JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE START PROGRAMME

Production of superconducting magnets for the NICA project

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Abstract

This report presents the work on developing the cable connector scheme for the system used to measure and record current and voltage parameters during the testing of superconducting magnets for the NICA project. Special attention is given to the necessity of data logging. The measurement system functions as a recorder, archiving data and displaying current and voltage parameters. This capability allows for diagnostics, the prevention of emergency situations, and the analysis of such events. The implementation of this system enhances the reliability and safety of the facility's operation, as well as enables the prompt identification and resolution of its failures.

The report describes the components used in the system, such as the voltage meter "E14-440" and the switching board "CR11-2V1", as well as the process of connecting them using an adapter. The application of the LGraph2 software for data collection and analysis is also discussed.

Contents

Introduction

The report outlines the work on developing the cable connector scheme for the system of measuring and recording current and voltage parameters. Modern scientific and industrial installations require high standards of reliability and safety, which cannot be achieved without meticulous monitoring of key parameters. The complexity and high cost of technological equipment, as well as the resource investments in such installations, necessitate the presence of data recording systems for diagnostics and accident prevention.

The magnet factory is a technological production line for manufacturing superconducting magnets, specifically created for the NICA and GSI projects. It represents a high-tech line that includes several key stages: the production of superconducting cable, winding of coils, mechanical assembly of magnets, magnetic measurements at room and cryogenic temperatures, vacuum testing, installation into cryostats, and cryogenic testing.

The current and voltage measurement system was specifically designed for use on the cryogenic testing stand. The report provides a detailed overview of the key components of the system, such as the "E14-440" voltage meter, the "CR11-2V1" switching board, as well as the software used for data collection and analysis.

Chapter 1. The NICA Project

The NICA (Nuclotron-based Ion Collider fAcility) project is focused on creating a unique scientific complex that will enable advanced research in the field of heavy ion physics and nuclear collisions. The primary goal of the project is to study the fundamental properties of matter under extreme conditions, similar to those that existed in the first moments after the Big Bang. [1]

The NICA project comprises several key components, each playing a crucial role in achieving the set objectives. The main elements of the project's structure include: [2]

- Magnet Factory

In 2013, the Scientific and Experimental Department of Superconducting Magnets and Technologies was established at the Joint Institute for Nuclear Research (JINR). This department is responsible for producing magnets for the NICA and FAIR projects. [3]

- Cryogenic Systems

Cryogenic systems provide cooling of superconducting magnets to temperatures of 4.3K (-269°C), which is necessary to achieve superconductivity. At JINR, a liquid helium circulation system is used to maintain stable and efficient cooling of the magnets and other components of the complex. [4]

- Ion Collider

The central element of the NICA project is the ion collider, where beams of heavy ions collide.

