



JOINT INSTITUTE FOR NUCLEAR RESEARCH  
JINR University Centre (UC)

**FINAL REPORT  
ON STAGE 1 OF THE  
INTERNATIONAL STUDENT PRACTICE**

*“Controls & Vacuum hands-on training”*

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**Participation period:**

01-24 March

Dubna, 2022

## 1. Abstract: -

The fundamental driving force behind high-energy physics experiments and the production of heavy elements on our plant is the vacuum system and technologies. We can simulate the same atmospheric circumstances as in space using them, and they give a clean, inert, collision-free experimental working atmosphere, which allows us to study elemental collisions and the formation of primary atomic components like quarks and bosons.

We'll need multiple stages of vacuum pumps, vacuum gauges, vacuum sealing, vacuum flanges, and vacuum tubing and connections to develop such a vacuum system. Integrating all of those components and making them operate together necessitates a precise timing sequence for turning on and off the pumps, as well as when to open and close certain valves.

We'll need to automate our vacuum system, which will give the required functioning protocol for each pump and monitor safety conditions for each valve, in order to develop that integration. That's all it takes to obtain the desired vacuum level quickly and with the least amount of effort from the scientist to do his experiment.

## 2. Introduction: -

The vacuum environment has come to play an important role in scientific research as new discoveries are being made by looking back to the fundamentals of pressure. The idea of "perfect vacuum" cannot be realized, but very nearly approximated by the technological discoveries of the early 20th century [1].

Vacuum engineering today uses a range of different material, from aluminum to zirconium and just about everything in between. There may be the popular belief that vacuum technology deals only with valves, flanges, and other vacuum components, but novel scientific discoveries are often made with the assistance of these traditional vacuum technologies, especially in the realm of high-tech. Vacuum engineering is used for compound semiconductors, power devices, memory logic, and photovoltaics [2, 3].

From a historical point of view, the word "Vacuum" is originated from the Latin word "vacua", which is translated to the word "empty". Physicists use vacuum to describe a partially empty space, where air or some other gases are being removed from one container. The idea of vacuum relating to the empty space has been speculated as early as 5th century from Greek philosophers, Aristotle (384-322 B.C.) was the one who came up with the relation of vacuum being an empty space in nature would be impossible to ever create.[2] This idea had stuck around for over centuries until the 17th century, when vacuum technology and physics was discovered. In the mid-17th century, Evangelista Torricelli studied the properties of a vacuum generated by a mercury column in a glass tube; this became the barometer, an instrument to observe variations in atmospheric air pressure.

Otto von Guericke spectacularly demonstrated the effect of atmospheric pressure in 1654, when teams of horses could not separate two 20-inch diameter hemispheres, which had been placed together and evacuated Figure 1.

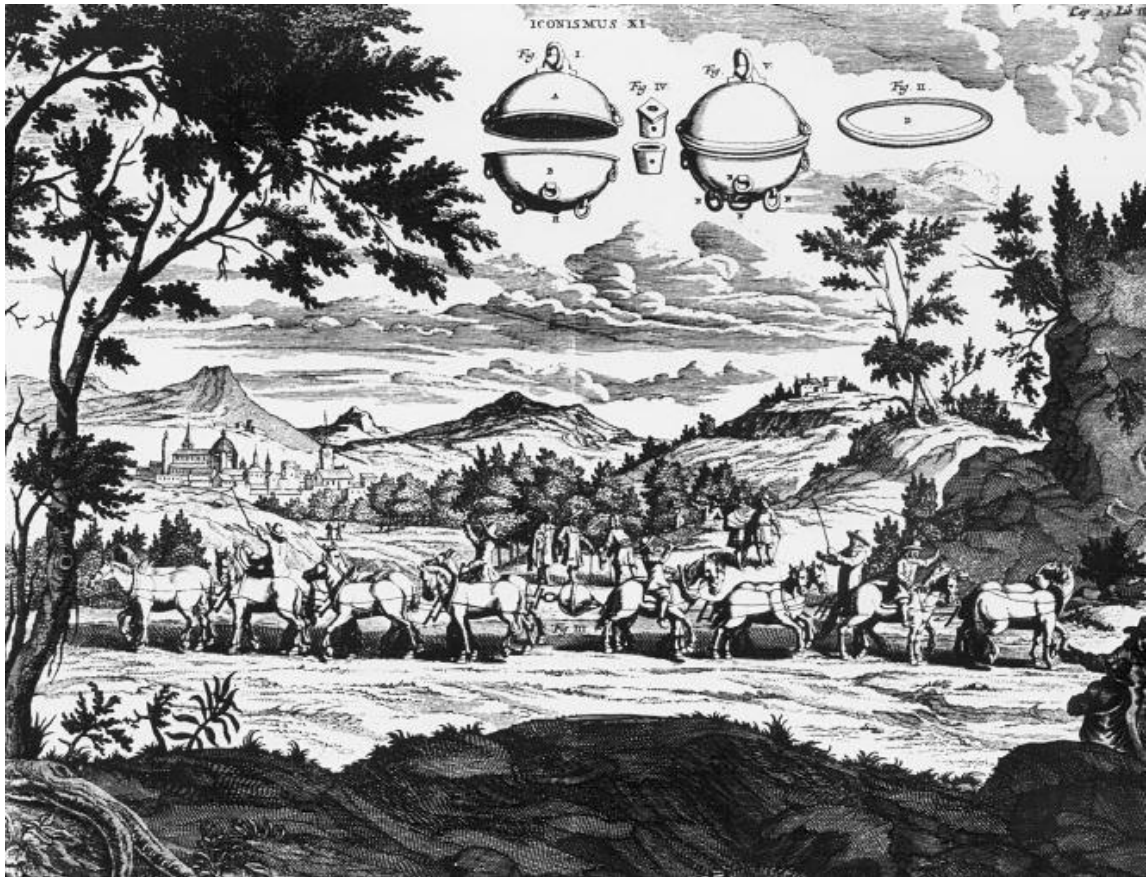


Figure 1: Experiment with the "Magdeburger Hemispheres" (1654) by Otto von Guericke (taken from an engraving of P. Gasparis Schotti "Technica Curiosa", Nürnberg, 1664. Courtesy Otto von Guericke Society in Magdeburg).

