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CONCEPT DESIGN OF CRYOGENIC SYSTEM OF THE SPD-DETECTOR FOR NICA PROJECT IN DUBNA

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ABSTRACT

The article describes the substantiation of technical solutions adopted to ensure a uniform distribution of the temperature field over the volume of the Spin Physics Detector (SPD) magnetic system, developed on the basis of the Joint Institute for Nuclear Research in Dubna (Russia). Two variants of the configuration of this system are considered: (1) a package of six-solenoids located in the axial direction, and (2) a hybrid system, including 8 solenoids for the formation of a toroidal field and two more solenoids on each side in the axial direction. The article describes conceptual solutions for the organization of a cryogenic system and placement of cryostat units in the inner cavity of an electromagnetic calorimeter, and defines the criteria for a qualitative comparison of the characteristics of the proposed design options. This analysis is carried out in order to determine the best design option for the magnetic cryogenic detector system.

It has been established that the hybrid magnetic system allows creating a magnetic field with better integral characteristics but for fastening and cooling the solenoids that form the toroidal field, a much more complex and material-intensive design is required than in the case of six-solenoids. In addition, a simple system demonstrates such advantages as free placement of automatic control devices, protection and emergency shutdown systems in the detector volume, which allows providing the required level of safety and flexibility of system configuration.

Keywords: Spin Physics Detector, superconductor magnets, cryogenic systems, low temperature superconductors, NICA accelerator.

1. INTRODUCTION

The SPD detector will be installed on the collider ring (JINR, NICA) to study the spin structure of protons, deuterons and phenomena arising in polarized beams of protons and deuterons at collision energies up to 27 GeV and luminosity 10e27 $cm^{2} \cdot s^{-1}$. The development of the detector is of great scientific importance, since the results, which are planned to be obtained, will significantly expand the understanding of nucleon-gluons, as well as accumulate experience for current and further research at the RHIC, measurements at the EIC (BNL) and fixed-target installations at the LHC (CERN) [1].

By now the Multi-Purpose Detector (MPD) has been designed, manufactured and delivered. From the point of view of the magnetic and cryogenic system, the MPD detector has a simpler design; therefore, it is not possible to design an Spin Physics Detector (SPD) detector in a similar way using existing solutions. The development of a complex unique design is required that meets the technical requirements for the characteristics of the generated magnetic field [2, 3]. Since technological cryogenic flows are limited, the developed structure should be cooled, if possible, without installing additional capacities.

2. MAIN SECTION

At the first stage of discussion of the design of the magnetic system of the SPD detector, technical requirements were put forward, which include the following provisions [4]:

- Ensuring the minimum possible weight and size characteristics of the internal elements of the detector;

— Creation of a magnetic field with an integral characteristic of (1...2) T·m (tesla multiplied by the meter) along the ion beam with a limitation of the peak value of the magnetic field strength inside the main solenoids 0.8 T;

— Provide the lowest possible total mass of the detector, the mass of solenoids and auxiliary structural elements that ensure the rigidity and strength of the magnetic system [5].

In accordance with the basic requirement that determines the type and size of the magnetic system, six of the most competitive concepts were identified from a large number of options, such as:

— One-piece multi-turn solenoid;

— Toroidal magnetic system of 24 coils, forming a distributed toroidal field in the volume of the detector;

— Hybrid system including in-cylinder toroidal coils and solenoid coils;

— A system of four differentiated coils with two configurations: (1) coils in series; (2) the coils are connected in pairs on the left and right sides;

— Hybrid system, including an assembly of 8 toroidal coils located in the centre of the cylinder, and a pair of solenoids on the left and right sides;

— A system of six differentiated solenoids arranged in series in the longitudinal section.

For each option, a Monte Carlo simulation of the magnetic field map was carried out and conceptual designs of the magnetic system were drawn up, which were presented at the European Conference on Applied Superconductivity EUCAS2019 [1].

