Laboratory designs, which consist of two thick and angled copper plates joined at the apex.[3] While not an operational function of FMIT, pulsed tune-up at full power has many side benefits among which is the checking of the rf control transient system's capability recovery.

Beamline Suspension System

The facility is being designed to allow the transport system to be suspended from overhead supports to facilitate maintenance of activated components. The transport support system is a grid of I-beams supported by the walls of the building. Alternate methods are being studied for attaching the beam line components to the support system and a variety of mounts have been proposed. The mounting stand will give all degrees of freedom of movement to the element allowing for its proper alignment.

Conclusion

The Hanford FMIT Linear Accelerator is a state-of-the-art accelerator. The transport system must handle a high-intensity beam with additional constraints imposed by the target system on the beam parameters. Recent developments in beam transport theory, pertaining to matching different periodic systems, have facilitated the design of the periodic HEBT concept.

The development of state-of-the-art diagnostics equipment is a major research and development area for this project. Detailed engineering studies are developing the energy dispersion cavity, the beam stop, and the suspension system for the transport system. The successful production and transport of the 3.5-MW, 100-mA continuous duty deuteron beams at 20 and 35 MeV will be an important step forward in accelerator technology.

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