ENGINEERING DESIGN OF THE NEW LCLS X-BAND TRANSVERSE DEFLECTING CAVITY*

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Abstract

This paper describes the engineering design and installation of the new X-band transverse deflecting cavity installed downstream of the FEL undulator at the LCLS. This is a companion submission to the paper "Commissioning the New LCLS X-Band Transverse Deflecting Cavity with Femtosecond Resolution" also presented at this conference. The project dealt with the challenge of installing a new high-power RF system in the undulator tunnel of the LCLS, outside of the linac tunnel itself and its accelerator engineering infrastructure. A description of the system design, installation, alignment, cooling, controls, vacuum, waveguide, low level RF, klystron and modulator systems for the XTCAV is given, with emphasis on achieving the performance goals necessary to achieve femtosecond resolution.

INTRODUCTION

The LCLS X-band transverse deflecting cavity (XTCAV) is a diagnostic device that has been installed just downstream of the undulator and analyses the spent beam before it reaches the electron beam dump. It is motivated by the need to provide temporal bunch length profile information of both the electron and photon beam with femtosecond resolution on a shot-by-shot basis at the full 120 Hz repetition rate of the LCLS. The engineering and installation project took approximately two years and $5M to complete, and was successfully commissioned with beam in May 2013. The commissioning and first beam measurements are described in a companion paper at this conference [1].

The XTCAV is installed in the undulator tunnel of the LCLS, as seen in Figure 1, and is almost 1 km away from any other high-power RF installation in the linac. One of the engineering challenges for this project was providing the infrastructure to support the installation of the klystron, cooling, power and controls on a green-field site. This paper describes each of the engineering subsystems for the project.

THE RF DEFLECTING STRUCTURE

The microwave structure is a $2\pi/3$ backward travelling wave type and is fabricated from copper discs, or "cups", as shown in Figure 2. The structure was designed at SLAC for a number of possible applications [2]. Each cup is diamond turned to micron tolerances such that the cups can be stacked in an oven and diffusion bonded without braze material. The finished structure requires minimal

Figure 1: View of the XTCAV installation in the LCLS undulator tunnel.

tuning to meet the final RF tolerances. The orientation of the deflecting mode in the axially symmetric structure is set by the orientation of the symmetric input coupler. The dual, symmetric input and output couplers were developed for the high-gradient X-band program at SLAC [3], [4]. Small notches in the outer wall of the cups prevent the deflecting mode rotating down the structure. The RF parameters for the structure are listed in Table 1.

Table 1: RF Parameters for the Deflecting Structures

Parameter	Value	Unit
RF frequency	11.424	GHz
Structure type	$2\pi/3$ backward wave	
Structure orientation	Horizontal	
Effective structure length	1	m
Total flange-flange length	118.8	cm
Number of structures	2	
Number of regular cells per structure	113	
Aperture 2a	10	mm
Cavity diameter 2b	29.77	mm
Cell length d	8.7475	mm
Quality factor Q	6320	
Kick factor k	2.849×10^{16}	V/C/m/m
Transverse shunt impedance	41.9	MΩ/m
Filling time	106	ns
Attenuation factor	0.62	Neper
Nominal power required at structure input	40	MW
Nominal transverse kick (on crest) @40MW	48	MeV/c

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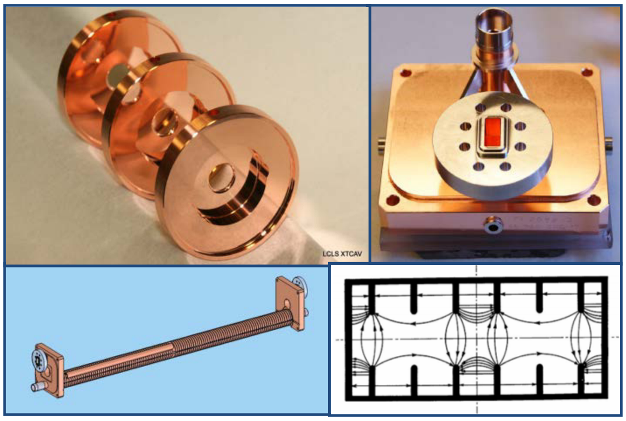

Figure 2: Fabrication details of the HEM_{11} $2\pi/3$ X-band transverse deflecting structure, showing the individual cups before bonding, and the coupler.

