BEAM TRANSPORT DEVICES FOR THE 10 kW IR FREE ELECTRON LASER AT JEFFERSON LAB*

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Abstract

Beam transport components for the 10kW IR Free Electron Laser (FEL) at Thomas Jefferson National Accelerator Facility (Jefferson Lab) were designed to manage 1) electron beam transport and 2) photon beam transport. An overview of the components will be presented in this paper. The **electron beam transport** components were designed to address RF heating, maintain an accelerator transport vacuum of 1 x 10^{-8} torr, deliver photons to the optical cavity, and provide 50 kW of beam absorption during the energy recovery process. The components presented include a novel shielded bellows, a novel zero length beam clipper, a one decade differential pumping station with a 7.62 cm (3.0") aperture, and a 50 kW beam dump. The **photon beam transport** components were designed to address the management of photons delivered by the accelerator transport. The optical cavity manages the photons and optical transport delivers the 10 kW of laser power to experimental labs. The optical cavity component presented is a unique high reflector vessel and the optical transport component presented is a turning mirror cassette.

INTRODUCTION

A 10 kW free electron laser (FEL) has been constructed at Jefferson Lab in Newport News, VA. The laser has both commercial and military applications e.g. polymer surface processing, micro-machining, and missile defense. Electrons are produced in the injector which travels through a three (3) cryomodule linac which accelerate and increase the electron bunch energy. The electrons travel around an oval transport system and through the wiggler magnet to produce photons. These photons are captured and managed within the optical cavity and the extracted photons are delivered to experimental labs via the optical transported system.

THE COMPONENTS

The accelerator transport components were designed to handle RF heating, vacuum region isolation, and recirculated beam power management. The components were designed to have a 7.62 cm (3.0 in) aperture to avoid beam scraping.

The optical cavity and laser transport components were designed to manage, condition, and direct the laser beam to experimental labs. Optical transport components were designed to have a 10.2 cm (4.0 in) aperture. The components are shown in **Figure 1.**

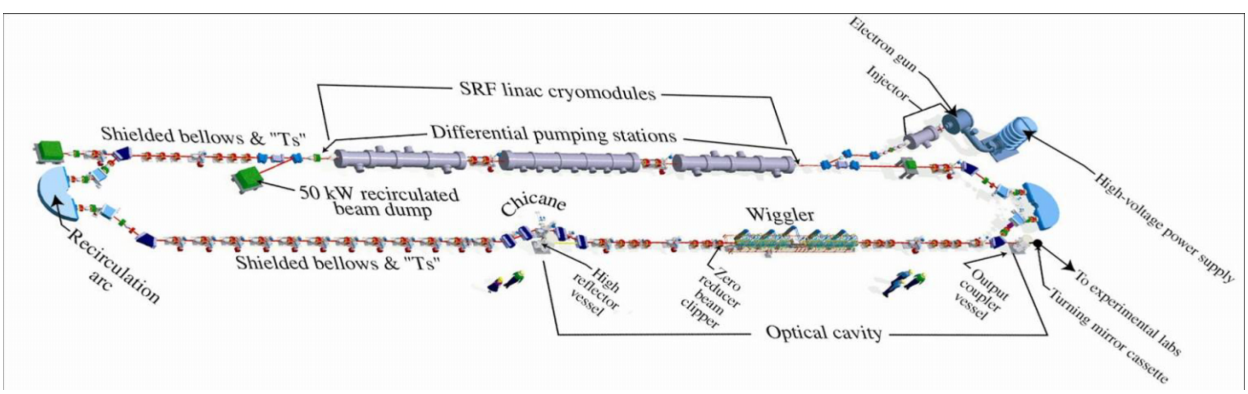

Figure 1: 10kW IR FEL Machine and Component Locations.

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ACCELERATOR COMPONENTS

RF Shielding Components The electron beam packets have a bunch repetition of 4.68-74.85 MHz and a charge of 135pC up to 10 mA. These parameters require that RF shielding be implemented to ensure beam quality. Vertical gaps, crevices, and pockets must be masked to minimize beam impedance and RF heating. Therefore, all electron beam transport components prior to the wiggler must be shielded.

