THE MECHANICAL DESIGN FOR THE SECOND AXIS BEAM TRANSPORT LINE FOR THE DARHT FACILITY[*]

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Abstract

This paper describes the mechanical design of the downstream beam transport line for the second axis of the Dual Axis Radiographic Hydrodynamic Test (DARHT II) Facility. The DARHT II project is a collaboration between LANL, LBNL and LLNL. DARHT II is a 20-MeV, 2000-Amperes, 2-µsec linear induction accelerator designed to generate short bursts of x-rays for the purpose of radiographing dense objects. The downstream beam transport line is an 18-meter long region extending from the end of the accelerator to the bremsstrahlung target. Within this proposed transport line there are 17 conventional solenoid, quadrupole and dipole magnets; as well as several specialty magnets, which transport and focus the beam to the target and beam dumps. There is a high power beam dump, which is designed to absorb 80-kJ per pulse during accelerator start-up and operation. The beamline vacuum chamber has an 8-cm diameter aperture and operates at an average pressure of 10^{-7} Torr.

1 INTRODUCTION

We are starting the engineering design for the downstream components of the DARHT II Accelerator [1]. Beam transport studies for this design are described elsewhere in these proceedings [2]. Figure 1 shows the proposed layout for the elements in the system. The beamline from the exit of the accelerator to the target is about 18 meters long. Only four short (16 to 100 nsec) pulses separated by about 600 nsec are desired at the bremsstrahlung target.

The function of the kicker system is to "kick" four pulses out from the main 2-µsec pulse leaving the accelerator. The kicker includes a bias dipole operated so that the non-kicked parts are deflected off the main line into the main beam dump, while the kicked parts are sent straight ahead. Focusing elements between the kicker and the septum would complicate operation. Therefore, to achieve a narrow beam waist at the septum, solenoid S3 must "throw" a waist to the septum. The first 3 meters of beamline allow the beam to expand from its 5-mm matched radius in the accelerator to 2.25-cm at solenoid S3. The system is designed to have a 20% energy acceptance to transport to the main beam most of the leading and falling edge of the pulse exiting the accelerator. The proposed system using a quadrupole septum magnet [2] allows for a larger beam pipe radius than the more conventional dipole septum magnet studied earlier. This increases the energy acceptance of the transport line to the main beam dump. Although desirable, we do not expect to include the "Enge-magnet" system described in the transport studies in the beamline for the initial commissioning of the accelerator.

The kicker system is described elsewhere in these proceedings [3]. After the kicker system, there are 3 quadrupole magnets to restore the beam to a round profile and to compensate for edge focusing from the bend elements (BM1, BM2, BM3, BM4 as shown in Figure 1.) in the Chicane. Also, we have included beamline elements in this region to allow energy and emittance measurements of the "kicked" pulses. Experience has shown ejecta material from the target can travel the length of the accelerator. To keep this material from reaching the injector and accelerator cells we have included a Chicane system that does not allow direct line-of-sight between the target and the upstream elements.

Finally the beam will be pinched to a tight focus at the target to provide an intense spot of x-rays for radiographic purposes. Work on the target is also presented in these proceedings [4].

2 MAGNETS

The magnets within the DARHT II transport line are all water-cooled conventional dc electromagnets with the exception of the final focus solenoid magnet, which is pulsed. The magnets are listed in Table 1 along with their design parameters.

The transport solenoids have external iron shrouds with water-cooled copper coils. Solenoid coils are wound into individual two-layer "pancake" coils. Each magnet has an even number of these pancake coils. The pancakes are installed in an A-B-A-B orientation to minimize axial field errors. The inside diameters of the solenoid coils are sized large enough to fit over the outside diameter of the beam tube flanges.

The transport quadrupole and dipole magnets have solid iron cores with water-cooled copper coils. The quadrupole magnets are two-piece, solid-core construction. The dipole magnets are two-piece, solid-core, "H" style construction.

The alignment requirements for the transport magnets are ±0.4-mm positional tolerance and ±3-mrad angular tolerance. All transport magnets have fiducials mounted on the outside of the iron. The magnets are magnetically

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mapped and aligned on the transport line with respect to the fiducials.