In 1698, Thomas Savery patented a steam pump that relied on condensation of steam to produce a low-grade vacuum, for pumping water out of mines [2].

Finally, in the thirties of our century, the invention of the wide variety of particle accelerators started and went on till today with the construction of huge machines. With accelerators, nuclear and high-energy elementary-particle physics began. All the inventions and sophisticated technological developments of today would have been unthinkable without high vacuum and its technology [1]. Therefore, vacuum physics and techniques paved the way for the development of modern high-technology and our industrial society.

### 3. Project Goals: -

the goals of this project are;

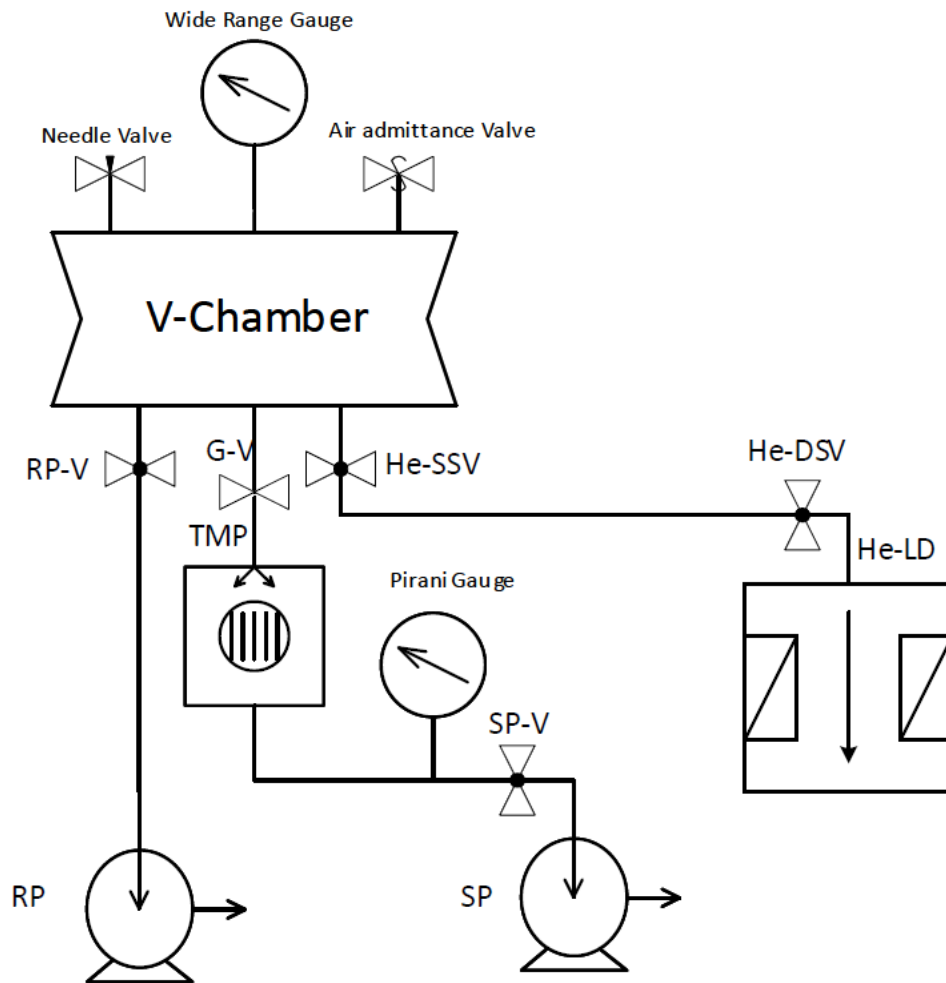
- Get acquainted with contemporary automation techniques and get basic skills of working with them
- Construct a PLC-based automated control system for the model of the particle accelerator vacuum system.

#### 4. scope of work: -

1. Real tasks demonstration, Tour to one of the JINR basic facilities with a focus on its control system.
2. Introduction to automation techniques, Programmable logical controllers (PLCs), their types and difference between them and other industrial electronic devices.
3. PLC programming, Introduction to the LOGO!Soft Comfort programming environment. Simple examples based on the previously assembled circuit.
4. Introduction to the automated control systems design through the example of an existing project of the clinic notification system. Assembling, commutation, programming, testing.
5. Introduction to Vacuum Technology (assembling and pumping, leakage, leak detection).
6. Finally, Main project : vacuum equipment remote control.

#### 5. Methods: -

As a reactor modelling setup, we are using a multiple port stainless steel chromium coated vacuum chambers, to act as our working space. Connected the several flanges types to other vacuum components as shown in Figure 2.



*Figure 2: Vacuum System Diagram.*

This chamber is equipped with;