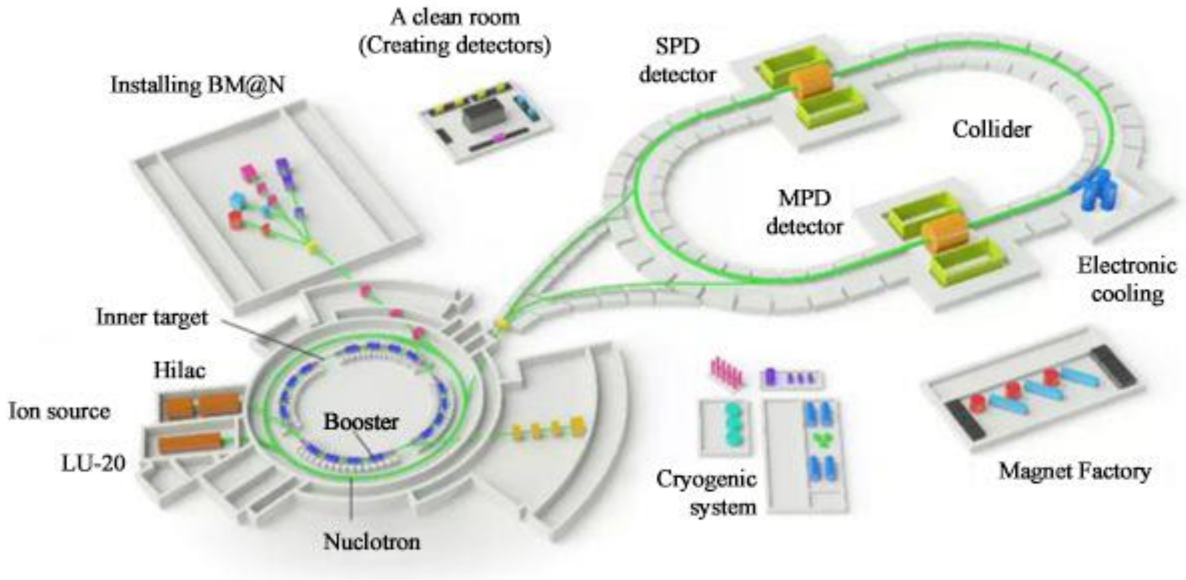

Figure 1. – Diagram of the NICA Accelerator Collider.

- Detectors and Measurement Systems

Detectors and measurement systems are used to record and analyze ion collision results. They track particle trajectories, measure their energy, and assess other characteristics.

- Infrastructure and auxiliary systems

The NICA project includes an extensive infrastructure that ensures the seamless operation of the facility.

Chapter 2. Magnet Factory

In 2016, the Joint Institute for Nuclear Research (JINR) launched the production of rapid-cycling magnets with superconducting cable windings operating at a liquid helium temperature of 4.3K for the NICA and FAIR projects. [5]

Figure 2. – Magnet Factory for the NICA and FAIR Projects.

The magnet factory includes several key areas:

1. **Production of Nuclotron-type superconducting cables**: This involves the manufacturing of cables made up of strands and tapes that combine superconductors with conductive metals such as copper and its alloys. These cables are used to create magnets with high performance characteristics.

2. **Production of windings**: In this stage, windings made from high-density superconducting cables are manufactured. This ensures the compactness of the magnets and a high current density. The quality of the winding is critical for the successful operation of the magnets.

3. **Mechanical assembly of magnets**: This stage involves assembling the magnets, including the installation and securing of windings into magnetic systems, taking into account the design specifications and project requirements.

4. **"Warm" magnetic measurements**: Magnets undergo measurements at room temperature to assess their key characteristics and identify any potential defects before cryogenic testing.

5. **Vacuum testing**: Checking vacuum integrity and other parameters to ensure reliable operation under ultra-low temperatures. All superconducting devices must operate in high vacuum conditions.

6. **Mounting magnets in cryostats**: After successful vacuum tests, the magnets are installed in cryostats, which provide the necessary thermal insulation and maintain the operating temperature using liquid cryogens.

7. **Cryogenic testing**: This final stage of testing involves cooling the magnets to operational temperatures (~4.2 K) and checking their stability against the loss of superconductivity. Normal zone detection systems are used to identify and address issues related to local heating in the superconductors.

8. **Power Supply**: Reliable power supply is provided for the magnets, which is crucial for their stable operation. Power supplies must maintain precise control and stability of the current necessary to sustain superconductivity in the magnets. Additionally, there are systems in place to protect the magnets in the event of a loss of superconductivity: a normal zone detection system (NZ) and an energy dump system. Energy dump keys (EDKs) are used to evacuate stored energy from superconducting elements in case of a loss of superconductivity [6]. EDKs are connected in series with the magnet and linked to the power supply.

Chapter 3. Cryogenic Testing Stand: Parameter Measurement System

On this stand, a Normal Zone Detection (NZD) system is used to protect the superconducting magnet windings. The NZD system does not have the capability to measure the current and voltage of the superconducting magnet when power is applied. To measure the current and voltage parameters, the module "E14-440" is used.

Figure 3. – Appearance of the "E14-440" measurement module.

The device is designed for precise voltage measurements in various parts of the setup, with a range from -10 V to +10 V and an accuracy of no more than 0.01%. It provides a fast measurement rate of up to 1000 measurements per second and easily integrates with other system components.

The "E14-440" module can be used in multi-channel measurement systems and is employed for continuous streaming input and output of analog information. It is equipped with a digital signal processor, enabling users to implement specialized signal processing algorithms in real time.

The external DRB-37F connector of the module provides lines for handling digital input/output signals.

