Magnet Inspection and Test Plan

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Abstract

The EIC General Purpose Detector system, ePIC, is located at Interaction point 6 (IP6) and includes a 2T solenoid (MARCO) at its heart with an operational central field of 1.7T. The solenoid will be centered in the interaction region (IR), IR is approximately 90 mm long centered around the interaction point (IP). The solenoid is 3.5 m in diameter and 3.8 m long, it will use a niobium-titanium conductor cooled at 4.5 K. The detector solenoid for the EIC is a large superconducting magnet. Figure 1 shows the layout of the ePIC detector and the figure 2 shows the overall dimensions of the magnet cryostat and phase separator.

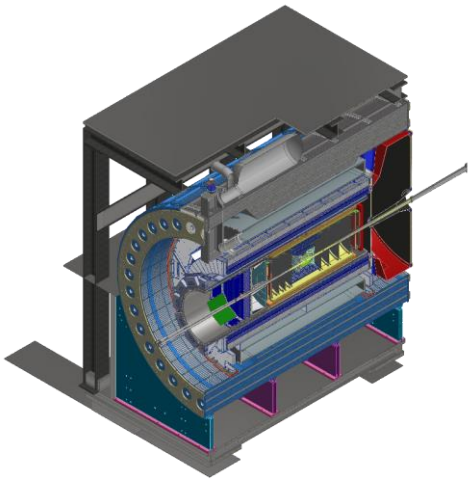

Figure 1. The Detector Layout

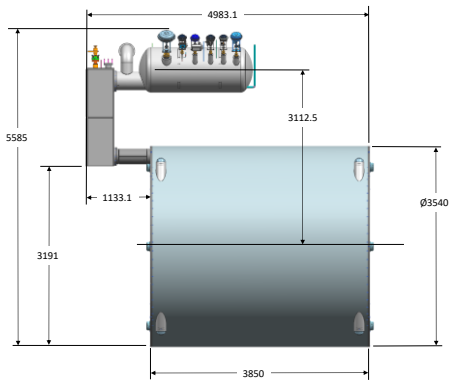

Figure 2. Overall Dimensions of the cryostat and Phase separator

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1. MAGNET PROPERTIES

The main components of the magnet system are:

- Coils with winding mandrel
- Cryostat including Thermal shields and Vacuum vessel
- Axial and Radial tie rods to support the magnet under operating conditions
- Magnet lifting arrangement
- Fiducials for the magnet alignment in the cryostat and in the experimental hall
- Phase separator
- Chimney including the vapor cooled leads
- Quench detectors
- Instrumentations and controls

The specifications of the superconducting magnet are given in Table 1.

Table 1. Magnet specifications

Parameter	**Value**
Magnetic Field Polarity	Bipolar
Coil length (mm)	3492
Warm bore diameter (m)	2.84
Cryostat length (m)	<3.85
Cryostat outer diameter (m)	<3.54
Flat Field area	± 100 cm around center 80 cm radius
Field uniformity in Flat field Area (%)	12.5
RICH area	From z=+180 cm to 280 cm, angles from 3.5 deg to 33.5 deg
Projectivity in RICH Area (mrad@30GeV/c) Projectivity in RICH Area (T mm²/A)	0.1 0.004
Stray field requirement at nearby IR magnets	<10 G* @ z=-5.3 m, @z=+7.4 m
Charging voltage (V)	10
Fast discharge voltage maximum (V)	500
Quench hot spot temperature (K)	<150
Temperature margin (K)	>1.5
Current margin (%)	>70
Charging time (hr)	2-3
Cooldown time (weeks)	3-4
Cooling scheme	Thermosiphon
Conductor	Cu Stabilized NbTi Rutherford cable
Operating Temperature (K)	4.5

The following are the key parameters that will be evaluated by the tests and inspections.

1.1. Dimensional checks

- Overall dimensions of the magnet system
- Dimensions of the mandrel
- Length and Inner and outer diameter of the coils
- Dimensions of the thermal shields
- Dimensions of the vacuum vessels
- Dimensions of the axial and radial tie rods

1.2. Electrical test

- Electrical resistance and inductance measurement at room temperature for all the coils
- Insulation tests on coils and magnet
- High voltage tests on coils, thermal shield and vacuum vessel

1.3. Pressure system and welding compliance

- Pressure testing according to ASME B31.3
- Welding/Brazing compliant to

1.4. Lifting and alignment fiducials

- Lifting arrangements
- Fiducials for the alignment

1.5. Instrumentation including quench detectors

- Verification of all temperature, pressure and stress sensors
- Quench detectors

1.6. Magnetic field test

- Full current testing
- Field mapping and validation against specification

2. PROCESSES AND PROCEDURES

This section will describe the processes and procedures that are required to evaluate each of the properties described the preceding section. There should be a level 2 sub-section for each of the properties identified in section 1.