Low power tuning was performed after fabrication using a nodal shift method with a metal rod passed vertically through the structure. The resulting flatness of the measured electric field amplitude is shown in Figure 3. The tuning was done at 20°C, corresponding to the temperature regulated environment of the undulator hall, whereas other RF structures in the SLAC linac operate at closer to 40°C.

Figure 3: Measured electric field amplitude inside the deflector after tuning.

ASSEMBLY AND ALIGNMENT

The two deflecting structures, the 3 dB power splitter, the waveguide phase shifter between the two structures, and all the waveguide and vacuum system hardware were preassembled on an optical bench, shown in Figure 4. The two deflectors could be aligned to within 50 µm on a coordinate measuring machine prior to installation in the tunnel.

A photon collimator was also included at the entrance to the deflector to prevent the wide angle spontaneous radiation from the undulator striking the irises of the deflector. A downstream protection collimator was also included in the event that the RF phase of the deflector is misadjusted and the beam is deflected into the beam pipe.

Process cooling water keeps the structure and waveguide at the nominal 20°C tunnel temperature using

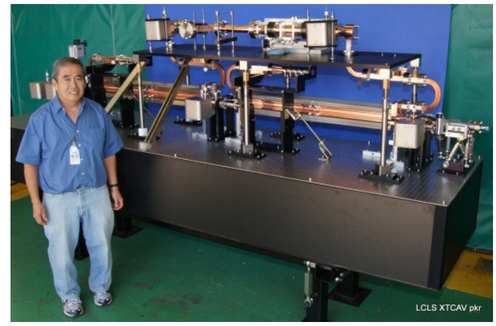

Figure 4: The deflecting structures preassembled and aligned on an optical bench before installation.

a closed loop heat exchanger installed upstairs that is supplied with chilled water.

Fourteen new vacuum pumps plus gauge sets were added to the beamline and waveguide and integrated into the existing controls and interlock system.

KLYSTRON

The klystron chosen for this application is the SLAC XL4 tube, which was initially developed for the linear collider program [5]. It operates at 120 Hz and delivers 50 MW with a pulse length up to 1.5 µs, although in our case the short structure fill time only needs a 0.2 µs pulse. The klystron sits in its own oil tank assembly, with an integrated HV transformer. The tank and external focusing solenoids are visible in Figure 5. The observed pulse-to-pulse phase stability of the klystron output is 0.15° X-band.

Figure 5: SLAC XL4 X-band klystron and assembly.

MODULATOR

The phase stability of the klystron output depends on the voltage stability of the modulator voltage pulse. Our original intention was to use a commercially available solid state induction modulator or one of the SLAC solid-state designs for this new installation. However, for budgetary reasons we reused a legacy 6575 modulator from the SLAC linac. A program is in progress to upgrade these modulators throughout the machine [6]. The modulators use an inductance-capacitance resonant charging system, a modified type-E pulse-forming network (PFN), and a pulse transformer. A different step-up transformer with a 17:1 turns ratio is required for this application in order to get the 450 kV at 350 A needed for the X-band klystron. A variac transformer was also installed to step-up the AC supply power from 480 V to the required 600 V.

