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CONCLUDING THE OPERATION AND DEVELOPMENT OF COSY

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Abstract

The operation of the COoler SYnchrotron and storage ring and its further development ended in October 2023. We briefly review the operation of the facility and continuous development of its sub-systems. Additionally, this work is put in context of the transformation process that COSY operation and the Institute of Nuclear Physics (IKP) of FZ Jülich went through starting 2015. Furthermore, the decommissioning strategy along with the possible further use of COSY components are discussed.

INTRODUCTION

In 2015 the FZ underwent a strategic realignment, establishing new objectives for the upcoming decade [1]. The implementation of the new strategy, among other things, resulted in the TransFAIR project that aimed at transferring human resources and know-how from IKP to GSI/FAIR and termination of COSY operation in 2023.

This article presents the COSY crew's view on the machine operation and its further development and does not aim at describing the numerous experiments that have been carried out by the international user community of COSY [2]. The machine delivered beam for up to 7500 hrs/year serving the experiments with about 500 visiting users from more than 50 institutions from about 25 different countries resulting in large number of scientific publications and more than 200 PhD theses [3]. A detailed review of the physics program starting from the early days of COSY until the end of 2014 is given in [4]. With the end of PoF-2 financing period of the Helmholtz association (12/2014) and the beginning of PoF-3 [5] the emphasis was put on providing beams for FAIR and EDM related activities. Starting 2014 the COSY Beamtime Advisory Committee [6] approved numerous beam time requests submitted by scientific collaborations like JEDI [7] and the ones planning to carry out their experimental research at the FAIR accelerator facility. New detectors, accelerator technologies like electron and stochastic beam cooling, beam instrumentation, cluster-jet target technologies were further developed and tested at COSY. The JEDI collaboration used the facility for research and developments towards a dedicated high-precision EDM storage ring and carried out first measurements at COSY.

New requirements towards precision beam control i.a. [8] emerged and had to be dealt with by the COSY crew jointly with the experimentalists. Doing so we tried to maximize the synergies with FAIR e.g. by using standard FAIR hardware and the in-house developments for FAIR where possible. Figure 1 shows the distribution of beam hours at COSY for the period 1993 - 2023. The smaller fractions usually indicate larger installation activities requiring longer shutdown periods. During the COVID-19 pandemic only a small fraction of granted beam times were cancelled or postponed due to the travel restrictions for the experimental groups. However, energy crisis and budget restrictions clearly left their mark. This article concentrates on the developments at COSY in the last decade of its operation.

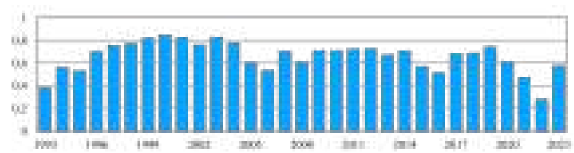

Figure 1: The distribution of COSY beam hours during the 30 years of its operation. Shown is the fraction of yearly hours. Diagram courtesy D.Grzonka [3].

UPGRADES OF ACCELERATOR SUBSYSTEMS

New precision experiments required better beam control in particular significantly smaller overall RMS beam orbit deviation. Therefore, an automated beam orbit correction had to be developed. Furthermore, other components were identified being in need to be upgraded or to be added. One example is the analog BPM readout electronics, whose drifting signal offsets prevented an accurate position determination for centered beams.

Control System Upgrades Instead of implementing the new sub-systems and features into the old control system (CS), a step-by-step upgrade was chosen in order to avoid long down-times of the machine. In addition, the following considerations were taken into account:

- Add a logging and archiving mechanism.
- Use software developed and supported by a large community.
- Software and compatible hardware available without protocol adaption.