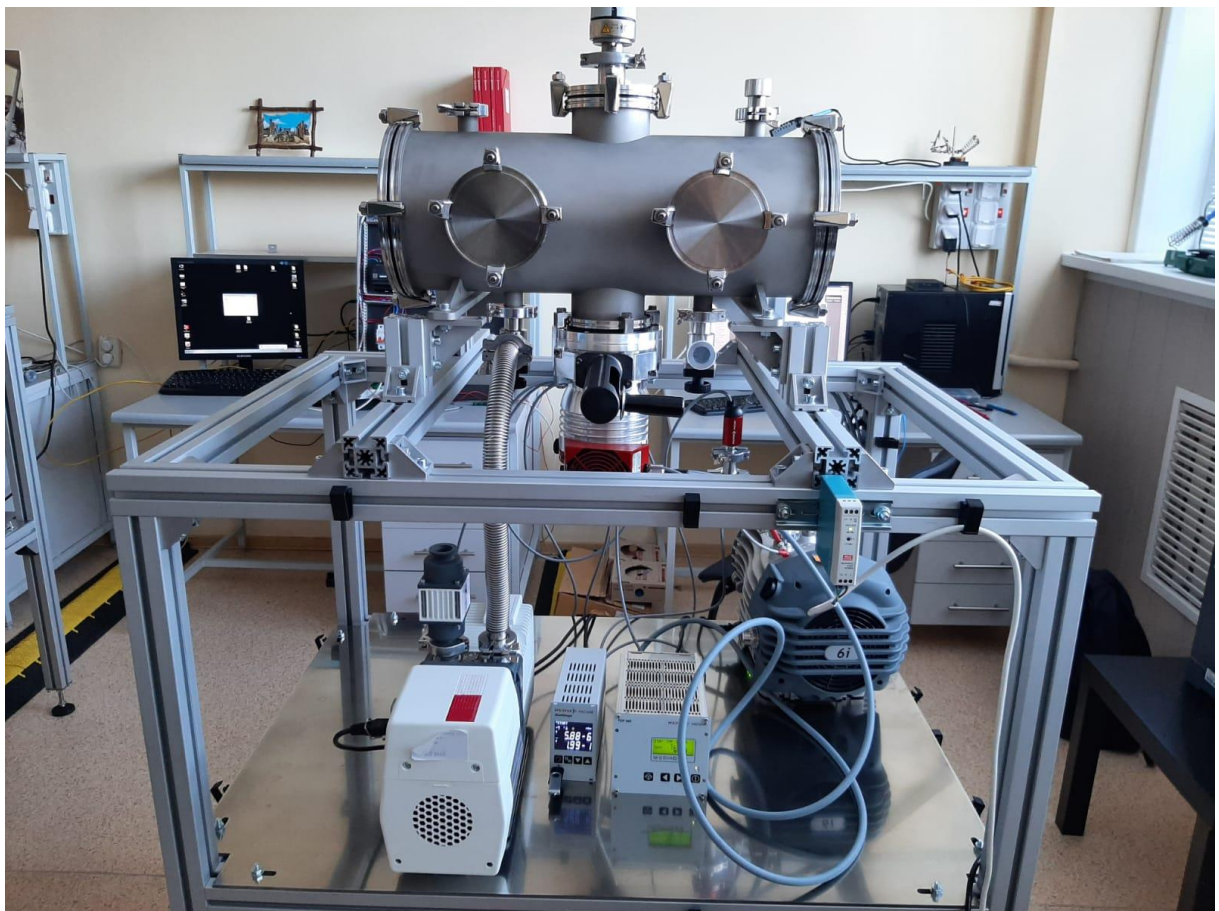
- A roughing vacuum with roughing pump “RP” (Pfeiffer ACP15 pump) line to excite fast venting and evacuation to the chamber fast, and it could be easily separated for the chamber when it’s not needed using its own valve “RP-V”.
- The main vacuum line has its own scrolling pump “scroll pump “SP” type Edwards nDXS” which used to pre-evacuated the line before starting turbo pump at a vacuum level on  $1 \times 10^{-2}$ .
- The scroll pump could be separated for the line using its own angle valve “SP-V”, when that is necessary.
- Due to the narrow reading range of pirani vacuum gauge. It is used only to monitor turbo molecular pump “TMP” pre-evacuation level.
- The turbo molecular pump “TMP” is loaded to main vacuum chamber via an ISO-100 flange and get In/Out of operation separately depending on its gate valve “G-V”, which gave us the benefit of fast evacuation and venting of vacuum chamber it integration with roughing vacuum line.
- At the left down side of the system we have a He-leakage “He-LD” detector separated from the system with two angle valves one at system side “He-SSV”,



and the other one at detector side “He-DSV”, which only be combined with chamber vacuum atmosphere only when we need to investigate any vacuum leaking spot.

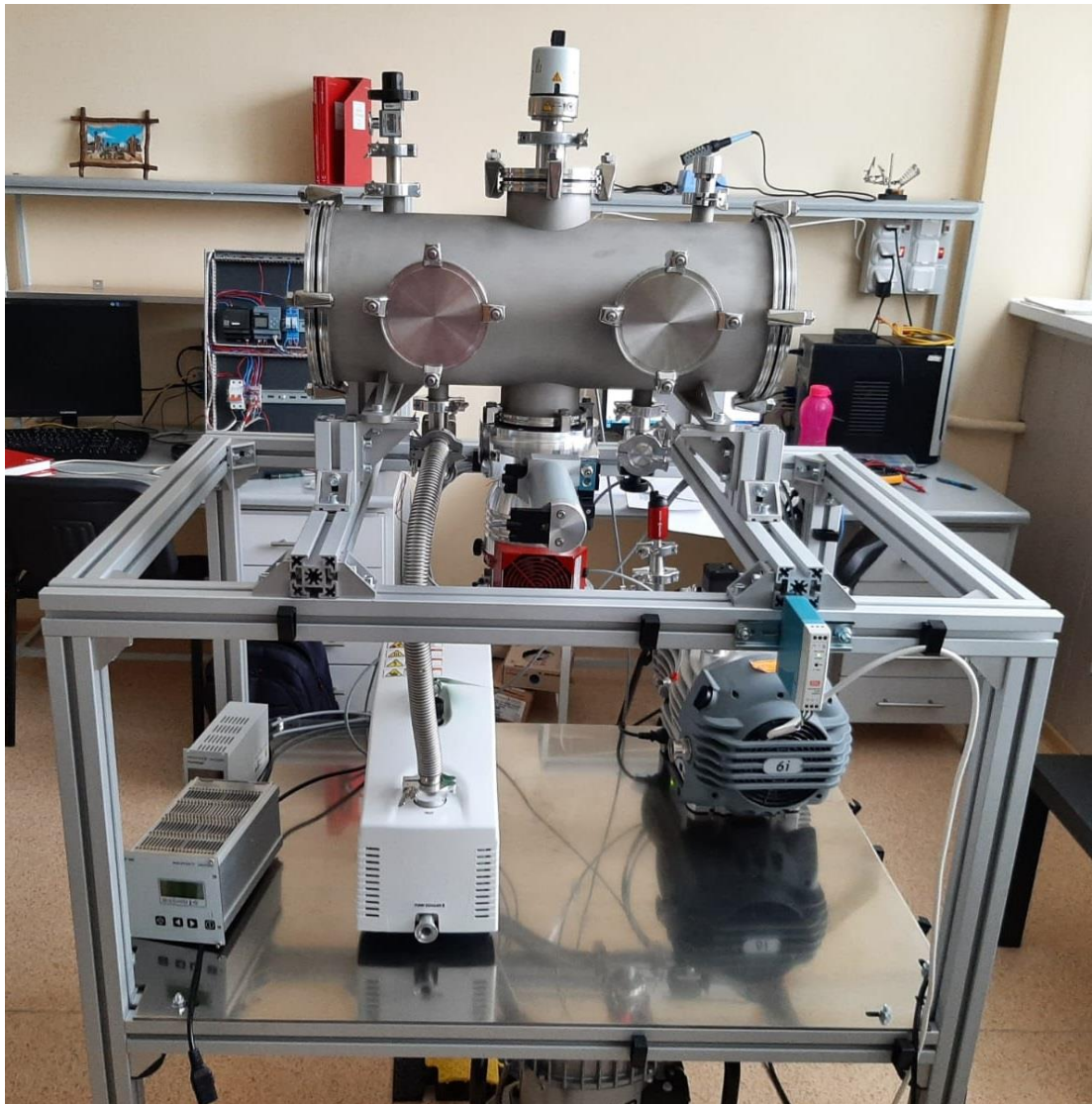
- At the chamber head, from left to right we have;
  - needle leaking valve used to modify the vacuum level inside the system by admitting a controllable levels of air flow inside the chamber.
  - A wide range thermo-Ionic vacuum gauge used to monitor system vacuum level at all of its steps.
  - An Air admittance valve for chamber venting.