- ***SHIELDED BELLOWS (Fig 2)*: The shielded bellows consists of a standard convoluted bellows shell with an internal stainless steel braided cloth attached to internal collars. The cloth provides RF shielding from the bellows convolutions and a path to vacuum pump the convolutions. The bellows features 1.27cm (.5in) compression and approx. 30^0 of angular deflection.

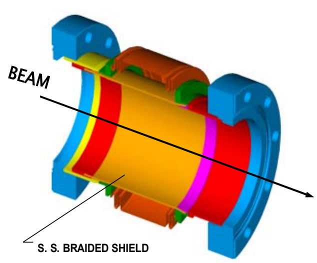

Figure 2: Shielded Bellows.

- ***ZERO LENGTH BEAM CLIPPER:*** The beam clipper (F ig. 3) provides an efficient means of conditioning the edges of the electron beam bunches before entering the wiggler. The clipper consists of a zero-length double-sided conflat flange with an attached corrugated poco graphite substrate to absorb impinging beam power. This configuration requires only 1.57 cm (0.620 in) of beam line slot length.

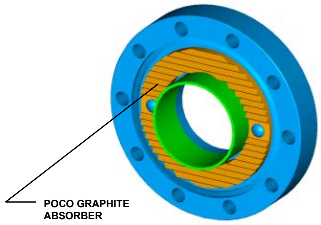

Figure 3: Zero Length Beam Clipper.

Vacuum Isolation Component

1 x 10^{-8} torr is the electron beam transport vacuum level specified for optimum beam performance, 1 x 10^{-7} torr for laser development in the optical cavity, and 1 x 10^{-5} torr in the laser transport to experimental labs. Achieving the vacuum specifications for most of the electron beam transport and the laser transport used routine applications of roughing pumps and noble gas ion pumps. The SRF cryomodule cavities operate between 10^{-10} and 10^{-13} torr and require an isolating vacuum of 1 x 10^{-9} torr at their entrance and exit. The ***DIFFERENTIAL PUMPING STATION-DSP (Fig. 4)*** provides a one decade vacuum pressure differential between the electron beam transport vacuum and the SRF cryomodule interfaces. The DSP consists of a 30.5 cm (12.0 in) cylindrical vessel that houses a 7.62 cm slotted transport tube, an array of non-evaporable getter modules, and accommodations for roughing and ion pumping.

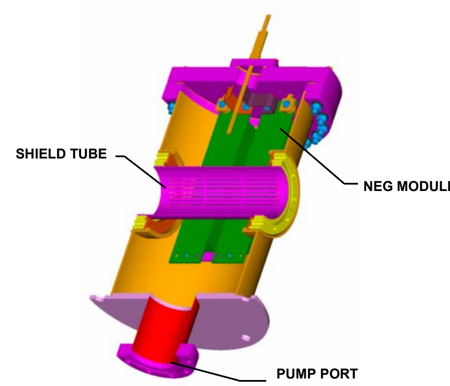

Figure 4: Differential Pumping Station.

Power Management Component

The decelerated electrons from the energy recovery process of the FEL must be managed. 10 MeV electrons at 5mA result from the deceleration process and have a penetration depth of 0.635 cm (.25 in) in copper. This shallow penetration of 50 kW of power presents a non-trivial problem of power management. Thermal analysis of the dump design showed that sufficient cooling is provided to manage 50 kW of input power and an incident flux of 1 kW/cm ^{2}.

Construction of the 50 kW beam dump shown in Figure 5 consists of a 20.32 cm (8.0 in) , .635 cm (.25 in) wall body tube with a copper plate attached to one end at a 30^0 angle. The copper plate is populated with numerous cooling channels fitted with special coolant mixers to create turbulent flow. The angle of the plate provides a larger surface area to disperse the incident power. The other end of the tube is fitted with a 25.4 cm (10 in) conflat flange. A

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concentric tube is fitted around the body tube to provide a water annulus for carrying away reflected power (15% of incident power). During operation the beam is rastered to reduce the incident heat flux to 200 W/cm ^{2}. The 30^0 angle of the dump face further reduces the incident heat flux to 100 W/cm ^{2} ; therefore the design has an adequate factor of safety.

