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CURRENT STATUS OF VEPP-5 INJECTION COMPLEX

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Abstract

VEPP-5 Injection Complex (IC) supplies VEPP-2000 and VEPP-4 colliders at Budker Institute of Nuclear Physics (BINP, Russia) with high energy electron and positron beams. Since 2016 the IC has shown the ability to support operation of both colliders routinely with maximum positron storage rate of $1.7 \cdot 10^{10}$ e+/s. Stable operation at the energy of 430 MeV has been reached. Research on further improvements on the IC performance is carried out. In particular control system was improved, additional beam diagnostics systems were developed, monitoring of RF system was upgraded. In this paper, the latest achieved IC performance, operational results and prospects are presented.

INTRODUCTION

Since 2016 the IC [1,2] has supplying the VEPP-2000 [3] and VEPP-4 [4] facilities with high energy electron and positron beams. The layout of BINP colliders together with IC is shown in Fig. 1.

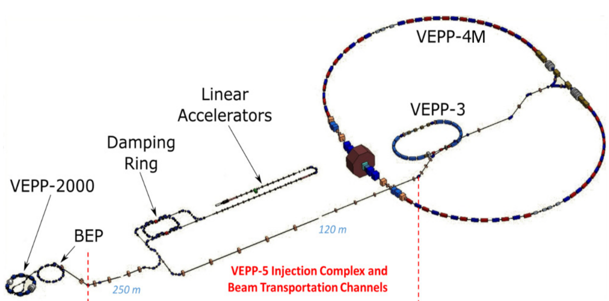

Figure 1: Layout of BINP accelerator facilities.

The IC consists of electron and positron S-band linacs with achieved energies of 280 MeV and 430 MeV, respectively, and the damping ring (DR) alternately storing both electron and positron beams. Then beams are transported to users via the set of K-500 beam transfer lines. Main IC parameters are presented in Table 1.

During the 2020/2021 run malfunction of positron solenoid reduced the positron storage rate, however by proper tuning the beam orbit and optimizing the regime-switching procedures positron storage rate of $0.9 \cdot 10^{10}$ e+/s was reached.

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Table 1: Main IC Parameters

Parameter	Value
Linac energy e-, e+ (reached)	280, 430 MeV
Linac RF frequency	2855.5 MHz
Energy spread e-, e+	±1%, ±3%
Linac repetition rate	up to 12.5 Hz
Extr. repetition rate	up to 1 Hz
Design horizontal emittance	$2.3 \cdot 10^{-6}$ rad·cm
Design vertical emittance	$0.5 \cdot 10^{-6}$ rad·cm
DR energy (design)	510 MeV
DR RF frequency	11.94 MHz
DR circumference	27.4 m
DR design current	30 mA
e+ storage rate (reached)	$1.7 \cdot 10^{10}$ /s
Damping time@510MeV(h/v/l)	11/18/12 ms

In terms of beam charge and injection repetition rate, VEPP-2000 collider imposes strict requirements on the IC performance. It requires constant beam injection due to small beam lifetime of 500 s. In order to achieve the desired luminosity a new portion of 10^{10} particles at least every 50 s has to be injected into the main ring. To meet these requirements switching between electron and positron beams in the IC was minimized up to 5 s by tuning both linacs to achieve equal energy for electron and positron beams, while keeping the DR operation mode to be constant. K-500 transfer line magnets and power supplies limit minimal switching time between the particle types to at least 30 s.

Due to small conversion efficiency for positron production, positron storage rate and extraction from the DR are the main concern. Considering achieved positron storage rate of $0.9 \cdot 10^{10}$ e+/s and transfer losses of up to 50-60 %, remaining time of 20 s to supply 10^{10} particles into VEPP-2000 main ring is sufficient. Thus, the IC meets the VEPP-2000 requirements. However, further improvement on the IC performance are essential for its reliable operation.

The IC has four operating modes: electron or positron production for VEPP-2000 or VEPP-4. The switching between these modes is automated with simple asynchronous state machine, 12 transitions between K-500 modes in order to reliably remagnetize its elements are utilized. Currently the IC is able to automatically supply the VEPP-2000 with all

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types of particles, but switching to VEPP-4 is still performed by operator request. More detailed description on operation modes can be found in paper [5].

PERFORMANCE 2020/2021

Reliability

During 2020/2021 run the IC was operated for over 7000 hrs with 50/50% user's ratio. Maintenance work took 10 % of the operation time, most of the system failures were caused by outdated electronics of the klystron modulators. The amount of failures due to magnetic system power supplies was decreased by their partial replacement: 9 of 500 A and 8 of 1000 A power supplies have been replaced in 2019/2020.

