Photon Emission Spectrometer for SASE3 beamline of European XFEL diagnostics

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The Photo-Electron Spectrometer (PES). Making scene of the PES system by Karabo

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Abstract

This report, in the context of the DESY Summer Student Program 2017, presents the concept of The Photo-Electron Spectrometer (PES) and scene of the PES system made by using Karabo software, performed at European XFEL between August 28th and September 7th 2017.

The European X-ray free electron laser (European XFEL) is an international project to create the world's largest free electron laser designed to monitor the course of molecular chemical reactions, and resolve the atomic structure of biomolecules and viruses, as well as many more applications in science and technology. European XFEL provides high average brilliance in the soft and hard X-ray mode. The high average brilliance is achieved due to acceleration of up to 27,000 electron bunches per second by the super-conducting electron accelerator. The European XFEL with its[used at the end station for various experimental techniques. For commissioning and of course during research photon beam diagnostic is necessary because of the statistical nature of SASE (Self-Amplified Spontaneous Emission). One of the most flexible photon beam diagnostics instruments is the Photo-Electron Spectrometer (PES). The photo-electron spectrometer (PES) measures the spectrum and polarization of the photon pulse based on an angular resolved time-of-flight measurement of photo-electrons. At the SASE3 FEL source, it is planned to use variable polarization schemes, so polarization measurements and monitoring is required. For supposed higher requirements for volumes and data rates of modern photon science facilities suchfigure as the software framework of free electron X-ray lasers called Karabo was written from scratch. Karabo is written in C ++, which uses the programming mechanisms for templates and the boost. Karabo is in fact a flexible application management system.

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Introduction to European XFEL

The 3.4 km long European XFEL with its three undulators (SASE1, SASE2, SASE3) generates coherent femtosecond pulses of X-ray radiation which will be used at the end station for different experimental techniques, (Fig.1) including plasma physics, single particle imaging, coherent scattering, time-resolved diffraction and spectroscopy. This will provide unprecedented understanding of the dynamics and structure of viruses, proteins, nanoparticles, etc.

Typical for XFEL machines is a high peak brilliance by several orders of magnitudes higher the existing synchrotron facilities. With a pulse duration of less than 100 fs and an extremely high luminosity of 30,000 flashes per second the European XFEL will have a worldwide unique time structure that will allow researchers to record ultra-fast process movies. [1]

The unique feature of European XFEL is the provision of high average brilliance in the soft and hard X-ray mode, combined with the pulse properties of FEL radiation of extreme peak intensities, duration of femtosecond pulses and high degree of coherence. The high average brilliance is achieved through acceleration of up to 27,000 electron bunches per second by the super-conducting electron accelerator. [2]