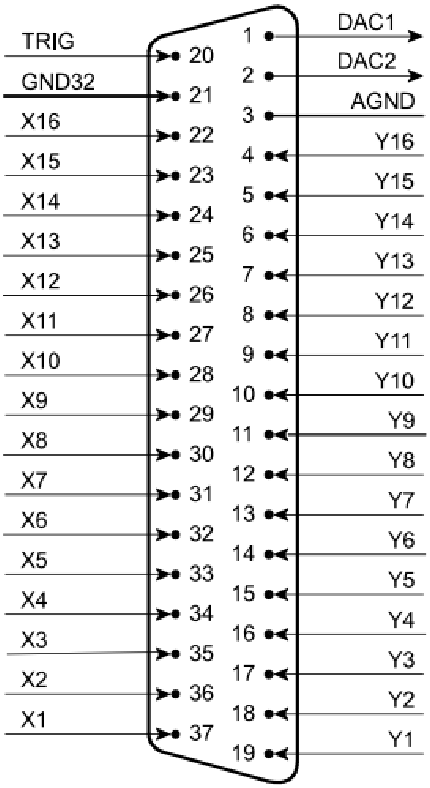

Figure 4. – Connection diagram of the "E14-440" measurement module.

Figure 5. – Signal monitoring and data recording using the "E14-440" module and LGraph2 software.

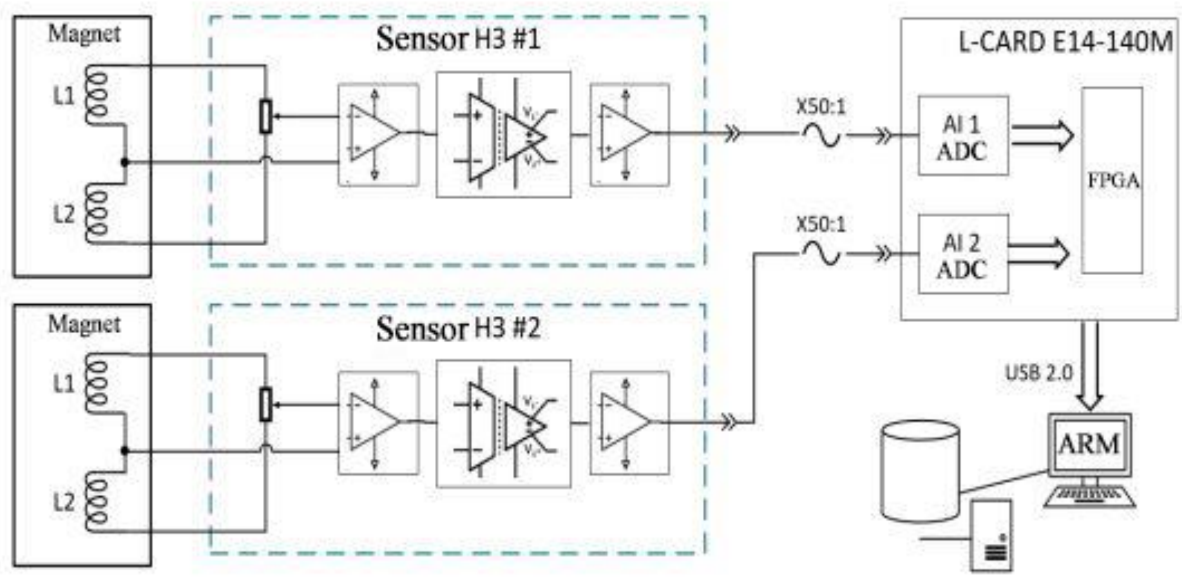

Figure 6. – Block diagram of the connection of the E14-140M module to the zone detector sensors.

Chapter 4: System Composition

The personal computer (PC) performs functions such as displaying, collecting, and storing data.

Minimum requirements:

- 32-bit (x86) or 64-bit (x64) processor with a clock speed of 1 GHz or higher.265 МБ ОЗУ.
- 70 MB of free hard disk space.
- Windows OS version XP or later (on some computers, the program may work with Windows 2000).
- A DirectX 9 graphics device with WDDM 1.0 or later driver.

The device "E14-440" is supported by specialized software: PowerGraph Professional [7] and LGraph2 [8], which are used for visualizing and archiving data obtained from measurement instruments.