Table 1: Magnet specifications

Magnet Name	Length (m)	Field (kG)	Bore (cm)	Bend (deg)
Solenoid S3	0.25	3.0	22	-
Quad Septum	0.15	15.0	16	-
Dipole Septum	0.40	1.2	16	-35
Quadrupole QV	0.15	1.0	16	-
Quadrupole QH	0.15	1.0	16	-
Quadrupole QS	0.15	1.0	16	-
Dipole EAM	0.40	1.5	16	-45, +90
Solenoid S5	0.25	3.0	22	-
Dipole BM1	0.15	1.0	8	+6.6
Dipole BM2	0.15	1.0	8	-6.6
Dipole BM3	0.15	1.0	8	-6.6
Dipole BM4	0.15	1.0	8	+6.6
Solenoid S6	0.25	3.0	22	-
Solenoid SFF	0.05	20.0	8	-

3 VACUUM SYSTEM

The vacuum chambers for the DARHT II Transport Line are circular beam pipes constructed from 304L stainless steel. The region from the end of the accelerator through the septum has a 16-cm bore diameter. From the septum to the target, the bore diameter is reduced to 8 cm. The vacuum seals are made with conflat style knife-edge flanges with annealed copper gaskets. RF seals between flanges are made with copper “gap rings” which are compressed between the conflat flanges and fill the gap at the inside bore of the beamline between the flanges. The use of all-metal seals is driven by the potential requirement to *in situ* bake the transport vacuum system. *In situ* bake-out may be required to minimize adsorbed gas on the beam tube walls, which may be desorbed by beam halo scraping the walls.

The vacuum design requirement for the transport line is 10^{-7} Torr average pressure. Above this pressure, predictions indicate that there will be detrimental effects to the beam. In addition, the vacuum pressure at the target is desired to be in the 10^{-8} Torr range. To meet these requirements, a combination of cryopumps, and turbomolecular pumps are employed along the length of the beamline. The pump sizes and spacing was determined by calculating the vacuum pressure profile along the beamline utilizing a one-dimensional pipeline pressure code [5]. For this analysis, the beamline is characterized as a series of discrete segments. Length, axial conductance, gasload, and pumping speed define each segment. The pump speeds and locations of the pumps were varied to determine the most economical approach to vacuum pumping the transport line. The pressure profile for the transport line is shown in Figure 1. The average beamline pressure is 8.5×10^{-8} Torr (85 nTorr).

The pump located at the end of the accelerator is a 20-cm diameter cryopump. A cryopump was selected for this location to pump the relatively high gas loads from the last accelerator segment. The remaining pumps in the transport line are 250 liters per second turbomolecular pumps because the gas loads in the transport line are lower and the axial conductance of the beamline is significantly less than in the accelerator. All vacuum pumps must pump the beamline through pumping crosses equipped with RF screens to minimize perturbations on the beam.

Throughout the beamline there are beam position monitors (BPMs) to measure the location and angle of trajectory of the beam. The BPMs mount between the flanges of adjacent transport beam tubes. The accurate transverse location of the BPMs is critical to the operation of the transport line and it is their positional requirements, which set the alignment tolerances for the beam line vacuum system. To satisfy the BPM requirements, the transport line beam tubes must be aligned to within 0.2 mm offset. Each beam tube will be manufactured with fiducials, which allow the survey crew to measure and position external to the centerline.

4 BEAM DUMPS

There are three beam dumps included in the DARHT II downstream transport system; a main beam dump, an energy analyzer dump, and an emittance diagnostic dump. The main beam dump absorbs the portion of the beam that is not deflected by the kicker magnet. The beam is initially deflected by the bias dipole, it then passes through the septum quadrupole to the septum dipole and into the main dump. The normal horizontal beam size at the main beam collector is 8 cm. However, the startup parameters for the beam will not be well known. We must therefore provide some safety margin. First consideration is to keep the instantaneous temperature (temperature at the end of the 2-μsec pulse) of the impact area below the damage point for the material. At a 5 pulse per minute repetition rate we can manage the average temperature increase. The beam’s energy is 80-kJ per pulse and the average thermal power is 6.67-kW. We also desire to keep the neutron yield low to minimize activation of components and simplify radiation shielding. The construction of the beam dump must be compatible with high vacuum as explained in the previous section. Studies are looking at using graphite material to decelerate the beam electrons.

The energy analyzer dump and the emittance diagnostic dump are similar in design. These two dumps are designed to absorb the kicked portion of the beam, which is deflected to either diagnostic for evaluation. This beam’s energy is 4.0-kJ per pulse and the average thermal power is 0.33-kW at 5 pulses per minute.