More delicate and accurate linac tuning has allowed us to reach energy beam of 430 MeV. Previously reached energy was 390 MeV. Energy increase leads to better injection efficiency in the DR and increase beam life time at the injection in VEPP-3. Positron solenoid malfunction reduced maximum achieved positron storage rate by the factor of 2.

New Electron Gun Cathode

In 2019/2020 a new cathode assembly with pulse current of 7.25 A and pulse duration of 7.3 ns was installed. Previous cathode had 5 A pulses with 3 ns duration. In the beginning of 2020 cathode heater current was reduced in order to extend cathode lifetime. Then in the middle of 2020 gun grid modulator was replaced with one with shorter pulses, and now gun provides about $1.5 \cdot 10^{11}$ electrons per pulse as shown in Fig. 2.

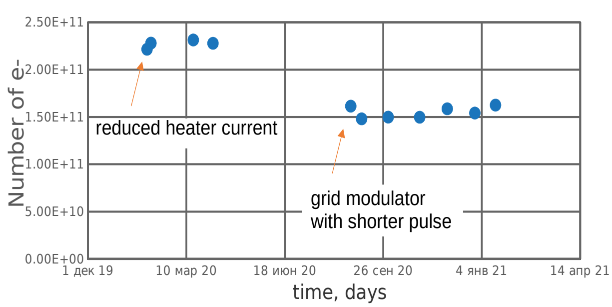

Figure 2: Cathode performance in 2020/2021 run.

Positron Solenoid Malfunction

In October 2019 positron solenoid was damaged resulting in decreasing the IC productivity by the factor of 2. And single e+ injection value in the DR equals to $0.8 \cdot 10^9$. The solenoid can only be replaced as a whole unit including conversion system and the 1st e+ RF section. New solenoid design with no gaps between coils, hence better field quality, is under development. Designed magnetic field is shown in Fig. 3. Mechanical design and construction of the solenoid is planned for 2021/2022 run.

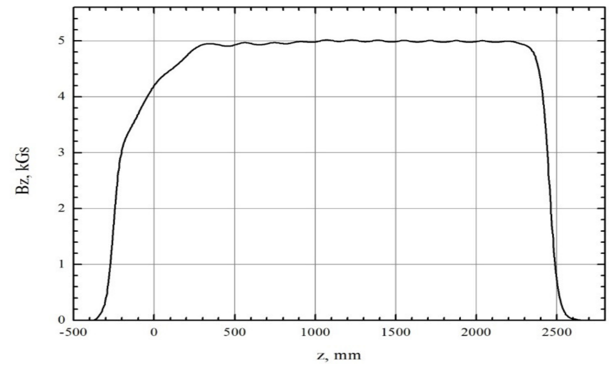

Figure 3: Designed magnetic field profile of a new positron solenoid.

IMPROVEMENTS

In order to provide better IC performance and operation stability several significant improvements of the IC systems were performed and further improvements are under consideration.

Beam Loss Monitor System

Fiber-based beam loss diagnostics system was developed and two beam loss monitors were installed at the DR extraction channels to both user directions (see Fig. 4). They allow online monitoring of beam loss distributions along the K-500 transfer lines. Devices are fully integrated in the IC control system and used in a routine operation [6, 7].

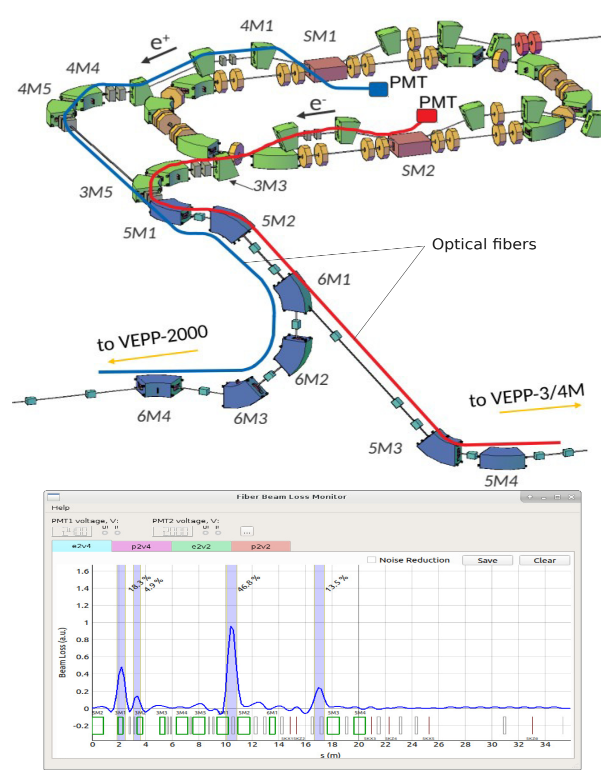

Figure 4: Beam loss monitor layout.

