Beamline Front Ends For CHESS-U

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Abstract. The CHESS-U upgrade[1] project transforms Cornell's 5.3 GeV, electron-positron colliding synchrotron into a dedicated 6 GeV light source and replaces the current experimental hall contents with six new end stations fed by pairs of canted CHESS compact undulators[2] through three new front ends. ADC is responsible for these new front ends (FE), which are comprised of all components involved in safely transporting the x-ray beams from the storage ring (CESR) to the first optical enclosure (FOE) beyond the storage ring shielding wall. Accelerated installation of each FE is achieved by installation and alignment of all components onto a single massive steel I-beam structure; improving on the SPring-8 parallel I-beam concept[3]. In this paper, ADC will discuss various unique design elements that reduce installation time and optimize the spatial envelope of the front ends.

Keywords: front end, beamline, modular, x-ray

INTRODUCTION

The CHESS-U project[1] is expected to shift from installation to commissioning by the end of 2018. In order to meet this tight schedule, installation and alignment of individual components must be streamlined. The three required front ends have been designed to meet this need by each being assembled and aligned as a single unit at ADC's facility before shipment and installation in the experimental hall at Cornell. The support structure was designed to allow the entire front end to be placed by crane and leveled into final position with adjustable feet. This design approach was made easier by the comparatively short front end and beamline lengths at CHESS, allowing a common base for all of the equipment to be practical.

Light for two beamlines passes through each front end, produced by a pair of CHESS compact undulators canted at ±1 mrad from the centerline of the front end. This makes the heat loads encountered in the front ends quite high, as the undulators produce 7.5 kW each, for a total heat load of 15 kW on the photon shutter. A summary of the front end specifications is presented in Table 1 below.

TABLE 1. A summary of the front end specifications.

Specification	Value
Source	CHESS Compact Undulator (x2)
Machine Parameters[1]	6 GeV, 250 mA
Source Parameters[2]	k = 2.35, n = 52

Specification	Value
Total Power	15 kW
Photon Beam Height from Floor	1.38 m
Source Separation Angle	2 mrad
Front End Acceptance	3.2 mrad H x 0.17 mrad V
Front End Length	9.51 m
Approximate Mass	4.5 tons (metric)

LAYOUT AND SUPPORT STRUCTURE

The front ends consist of a set of diagnostics and safety equipment on modular alignment bases all fixed to a large steel support structure. Most of the components have been placed as close to the source as possible to provide space for mirrors. These mirrors are not needed for initial commissioning, and will be different among the three front ends, so it was deemed best to make three identical front ends with space to install the mirrors at a later date. Components were divided into five groups, with each group placed on an alignment base.

The alignment bases (example in Fig. 1) consist of a pair of aluminum plates separated by threaded rods with the usual arrangement of nuts and spherical washers allowing for vertical, pitch, and roll adjustment. To save space, the third plate was eliminated and the horizontal pushers anchor to the common steel structure, sliding the lower plate across it for 2-axis horizontal and yaw adjustments. Compacting the design further, the pusher units provide two push directions with a pair of crossed set screws passing through a block bolted to the steel beam's upper flange. For stiffness and vibration resistance the plates of the bases were made as thick as practical, the threaded rods are of a large diameter, and clamps are used to hold the lower plate to the common support.

A backbone of steel (Fig. 2) holds the entire front end together and allows it to be lifted as a single structure for transport and installation. The system can be lifted by forklift with permanent fork sockets, or by crane with cross bars through one permanent and one removable socket. Aligning all components of the front end on a common base and lifting from that common base allows the front end alignment to be done in parallel with other tasks occurring at Cornell, speeding the schedule by freeing valuable floor space and requiring only to be set in place and leveled as a single unit upon arrival. The support also minimizes the number of objects to be lifted by the crane, which speeds up the process as the shield wall will be under construction at the same time as the front ends are installed.

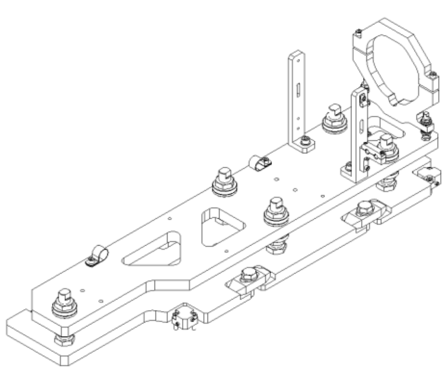

FIGURE 1. Alignment base (~1 m long) for first mask, gate valve, and pumping cross.