As shown below in Figure 3 the vacuum chamber after assembling based on manual valves.



*Figure 3: Vacuum chamber assembly based on manual valves.*

After installing the system and testing its performance using manual vacuum valves and testing all chamber spots to make sure there is not any leaking point in the system using, He Leak Detector “adixen ASM-310”. We can switch manual valves with automatic valves to start system automation process.



*Figure 4: Vacuum chamber assembly based on pneumatic valves.*

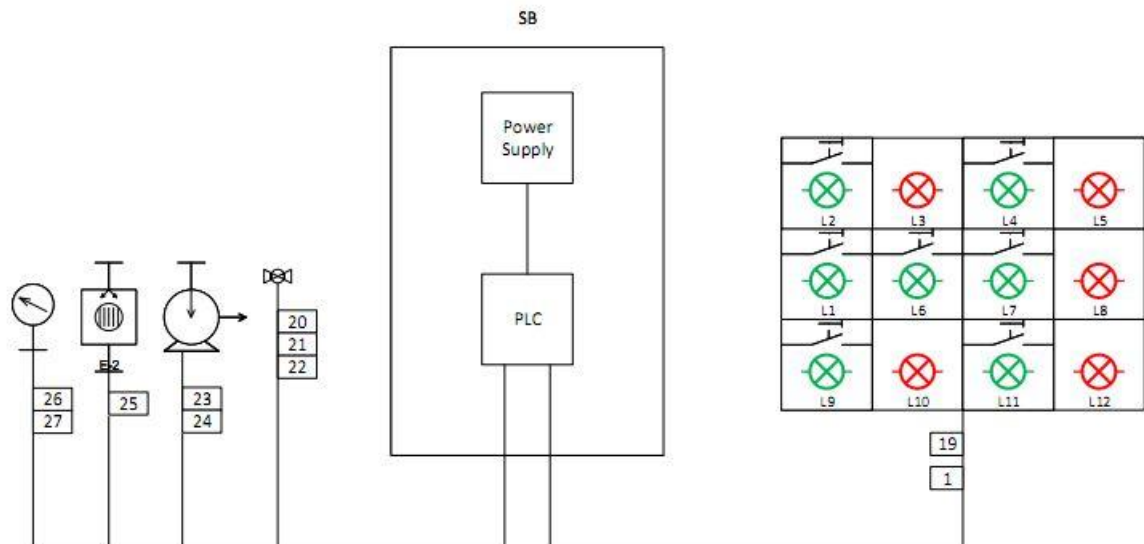
To start Automation process, we create the control circuit for each part individually then they can integrate all of the together to create the complete framework of the system.

## 5.1. Automatic control Vacuum System: -

In our Vacuum system we have three vacuum pumps, three vacuum gauges, and two vacuum gauges. We need to integrate them together via automation system the be capable of running evacuation, fast evacuation, and venting the Vacuum system in a reliable, safe way.

### 1. Schematic Diagram;

The general system layout is simplified to make it more user friendly as described in the following diagram.



#### Diagram Legends

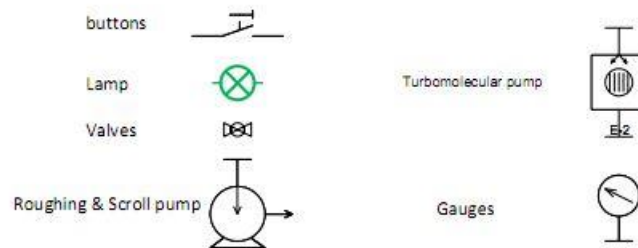


Figure 5: Control system layout schematic Diagram.

As shown in Figure 5, At the user side there is a 12-hole control box, which is used for controlling and monitoring all vacuum system components, which operates as following,

Hole #	Switch/Button	Indicator
1	B2: RP-Button	L2: RP-Status
2	N/A	L3: RP- Low speed mode
3	B3: RP-V Button	L4: RP-Valve open status
4	N/A	L5: RP-Valve closed
5	B1: Main Power Switch	L1: Main Power
6	B4: SP-Button	L5: SP-Status
7	B5: SP-V Button	L7: SP-Valve open status
8	N/A	L8: SP-Valve closed
9	B6: TMP-Button	L9: TMP-Status
10	N/A	L10: TMP- Speed
11	B7: G-V Button	L11: GP-Valve open status
12	N/A	L12: G-Valve closed





Figure 6: User Control Box Outlook.