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Linac RF Monitoring System

For simultaneous monitoring all main points of the linac RF system, 10 new ADC250x4 assembled in one VME64 crate with L-timer [8, 9] were developed at BINP and installed. Measurement point layout of RF signal is shown in Fig. 5. L-timer was adapted to operate with the IC master generator and synchronization system as clock and start signals and read all ADC signals simultaneously. The RF monitoring system is fully integrated into the IC software. More automatic data preprocessing is now under consideration.

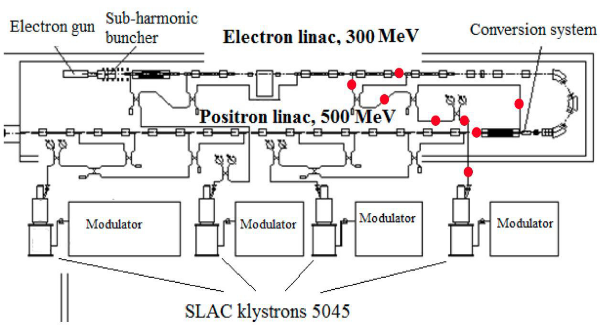

Figure 5: Measurement point layout of linac RF system.

Control System

The IC software is based on CXv4 framework [10], control software set is constantly improved [11]. The recent changes are the following:

- Many base framework improvements were implemented;
- Server-side device/channel bridging, used to easily interface beam user control systems;
- EPICS and TANGO client modules for CX;
- Improved Python bindings for CX client libraries;
- Improved CX-connected Qt widgets set;
- Improved database tools for machine configuration, configuration files generation;
- Improved machine state snapshot storage and manipulation programs;
- Improved automatic and data preprocessing software;
- Developed a software set for the DR optic measurements and studies;
- Developed few data preprocessing services and operators front-end applications.

Full automatic operation with VEPP-2000 is performed. Switching to VEPP-4 is still performed by operator request, but full automatic operation with both colliders is under development.

Injection Efficiency

Several programs for measurement and correction of the DR parameters were developed. They allow orbit correction, betetron tune and optics measurements. Injection efficiency study was performed using new software for tune control [12]. Tune scan was performed and optimal working point for the DR was determined, as shown in Fig. 6.

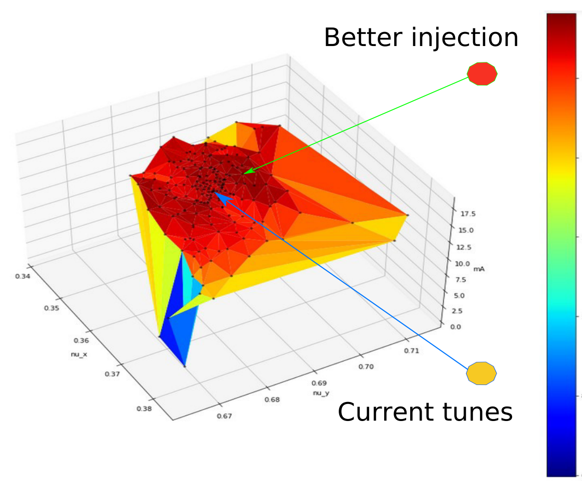

Figure 6: Amount of captured positrons in the DR vs tunes.

Beam Diagnostics for Injection Channels

To improve injection efficiency in the DR, we propose to use additional beam diagnostics in both injection channels: 6 and 3 BPMs for the e+ and e- channels, respectively [13]. Layout of proposed BPMs is shown in Fig. 7. New set of BPMs should decrease additional losses related to trajectory or optics mismatch.

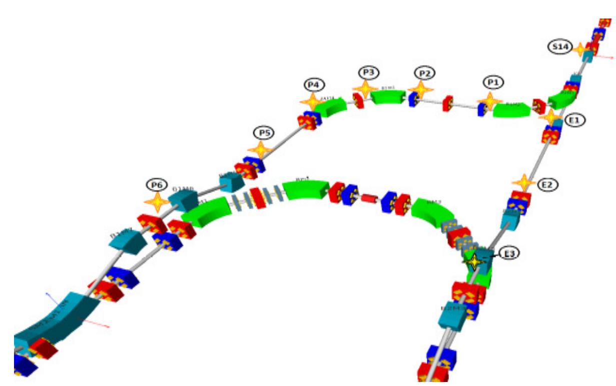

Figure 7: Layout of proposed BPMs for the DR injection channels.

CONCLUSION

Over the past five years, the IC successfully has been supplying both BINP colliders simultaneously. Maximum positron storage rate of $1.7 \cdot 10^{10}$ e+/s was achieved prior to positron solenoid malfunction. Stable IC operation at the energy of 430 MeV has been reached. New 10 A electron gun was installed. Positron solenoid replacement is planned for 2021/2022 run. Significant improvements on beam loss monitor system, RF monitoring system, control system were performed. Further IC performance and operation stability improvements are under consideration.

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