FIELD INTEGRAL MEASUREMENT SYSTEM AND OPTICAL ALIGNMENT SYSTEM FOR HUST THz-FEL

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Abstract

A Free Electron Laser oscillator with radiation wavelength 50–100 µm is under construction in Huazhong University of Science and Technology (HUST). The linear polarization undulator with K=1.0-1.25 has been designed and manufactured by Kyma s.r.l., by using a pure permanent magnet scheme. Acceptance test bas been performed in Kyma factory with well controlled phase error and field integrals for all gaps. This paper introduces the development of an online field integrals measurement system for the undulator, using the stretched wire method. The design and considerations of the optical alignment system is described as well.

INTRODUCTION

High average power and continuous tunable terahertz (THz) sources based on low gain FEL oscillator scenario have widely applications covering materials, security inspection, molecule imaging etc.

A compact THz FEL oscillator for prototype study was proposed by Huazhong University of Science and Technology (HUST) and National Synchrotron radiation Laboratory (NSRL/USTC), which is designed to generate 50–100 µm coherent radiation with Watt level average power at initial stage [1, 2]. The general view is shown in Fig. 1, with the main parameters listed in Table 1. For the injector, a thermionic electron gun with an independently tunable cell (ITC) was chosen as the electron beam source for simplicity, and a S-band linac with traveling wave structure will accelerate the beam to range of 6 MeV to 14 MeV [3]. The macro pulse duration 5 µs is long enough for the power build up process which is around 1 µs. A 2.93m symmetrical near-concentric optical cavity is formed by two gold-coated copper toroid mirrors and a rectangular partial waveguide installed with the range covering the undulator, with estimated 15% total round trip loss [4]. The schematic view of this facility is shown in Fig. 1, with main specifications in Table 1.

STATUS OF THE PLANAR UNDULATOR

A pure permanent planar undulator with a moderate K is adopted, and design considerations were described in Ref. [2]. We signed contract with Kyma s.r.l. for design and manufacturing of the undulator, and the assembly was accomplished in November 2013, as shown in Fig. 2.

Main characteristics of this undulator are:

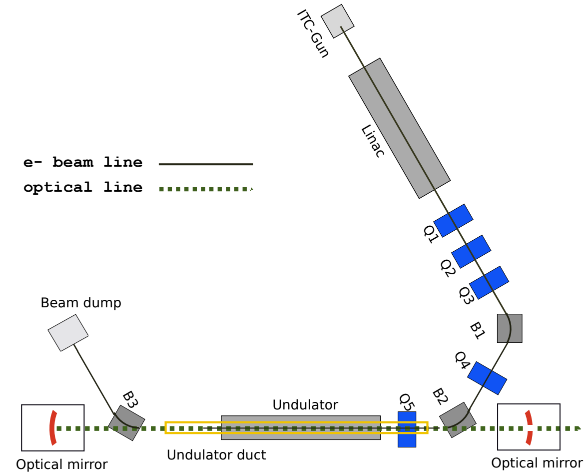

Figure 1: Schematic view of HUST THz-FEL oscillator.

Table 1: Parameters of HUST THz FEL Oscillator

Beam energy	8–12 MeV
Radiation wavelength, λ_r	50–100 µm
Bunch charge	$\geq$ 200 pC
Bunch length (FWHM), σ_s	5-10 ps
Energy spread (FWHM)	0.3%
Macro pulse duration	4-6 µs
Repetition rate	10–200 Hz
Number of the full strength period, N_u	30
Undulator period, λ_u	32 mm
Undulator parameter, K	1.0–1.25
Optical cavity length	2.9 3m
Peak power	0.5–1 MW

- Total length 1.03 m, with $N_u = 30$, $L_u = 32mm$; Nu is optimized by balancing the single pass gain and the natural extraction efficiency ($\approx 1/4N_u$)
- Pure permanent magnet (PPM) structure was chosen, and some techniques such as pre-sorting in block modules and "virtual shimming" [5] are used for controlling the field homogeneity and phase error. To achieve designed K for short period, high coercivity grades ($H_{cj} > 20kOe$) of NdFeB material was chosen; and the deviation of polarization and spread of the remanent field B_r were controlled within 1% level (rms)
- $K = 1.0 - 1.35$, by varying the gap from 19mm to 16mm, and two pair of independent controlled correction coils are installed in the transverse side of the undulator end, to correct the first and second field integrals both in vertical and horizontal directions

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Figure 2: Linear polarization undulator, manufactured by Kyma s.r.l.

