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THE DESIGN OF TEST BEAMLINE AT HEPS

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Abstract

This paper describes the design of a test beamline for a new generation of high-energy, high-flux, and high-coherence synchrotron radiation beamlines. The beamline will be built at ID42 of HEPS. The beamline includes two sources, a wiggler and an undulator, to provide high-energy, high thermal power, large size, and high-coherence, high-brightness X-ray beams, respectively. In the current design, the beamline mainly has optical components such as monochromators, CRLs, and filters. With different combinations of sources and optical components, the beamline can provide various modes, including white, monochromatic, and focused beam. Using a Si(111) double-crystal monochromator (DCM), the beamline covers a wide photon energy range from 5 to 45 keV. In the future, the beamline will be capable of providing monochromatic beam with photon energy higher than 300 keV. And the wiggler's white beam can provide high thermal load test conditions over 1 kW. The beamline offers high flexibility and versatility in terms of available beam size (from 1 μm to over 100 mm), energy resolution, and photon flux range. Various experimental techniques including diffraction, spectroscopy, imaging, and at-wavelength measurement can be performed on this beamline. At present, the construction of the radiation shielding hutch for the beamline has been completed.

INTRODUCTION

For the fourth-generation synchrotron source (SR), high brightness, high flux, and high coherence are its main characteristics. To match the advanced performance of the fourth-generation SR, the use of the highest performance optical elements and detectors is necessary. However, these optical elements and detectors are not widely used, and their quality and performance cannot be fully guaranteed. To ensure successfully operate the beamline, comprehensive testing and evaluation before the equipment goes online is essential. Furthermore, even with the highest performance optical elements and detectors in current state of the art, it is difficult to achieve certain extreme performance limits of the fourth-generation SR. Therefore, continue research and development (R&D) are needed to improve the performance of various optical elements and detectors. Testing is a necessary step in the R&D of new equipment [1, 2]. To achieve these goals, a test beamline has been designed at high energy photon source (HEPS). This paper mainly introduces the sources, beamline layout, and expected performance of the beamline.

SOURCE OF THE BEAMLINE

The HEPS design has an electron operating energy of 6 GeV, a beam current of 200 mA, and a natural horizontal emittance of smaller than 60 pm·rad, which can accommodate up to 48 straight sections [3]. The test beamline occupies a straight section with a total length of approximately 6 m, located at ID42. From upstream to downstream, arrange two sources, an undulator source with a length of 1.94 m and a wiggler source with a length of 1.05 m, as well as a reserved space of approximately 1.5 m that can be used for future light source performance upgrades. The main parameters of the HEPS storage ring and the straight section where the test beamline are summarized in Table 1. The design of the test beamline's sources considers the requirements of HEPS engineering tests and various experimental methods as much as possible. The undulator source is designed to provide conditions such as high brightness, high coherence, and micro-focusing. The wiggler sources are used to provide conditions such as continuous spectrum, large spot size, and high thermal load.

The undulator source is cryogenic permanent magnet undulator (CPMU), with a gap range of 7.2-16.0 mm, a magnetic period of 22.8 mm, a number of periods of 85, and a maximum peak magnetic field $B_0 = 1.18$ T. Table 2 provides the basic parameters of the CPMU22.8 source. Figure 1 shows the brightness and coherent flux spectrum of the CPMU22.8 source, and the results show that its brightness can reach 2.5×1021 phs/s/mr2/mm2/0.1%BW, with a maximum coherent flux of 0.9×1014 phs/s/ 0.1%BW.

Table 1: The Main Parameters of the HEPS Storage Ring and the Straight Section where the Test Beamline

Parameter		Value
Electron energy		6 GeV
Beam current		200 mA
Circumference of the storage ring		1360.4 m
Natural horizontal emittance		<60 pm·rad
Parameters of straight sections	βx	10.12 m
	βy	9.64 m
	σx	17.74 μm
	$\sigma x'$	1.753 μrad
	σy	5.48 μm
	$\sigma y'$	0.568 μrad

The wiggler source is permanent magnet wiggler (PMW), with a gap range of 11−46.5 mm, a magnetic period of 73 mm, a number of periods of 14, and a peak magnetic field of 1.64 T. Table 3 provides the basic parameters of the PMW73 source. Figure 2 shows the energy spectrum of the PMW73 source at different gaps and the angular distribution of flux density at different energy values at the minimum gap. The results show that it can provide photons with energy above 300 keV. The light source size of