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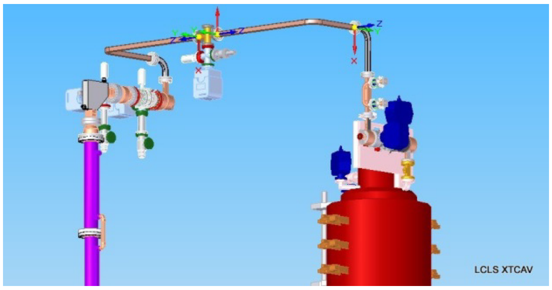

Figure 6: X-band waveguide layout from the klystron to the tunnel penetration.

WAVEGUIDE INSTALLATION

A window assembly at the klystron output coupler uses two mode converters to go from WR90 to circular waveguide where the window is mounted and then back to WR90. The WR90 is routed to the vertical penetration to the undulator tunnel where a mode converter changes to WC293, as seen in Figure 6. This over-moded circular waveguide runs approximately 100 feet to the structure in the tunnel, where another mode converter changes from WC293 to WR90 at the structure. The long, over-moded waveguide accounts for 1 dB of power loss and the shorter WR90 and converters add another 1 dB, so that approximately 32 MW of power is available at the input to the structure with 50 MW delivered by the klystron.

LLRF AND CONTROL SYSTEM

The LLRF drive and controls are modelled after the LCLS X-band linearizer installed in the linac. A VME based EPICS controls and timing system integrates this with the LCLS system. A 476 MHz phase-stabilized reference is available in the undulator tunnel and is brought upstairs to the coupler chassis, X-band multiplier and local oscillator. A Phase and Amplitude Controller (PAC) based on the LCLS design with I&Q modulator provides fast feedback control to the LLRF drive. A SLAC built travelling wave tube amplifier provides up to 1 kW drive power to the klystron. A SLAC designed Phase and Amplitude Detector (PAD) chassis down mixes the 11424MHz RF signals with 11398.5MHz from the local oscillator to a 25.5MHz IF frequency. This signal goes to a 4 channel 16 bit ADC clocked at 102 MHz. This allows monitoring and feedback control based on the signals from the klystron output, the input couplers to the deflecting structures and the load couplers at the structure output. The VME controller can provide feedback at 120 Hz on the phase and amplitude.

A new Modulator Klystron Support Unit (MKSU-II) was commissioned for this installation since the legacy units still used in the linac rely on the obsolete CAMAC system. The MKSU-II connects directly to the EPICS control network. Firmware on an internal FPGA provides the interlock capability controlling the system-enable state plus triggers to the modulator and the PAC. The modulator HV pulse, the klystron beam current as well as the forward and reflected power at the klystron output are digitized and discriminated on every pulse to verify they are within limits set by programmable thresholds. It also receives inputs from the modulator and klystron power supplies, as well as a variety of temperature, water flow and vacuum signals to ensure safe, interlocked operation of the klystron.

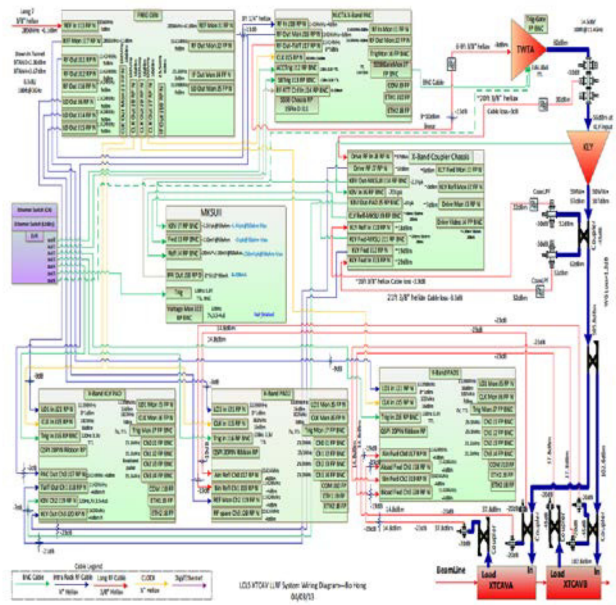

Figure 7: LLRF controls block diagram.

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