In addition to the beam dumps, there is a beam stop, which is a safety feature in the transport line. The purpose of the beam stop is to allow accelerator operations to continue while personnel are working in the target area outside the accelerator hall. The beam stop is located at the end of the accelerator hall, within the penetration in the 5-foot thick concrete wall. The beam stop is a composite absorber, made up of a 3-inch thick graphite block, backed by 12-inches of tungsten. There is additional shielding surrounding the beam stop to absorb radiation. A permanent magnet dipole will be installed administratively before the beam stop to deflect any beam accidentally transported beyond the diagnostic dumps.

5 INSTRUMENTATION AND DIAGNOSTICS

Beam diagnostics for the DARHT II transport line include BPMs which feed back to corrector magnets for steering, a spectrometer for measuring beam energy, and a “pepper-pot” for measuring beam emittance.

Vacuum diagnostics include convectron and ion gages located at each pumping cross. There are convectron gages located on either side of the beam line isolation valves to prevent opening the valve when one side is “up to air”.

6 REFERENCES

[1] M.J. Burns, et al., "DARHT Accelerator Update and Plans for Initial Operation," to be published in the proceedings of this conference.

[2] A.C. Paul, et al., "The Beamline for the Second Axis of the Dual-Axis Radiographic Hydrodynamic Test Facility," to be published in the proceedings of this conference.

[3] Y.J. Chen, et al., "Precision Fast Kickers for Kilo-ampere Electron Beams," to be published in the proceedings of this conference.

[4] S.E. Sampayan, et al., "Beam-Target Interaction Experiments for Bremsstrahlung Converter Application," to be published in the proceedings of this conference.

[5] “A Method for Calculating Pressure Profiles in Vacuum Pipes,” PEP-II AP Note 6-94, March 1994.

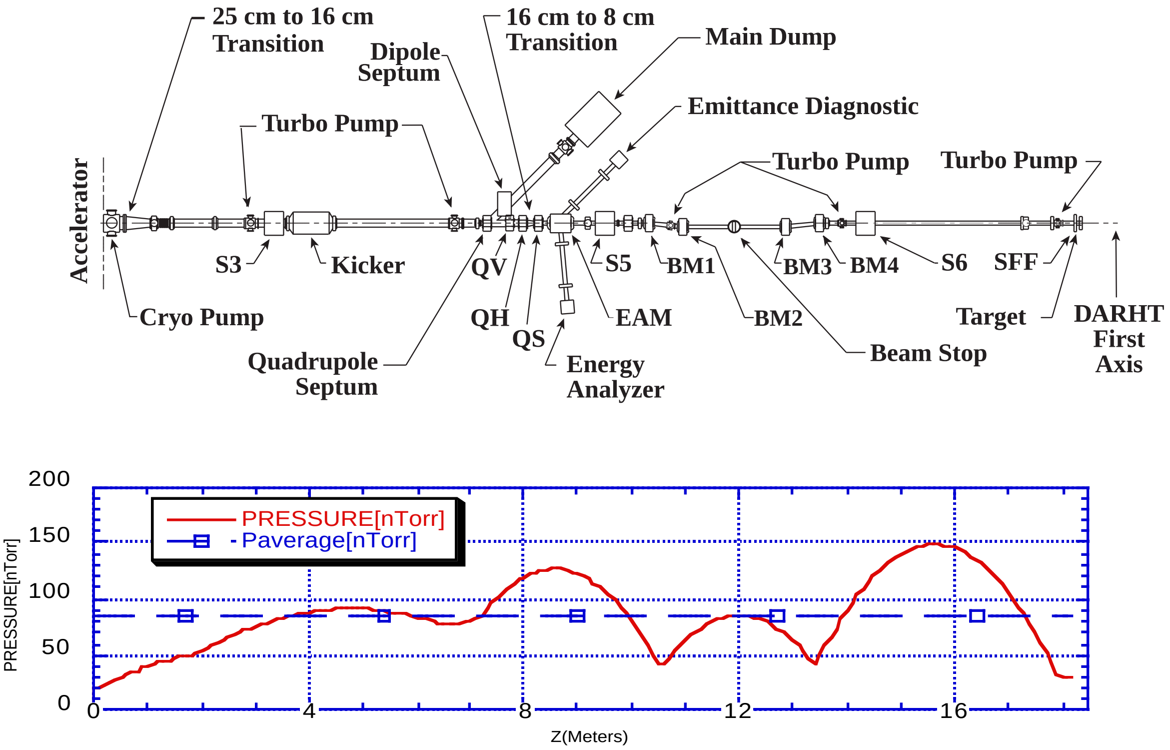

Figure 1. Proposed DARHT II Downstream Beam Transport Layout and Vacuum Pressure Profile