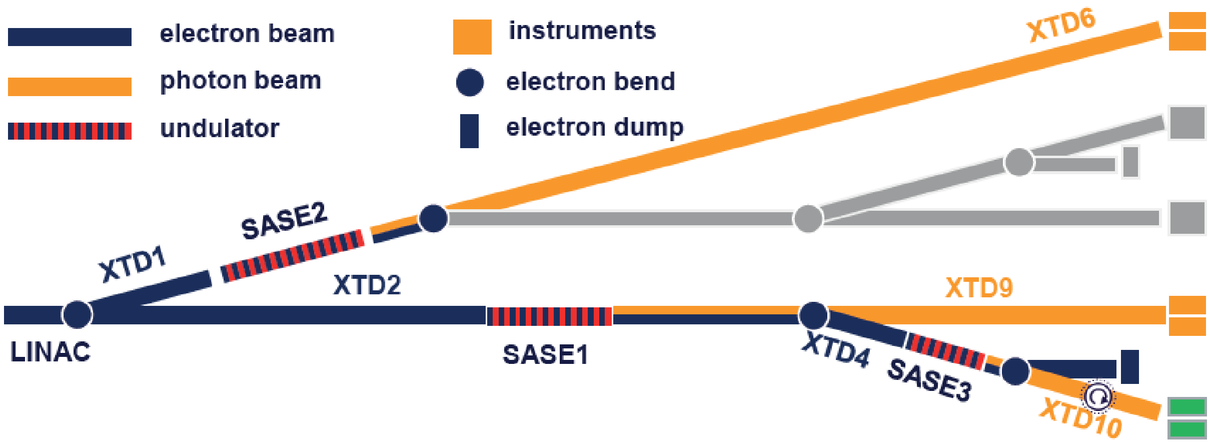

Figure 1. XFEL beam with SASE1, SASE2, SASE3 undulators

For commissioning and of course during researches, photon beam diagnostics is necessary because of the statistical nature of SASE (Self-Amplified Spontaneous Emission). The radiation generated by three FEL sources (SASE1, SASE2, SASE3) is distributed via long beam transport systems to the experiment hall where scientific instruments are situated. X-ray beam transportation systems are optimized to maintain the unique characteristics of the FEL radiation, which will be monitored using built-in photon diagnostics. Six scientific instruments are optimized for specific applications using soft or hard X-ray technologies and include integrated lasers, dedicated sample environment, large area high frame rate detector(s) and computing systems capable of processing large amount of data.

Photon Diagnostics Systems

Diagnostics of X-ray photons is necessary for monitoring the parameters of the photon pulses generated by the European XFEL. The diagnostics systems provide necessary information to the machine for setup, operation and optimization of the accelerator, undulator and X-ray optics, especially during commissioning. Diagnostics is also necessary for the normalization and interpretation of experimental data. Several properties of the beam will be measured by the so-called online methods, that is, for each photon pulse and with minimal distortion of the pulse. Examples are the pulse energy and beam position. Pulse-to-pulse capability is challenging because of the 4.5 MHz repetition rate, but it is especially important to be able to normalize data for fluctuations of photon pulse parameters due to the SASE process or due to electron or X-ray beam unsteadiness. In addition, for installation and special measurements, several invasive photon diagnostic systems have been installed which stop the X-ray pulses, or at least severely modify properties of the pulse.[3]

Online Photon Diagnostic Systems

These systems can be separated into residual gas systems, naturally interfering only minimally with the X-ray beam, and systems using very thin solid films or crystals, thereby absorbing only a small fraction of the FEL pulse. This latter method is applicable only to hard X-ray radiation, otherwise the absorption is too strong.

For the diagnostic systems of the residual gas, photoionization of rare gases (Xe, Ne, Ar or Kr) or nitrogen is used, and this makes these devices inviolable and highly translucent. This non-invasive diagnostic method is best suited for high peak energies and high average flux since in this case there is no issue with damage or heating due to the absorbed energy of X-ray pulse. At European XFEL, these systems are used in the transportation of the beam to measure pulse energy, the polarization of the X-ray pulse and position of the beam. Residual gas monitors can continuously operate up to very high pulse repetition rates limited by the flight time of ions and electrons, which are used to measure impulse properties, and work even for hard X- if sufficient sensitivity is able to compensate for the reduction in cross section. [3]