Acceptance tests for magnetic field and mechanical characteristic have been performed in Kyma Tehnologjia laboratory, Sezana. Figures 3 and 4 show the K value and rms phase error corresponding to varying gaps, calculated from the mapping result using the hall probe. The phase error is well controlled within required 2 degrees. First field integrals $I_z < \pm 5 Gs \cdot cm$, using a flip coil system with $2.5 Gs \cdot cm$ repeatability. Second field integrals $II_z < 0.08 Gs \cdot m^2$ from hall probe mapping with $0.025 Gs \cdot m^2$ repeatability. These can be corrected by using correction coils based on beam alignment process.

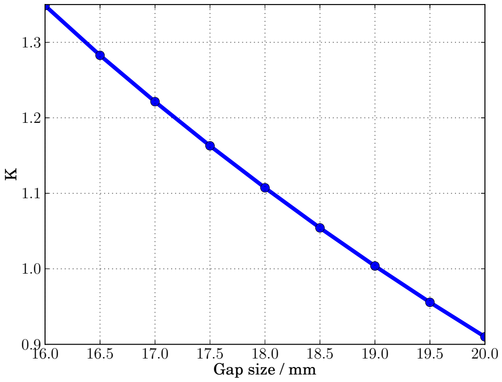

Figure 3: K value with variable gaps, K=0.91-1.35 for gap between 16 mm to 20 mm, and K=1.25@gap=16.77 mm, K=1.0@gap=19.04 mm.

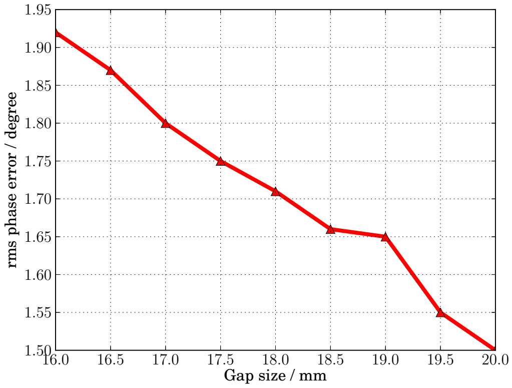

Figure 4: rms phase error with variable gaps.

DEVELOPMENT OF ONLINE FIELD MAPPING SYSTEM

A high precision Cartesian mapping system using Group3 MPT-141 Hall probe and DTM-151 Teslameter was developed in HUST [6], originally used for field mapping of a 10 MeV compact cyclotron. However the maximum range of this system is about 0.9 m, which can't cover HUST undulator. Kyma's mapping result can be trusted, but we decide to make an online integral field mapping system for commissioning and reference of beam alignment.

For fast online integral field measurement, some existing methods are considered and stretched wire method (SWM) [7] was chosen due to its simplicity and stability. Figure 5 shows the experiment setup for the SWM for field integral measurement. A 7.5 period test undulator with hybrid permanent magnet structure was used for experiment study, and the field distribution along the beam axis was measured by the hall probe system, with 1mm step and total 640 mm length. A 1.1 m stretched wire is wounded in series by 50 turns Elektrisola Litz wire with 80 µm diameter, to enhance the integrated voltage signal due to first field integral I_y:

$$\int V \cdot dt = N \cdot \Delta x \cdot I_y \qquad (1)$$

For the movement platform with synchronous horizontal / vertical motion to measure I_y, I_x, II_y, II_x, Kohzu positioning stages XA10A-L2 / ZA16A-X1 are combined to fulfill 2D positioning, and SC410 Motion Controller was chosen to provide maximum 4 axis synchronous motion control, with high repetitive positioning precision 2 µm. Agilent 3458A 8.5 digits multimeter is used for voltage integration. A Labview code was written to control the synchronous motion of the positioning stages, and trigger 3458A to record the voltage signal induced by wire movement, by serial GPIB interface (see Fig. 6). A soft trigger is used for timing between the stage motion and the multimeter's recording.