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Table 2: The Main Parameters of the CPMU22.8

Parameter	Value	Parameter	Value
Number of periods	85	Phase error	3: gap≤12.3 mm 6: gap>12.3 mm
Period length	22.8 mm	Fundamental energy range	3.622−10.892 keV
Total length	1.94 m	Brightness	2.5×10^{21} phs/s/mr^2/mm^2/0.1%BW @10.8 keV
Maximum magnetic field	1.18 T	Flux	5.1×10^{14} phs/s/ 0.1%BW@10.8 keV
Minimum magnetic gap	7.2 mm	Maximum central power density	277.7 W/mrad^2
K-value range	0.8679-2.5061	Divergence angle	11 μrad×11 μrad @10.8 keV
Maximum harmonic number	11	Source size (FWHM)	34 μm×11 μm@10.8 keV

Table 3: The Main Parameters of the PMW73

Parameter	Value	Parameter	Value
Number of periods	14	Maximum power	12.52 kW
Period length	73 mm	Maximum central power density	64.43 kW/mrad2
Total length	1.05 m	Brightness	4.45×10^{18} phs/s/mm^2/mr^2/0.1%BW@15 keV
Magnetic field range	0.22~1.64 T	Flux	5.96×10^{14} phs/s/ 0.1%BW@15 keV
Minimum magnetic gap	11~42.5 mm	Divergence angle	1.8 mrad×0.18 mrad @15 keV
K-value range	1.5~11.186	Source size (FWHM)	42 μm×11 μm
Maximum critical energy	39.26 keV		

CPMU22.8 and PMW73 simulated by Shadow, with a full width at half maximum (FWHM) of 34 μm × 11 μm and 42 μm × 11 μm (H×V), respectively.

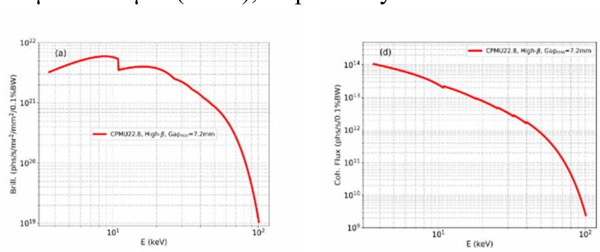

Figure 1: Brightness and coherent flux spectrum of CPMU22.8 Source.

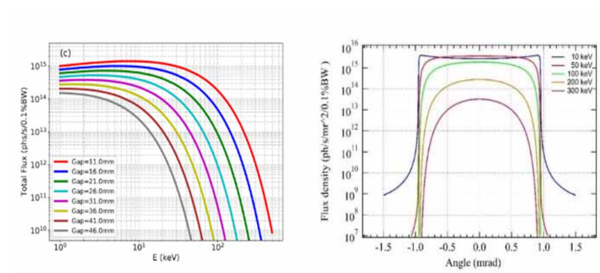

Figure 2: Energy spectrum of PMW73 source at different gaps and angular distribution of flux density at different energy values at minimum gap.

DESCRIPTION OF THE BEAMLINE

The test beamline includes two testing hutches, hutch1 and hutch2. Hutch1 is mainly used for testing sources, front-end (FE), and beam equipment in vacuum. Hutch2 is mainly used for testing optical elements, detectors, R&D, and conducting various experimental methods. The FE of the beamline ends at 32.8 m. The maximum acceptance of the beamline is 1.8 mrad × 0.2 mrad with PMW, and 50 µrad × 50 µrad with CPMU. In hutch1, the X-ray beam passes through XBPM, attenuator, and white beam slit, followed by the diagnostic area of the source and FE. At 46m is the Si(111) double crystal monochromator (DCM), followed by the testing area for monochromators, mirrors, and other equipment, as well as the reserved area for future beamline upgrades. hutch 1 ends at 61.2 m. In hutch2, there is also a section of equipment testing area. A set of CRLs suitable for a wide energy range is located at 69.5 m, and X-ray is focused at 73 m after passing through the CRL. The X-ray enters the air through a Be window at 72 m, and then there is an optical platform that can be used for various tests. The beam ends at 81 m. Figure 3 is the configuration diagram of the test beamline.