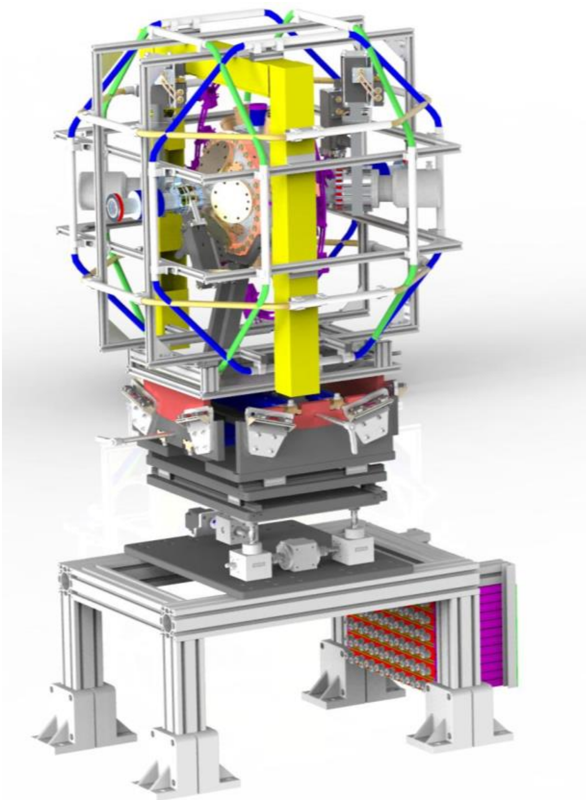

Figure 2: 3D model of Photoelectron Spectrometer

Photoelectron Spectrometer

One of the most flexible photon beams diagnostic instrument is the Photo-Electron Spectrometer (PES) that is equipped with 16 electron Time-of-Flight (eTOF) drift tubes in a cylindrical configuration. The photo-electron spectrometer (PES) measures the spectrum and polarization of the photon pulse based on an angular resolved time-of-flight measurement of photo electrons. This device is integrated only in the SASE3 beam transport, because for soft X-rays one cannot employ crystal-based schemes to measure the spectrum, and instead the energy distribution of XFEL-generated photo-electrons can be used to deduce the center and width of the photon energy spectrum. At the SASE3 FEL source, it is the planned to use variable polarization schemes, therefore, polarization state measurements and monitoring are necessary. The PES has a spectral resolving power of $\frac{\Delta E}{E} \leq 10^{-4}$ and the polarization direction and degree can be measured with an accuracy of 1%.[3]

In the TOF technique, kinetic energies are determined by measuring flight times of electrons traveling a fixed distance between an interaction region and a detector, typically up to several hundred nanoseconds. The method is based on the coincidence between a timing pulse and an electron signal; background noise is suppressed and distributed evenly through the entire time spectrum, which greatly simplifies data analysis. Another advantage of the TOF technique is that an entire electron spectrum can simultaneously be collected. Compared with electrostatic analysis, simultaneous collection of the whole spectrum eliminate fluctuation effects and can increase the measurement efficiency of the electron-TOF method. This electron-TOF system is capable to efficiently slow down high-kinetic-energy electrons and is convenient in situ analyzer alignment.

PES work structure

To measure the photoelectron spectra perpendicular to the beam, 16 TOF spectrometers were arranged in 22.5° steps around the beam as shown in Fig. 3. When all undulator segments are inserted to establish the SASE condition, MCP Based detector measures intensities from the initial signs of lasing up to saturation. [4]

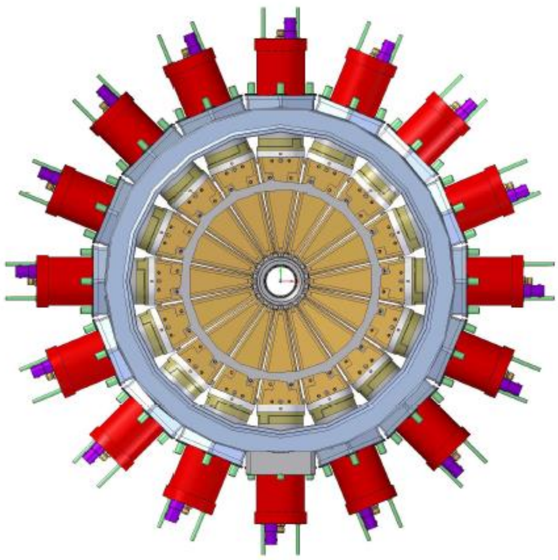

Figure 3: 16-fold electron TOF spectrometer
setup.. The FEL beam enters perpendicular into the plane of the figure.

Electron beam passes through the SASE3 undulator after which there is a PES and after that the photon beam comes in the center to the extraction region, hit atoms in extraction region, and ionizes atoms which are all in the center. Consequently, atoms emit electrons. In addition, there is an electric field and the purpose of the electric field is mostly to retard the electron, making it go slower, electrons go to one of 16 directions. There are four electrostatic lences inside TOFs: A, B, C, D. The purpose of electrostatic lances is to focus the beam. And after electrostatic lences it goes to the detector, and the signal from the detector is read by digitizer, where we measure the time difference from start to finish (Fig.4). If we know how long it takes the electrons to go then we know the kinetic energy of the electron, and consequently we are aware of the photon energy.

