ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-THPDP034

THE APPLICATION OF PYAPAS IN LINAC BEAM COMMISSIONING AT HEPS*

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Abstract

The High Energy Photon Source (HEPS) is a 6 GeV, 1.3 km, 4th generation storage ring light source being built in Beijing, China. The development of high-level applications (HLAs) for HEPS started in early 2021. A new framework named PYthon-based Accelerator Physics Application Set (Pyapas) was developed for building HLAs. Based on *Pyapas*, the application development for Linac was completed in June 2022. And then the joint test with hardware system was performed, all the applications worked well in the Linac control room. Beam commissioning for the Linac began in March 9 of this year, and all the HLAs for the Linac are functioning well. This paper will present the application of *Pyapas* in linac beam commissioning.

INTRODUCTION

The High Energy Photon Source (HEPS) is a 6 GeV, 1.3 km, fourth-generation light source [1]. It began construction in Beijing, China in mid-2019 and is expected to become one of the world's smallest emittance light sources after completion. The Linac of HEPS began beam commissioning in March 9 of this year. In order to meet the beam commissioning needs of HEPS, we began developing high-level applications (HLAs) in early 2021 and a new framework was designed for the development of HLAs [2].

As a fourth-generation light source, HEPS adopts a compact multi-bend achromat(MBA) lattice design for the storage ring [3, 4]. With MBA lattice the number of magnets in fourth-generation light sources has increased by an order of magnitude compared to existing third generation light sources. This means that the variables to be controlled have increased by one or two orders of magnitude. The error tolerances of the fourth-generation light sources are also tighter due to the ultralow emittance and stronger magnetic fields. Therefore, higher control precision and faster response times need to be considered in the HLA development. To address these issues, we have designed a new HLA framework named *Pyapas* [5], as shown in Fig. 1. It adopts a modular design philosophy and increases overall scalability. A dual-layer physical model module has been designed to meet the replaceability of online calculation models. In addition, the communication module, database module, and server module have all been specially designed to meet the needs of adjusting a large amount of parameters.

Based on *Pyapas*, we have completed the development of HLAs for the Linac [6] and successfully applied them to beam commissioning [7], verifying the practicality and reliability of the applicatoins. This paper will briefly introduce the design of *Pyapas* and the progress of the development of HLAs for HEPS.

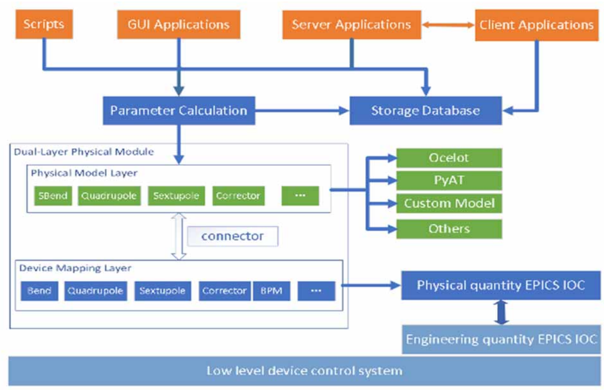

Figure 1: The complete workflow of new framework Pyapas.

HLAS DEVELOPMENT FOR LINAC

To meet the beam commissioning needs of the Linac, we developed corresponding HLAs based on *Pyapas*, including orbit correction, emittance measurement, energy and energy spread measurement, phase scan, beam based alignment (BBA) and phys ics-based linac control application [8].

As shown in Fig. 2, the physics-based control program allows beam commissioning operators to directly adjust physical quantities such as magnetic fields, angles, and energies, enabling them to quickly find the appropriate working mode. The energy and energy spread measurement systems locate in the two energy analysis stations. AM1 and AM2 are dipole magnets which creates dispersion for measuring beam energy and energy spread. AM1 deflect beam in horizontal direction, while AM2 in vertical. According to the field of dipole magnet and the beam position in the profile monitor, the beam energy can be obtained. Then the beam energy spread can be calculated with the beam size measured by the profile monitor, as shown in Fig. 3.

For the orbit correction, one-to-one feedback correction method and global correction method based on response matrix is used. For BBA, Two methods are used to measure the BPM offset for the HEPS Linac, linear fitting method and parabolic fitting method [8], the application shows in Fig. 4. Transverse emittance is an important parameter of characterizing accelerator performance. For the main Linac, dispersion is negligible and the beam size mainly

* Work supported by NSFC12005239
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determined by the betatron-oscillation and transverse emittance. The quadrupole scanning method [9] is one of the most commonly used method to obtain the emittance and Twiss parameter. It is necessary to find out the correspondence between the setup phase in the low-level radio frequency (LLRF) system and the real (physical) accelerating phase. We scan the phase setting of LLRF and measure the beam energy to fit the phase offset.