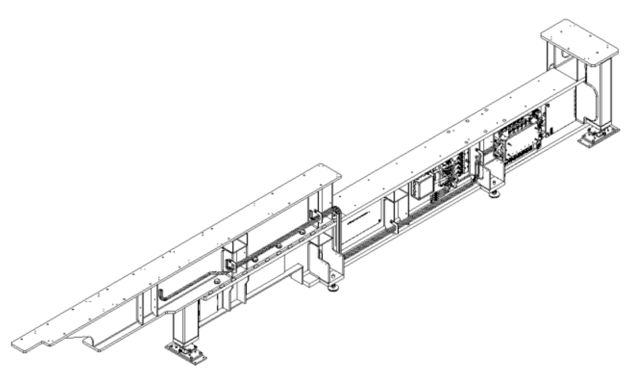

FIGURE 2. Support structure for front end (7.7 m long). Notice ancillary equipment tucked into lower portion.

COMPONENTS OF THE FRONT END

An elevation view of the entire front end is shown in Fig. 3, with all major components numbered for discussion. Most of the major components are grouped with adjacent vacuum pumping and diagnostics to sit on alignment bases, with a few of the optical components themselves grouped together into single objects. For instance, the primary shutter carries a tungsten block to stop bremsstrahlung radiation and the second mask and bremsstrahlung collimator are combined into a single structure. The grouping of components onto common bases provides flexibility to adapt these component designs to other front ends in the future.

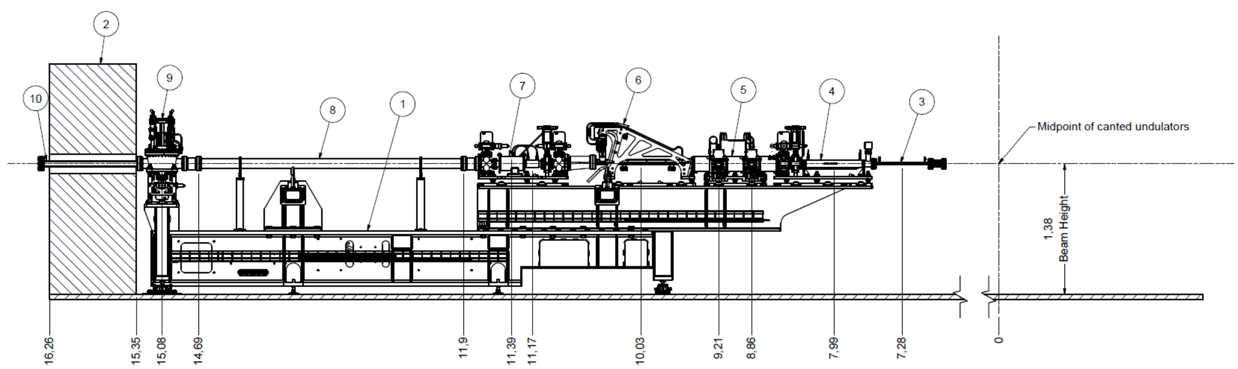

FIGURE 3. Layout of front end with beam direction right to left (numbered items are discussed in the text). Dimensions are in meters, rounded to the nearest centimeter.

(1) Support Structure The steel support structure, which has been discussed in part above, is a welded structure with two very large I-beams at its core. A combination bolted-welded joint provides a particularly rigid connection between these beams, and numerous welded ribs stiffen the beams against bending of the webs. Sockets centered fore-and-aft around the center of gravity facilitate lifting by forklift, while another pair of sockets set farther apart and higher accepts cross bars for crane lifting. The second crane socket is removable for later mirror installation. The support beam sits on three primary feet for kinematic alignment, and four additional pusher feet are provided for additional stability and elimination of sag. Tucked into the space between the flanges, the support structure also holds a manifold for cooling water, a large electrical panel, an air manifold for the pneumatic actuators, and a junction box for safety interlock wiring. The water manifold has ports, valves, and space for six cooling circuits, of which four will be in use when the front end is installed. A lead box attached to the water manifold protects the flow meters from radiation damage, and the entire water manifold module was designed to occupy as little space as possible.

(2) Shield Wall Designed and constructed by CHESS from blocks of high-density concrete, the shield wall stops all stray radiation from the storage ring. The beamline ports are rectangular and intended to be filled with lead bricks surrounding the transport pipes provided by ADC.

(3) Upstream Transport Pipe Due to the radiation fan from the nearby bend magnets, as well as the ray trace requirements for the undulator beams, the upstream transport pipe is constructed from copper and water cooled, with slightly tapered interior surfaces. External space constraints limited the shape and cooling possibilities as the transport pipe passes through the frame of a quadrupole magnet. The height is restricted to 1 inch (25 mm) total inside the magnet assembly.