The device features a 14-bit ADC operating at 400 kHz, capable of supporting up to 16 differential channels or 32 with a common ground, 16 TTL-compatible digital input and output channels, and 2 12-bit DAC channels with a range of ±5 V. [9]

The device connects to the PC via a USB interface, ensuring reliable data transfer.

The switchboard allows for the connection of cables from measurement system components to digital and analog outputs.

Key features of the switchboard include:

- Number of channels: 16
- Signal type: Analog/Digital
- Interfaces: Standard connectors for sensor and ADC connections
- Additional: Built-in overload and short-circuit protection

The switchboard provides reliable connectivity and protection for the system against potential electrical interference and overloads, which is critically important for stable operation under cryogenic testing conditions.[10]

Figure 7. – Switchboard "CR11-2V1".

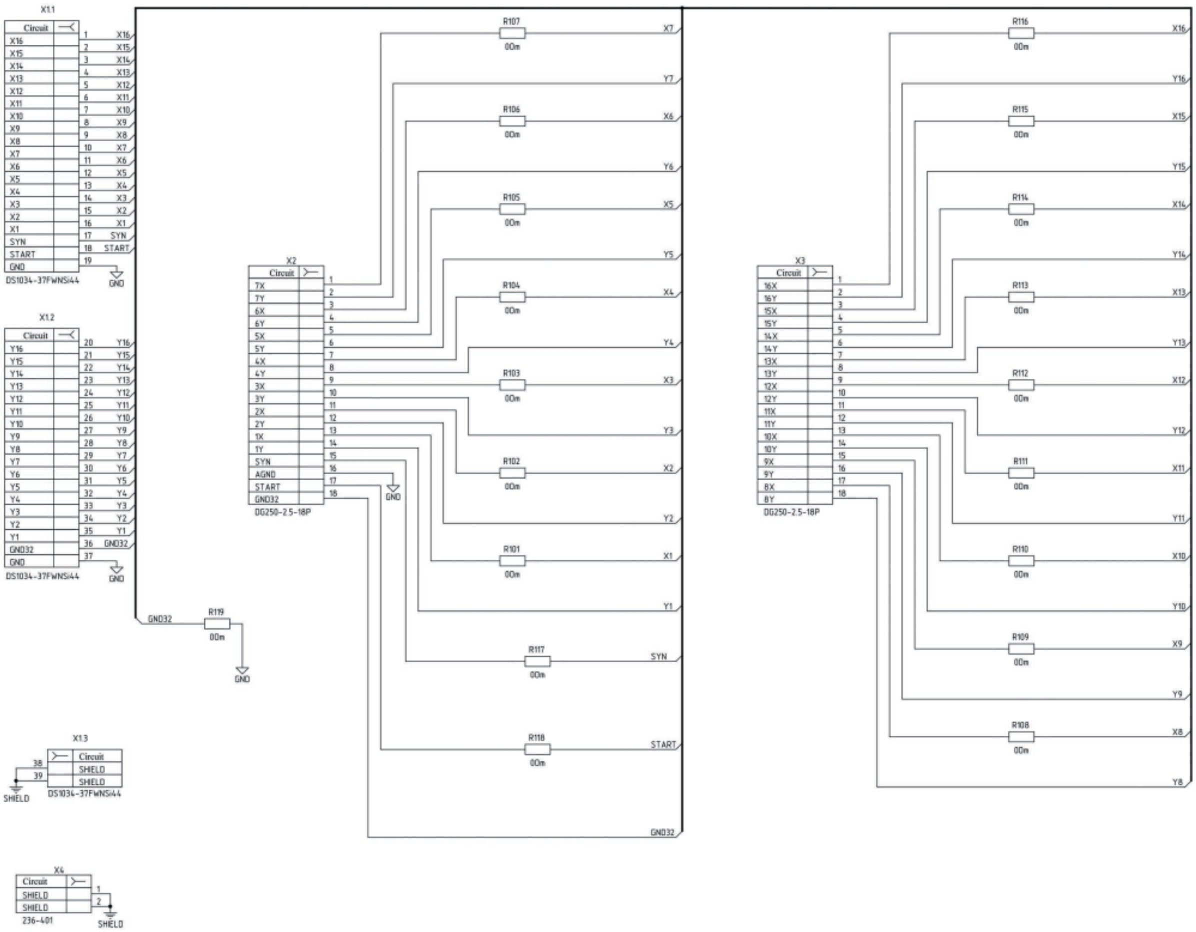

Figure 8. – Connection diagram of the "CR11-2V1" switchboard.