Figure 7 shows 5 sample signals of the voltage and its integration on time, for the same position x=0 mm. The stretched wire is moved from -2 mm to +2 mm in horizontal direction, with 2mm/s speed, and then return to original

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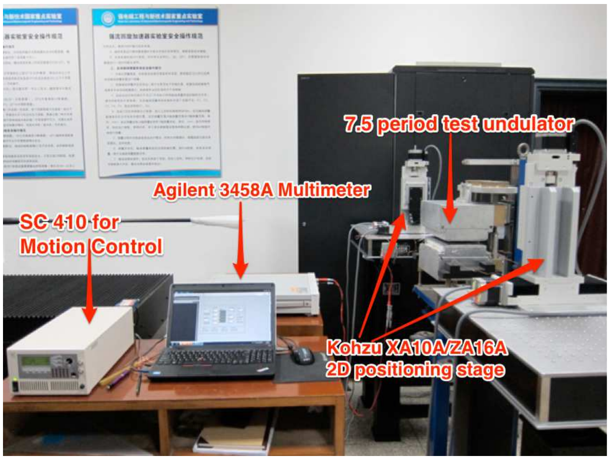
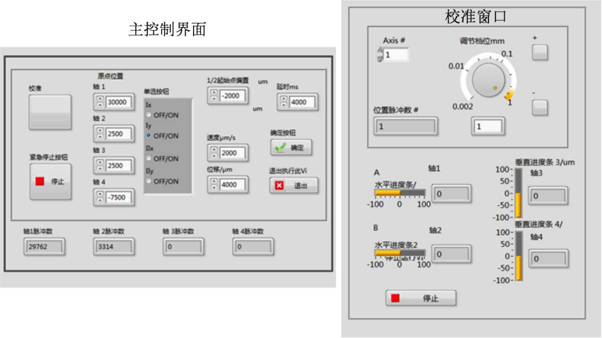


Figure 5: Experiment setup for online field integral measurement with stretch wire method.

-2 mm after 4 seconds. The voltage integrals have been corrected by removing the accumulated background error, by assuming the final voltage integral to be zero when returning to the original point. To improve the repeatability accuracy of the measurement, 20 sets of measurements were used for one position, and the repeatability (rms error) is better than $2.5\text{Gs}\cdot\text{cm}$.

As shown in Table 2, four times of measurement were taken within 40 days, with the reproducibility of $5\text{Gs}\cdot\text{cm}$. The difference between the SWM and hall probe mapping is about $20\text{Gs}\cdot\text{cm}$, which is mainly caused by the earth field integrals introduced by the longer 1.1 m stretched wire (hall probe only covers 0.64 m). For the second field integrals, the signal to noise ratio is much lower due to the cross movement of the stretched wire, which increases the repeatability error to about 5%.



原点位置
轴 1 30000
轴 2 2500
轴 3 2500
轴 4 -7500
Ix ○ OFF/ON
Iy ● OFF/ON
IIx ○ OFF/ON
IIy ○ OFF/ON
1/2起始点偏置 um -2000
延时ms 4000
速度μm/s 2000
位移/μm 4000
轴1脉冲数 29762
轴 2脉冲数 3314
轴 3脉冲数 0
轴 4脉冲数 0

Axis # 1
调节档位mm 1
位置脉冲数 # 1
A 轴1 水平进度条/ 0
B 轴2 水平进度条2 0
垂直进度条 3/um 轴3 0
垂直进度条 4/ 轴4 0

Figure 6: Labview GUI for integral field measurement.

Based on this SWM field integral measurement system, another system using pulsed wire method (PWM) is under development. The main challenge for PWM is its high sensitivity and dependence on circumference factors and configuration of wire characteristics. A good point for PWM is that the field distribution can be extracted from the distributed second field integrals.

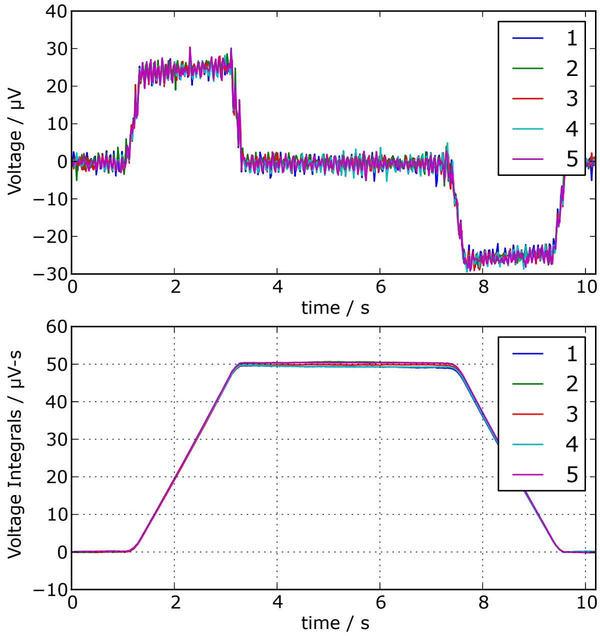


Figure 7: Voltage and voltage integral during horizontal movement from -2 mm to +2 mm. (5 times).