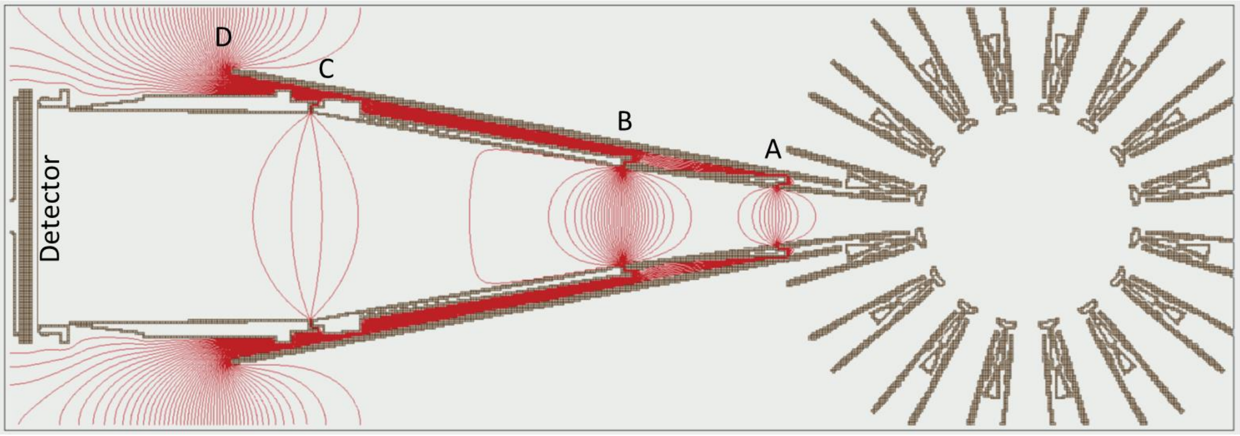

Figure 4: The structure of TOF

Helmholtz-coils with magnetometer

We tested settings on Helmholtz-coils with magnetometer for cancelling out stray magnetic fields so we optimized the condition for the lab. Because we have a rough starting point when we are in the tunnel. The magnetic field is not the same in the tunnel so we cannot use it anyway but we can use it as a starting point to look for a good one. The objective is to have zero magnetic field in the PES everywhere, especially in the extraction region. Also outside is important so for that reason we have to compensate the magnetic field rounding. To compensate that we have Helmholtz coils and the objective is to find the current that gives us zero magnetic field in the center. Our Magnetometer is Mag-03MC250 and Power supply including Display Unit Magmeter-2 from the company Bartington. Settings for this model that measures in the range +/-250 µT must be:

Sensitivity: 4. +/-25 µT/1V

Output type: Unbalanced

DC/AC Coupling: DC

Earth magnetic field ranges from 25 - 65 µT

	Vset(V)
X left	0,50
X right	1,45
Z us	0,54
Z ds	0

Axis	Field [uT]
X	0.0
Z	0.0

Figure 5: Magnetometer and test results

For understanding the position of coils in Fig. 6 PES was presented from upstream perspective.

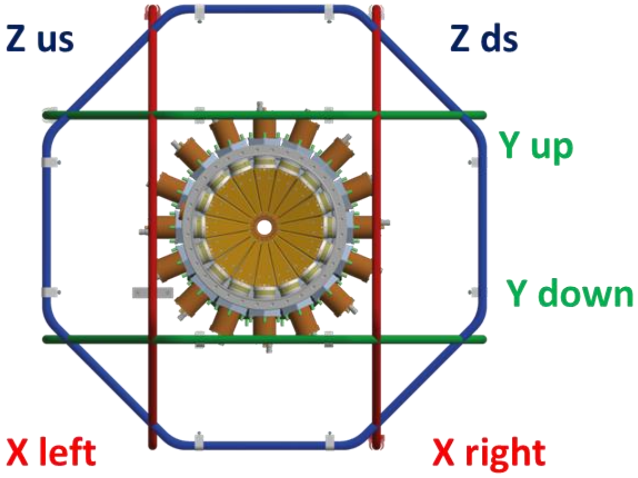

Figure6: PES from upstream perspective

MCP detector results

We also tested MCP detectors by measuring dark counts on all 16 detectors to find out if everything works properly, are there any problems with the detectors or not. It was a slow ramping the MCPs up to 2100V and pre-amp, voltage was 15V. In pictures, presented below, you can see the oscilloscope, which showed signal and screenshot of control software for voltage supplies. The scope we use is ROHDE&SCHWARZ RTB2002 Digital Oscilloscope 2.5 GSa/s.