(4) First Fixed Mask The first mask sets the initial acceptance of the front end, and guards the remainder of the equipment against mis-steered x-ray beams from the undulators. Made from copper, the body of the mask has a helical channel cut around its outer surface. A stainless-steel shell encloses this channel to make a tube through which water is pumped to cool the mask. While similar in concept to masks at ESRF in France[4] and ALBA in Spain[5], this mask design uses more readily available stock materials.

(5) Video Beam Position Monitors Two beam position monitors (BPMs) are used to track the location of the two x-ray beams in the front end. Each consists of a pair of diamond blades whose fluorescence under x-rays is viewed on a CCD camera. The diamond blades are water cooled to handle the beam intensity, and each monitor can be positioned independently to establish the position of one of the beams. Bellows are provided between the two monitors, and at the end of each monitor to allow for a driven scanning motion across the beam, and to provide some isolation from vibration of adjacent components. The steel structure on which the beam position monitors, and the remainder of the front end, are mounted matches the thermal expansion rate of the steel supports for the storage ring, allowing slow orbit corrections to counteract thermal growth. Particularly in light of the shorter-than-typical beamlines at CHESS, it was determined that this mounting method would be sufficiently stable. Any future upgrades to monitoring stability would involve not only these BPMs, but the positron BPMs in a large sector of the storage ring.

(6) White Beam Shutter To handle the large heat load from two undulator beams, the shutter consists of a long, water cooled copper block which pivots around one end to open or close. The pivoting motion places the block at a very small angle to the x-ray beam in order to keep the heat flux at a manageable value. The shutter saves space by being a part of the vacuum chamber in the same way as the fixed masks. In the lowered position, the cooled wall intercepts the beam, while in the open position, the beam passes through a rectangular aperture. Tungsten backing is provided in the shutter, essentially placing the redundant bremsstrahlung shutter into the white beam shutter, with the tungsten and copper blocks traveling together.

(7) Second Fixed Mask and Bremsstrahlung Collimator These two components were combined into a single unit to save space and trade alignment simplicity for machining precision. The two parts were carefully designed and manufactured to locate into each other in a known orientation so that they could be aligned into the beamline as a single unit. The second fixed mask uses the same helical water channel with stainless-steel cover as the first mask, while the collimator is the traditional tungsten block with an appropriately shaped (in this case rectangular) aperture cut through it.

(8) Flight Tube An evacuated flight tube is provided to bridge the gap that will later be filled with mirror systems on the front ends. Since each front end will contain a different set of mirrors, and the mirrors are to be installed later within the context of CHESS-U, the customer required a space with a minimum clearance from the beam of 24 inches and a flat surface on which to mount equipment associated with the mirrors.

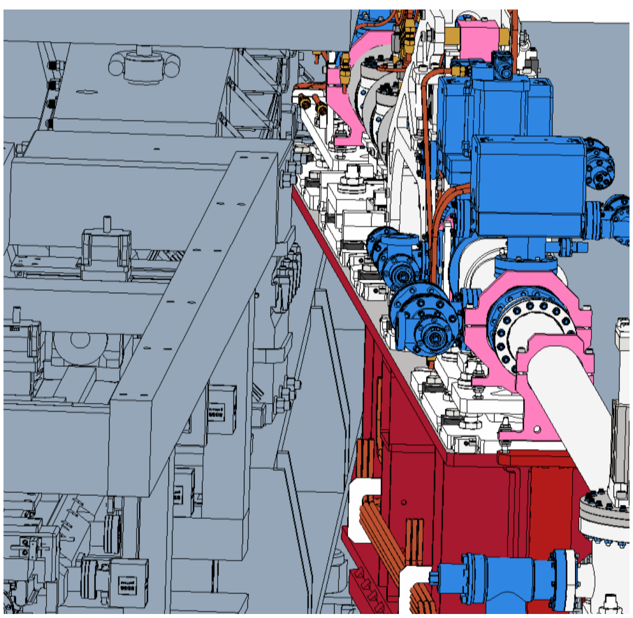

FIGURE 4. Intersection of front end and CESR, viewed from downstream.