ALIGNMENT SYSTEM FOR OPTICAL CAVITY

To achieve optimum lasing performance, it is important to align three axises: the optical axis, the electron beam axis, and the magnetic axis in the undulator. An elaborate scenario applied in ALICE IR-FEL [8] was adopted, but with some modifications.

The overall view of the optical cavity alignment is shown in Fig. 8. Since the optical cavity of HUST THz-FEL is only 1/3 compared to ALICE case, only one central wedge is used. The wedge has two functions: a 1 mm hole is used for angle correction of optical mirrors by using two independent HeNe laser beam, which are installed in the bottom of 45 degree pop-in mirrors; YAG:Ce crystal is embedded in the wedge tip for monitoring the electron beam. This wedge can be remotely controlled by a staging platform with 5 μm repeatability precision.

The reference axis will be established by align the wedge hole, centers of two YAG screens to the magnetic axis of the undulator by telescope survey; then the optical axis is aligned to adjusting two optical mirrors by HeNe auxiliary laser, with goal of observing centered diffraction pattern at the central wedge using CCD camera; and by using steering magnets, the electron beam can be centered at both YAG screens and pass through the wedge hole.

CONCLUSION

The THz-FEL facility in HUST is under installation in the new experimental hall, and the commissioning of the injector was initiated. The acceptance test of the planar undulator was performed, with all required specifications

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Table 2: Measurement Results of First Field Integral with SWM (Unit: Gs · cm)

Date	x=-5 mm	x=0 mm	x=+5 mm
2013.10.06	$I_y = 199.76, \sigma = 1.36$	$I_y = 222.63, \sigma = 2.05$	$I_y = 249.47, \sigma = 1.36$
2013.10.18	$I_y = 196.93, \sigma = 1.64$	$I_y = 218.64, \sigma = 2.37$	$I_y = 245.78, \sigma = 2.09$
2013.10.22	$I_y = 196.18, \sigma = 1.34$	$I_y = 220.80, \sigma = 1.70$	$I_y = 249.76, \sigma = 1.87$
2013.11.11	$I_y = 194.46, \sigma = 1.32$	$I_y = 217.20, \sigma = 1.68$	$I_y = 246.32, \sigma = 1.72$
Hall probe mapping	$I_y = 170.28$	$I_y = 200.34$	$I_y = 234.42$

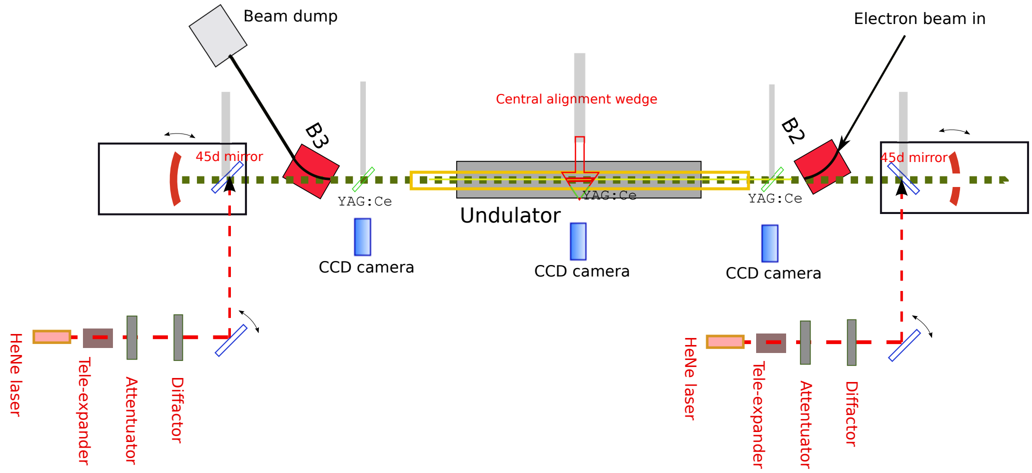

Figure 8: Schematic view of the optical alignment system.

passed. This undulator has been delivered to HUST, and will be installed after completion of the injector commissioning. A fast online integral field measurement system using the stretched wire method was developed, with repeatability of 2.5Gs · cm for the first field integrals. The alignment scheme is determined for optimizing the performance of FEL lasing.

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