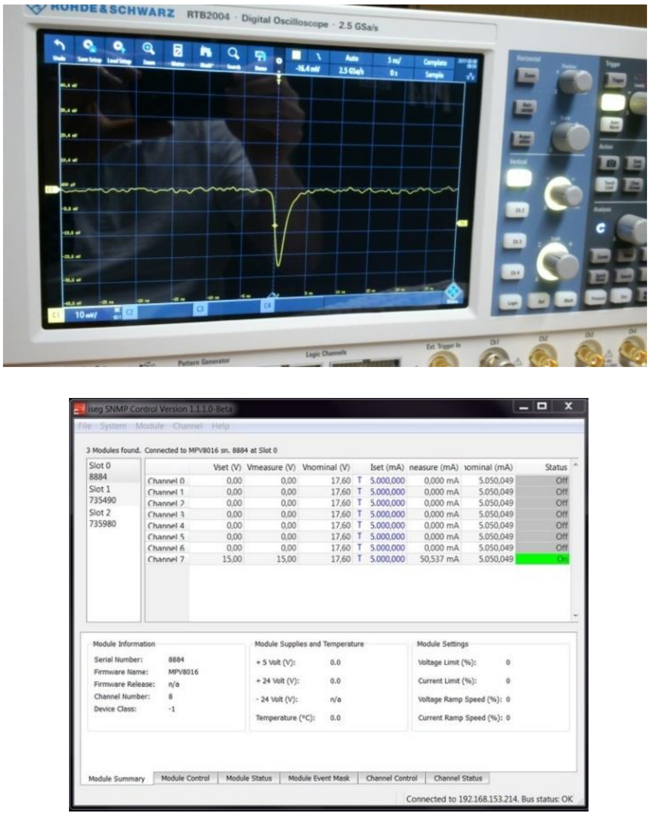

Figure 7: Oscilloscope and voltage supply software

Karabo Scenes

For intended higher requirements for volumes and data rates of modern photon science facilities, such as free electron X-ray lasers, software framework called Karabo was written from scratch. Karabo is written in C ++, which uses the programming mechanisms for templates and the boost. By its design, it contains data collection, management, data management and scientific computing tasks into one homogeneous software framework. It relies on modern programming language technologies and it has a purpose to provide users and developers intuitive access to data, hardware and computing resources. Karabo and all its elements are available to the Python programming language. Karabo runs on Linux operating systems (Ubuntu, Scientific Linux) and under Mac OS X and is distributed as a software bundle including all necessary dependencies. Karabo is actually a pluggable, distributed flexible application control system. All Karabo applications have a standardized interface for self-description, program-flow organization, logging and communication. Central services exist for user management, data logging, configuration management, access control, etc. The design provides a very scalable but still maintainable system that at the same time can act as a fully-fledged control. It permits simple integration and adaption to changing control requirements and the addition of new scientific analysis algorithms, making them automatically and instantly available to experimenters. [5]

The GUI is a versatile tool that provides all the functionality needed to configure and interact with the Karabo system. The seven dock-able main panels form the basic layout (see Figure 8): [5]