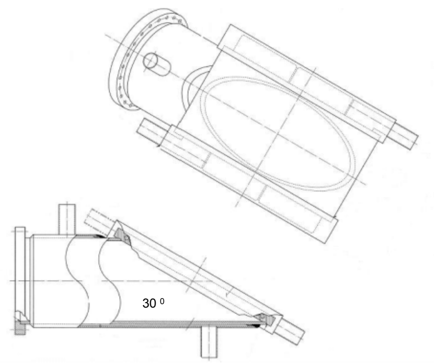

Figure 5: 50 kW Electron Beam Dump.

OPTICAL COMPONENTS

Optical Cavity Components

The photons produced in the accelerator wiggler are captured and managed in the optical cavity to extract 10 kW laser output. The optical cavity is composed of the High Reflective (HR) vessel and the Output Coupler (OC). These vessels house the reflective and output mirrors which reflect the captured photons (laser) between them until the desired power is achieved. Thermal input from the laser changes the mirrors' radius of curvature (ROC), thus changing the optical cavity length. Calibration of the cavity length is accomplished by sensing the thermal input from the laser and adjusting the mirrors' ROC (~16 m) using the Deformable Mirror Assembly (DMA). Mirror alignment is accomplished through a translation (translation, pitch, roll, and yaw) holder and a gimbaled mirror mount that employs LVDT's and micro-pushers for nanometer adjustment in two axes. Mirror cooling is accomplished through the use of flexible water supply tubing and vacuum fittings. Output Coupling is accomplished through the second vessel which has special mirrors that reflect incident laser light but transmits a percentage of that light through the transport system to experimental labs. Figure 6 shows the features for the HR cavity vessel which are typical for the OC vessel. The vessel consists of a 60.96 cm (24.0 in) stainless steel cylindrical vacuum vessel and an invar translation holder. The motor driven translation holder accommodates four different diameter mirrors for multiple wavelength selection.

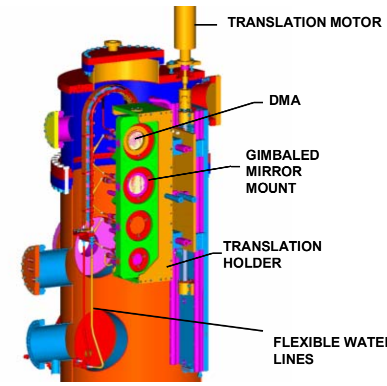

Figure 6: Optical Cavity High Reflector Vessel.

Optical Transport Component

Once the desired laser power is achieved in the optical cavity, delivery of the beam to experimental labs is accomplished through four (4) optical transport devices called Turning Mirror Cassettes (TMCs). Figure 7 shows the typical design for the TMCs. The translation holder is moved by a motorized ball screw arrangement. The mirror alignment features of this device are similar to the optical cavity HR vessel-- i.e. LVDT's and micro-pushers.

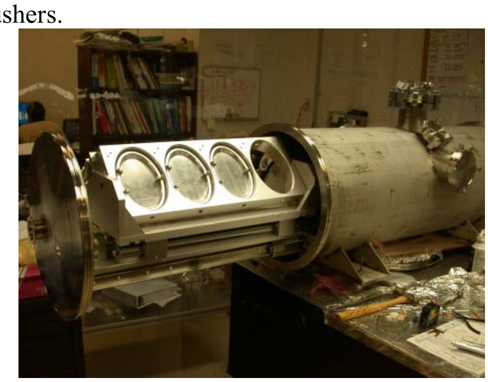

Figure 7: Optical Cavity Turning Mirror Cassette.

CONCLUSION

The beam transport components and devices discussed have provided successful RF shielding, vacuum isolation, power management, laser beam management, and delivery of productive laser power for user experiments. Efforts are continuing to improve and adapt these devices and technology to the Ultra Violet (UV) FEL machine currently under construction.

REFERENCES

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[2] Neil, George, Jefferson Laboratory IR & UV FEL Upgrade 9/13/02 internal report.