Finally, an EPICS [9] based system utilizing Control System Studio (CSS) [10] was chosen as new CS environment. This approach combined the speed and low cost of development, since many of the free software tools work out of the box. Broad support by the accelerator community using similar systems as well as support by the industry partners

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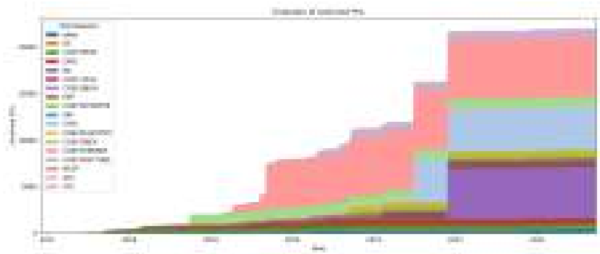

Figure 2: Progress of systems integration expressed as number of archived PV.

were considered crucial. The state-of-the-art CS environment boosted new developments and integration of existing systems. More importantly, once any sub-system publishes measurement results as EPICS process variables (PV) which can be archived, machine performance analysis can be carried out in great detail, correlating the machine settings with actually measured beam parameters. This, together with an improved integration of the machine model enabled further machine improvements. Beam instrumentation sub-systems were among the first ones to be integrated. Beam position monitors, schottky pickup, ionization profile monitor, tune and chromaticity measurements, beam profile measurements in the injection (profile grids) and the extraction beamlines (MWPC), beam cooling devices, and others started delivering EPICS data and got new GUIs. This article covers only of few. Figure 2 shows the progress in EPICS integration of various systems expressed as number of archived PV [11].

Orbit Correction - OC In order to achieve the requested RMS orbit deviation of < 100 µm an upgrade of the BPM readout with new beam processors and signal amplifiers, and the software based online manipulation of the steerer magnets were required. The orbit correction algorithm was presented in [12]. Once beam position measurements together with steerer controls and readback became available via EPICS automated ORM measurements were implemented. With that OC can be performed based on the ORM calculated from the model or the measured one. Both methods worked well.

Magnet Control For orbit control of the circulating beam, only the steerer magnets are used. Therefore, these magnets were the first to be converted to an EPICS control. Classically, the control of the magnets is done by function generators, running a pre-defined cycle. However, they allow an online-control mode taking over at a pre-defined time in the cycle. Easy script-based access to the steerer controls enabled the development and use of automatic optimizers. Such optimizers were successfully used to increase the intensity of stored beam.

BPM Upgrade & Software Tools The signal digitization and position processing of the BPMs were upgraded using the commercially available Libera Hadron that include an EPICS server. To further enhance the beam position measurements, an upgrade of the head-on amplifiers of the BPMs with the variable gain ones was necessary. In addition, a semi-automated balancing mechanism to match the gains off the corresponding amplifier pairs was introduced. Since the new beam position processors deliver bunch-by-bunch position data as well as raw ADC data this paved the way for the development of a variety of additional beam diagnostics tools.

Fast Tune and Chromaticity Measurement System In combination with the beam exciter upgrade a new system for tune and chromaticity monitoring was implemented [13]. The system is capable of measuring betatron tunes of bunched (BbB position data) and coasting (raw ADC data) beams. It allows for a discrete tune measurement within a few milliseconds, as well as continuous tune monitoring during e.g. beam acceleration. Tune tracking and manipulation during the acceleration ramp is crucial for the handling of polarized beams [14]. A reliable chromaticity measurement tool was vital during various JEDI beam times.

Bunch Shape Monitor provides a convenient and accurate display of the longitudinal charge distribution in the bunch by means of a 2D Plot and a 3D colormap. This helps among other things optimizing the settings of the RF system during bunching and acceleration.

Beam Loss Monitor A few existing liquid scintillator BLM were complemented by the ones made from plastic scintillators and photomultipliers left over from earlier experiments. HV for the BLM detectors is supplied by commercially available multichannel power supplies, featuring an internal EPICS control from CAEN. Red Pitaya boards are deployed providing discriminator/counter functionality with an onboard EPICS IOC. A GUI routinely running in the control room displays the beam loss distribution around the ring and the loss behavior over time. Furthermore, FAIR BLMs based on plastic scintillators read out by μTCA scalers running in a FAIR FESA environment were set up and used for COSY operation.

Slow Control For slow control and readback an integrated, low cost scalable system was searched for. DIAMOND EtherCAT system [15] - a nearly ready-to-use package was used for numerous EtherCAT hardware modules at COSY. The EtherCAT system is used for a variety of applications, like:

- the control of the variable-gain BPM pre-amplifiers,
- the readout and control of the Bergoz Parametric Current Transformer,
- readback of magnet power supplies,
- control of pneumatic drives via a 24 V digital output,
- stepper motor control of Beckhoff stepper motors utilizing an extension of the DIAMOND implementation provided by iThemba LABS.

