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PROGRESS OF HEPS ACCELERATOR SYSTEM DESIGN

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Abstract

The 4th generation ring-based light sources, HEPS (High Energy Photon Source) 7BA lattice has been developed at IHEP. This is 6Gev, 200mA machine which has horizontal emittance Ɛh around 34pm.rad to gain the high brilliance photon beam. this compact lattice design bring so many engineering challenges for accelerator magnets, vacuum components, beam instrumentation, etc. This paper will present the novel lattice design and subsystem design progress.

FACILITY OVERVIEW

The new facility HEPS will be placed at a "green field" site just about 80km away from Beijing. An S-band linear accelerator equipped with an RF photocathode gun will accelerate electrons up to an energy of 500MeV. And then, the electron beam will be injected into the booster through the low energy transport line(LTB, linac to booster) which is about 25m in length. The electron beam will be accelerated from 500MeV to 6GeV during the circling around the booster. The electron beam finally feed into the storage ring at 6GeV. Between the booster and storage ring, there are two high energy transfer lines, one is BTS(booster to storage ring), the other is STB(storage ring to booster), both are about 105m. The booster has two functions: the first one is accelerate the e-beam from 500MeV to 6GeV, the second one will accept the e-beam from storage ring, merge into the existing bunch in the booster, it will re-injected into the storage ring after the completion of e-beam accumulation. Due to the small dynamic aperture, the on-axis swap-out injection scheme will be used as the base line design.

THE LINEAR ACCELERATOR

For the simple and robust design solution, normal conducting bunching and accelerating structures are employed in the linac to provide a pulse charge up to 7 nC. A relatively low accelerate gradient 20MeV/m was chosen with economically optimizing consideration. At the exit of the linac, the beam energy is 500 MeV and the normalized emittance is 40 μmrad. The layout is shown in Fig.1.

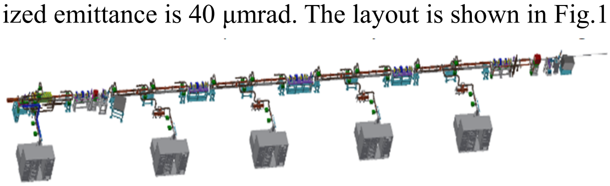

Figure 1: Linac system layout.

THE BOOSTER

The booster of the HEPS is designed with a four-fold symmetric lattice, which is shown in Fig.2. FODO cells are used in each of the four arcs. The circumference of the booster is about 454 m. At extraction energy, 6 GeV, the typical beam emittance is 32 nmrad, and can be further optimized to 16 nmrad by adjusting the strength of the magnets. The booster is not only used to boost the beam energy, but also accumulate charges at the extraction energy. Combining the charges from the linac and storage ring, the booster could provide a single-bunch charge up to 15 nC for the storage ring.

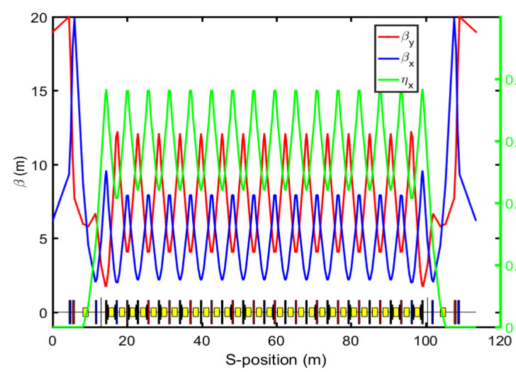

Figure 2: The optics function of ¼ booster.

THE STORAGE RING

24 dual 7-BA cell (Fig.3) with antibends and superbends, alternating high and low-beta sections are used for achieving an ultralow electron beam emittance[1]. The lattice design was iterating with the accelerator hardwares, for instance: magnet lengths, strength limited based on the material properties, gaps between magnets(necessary space), vacuum chamber transverse dimensions, photon exit port clearance, and so on.

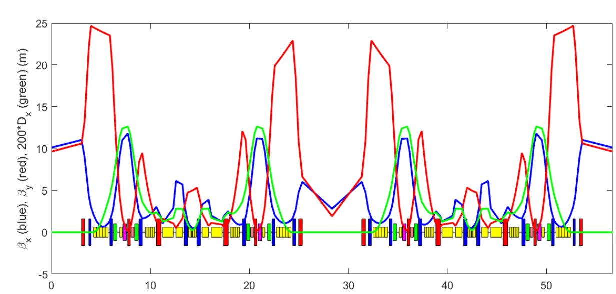

Figure 3: Storage ring achromat.

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The main parameters of the storage ring are displayed in Table 1. Both emittance reduction and beam stability require integrated state-of-the-art design of most accelerator subsystems.