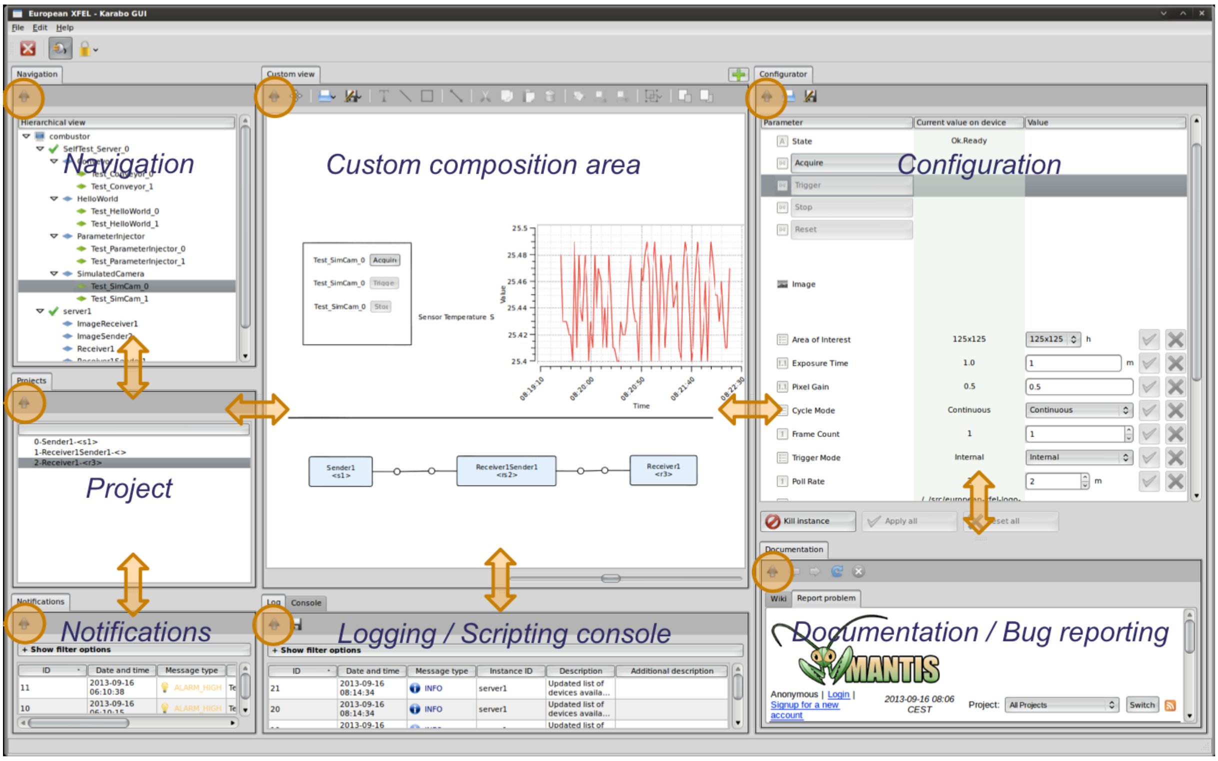

Figure 8: Multi-purpose GUI. Each panel may be undocked and made full screen on different monitors (orange circles).

1. Navigation – Real-time view of the system
2. Project – Offline configuration of projects
3. Notification – Informs about warnings, alarms, end-of-runs, etc.

4. Custom – PowerPoint like page allowing to build expert panels from a mixture of online and layout widgets
5. Logging – Accumulated logging information of all currently running devices
6. Configuration – Auto-generated panel giving access to properties/commands of the currently clicked device
7. Documentation – Integrated internet-browser allowing wiki-page editing for device documentation and also bug-reporting

Prior to using GUI control interface users must log in with username, password and authentication provider. This information gets automatically extended with data describing the broker and the local machine. The authentication service is connected to a central database, which controls the current access levels for the requesting user from the context of the provided information. The following properties are taken into account: 1) users role 2) IP address of the user 3) Karabo sub-system used and 4) current time. The web-service subsequently sends back a global access level and a list of device instance specific exceptions. Presently, five different access levels are used: observer, user, operator, expert, and admin. GUIs do not directly communicate with the broker, but connect via TCP (Transmission Control Protocol) to a GUI-Server device, which forwards the communication to the broker. This architecture facilitates a server side pre-processing of data reducing each client's computing time. During operation, the GUI always keeps track which properties are currently visible, and passes this information to the GUI server, which then sends only the data that is currently needed, which greatly reduces the load on the network.

In Fig. 9 an image of PES vacuum and gas supply is presented. It consists of ascroll pump also known as scroll compressor and scroll vacuum pump, of valves, valves with controller, prevacuum measure and upstream turbo parts, in main chamber ultra-high vacuum (UHV) measure parts, Nitrogen, Neon, Krypton and Xenon valves and Nitrogen, Neon, Krypton and Xenon gas boxes.