Chapter 5: My Work

My work began with a detailed study of the schematic of the analog inputs used in the system. I analyzed the specifications and operating characteristics of the device, paying particular attention to the following aspects:

- Conversion frequency and resolution
- Types of supported analog signals
- Connectivity options and interfaces (USB, Ethernet)
- Signal filtering and processing
- Connection diagrams to signal sources

This research allowed me to understand how the device processes input signals and what parameters need to be considered when designing the connection scheme.

The next step involved studying the existing switchboard schematic through which the measured signals need to be transmitted. I examined:

- The number and types of channels on the board
- The layout of connectors and contacts
- Built-in protection features (against overloads and short circuits)
- Methods of connecting the board to the device and other system modules

This analysis helped me understand the current capabilities and limitations of the switchboard, which was essential for its further improvement.

Based on the acquired knowledge and analysis of existing circuits, I developed my own design, optimized for the specific requirements of the current and voltage measurement and recording system. In my work, I focused on minimizing interference and noise in the measured signal through shielding, which improved signal accuracy. I also considered the convenience of connecting the measurement system components.

The circuit I developed was implemented, and a cable assembly was fabricated, tested, and integrated into the measurement system. This integration led to improved operational performance and reliability of the system.

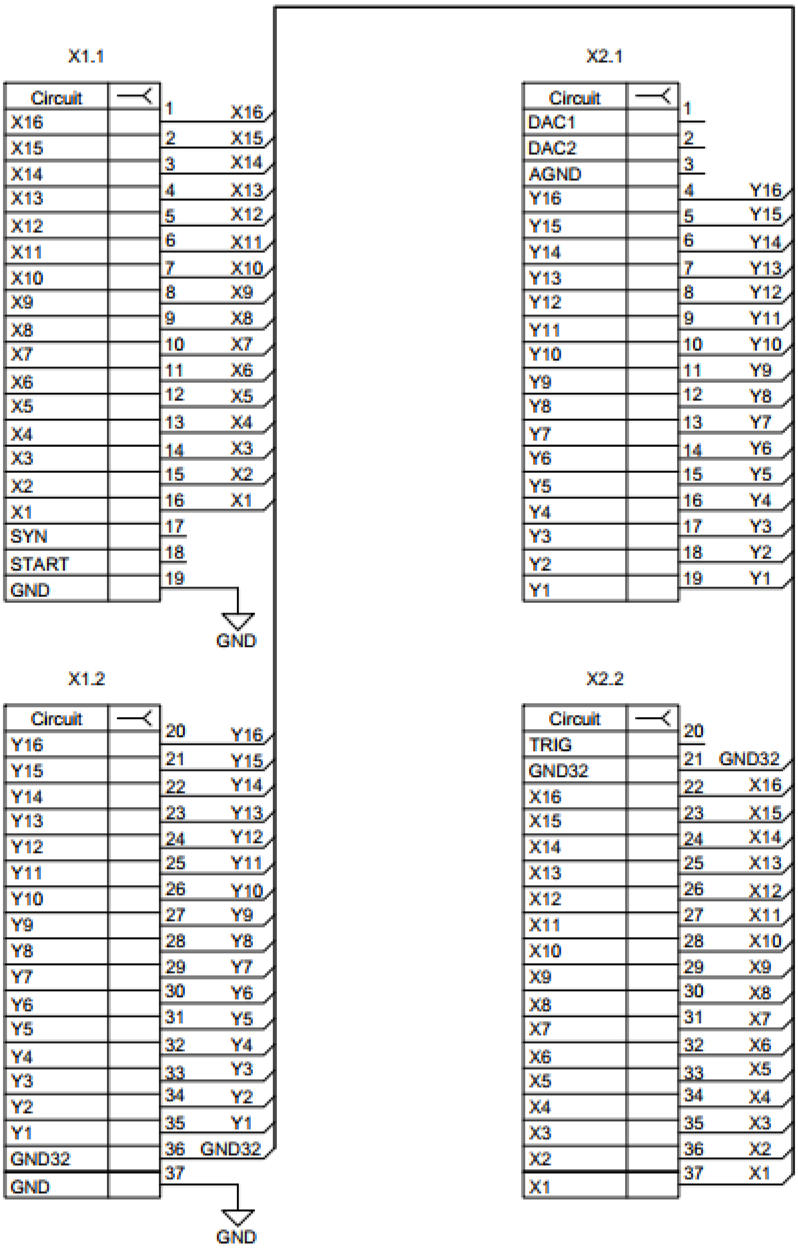

Figure 9. – Wiring Diagram for Connecting the Measurement Module "E14-440" with the Switching Board "CR11-2V1".

Chapter 6: Results