Table 1: HEPS Storage Ring Main Parameters

Parameters	**Values**
Beam current I_0	200 mA
Circumference	1360.4 m
Horizontal damping partition number $J_x/J_y/J_z$	1.85/1/1.15
Natural emittance	34.2 pm·rad
Working point (x/y)	115.17/104.30
Beta functions at the center of high-beta sections (x/y)	7.4/7.1 m
Beta functions at the center of low-beta sections (x/y)	2.60/1.91 m
Momentum compaction	1.88×10^{-5}
Energy loss per turn, U_0	2.65 MeV
Energy spread s_d	1.0×10^{-3}
Fundamental frequency (166.6 MHz) RF voltage	3.64 MV
Harmonic (499.8 MHz) RF voltage	0.65 MV
Bunch length without / with harmonic cavities	4.9/29.0 mm
Harmonic number	756

Magnet

To achieve the pmrad level emittances, the longitudinal gradient dipole, high gradient quadrupole on the order of 90T/m, quadrupole together with anti-bend magnet, and combined dipole quadrupole(high transverse gradient dipole) are necessary. After iterations of joint discussions with other related accelerator sub-systems, the key parameters of magnet including the magnet length, field gradient, etc. are determined based on the baseline lattice. Other design goals are to provide sufficient space for the vacuum system, low power consumption, reliability, field quality, and ability to align accurately and efficiently, etc. The magnets array in one 7BA cell is shown in Figure 4.

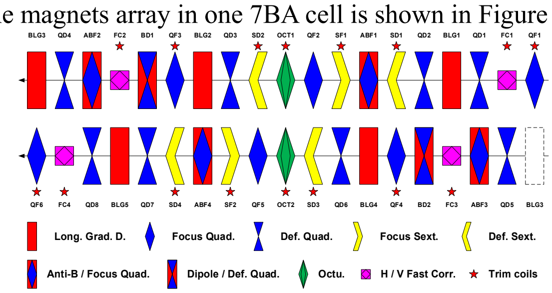

Figure 4: Magnets array in one 7BA cell.

Preliminary designs have been done for all magnets that are used in the baseline lattice. The designs for magnets are all feasible, however, some of them require special materials or other design features to fit with the vacuum system and achieve sufficient field quality. Now we are under the phase of dedicated engineering design.

Vacuum

The vacuum systems are compatible with a multi-bend achromat(MBA) compact lattice[2], they are designed around careful interfaces with the needs of accelerator physics, magnets, and more. Vacuum components, flange seals, and absorbers must minimize impedance losses through the use of subtle transitions and reliable RF seals. The magnets quantities, spacing, and narrow pole gaps drive thin walled vacuum chamber designs[3]. The vacuum system is also designed around numerous internal interfaces. Photon absorbers, both mounted and compact 'inline' style, are used to shadow and protect uncooled components such as BPMs, flange joints, and gate valves. Generally, the chambers are required to have a circular cross-section with 22 mm inner diameter and 1 mm wall thickness to fit inside of magnets. The NEG coating at the inner surface of the chamber are considered, it will provide the distributing pumping and vacuum performance is thus not hampered by the poor conductance of narrow chamber bore. The layout of the storage ring vacuum system was optimized and a preliminary design of the vacuum chambers was done. TIG welding experiments between Cr-Zr-Cu (C18150) and stainless steel pipes were carried out, the tensile strength of the welding meet the engineering requirements. Many NEG coating experiments and measurements of pumping speed have been done, Figure 5 shows the pumping speeds for the different times and different NEG film compositions.

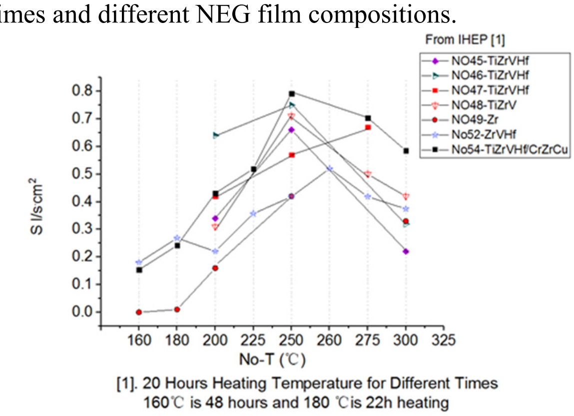

Figure 5: NEG coating pumping speed measurement.