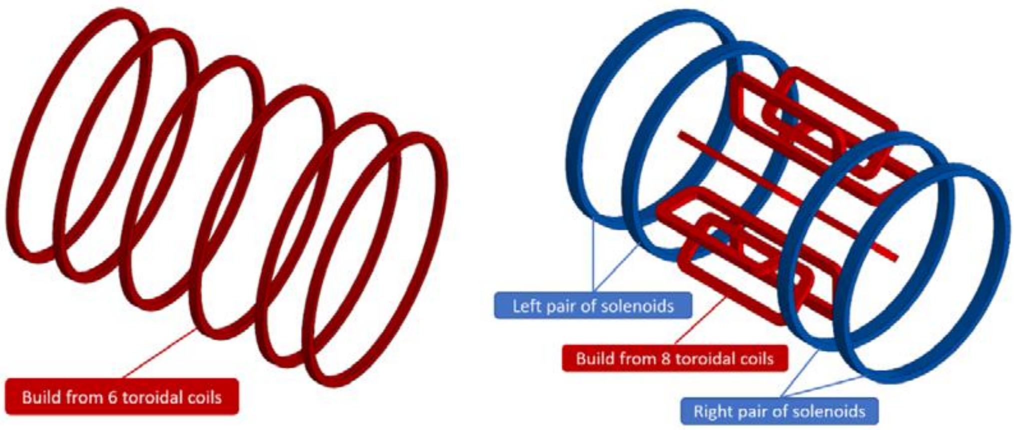

Figure 1: Magnetic system of the SPD, left side (a) - including six-solenoids located in the axial direction, right side (b) - including 8 toroidal coils, and two more solenoids on each side in the axial direction

Taking into account the requirements for achieving the universality of the experimental program and optimization in terms of weight and size characteristics, most of the concepts were discarded. To date, two most priority variants of the magnetic system have been identified - (1) a package of six-solenoids located in the axial direction, as shown in figure 1-a, and (2) a hybrid system, including 8 solenoids for the formation of a toroidal field, and two more solenoid on each side in the axial direction, as shown in figure 1-b. Consider these options for organizing the magnetic system in more detail.

2.1. Hybrid topology of the magnetic system

When forming the options for organizing the magnetic system of the SPD detector and calculating the distribution of the magnetic field, it was found that the toroidal topology of the arrangement of the coils has the best characteristics in terms of integral characteristics and minimizing the effect of the magnetic field on the interaction zone of polarized particles [2, 3].

In [6], the concept of a magnetic system is described, built only on toroidal coils, excluding solenoids on the sides. This version of the system was worked out in detail and presented, but was not accepted for further comparison. The main reason for this decision was the significant complication of winding toroidal coils with a superconducting cable with flow cooling with liquid helium. In addition, it will be necessary to develop technical solutions associated with fastening solid coils in the inner cavity of the cryostat at a certain angle with high accuracy, although this problem will partly remain in the hybrid topology.

The most universal and compromise topology is a hybrid system, since with such an arrangement of solenoids, minimization of the influence of the magnetic field near the interaction zone of polarized particles is achieved with a simplification of the overall design by placing pairs of solenoids on the left and right sides.

An important feature of the SPD detector in comparison with the MPD detector is the increased overall size in the axial direction, which makes the issue of rigidity and mechanical strength the most urgent [7]. From this point of view, the hybrid system can be housed in three uncoupled cryostats located on annular supports inside the detector yoke. For the toroidal assembly, it will be necessary to manufacture a toroidal cryostat and a screen with liquid nitrogen of a unique shape [8], since the cryostat will have a large wall area on the sides.

Since the (low temperature superconductor) LTS cable is cooled by the flow method, in order to ensure a uniform temperature field along the elements of the toroidal system, due to the uneven heat release, there will be a need for a system for regulating the flow of liquid helium through the coils [9]. For this system to operate accurately, multiple sealed inlets and outlets in the cryostat will be required. This is also complicated by the large number of soldered joints between the ceramic insulators and the metal tubing required to inject the liquid helium flow into the coil cable.

Based on the above-described technical difficulties that may arise when creating a topology of this type, even in spite of the existing advantages, a simpler design, consisting of six solenoids, is considered the highest priority at the moment.

2.2. Six-solenoid topology of the magnetic system

As noted earlier, the magnetic system of the SPD detector is elongated in the axial direction, and, in contrast to the MPD detector, in which one single solenoid, will be built on a topology of six-solenoids. This option is the simplest not only from the side of winding solenoids of this type, but also from the side of the cryogenic supply system, mechanical strength and reliability. Since the six-solenoid topology is currently being actively discussed and refined, a conceptual solution is proposed for this option, which is presented in figure 2:

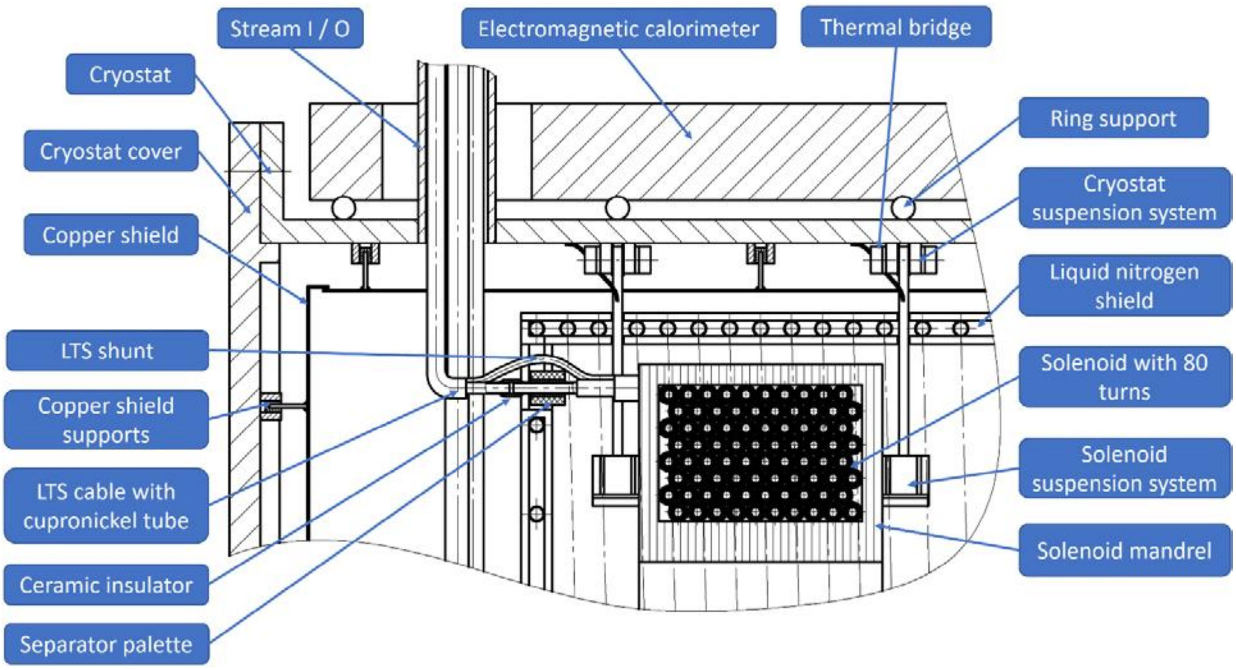

Figure 2: Conceptual solution for organizing cooling of solenoids

A cryostat is placed on supports in the form of an open ring in the inner cavity of the electromagnetic calorimeter. To prevent axial displacement, Teflon spacers are used (not shown in figure 3). One cryostat is equipped with two solenoids, which are suspended on rod supports providing the lowest thermal conductivity. For additional compensation of heat leak due to thermal conductivity, the rod supports are connected to the cryostat body by thermal bridges. Metal parts do not have direct contact with each other and are insulated with packets of fiberglass plates.

To compensate for heat fluxes caused by radiation and convection, a liquid nitrogen coil wrapped in a large number of thin alternating layers of mylar (or DARCON) and glass wool is attached to the cryostat body. For the supply of cryogenic communications and the organization of a power suspension, free cavities are provided in the structure of the nitrogen screen.

To cool the LTS cable, an internal channel in a cupronickel tube is used, into which supercooled helium is supplied. To insulate metal channels inside the LTS cable and cryogenic system, a ceramic insulator is used, which is soldered to the channels using a special technology. Electric current is supplied through the LTS cores bypassing the insulator and performs a protective function, breaking the circuit in the event of quench [10, 11].

Since the influence of Foucault eddy currents and an external alternating field is large, a screen made of a thin copper sheet is placed in the cryostat. The screen is a flexible structure with the necessary longitudinal and cross sections for supplying nitrogen and helium feed flows, placing cryostat suspension system and LTS current leads.

For six-solenoid topologies, due to the relatively free placement of the coils, it is possible to control and ensure the uniformity of the temperature field individually for each solenoid. In the event of the formation of local "hot" spots, a higher flow rate of liquid helium is supplied to the cooling channel of the LTS cable to compensate for the excess heat release [12, 13].