## 2. Electrical Diagram;

To integrate the control box, and vacuum system components with PLC, we need to use 16 inputs and 7 outputs of PLC, that has been done using a SIEMENS LOGO 12/24 RCE with extension module DM16 24R which are connected and configured as following;

PLC Terminals			
I1	RP-Start/Stop Order	Q1	RP-Start/Stop
I2	RP-Status	Q2	RP-Low Speed
I3	RP-V-Open/Close Order	Q3	RP-V-Open/Close
I4	RP-V-Opened	Q4	SP-Start/Stop
I5	RP-V-Closed	Q5	SP-V-Open/Close
I6	SP-Start/Stop Order	Q6	TMP-Start/Stop
I7	SP-Status	Q7	GV-Open/Close
I8	SP-V-Open/Close Order		
I9	SP-V-Opened		
I10	SP-V-Closed		
I11	TMP-Start/Stop Order		
I12	TMP-Status		
I13	TMP-ERR		
I14	GV-Open/Close Order		
I15	GV-Opened		
I16	GV-Closed		

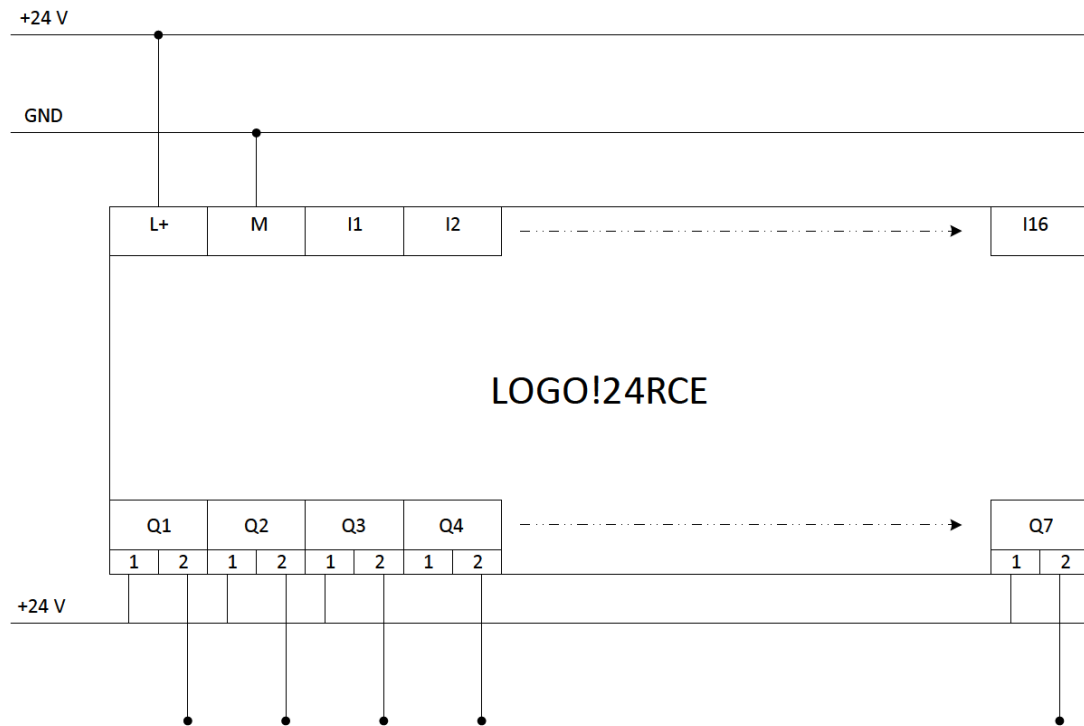


Figure 7: Schematic layout of PLC.

And to make a safely isolated interface buffering between PLC and Vacuum system inputs and out but, we would use a set of solenoid-based relays in the following configuration;

#	Type	Role
K1	N/A	Main Circuit Power Relay
K2	Output	RP-Start/Stop
K3	Output	RP-Low Speed
K4	Input	RP-Status Transfer
K5	Output	RP-V-Open/Close
K6	Output	SP-Start/Stop
K7	Input	SP-Status Transfer
K8	Output	SP-V-Open/Close
K9	Output	TMP-Start/Stop
K10	Input	TMP-Status Transfer
K11	Output	GV-Open/Close

After configuring PLC Inputs/Outputs and interfacing elements, we need to set control circuits for system pumps and valves.

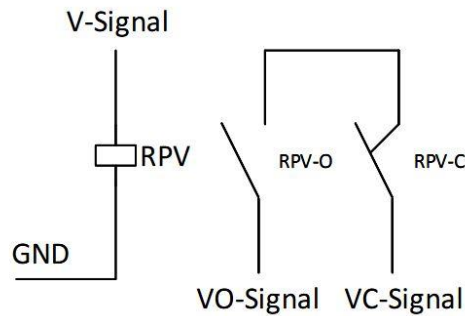
Starting for Valves, here we are using an Angle valves roughing pump (RP-V), and Scroll Pump (SP-V), and a Gate Valve (GV) for TMP.

All the valves we are using are pneumatically driven Via a solenoid coil used to trigger inner manifolds to transfer its normally closed status into open state.

Each valve has three main components;

- Solenoid coil (Blue + Blue/White Terminals).
- Valve-Closed state Limit Switch (Brown + Orange Terminals)
- Valve-Opened state Limit Switch (Green + Orange Terminals)

And the wiring lay out of roughing pump valves (RP-V) as an example is shown below.



*Figure 8: Valves wiring Layout.*

The Limit switches common terminal “Orange” is connected to +24 V, and the solenoid terminal “Blue/White” is connected to GND.

Valve I/P signal is transferred via “Blue” Terminal and Opened/Closed O/P signal are transferred via “Green/Brown” Terminals.

The next step, is how to control each of vacuum system pumps, each pump has its own configuration pins and control signal;

The Pfeiffer ACP15 is the roughing line pump used in our main vacuum chamber automation project, this pump could be remotely controlled on/off and rotation speed is configurable by opening or closing different dry contacts terminals on the remote-control connection.

