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STATUS OF VEPP-5 INJECTION COMPLEX

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Abstract

The VEPP-5 injection complex was put into operation as a source of electronic and positron beams for the VEPP-2000 and VEPP-4M colliders at the end of 2016. To date, an operating energy of 430 MeV and a positron accumulation rate of 3.5 nC/s have been achieved. Options for improving the complex for working with promising installations are being considered. The latest results and prospects of operation are presented.

INTRODUCTION

VEPP-5 injection complex (IC) [1, 2] is electron and positron beam source for BINP colliders VEPP-4 [3] and VEPP-2000 [4]. Layout of injection complex with colliders is shown in Fig. 1. It consists of electron and positron S-band linear accelerators with achieved energies 280 MeV and 430 MeV, damping ring and a set of beam transfer lines named K-500.

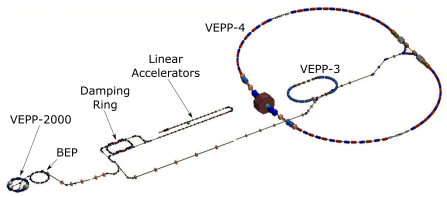

Figure 1: Injection complex and colliders layout.

Injection complex was designed to provide beams for next collider with acceleration to experiment energy by S-band linear accelerator. Therefore 700 MHz RF cavity was used in damping ring. In order to supply current beam users in 2017 RF cavity was replaced by 1st revolution harmonic 10.94 MHz one. Key parameters of injection are shown in Table 1.

Electron beam after first linear accelerator can hit tantalum target which in order to produce positrons or bypass it and further accelerate electrons. In this case, the maximum energy of the positron beam is lower than that of the electron beam. Due to beam users requirements and other operational reasons we are trying to make the switching time between the particles minimal for all parts of the complex. Currently full switching time is limited by K-500 magnets power supplies and is 26 s for particles switching or 52 s to change beam user. In order to make particles switching fast we keep damping ring in very close mode for both types of particles and preparing linac modes with the same beam energies for electrons and positrons. This allows to switch particles and start storage in 6 seconds. Since 2020 injection complex operated at 430 MeV beam energy.

Table 1: Injection Complex Parameters

Parameter	Value
Linac energy	280, 430 MeV
Linac RF frequency	2855.5 MHz
Damping ring max.energy	510 MeV
Damping ring perimeter	27.4 M
Damping ring RF frequency	11.94 MHz
Max. e+ storage rate	$2.7 \cdot 10^{10}$
Damping ring design current	30 mA
Linac beam energy spread e+, e-	3%, 1%
repetition rate	12.5 Hz
Damping times at 510 MeV, h/v/l	11/18/12 ms
Design horizontal emittance	$2.3 \cdot 10^{-6}$ rad · cm
Design vertical emittance	$0.5 \cdot 10^{-6}$ rad · cm

Beam storage/transfer, particles and users switching was automated with simple asynchronous state machine which uses 4 pre-tuned modes for the same beam energy (one for each beam user and particles kind). We use 12 transitions between K-500 modes in order to remagnetize its elements predictably. Currently injection complex can feed VEPP-2000 automatically but operator attention is required to switch to VEPP-4. More detailed description of operation techniques can be found in paper [5].

CONTROL SYSTEM SOFTWARE

Injection complex controlled by computers running few Linux distributions. Its software based on CXv4 control system framework [6], PostgreSQL databases and many other open-source software. Control system includes a set of server programs which implements work logic and GUI applications for interaction with operators. Server programs are running on virtual machines in dedicated infrastructure [7]. GUI applications are used on control room workstations or terminals. Injection complex software constantly improved and states are described in papers [2,8,9] but there is still a lack of some software tools. Recently following programs were developed:

- journaling system (archiver),

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- automatic reports,
- alarm system,
- operator GUI application for K-500 magnetic system.

Journaling System

Historical data on accelerator run needed in many cases. There was no specialised software for archiving data for CXv4. Since CXv4 servers are support EPICS channel access protocol it is possible to use EPICS Archiver Appliance. But for our relatively small machine with about 6000 channels it looks like over complicated solution with very high requirements to server. That's why we created our own journaling system which written in Python and use PostgreSQL with TimescaleDB to store data. Journaling service GUI application shown good performance for our conditions.

Automatic Reports

As the first historical data analysis application were created programs to generate and view reports on the operation performance of the injection complex. Data processing service starts periodically to create reports for shift, day, week, month and year. Reports organized in tree-like structure. For shifts journaling system data is analysed and saved to dedicated database. When creating higher-level reports, prepared shift data is used. Each data set contains the following metrics: total operating times for each beam user and downtime, bypass coefficients from the cooler storage to the user's booster, statistics on the time spent on each accumulation of the user's booster, and total transferred beam charges. In order to view reports Django based web-site was developed. Example of shift time distribution between users shown in Fig. 2 and shift beam transfer efficiency shown in Fig. 3. On that figures codenames of main operation modes are used: "e2v2" - electrons for VEPP-2000, "p2v2" - positrons for VEPP-2000, "e2v4" - electrons for VEPP-4, "p2v4" - positrons for VEPP-4.