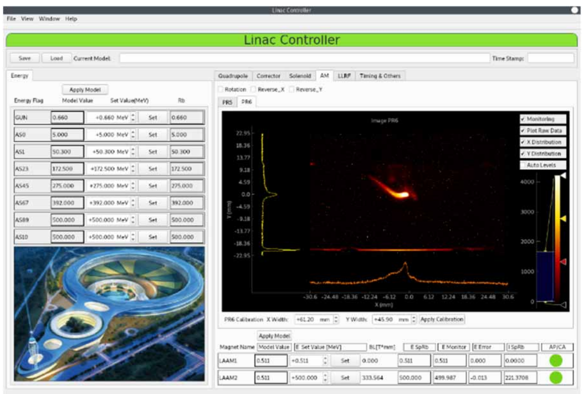

Figure 2: Linac Controller based on physical quantities.

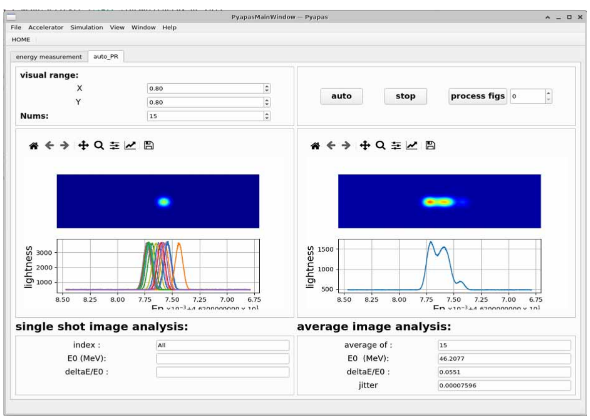

Figure 3: The energy and energy spread measurement application.

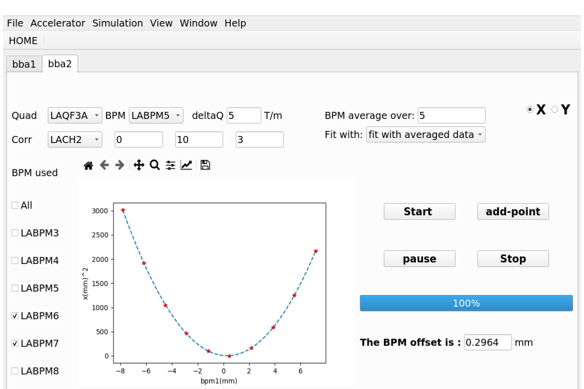

Figure 4: The beam-based alignment application.

All the HLAs of Linac are fully tested before going live on the virtual accelerator system [10]. As a result, all the HLAs for the Linac are functioning well during the beam commissioning.

APPLICATION OF HLAS AND BEAM COMMISSIONING RESULT

In early March 2023, we obtained the radiation protection permit for the Linac beam commissioning, and beam commissioning started on March 9, 2023. On that day, the first electron beam was observed on the first profile monitor at 10:28 am and the electron beam was successfully transferred to the end of the Linac at 12:15 am with beam energy reaching 500 MeV. The physics-based control program played a crucial role in this achievement. After 3 months of beam commissioning, the test and acceptance of the Linac was completed. The measured parameters are shown in Fig. 5. Due to the high performance of the IGBT based solid-state modulator with pulse repetition stability of 0.02% and LLRF, the beam energy stability is better than 0.02%.

Parameter	Unit	Design		Measurement	
		Mode1	Mode2	Mode1	Mode2
Pulse charge	nC	≥2.5	≥7.0	2.84±0.02	7.29±0.02
Energy	MeV	≥500	≥500	501.4	501.2
Energy spread	%	≤0.5	≤0.5	0.31	0.45
Energy stability	%	±0.25	±0.25	σ=0.014 peak-peak=0.04	σ=0.014 peak-peak=0.05
Repetition rate (Burst mode)	Hz	50	50	50 （10 pulse/s）	50 （10 pulse/s）
Geometric emittance	nm·rad	≤41	≤70	37.2 （H） 36.9 （V）	56.4 （H） 58.5 （V）

Figure 5: Comparsion of design and measurement parameters of Linac.

The beam commissioning for the booster began on July 25th, 2023. To fulfill the requirements for beam commissioning, we have developed various HLAs based on *Pyapas*. These include global and local orbit correction, dispersion measurement, physics-based control programs, chromaticity measurement, first-turn beam analysis, and other related functions. Two days after the injection commissioning process began, we witnessed the first synchrotron radiation light. Then we tried to ramp up the beam energy and reached 6 GeV by August 9th.

CONCLUSION

To meet the beam commissioning requirements of the HEPS, the new HLA development framework *Pyapas* had been designed. Based on this framework, we have completed the HLAs development for the Linac respectively. The HLAs for the Linac have been successfully applied to beam commissioning and have achieved excellent performance, assisting beam commissioning operators in quickly achieving beam transmission throughout the entire system. The successful application of *Pyapas* in the Linac demonstrates its reliability and practicality.

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ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-THPDP034

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