To meet the requirements of various experiments for high stability, high energy resolution, and spectral scanning of monochromatic beam, the test beamline uses a fixed-exit type liquid nitrogen-cooled Si(111) DCM with a height difference of 15 mm. The photon energy range covered is 5−45 keV. In addition, considering the imaging

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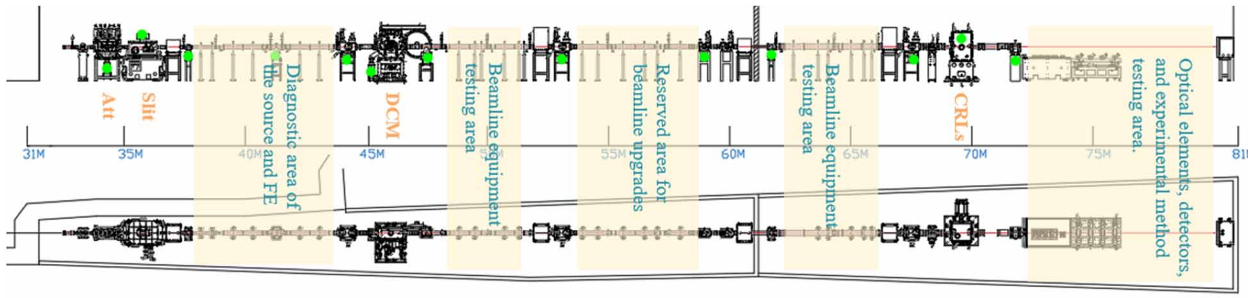

Figure 3: Configuration diagram of test beamline.

experiments require a larger spot size, the maximum acceptance angle of the DCM is set to 0.3 mrad × 0.05 mrad.

The transfocator, consisting of 11 arms, is located after the DCM, and each arm can accommodate up to 10 Compound Refractive Lenses (CRLs). By combining multiple CRLs with different curvature radii, the transfocator can operate in the energy range of 5−45 keV, achieving a focal spot size smaller than 1 μm at a distance of 73 m. This transfocator can be operated under water-cooling conditions, allowing the CRLs to be used for focusing the beam emitted from the CPMU source, thereby obtaining pink beam.

The attenuator (ATT) is installed at 34.2 m and consists of graphite, aluminium, and copper plates of different thicknesses. It can attenuate the X-ray beam emitted from the PMW, which has a power exceeding 10 kW, with a step size of approximately 15% in $\Delta P/P$, down to 1 kW. Additionally, there are vacant slots on the attenuator, allowing for the installation of attenuator plates made of different materials to modulate the energy spectrum according to specific experimental needs. Furthermore, the use of attenuator plates can also generate pink X-ray beams.

Using different combinations of sources and optical elements, the test beamline offers several operational modes including white, pink, monochromatic, focused and unfocused beam (Table 4). Table 5 provides the main expected performance parameters of the test beamline.

Table 4: Operational Modes of the Test Beamline

Mode	CPMU	PMW	ATT	DCM	CRL
White beam		√			
Monochro-matic beam	√			√	
		√		√	
Pink beam	√		√		
		√	√		
Monochro-matic fo-cused beam	√			√	√
		√		√	√
Pink fo-cused beam	√		√		√
		√	√		√

SUMMARY

The HEPS test beamline is a flexible and versatile beamline with excellent optical performance. It can provide various modes of beam, including white, pink, monochromatic, and focused beam. It is the only test beamline in the world that includes both a wiggler and an undulator as sources. Currently, the final design has been completed, and the radiation shielding hutch has been constructed. It is expected to start operation in 2025. By then, this beamline will cover a wide energy range and exhibit high flexibility in terms of available beam size and energy resolution. Various experimental techniques, including diffraction, spectroscopy, imaging, and wavelength measurements, can be realized on this beamline. It will meet the testing needs of HEPS projects and various advanced performance optical elements and detectors. In conclusion, it will be a flexible and multifunctional beamline.

Table 5: Main Parameters of Expected Performance of the Test Beamline

Parameter	Value
Energy range	5 – 45 keV
Energy resolution	2×10^{-4}
Photon flux @ 73 m	3.31×10^{12} phs/s@15 keV, W 6.32×10^{13} phs/s@10.8 keV, U
Beam size range	＜1 μm–100 mm
Thermal load range	＜10 kW
Energy upper limit	＞300 keV

ACKNOWLEDGMENT

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