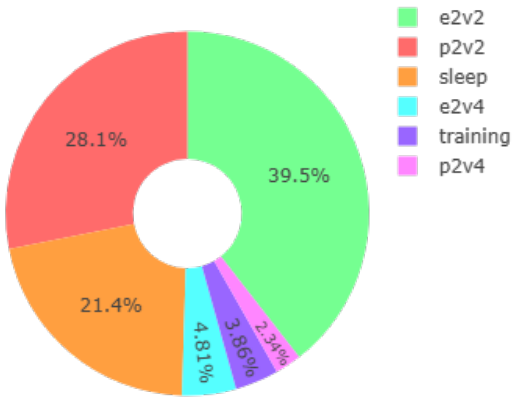

Figure 2: Injection complex operation statistics for April 2025.

Alarm System

There are about 1000 controlled devices operating at the injection complex. Therefore it takes a significant amount of time for the operator to figure out reason of some failure on the accelerator. This time can be reduced to almost zero if the detection of problems and notification of the operator are automated. That's why alarm system strictly needed. To date, a prototype of such a system for injection complex has been developed. The main service analyses the control system data for each device, checking status according to a set of conditions. These conditions are defined in the configuration database of the complex in such a way that they can be easily converted into Python code. Therefore, it is sufficient to create one general class of a state machine for analysing data from any device.

Operator GUI Application for K-500 Magnetic System

The K-500 beam transfer line was controlled using engineering applications that provide an excessive amount of data for regular operation and are not optimized for searching necessary accelerator elements. In order to solve this a new operator's application prototype was created. This program is configured directly from injection complex database and is designed in such a way as to extend it to other parts of the injection complex in the future.

KICKERS POWER SUPPLIES UPGRADE

At the beginning of 2025, the new damping ring kickers power supplies was fully put into operation. In order to do this we have changed the synchronization scheme of the kickers since old tyratron based power supplies required pretrigger signal (about 1 ms before kicker trigger). Installed power supplies has a 50 ns flat top on high voltage pulse (old ones had only about 1 ns). Due to this there is no more need to frequently adjust kickers trigger delays.

FUTURE UPGRADES

Previously a new positron solenoid was discussed [10] to replace our damaged one. To date calculations have been performed that have shown that replacing the solenoid will improve positron capture by about 3 times. Than the mechanical design of new solenoid was carried out. The solenoid is currently being manufactured and it installation is scheduled for 2026.

A new fully semiconductor linac klystron modulators was developed for SKIF facility. We have planned to replace injection complex modulators by the same type units starting from 2026 for first.

OPERATION IN SEASON 2024/2025

Previous seasons operation results were reported in papers [2, 10, 11]. Currently injection complex is routinely proving beams for VEPP-2000 and VEPP-4M colliders and covers all the needs of current beam users. Upgrade of kickers power

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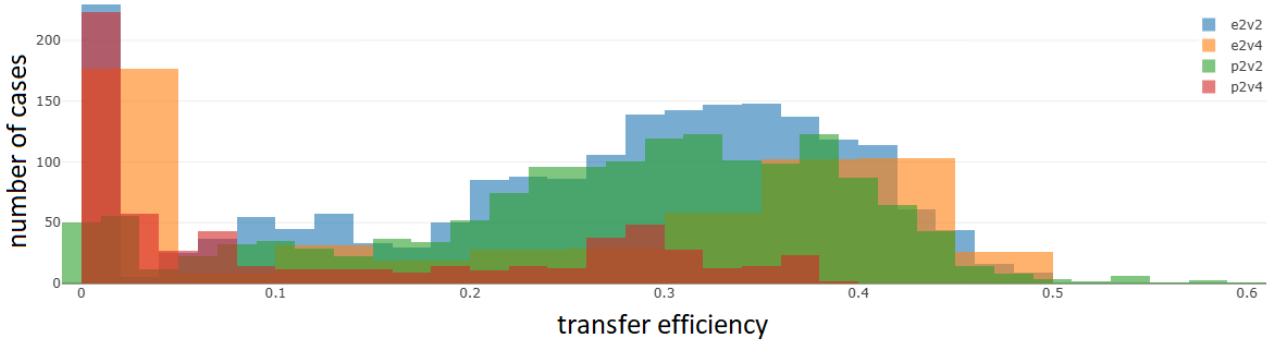

Figure 3: Beam transfer efficiency from damping ring to beam users.

supply system performed this season have significantly improved the stability of the injection complex, and now small adjustments to the accelerator may be needed several times per shift. Achieved beam transfer coefficient from damping ring to VEPP-3 is about 0.6 and 1 to BEP. But Fig. 3 shows typical shift values which are significantly lower. It depends not only on injection complex and demands more studies in order to find a way to constantly maintain good transfer efficiency. In the current season, the lack of objective operation monitoring has been significantly reduced at the complex. But it is still necessary to develop the tools for this.

CONCLUSION

The VEPP-5 injector successfully performs its task of delivering electron and positron beams to BINP colliders. A record-high rate of positron injection into the damping ring $(1.7 \cdot 10^{10} p/s)$ was reached in 2019. Current capabilities of the injection complex cover the all needs of existing beam users. Work is underway to improve the reliability and stability of the complex, and the possibility of operation with next facilities is being studied.

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