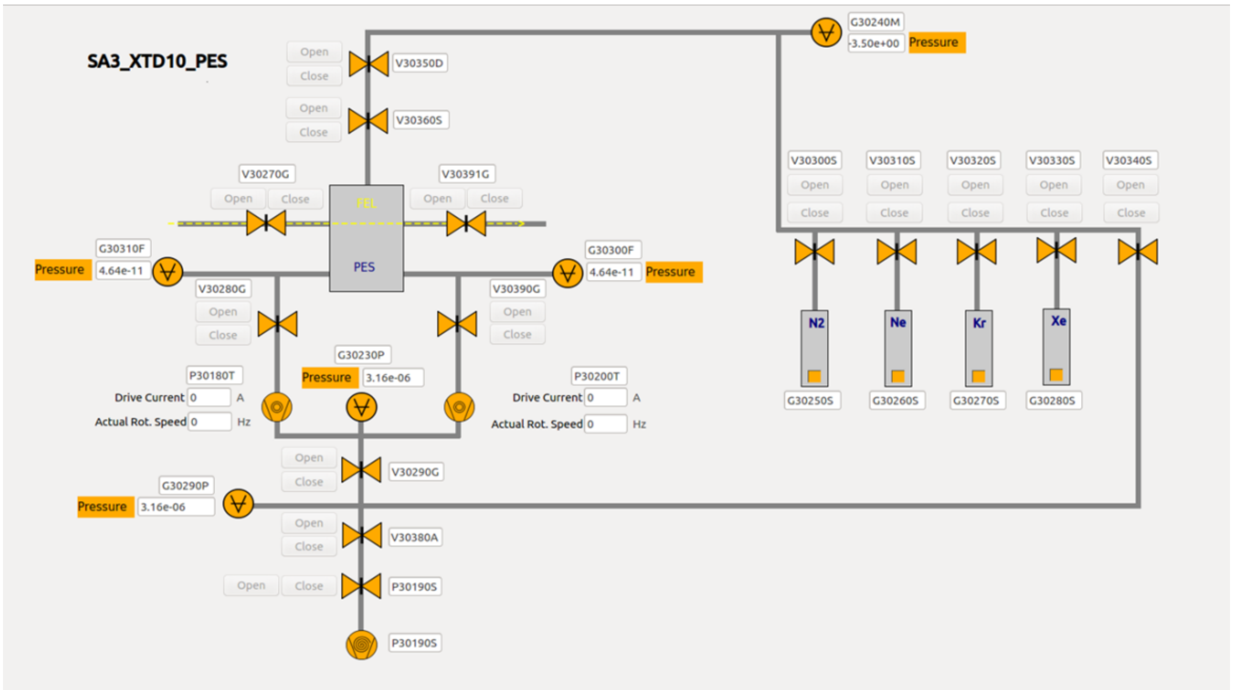

Fig.9 scene of PES vacuum and gas supplay

For the usage of one of the four gases, we must open only the one we want to. Gas will pass through a tube and turn in the PES. G30310F and G30300F chambers will show the pressure in the PES. Pressure in the PES can be controlled by V30350D valve. V30280G and V30390G valves are always open (they are just for safety). Upstream turbo is P30180T and downstream turbo is P30200T, they are for pumping the chamber. We use G30230P and G30290P gages to know the pressure during the cleaning of the system. Turbo pumps cannot work if you have vacuum only in one side and in other side air pressure. Pre vacuum is required that pre vacuum can done by P30190S pre vacuum scroll. P30190S is a scroll pump, it is used to pump gases. For cleaning the system, we have to close the valve of gas, which we used. We must close V30290G valve, then we have to open V30340S valve. It is necessary to know that for cleaning the system, we have to open evacuation line, but it can only be opened if V30290G is closed. Only one gas line can be open at the same time G30250s or G30260S or G30270S or G30280S.

Acknowledgement

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Conclusion

To conclude, we have tested 16 MCP detectors, as a result we can suppose that they basically work well. As a result, having tested the Helmholtz Coyle for cancelling out stray magnetic fields to compensate the magnetic field rounding, we have a starting point. For some reason we have a result only for the x and z components. To do this, it was necessary to impart the following voltage to the Helmholtz coil components. X left – 0.50 V, X right – 1.45 V, Z us – 0.54 V, Z ds – 0 V. As a result, having studied the Karabo software framework, we have obtained the images for vacuum and gas supply.

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