Beam Instrumentation

The beam stability in storage ring depends very much on the quality of BPMs. The type and quantity of beam instrumentations are determined. The detailed design of key components is undergoing. The button BPM with 8mm diameter button type BPM and sensitivity 8.3 is selected for storage ring. The design of beam position measurement signal processor is completed, and the laboratory test results show that the performance of home-made electronics is as good as the commercial one. The beam position monitor electronics(Fig.6) SA(10s) resolution is better than 0.1μm, the FA(3s) resolution is better than 0.3μm, and the turn-by-turn resolution is better than 1μm. The BPM processor has completed the beam test in BPECII storage ring. Based on the test results, performance optimization and improved design are underway.

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At the same time, the online calibration system and the constant temperature cabinet are also in research for the electronics long-time stability.

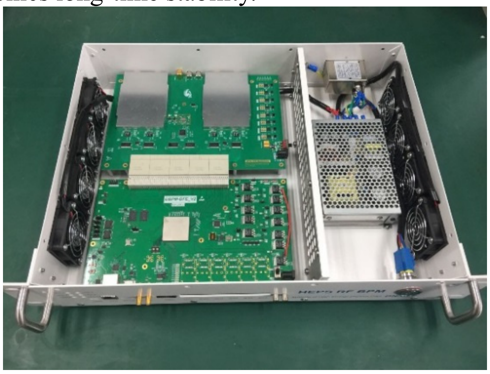

Figure 6: The beam position monitor electronics.

Synchrotron radiation (SR) based beam diagnostics(Fig.7) which is used for the measurement of beam profile has been designed. It provides online information of various beam parameters without any perturbations to the beam. Also the design of X-ray beam line for the bunch length and emittance measurement based on visible light is completed. The test results at SSRF show that the bunch size measurement was consistent well with the theoretical values and the values measured by the SSRF pin hole system[4]. The point spread function of the entire system is approximately 4.97μm in the vertical direction and 6.08μm in the horizontal direction. The test resolution of the whole system is 0.1μm.

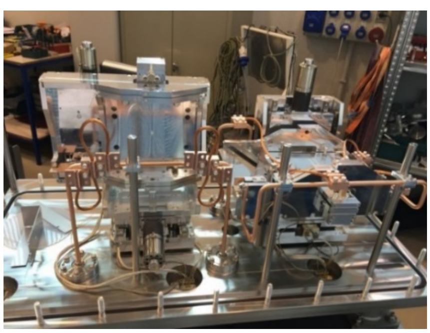

Figure 7: The KB mirror measurement system.

RF

The focus of this task is on two different superconducting RF (SRF) cavities: 166.6 MHz(main cavity) and 499.8 MHz(third harmonic cavity). Due to a low RF frequency and β=1, a quarter-wave geometry has been chosen for the 166.6 MHz cavity, while on the other hand, the single-cell elliptical shape is favored for the 499.8 MHz one. Concerning the 166.6 MHz cavity, A proof-of-principle (PoP) cavity was planned as the first cavity to be built in order to maximize learning on cavity manufacturing techniques, surface treatment and higher order mode (HOM) characterization. The cavity was in-house designed, fabricated, surface treated and vertical tested. Its cryogenic performance largely exceeded the design goal(Fig.8), serving as a good starting point to proceed with the final cavity design. Concerning the 499.8 MHz cavity, KEKB type single-cell elliptical SRF cavity has been chosen.

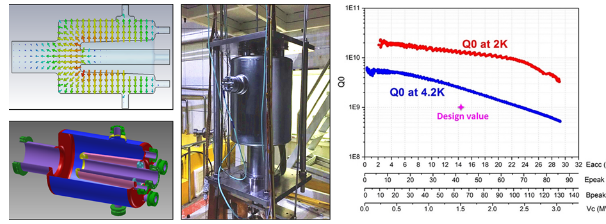

Figure 8: The 166.6 MHz PoP cavity and test results.

Magnet Support and Girder

The magnet support design have to avoid resonance frequencies that normally excited in the storage ring tunnel floor, typically in the range from 2~100Hz. This implies in high rigidity, which makes the required fine alignment adjustments difficult. So the compromise between two each other has to be seriously considered. HEPS magnet girder 1st mode frequency is designed at least 54Hz, Topological optimization of the girder design was performed. Study of the wedge stiffness is also in progress.

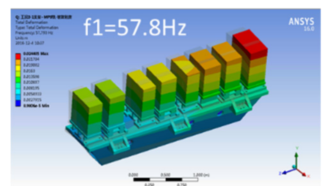

Figure 9: Magent girder FE analysis.

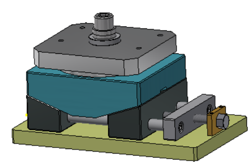

Figure 10: Wedge prototype.

CONCLUSION

A technical design has been developed for the HEPS accelerator systems. Many technical problems have been successfully solved. The construction of the HEPS will start soon, may happened by the end of June of 2019.

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