There are 15-dry contact inputs (15-pin Male D-Sub connector) and for logic control we are using terminals S1, S3, S4 and S5 as following;

- S1 (7-8): “start/stop control” Contact open, S1=0: the pump stops OR Contact closed, S1=1: pump start-up.
- S3 (9-10), S4 (11-12) and S5 (13-14): “speed configurations” Depending on the contact status (open or closed), the rotation speed changes.
- S2 (5-6): “status monitoring” Contact closed: nominal speed reached.

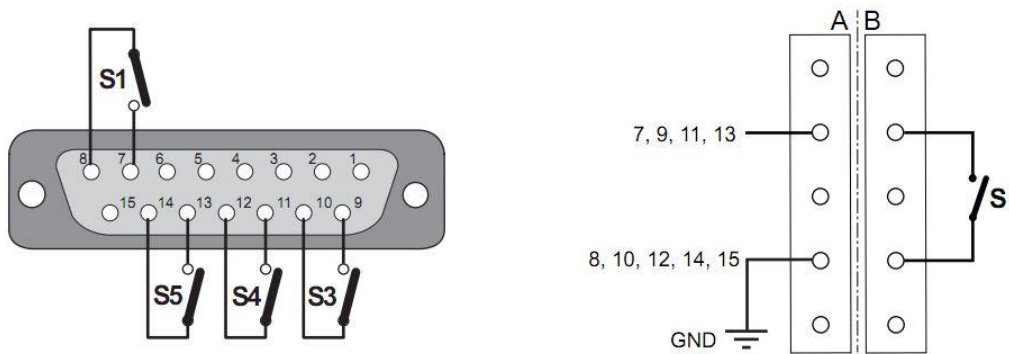


Figure 9: Pump Dry contact remote control interface layout, A) Pump Side, B) User Side.

We need to start the pump at 60 % of its full power, then after one minute we will run it at 100% power. That's to prevent any effect of sudden atmospheric load on pump mechanical parts.

To do that as referred in in manual at section 5.5.2 Tbl.1 we need to configure speed terminals as following;

- 60 Hz = (S3-closed) + (S4-open) + (S5-closed)
- 100 Hz = (S3- open) + (S4-open) + (S5- open)

The Edward-nXDS is the main line pump used in our vacuum chamber automation project, this pump could be remotely controlled on/off configurable by opening or closing different dry contacts terminals on the remote-control connection.

There are 15-dry contact inputs (15-pin Male D-Sub connector) and for logic control we are using pins 2, 8, 3, 14, and 15 as following;

- Pin (2, 8): zero voltage reference for all control functions.
- Pin (14): enable remote control mode. By contacting (2+14) pins.
- Pin (3): “start/stop control” Contact pin. When (2+3) pump start-up, and when its open pump stops.
- Pin (15): “status monitoring” Contact closed: nominal speed reached.



Figure 10: Pump Dry contact remote control interface layout at Edward-nXDS Pump Side.

The integration of the three pumps, and the three valves is shown in the next circuit diagram.



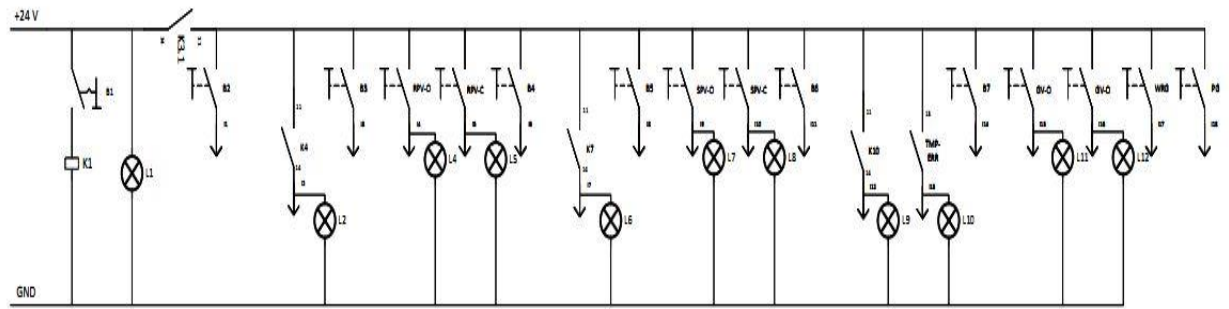


Figure 11: PLC I/Ps layout and system indicators.

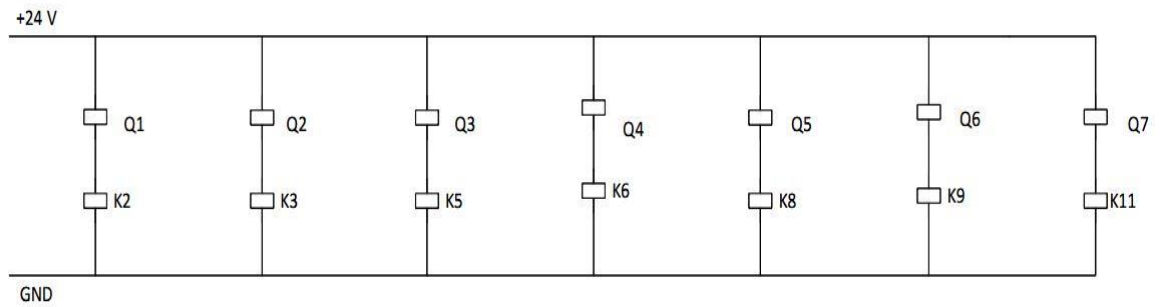


Figure 12: PLC O/Ps Layout.