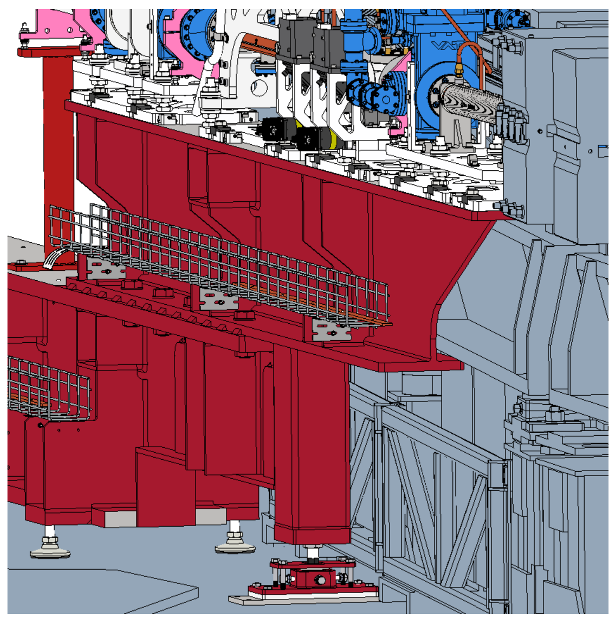

FIGURE 5. Intersection of front end and CESR, viewed from upstream.

(9) Bremsstrahlung Shutter Electron beam interactions with residual gases in the storage ring produce gamma-energy photons (“bremsstrahlung” or “braking” radiation) which can only be stopped in a reasonable thickness by tungsten or other very high-density metals. In order to block this radiation from entering the hutch when the beam is closed off, the white beam shutter carries a block of tungsten, and redundancy is provided by the bremsstrahlung shutter. This shutter is a simple block of tungsten lifted by a pneumatic cylinder from a position blocking the beam to a position out of the way of the beam.

(10) Transport Pipe An evacuated flight tube is provided to transport the photon beam through the shield wall. The tube was made rectangular in cross section to allow lead bricks to be more easily stacked around it to fill the gap between it and the shield wall opening.

Gate Valves (Not Numbered in Fig. 3) Valves upstream of (5) and downstream of (6) provide isolation for sections of the front end, as well as isolating the remainder of the beamline from the storage ring when closed. The shutters and gate valves are all wired to the interlock system. Each gate valve is trigged by a dedicated cold cathode gauge located nearby and closes in approximately one second. The "fast valve" is conspicuously absent from the vacuum interlock arrangement of these front ends. Operational experience at CHESS with front ends containing fast valves has shown significant lost time due to false trips of the fast valve, but no instances of unplanned venting. Simulations using MolFlow have indicated that the 1-second response time is sufficient to prevent harm to the machine in the event of a ruptured beryllium window at the junction of the front end and storage ring. To safely handle partial venting, the bremsstrahlung shielding has been designed to accommodate continuous operation at pressures near $1x10^{-7}$ mbar in the storage ring.

ENVELOPE CONSTRAINTS

The stacked I-beam arrangement and unusually cut shape at the upstream end of the support structure are the result of a few intersecting requirements: (1) the structure must be a single, continuous unit (2) the structure must allow at least 24" from its top surface to the beam height in the region of the mirrors (3) the upstream end must reach over a portion of the CESR support structure (4) items must be supported far ahead of the first possible foot location. Figures 4 and 5 on the previous page illustrate the limited space and the intermeshing of the front end supports and CESR supports.

One of the three front ends passes through a narrow restriction between CESR and the walls of the experimental hall. This restriction influenced the orientation of several vacuum components and also prompted the forward cable tray to be inset as shown in Fig. 5.

CONCLUSIONS

All three front ends have been built and aligned and are presently undergoing vacuum conditioning at ADC's production facility. Views of the front ends assembled and being tested are shown in Figs. 6 and 7. Several change-orders from the customer were accommodated while continuing to meet schedule requirements. The front ends are slated to be installed during the summer of 2018.

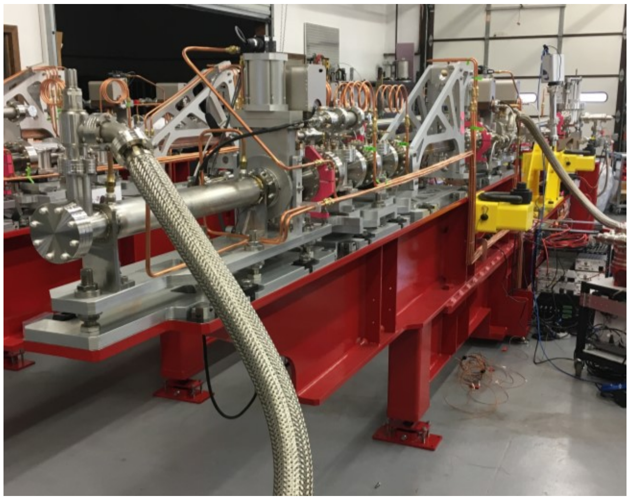

FIGURE 6. Front end undergoing leak testing; viewed from the upstream end.

FIGURE 7. Front end undergoing leak testing; viewed from the downstream end.

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