This chapter presents the results of the work carried out on the development and implementation of a cable connector for the current and voltage measurement and recording system used in the testing of superconducting magnets.

Figure 10 shows a measurement graph obtained using the new system. The graph demonstrates that the system can simultaneously record electrical signals with time synchronization.

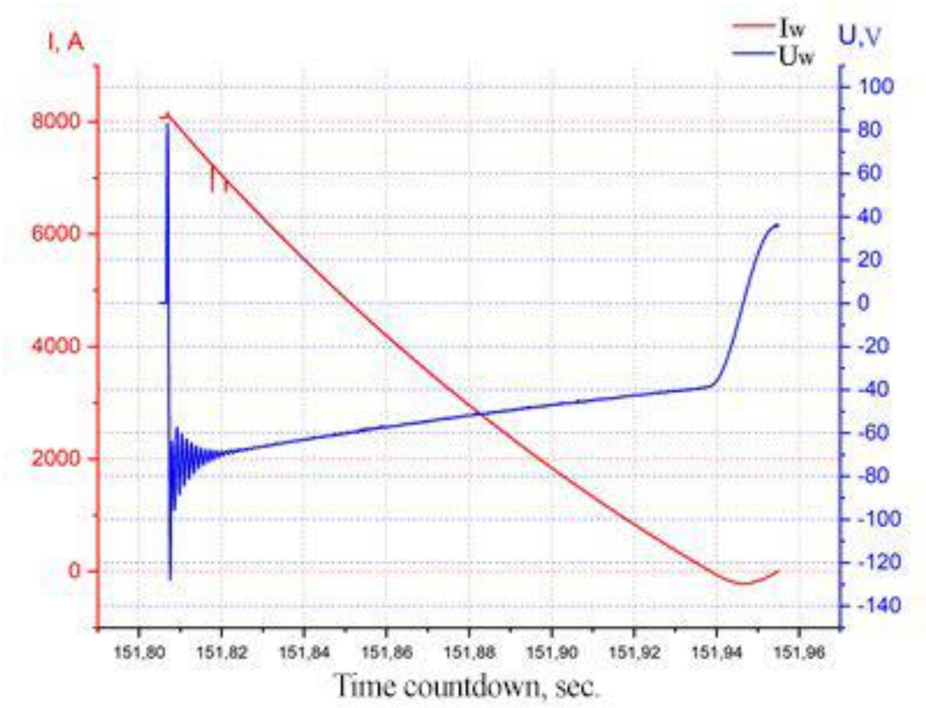

Figure 10. – Graph of energy discharge from the NICA collider magnet during cryogenic testing.

Figure 11 the connector I designed, used for connecting to the "CR11-2V1" board. This connector provides a reliable and convenient connection, significantly simplifying the installation and operation of the system.

Figure 11. – Appearance of the connector.

Evaluation of Results

The completed work has simplified the connection of external signals to the system, improved connection reliability, and reduced the overall time required to prepare the device for operation.

Conclusion

As part of the project, I completed several important tasks, including the development of the electrical schematic, soldering the cable connector, working with documentation, configuring the software, and analyzing electrical circuits. This work enabled the successful implementation of a reliable and user-friendly measurement system.

Working on the START (STudent Advanced Research Training) program provided me with the opportunity to learn more about the NICA complex megaproject, where I observed the production of superconducting magnets. I applied previously acquired knowledge in practice, which enabled me to achieve the project's objectives. Additionally, my colleagues generously shared their expertise and knowledge, which helped me quickly grasp the complex aspects of the work and enhance my professional skills.

References

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