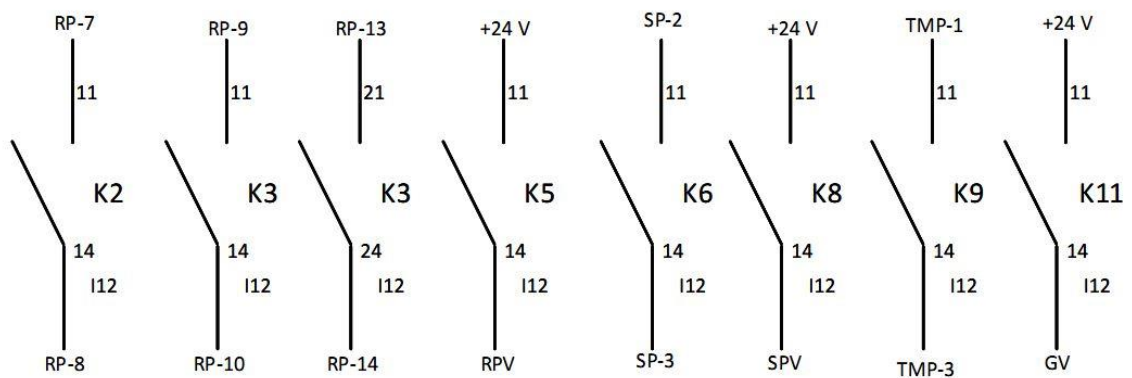


Figure 13: System relays/ pumps interfacing.

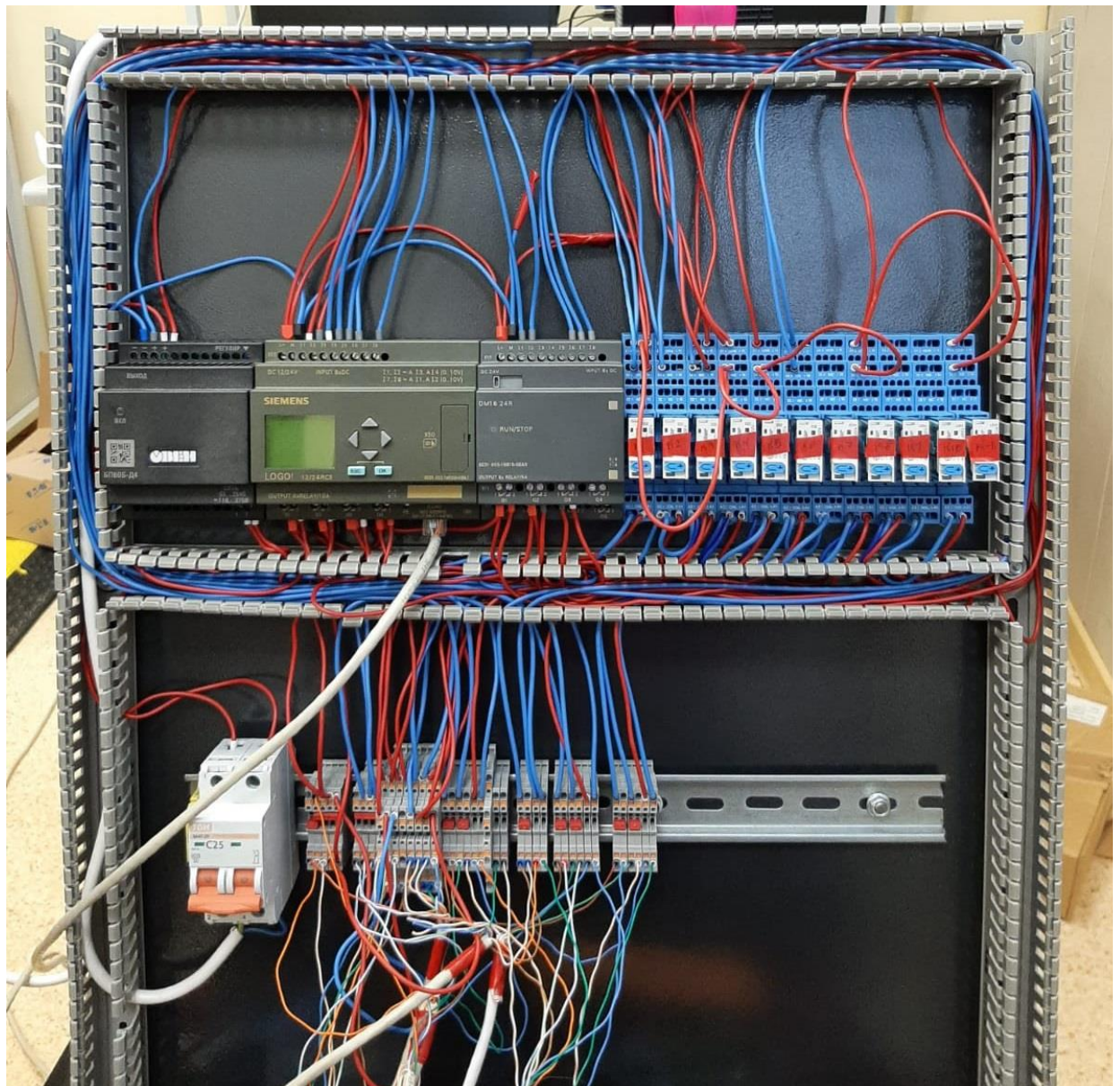


Figure 14: Vacuum System control panel including; Power supply, PLC, Relays, bridges, and main power switch.