Furthermore, the stand-alone vacuum CS of COSY based on Siemens PLC got a read-only EPICS interface. This al-

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lowed for the vacuum data to be continuously monitored and archived within the integrated machine data set. JEDI experiments and others, who operate internal targets, affecting the vacuum conditions in the ring benefited greatly from this development.

Standard Scalable DAQ In accelerator and experimental physics environments there is often a need for scalable data acquisition and analog&digital control solution that can be quickly deployed at low-cost. A Red Pitaya board featuring 2 125 MS/s ADC channels and a Xilinx Zynq 7010 FPGA including a dual ARM Cortex A9+ processor became such a solution at COSY [16]. The FPGA code includes several modules behaving differently depending on the specific application. The proper configuration is activated by an external parameter depending on the deployment scenario. On the CPU side an EPICS IOC connects the signals and results processed on the FPGA side with the main CS and archiving. The board running the in-house developed firmware and software, was successfully used for/with:

- Beam Loss Monitors.
- Ionization Chambers in the ExBL.
- beam current measurements in the NESP beam line.
- Frequency measurements.
- H^0 monitor, discrimination and coincidence logic.

Save & Restore and Archiving With the EPICS CS several methods of Save & Restore and archiving are possible. For the archiver we chose "The EPICS Archiver Appliance" [17]. For the Save & Restore feature the method implemented within the Control System Studio is used.

Injection Optimization using Machine Learning With the control and readback converted to EPICS access, an easy access to control of the beam optics of the injection beamline was possible. Reinforced learning optimization for the injection into the COSY synchrotron was developed [18] [19].

DEVELOPMENTS FOR FAIR

Since the limitations of this paper do not allow us to present numerous very important activities with any adequate level of detail they are just listed in this section. The reader is advised to consult the corresponding publications.

- RF knock-out slow extraction with spill feedback [20]
- HESR RF System at COSY [21]
- Barrier Bucket RF System [22]
- stochastic cooling [23] [24]
- High energy electron cooling [25] [26]
- Panda Cluster Jet Target, Uni Münster [27]
- Detector developments for FAIR [6]

Polarized Beams

Many weeks of polarized deuteron beams were delivered to the JEDI collaboration over recent years. However, much more challenging from the accelerator point of view polarized protons have not been dealt with for many years until 2023. In the last year of COSY operation polarized proton beam was accelerated to 1950 MeV/c and extracted from the ring by the newly established RF-KO method with spill leveling [20]. The extracted beam was successfully delivered to the TOF experimental area [28].

Developments for HBS

A new low energy (NESP) beamline providing beams from the cyclotron to the Big Karl experimental area was established in 2019 [29]. Jülich Center of Neutron Science installed the Target-Moderator-Reflector (TMR) -demonstrator that made is possible not only to carry out research towards realizing the HBS project [30] but also to perform various experiments with moderated neutrons [31].

SUMMARY AND OUTLOOK

The operation of the COSY accelerator facility started in 1993 and terminated in 2023. The point in time for the end of COSY operation aligns along the current strategy of the FZ-Jülich and GSI/FAIR to meet their objectives. The facility served the large international user community in the field of hadron physics, detector development and accelerator science and technology. It supported the FAIR project providing beams and human resources. The facility was intensively used for education by the nearby universities and schools as well as by the internal training program of the FZ-Jülich. To answer the user demands in regard of the beam properties, data acquisition and handling numerous upgrades and improvements were successfully implemented jointly with the colleagues from other labs and industry partners. Soon after announcing the new strategy of the FZ-Jülich and its consequences for IKP and COSY the TransFAIR project was initiated by the boards of directors of both institutions. The project aims to make transferring human resources and know-how from the FZ to GSI/FAIR as smooth as possible. The goal was to make sure, that personnel working in the area of accelerator physics joins the FAIR project rather than leave the field. 9 accelerator scientists, 2 engineers and 3 technicians previously working at COSY joined accelerator related departments of GSI. While the preparation for the transport of the FAIR components developed and tested at COSY is well underway, the proposed scenarios of decommissioning and re-use of the COSY sub-systems are under discussion. Equipment, which can immediately help operating GSI facilities or advancing the FAIR project is being transferred to GSI.

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