A general view of the organization of the magneto-cryogenic system is shown in figure 3. Since at the moment there are no exact technical and dimensional characteristics of the main elements of the detector design, as well as information about the possibility of laying the supply channels through certain elements of the magnetic system design, two options are proposed: (type A) three cryostats with individual collectors of liquid helium and nitrogen; (type B) three cryostats with a common collector of liquid helium and nitrogen;

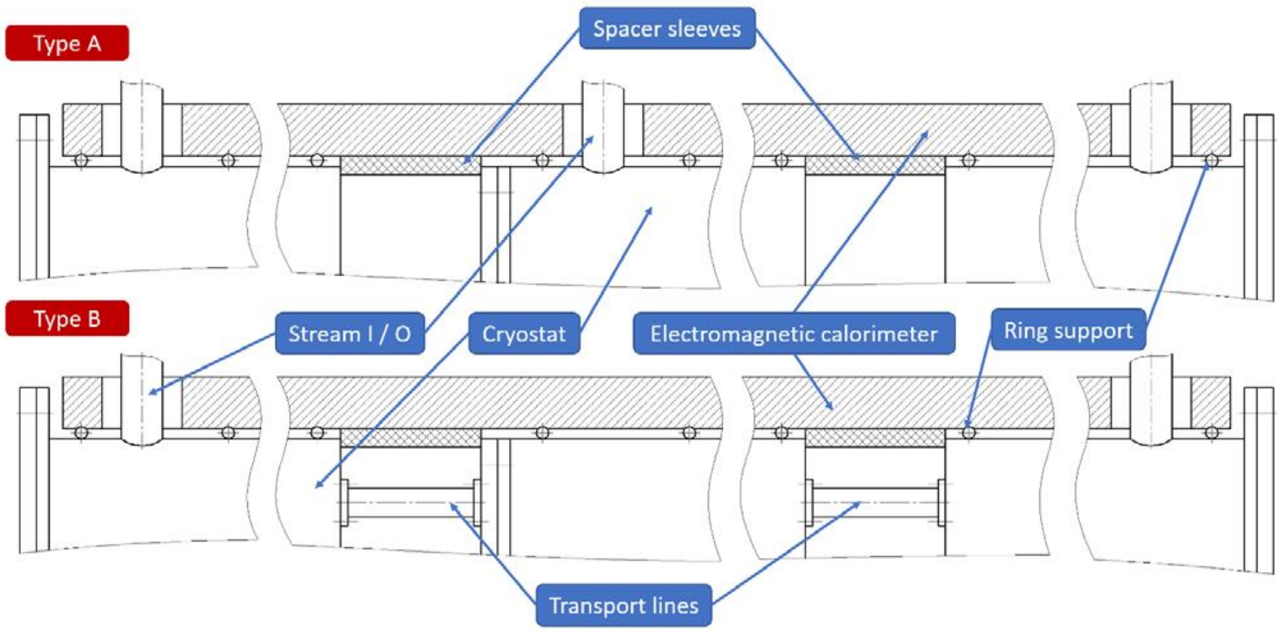

Figure 3: Layout options for the magnetic cryogenic system

Organization of the system according to type A will provide a more uniform temperature field over the volume of the magnetic system due to differentiated local control of the flow rate of cooling liquid helium in the LTS cable. The disadvantage of this design is the large number of technological holes for the organization of cryogenic and current-carrying communications. The creation of a vacuum in the internal cavities of the cryostat will also be difficult, since a large capacity of the vacuum system will be required due to the parallel connection of the pumped volumes.

For a system built according to type B, an objective advantage is the smaller number of technological holes in the electromagnetic calorimeter, the presence of which is still unknown. On the other hand, the presence of a common distribution manifold of cryogenic streams worsens the overall level of controllability of the system and makes this process more complicated than in a type A system.

From a technical point of view, type A turns out to be the most convenient, but it is necessary to clarify the possibility of creating technological holes for the input and output of streams. Therefore, it is not possible to single out the most priority option in the current conditions, but this will be considered in the future.

Based on the foregoing, six-solenoid topology with coils placed in the axial direction remains the highest priority for further analysis and more detailed elaboration and optimization of the cryogenic liquid helium supply system itself, taking into account the already existing helium consumption. [14].

3. CONCLUSIONS

The article compares two design options for the cryogenic system of an SPD detector based on six-solenoid and hybrid topologies of the magnetic system. A comparison is made of the qualitative characteristics of possible technical solutions that can be applied in each option. In the course of the analysis, it was found that from the point of view of reliability, mechanical strength, controllability and uniformity of the temperature field distribution over the volume of the magnetic system, the best compromise properties are possessed by the six-solenoid topology of the magnetic system, for which two types of construction of cryostat blocks in the inner cavity of the electromagnetic calorimeter have been proposed.

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