### 3. Logic Diagram;

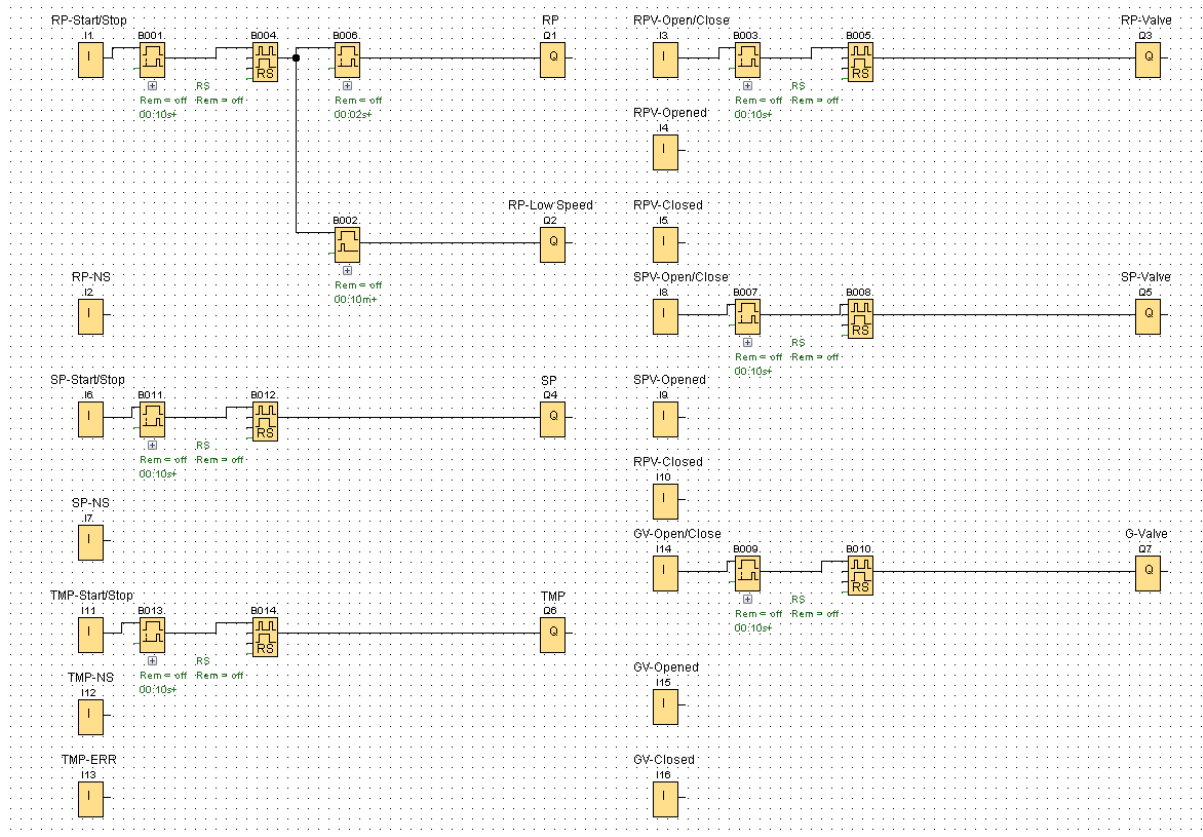


Figure 15: Logic Diagram of Individual components of Vacuum System.

System mainly running on a status triggering logic, protected with delayed inputs of (5 mSec) to block any parasitic noise.

The logic sequence used to operate pumps is based on a single button operation mode;

For the Pfeiffer ACP15 pump, when controller gets signal form I1, a parasitic delay of 5 mSec. start counting, then a pulsed relay transfers that signal to pump start/stop output “Q1” after counting on an On-Delay for 2 sec.

At the same time the Pulsed Relay signal transfers to pump low speed output “Q2” via Wiping-Relay, this relay counts for 60 Sec then Low speed mode turned off.

For the Edwards-nXDS, when controller gets signal form I6, a parasitic delay of 5 mSec. start counting, then a pulsed relay transfers that signal to pump start/stop output “Q4”.

For RP-V, when controller gets signal form I3, a parasitic delay of 5 mSec. start counting, then a pulsed relay transfers that signal to valve open/close output “Q3”.

For RP-V, when controller gets signal form I8, a parasitic delay of 5 mSec. start counting, then a pulsed relay transfers that signal to valve open/close output “Q5”.

For G-V, when controller gets signal form I14, a parasitic delay of 5 mSec. start counting, then a pulsed relay transfers that signal to valve open/close output “Q7”.

## 5.2. Operation manual

1. Supply power to the SB1 switchboard.

2. For power on/off press B1 button.

Green lamps (L1) at the control unit will light up. So, system is ready for operation.

3. To turn on the Pfeiffer ACP15 press B2 button.

A red lamp (L3) at the control unit will light up indicating that pump is working in low speed mode, and a Green lamp (L2) would light up when pump reach its normally working speed.

After 60 Sec. The red lamp (L3) at the control unit would be turned off indicating the end of Low speed mode working period, and the green lamp (L2) would be flashed for few second due to the transient from low speed to high speed.

4. To turn off the pump press B2 button.

L2, and L3 lamps would be turned off.

5. To turn on the Edward-nXDS press B2 button.

A Green lamp (L2) would light up when pump reach its normally working speed.

6. To turn off the pump press B2 button.

L2 lamp would be turned off.

## 6. conclusion (discussions, prospects)

By the end of this training I'm able;

1. Identify different types of vacuum pumps, valves and detectors.
2. How to Assemble and disassemble vacuum system components.
3. Investigating system leakages and malfunctions.
4. The difference between, manual and pneumatic components.
5. Running the basic automation circuits using PLC.
6. Automate vacuum system component to see how it should be integrated inside the accelerator environment.

## 7. references

[1] Atta, C.M. Van (1965). Vacuum Science and Engineering. New York: McGraw-Hill. p. 303.

[2] Vacuum Technology. Hydraulics & Pneumatics. 2017. pp. 83–86.

[3] Karl Jousten (ed), C. Benjamin Nakhosteen (transl.), Handbook of Vacuum Technology, John Wiley & Sons, 2016 [ISBN 3527688242](#), chapters 1, 2.



## 8. acknowledgments.

I am grateful to the Egyptian academy of scientific research (ASRT) that gave me the opportunity to participate in Stage 1 of the International Student Practice in JINR Fields of Research. Thank you for providing a healthy environment for all students, as well as encouraging creativity, interaction, and participation in academic activities. I am grateful to JINR institute for their good welcoming and preparing good program for us to get more information during our practice. I would like to express my special thanks of gratitude to Prof. Dr. Medhat Ibrahim, Prof. Dr. Walaa Seif, and Prof. Dr. Wael Badawy for their concern and facilitating all difficulties those we faced during the practice. I would like to express my special thanks of gratitude to my supervisor Dr. Mikhail Nozdrin and Eng. Dmitriy zlydyonniy for support, attention to guide me to do my tasks and I came to know about so many new things. I would like to thank Ms. Julia, Elena, and lyndish for the excellent organization and for quick response.