2.1. Dimensional Checks

The overall dimensions of the magnet system are very crucial for the magnet installation in the experimental hall. The magnet sits inside the barrel HCal, therefore, the overall dimensions of the magnet cryostat are crucial for the installation. There are several other dimensional checks for the magnet system (i) dimensions of the coil mandrel, (ii)inner & outer diameters of the coils, (iii) dimensions of the thermal shields, (iv) dimensions of the vacuum vessels and (v) the dimensions of the axial and radial tie rods

2.1.1. In-Process Testing

All these dimensions checks will be done while manufacturing, only the cryostat outer dimensions will be checked as a part of the magnet arrival checks. All the lengths will be checked using a dimensions inspection tool and all the diameters will be checked using a pi-tape. These will be calibrated.

2.1.2. Incoming Inspections or Acceptance Testing

The cryostat outer dimensions will be checked as part of the acceptance testing.

2.1.3. Verification Testing

All the dimensional checks will be verified either by the quality person from the vendor and/or technical representative of JLab.

2.1.4. Failures and Non-Conformances

If any of the dimensions is out of specification range, immediate corrective action will be taken by the vendor and approved by JLab technical representative.

2.2. Electrical Tests

There are a number of electrical tests to be performed during magnet manufacturing and installation. Electrical resistance will be measured for each layer in all 3 modules; this value will be compared with the theoretical value. Any discrepancy or deviation from theoretical values should be notified to the JLab and winding will be paused till a cause and solution is found. After making the joints, the resistance checks will be made after every joint. These values will be compared with theoretical values. The inductance of the magnet will be measured in the frequency range of 50 Hz to 1kHz. A difference greater than 5% between the measured and the computed inductance will be considered as an indication of a short circuit.

In order to verify the quality of turn-to-turn insulation and to prove the dielectric strength of the insulation winding should be tested with an impulse voltage. All the conductive parts should be connected to the ground to the ground or to the high potential terminal of the coil under test. The potential of the conductive parts should be selected in accordance to the operating conditions of these parts. The detailed design of the test circuit is the responsibility of the vendor. The test circuit must be designed to produce an oscillatory test voltage with the following electrical characteristics:

- Frequency: less than 1000 Hz
- Direct polarity voltage peak (Ud) greater than twice the maximum quench voltage.
- Reverse polarity voltage peak (Ur) greater than 0.95 Ud
- The impulse voltage test must be initially applied at reduced voltage. After that, the voltage of the impulse will be progressively increased up to the maximum value indicated in the test program.

The absence of phenomena that can be interpreted as an indication of voltage breakdown will be the acceptance criterion.

All the coils and joints should be tested to qualify the ground insulation. All the conductive parts should be connected to the ground or to the high potential terminal of the coil under test. The potential of the conductive parts should be selected in accordance to the operating conditions of these parts. The insulation to ground must be tested at atmospheric pressure and voltage in both polarities. The test voltage should be twice the operating voltage.

2.2.1. In-Process Testing

All the electrical tests will be done several times during the manufacturing process.

2.2.2. Incoming Inspections or Acceptance Testing

Some of these electrical tests will be part of the final acceptance as well.

2.2.3. Verification Testing

The electrical tests will be done by the magnet vendor and will be witnessed by the JLab technical representative.

2.2.4. Failures and Non-Conformances

Corrective actions will be taken by the vendor for any discrepancy or failure in the electrical tests. The corrective actions will be approved by JLab technical representation.

2.3. Pressure system and Weld compliance

All the piping in the system is governed by AME B31.3. All the pressure and vacuum vessels are designed using the ASME code. All the design calculations should be verified by the JLab pressure vessel authority and/or should be ASME stamped.

As JLab considers all the brazing critical to the success of the project, vendors are requested to provide ASME BPVC, Section IX-qualified Brazing Procedure Specification (BPS), supporting Procedure Qualification Record (PQR), Brazing Performance Qualifications (BPQ) of brazers and brazing operators in accordance with Subsection 328.2. Requirements in B31.3 Section 333 that are applicable to brazing must be followed.

2.3.1. In-Process Testing

The pressure system design calculation and weld qualification will be approved by JLab prior to start work on these.

2.3.2. Incoming Inspections or Acceptance Testing

All the pressure system design calculations and required qualification documents will be approved by JLab technical representative.

2.3.3. Verification Testing

All the calculations and the required qualification document will be verified by JLab technical representative.

2.3.4. Failures and Non-Conformances

Any failure to provide the required document and analysis work will be paused by JLab till these are provided.

2.4. Lifting and Alignment Fiducials

The magnet assembly weighs approximately 25-ton, proper lifting arrangements should be planned for lifting the magnet at the vendor site and at the time of arrival at BNL. The magnet assembly will be installed in the barrel HCal, fiducials are required to align the magnet during installation.

2.4.1. In-Process Testing

The lifting lugs will be designed for magnet lifting. The magnet vendor will design the lifting arrangement and share their design report with JLab technical representative. The fiducials details will be shared with JLab and BNL technical team.

2.4.2. Incoming Inspections or Acceptance Testing

The lifting lugs design and calculations along with the required qualification documents will be approved by JLab technical representative.

2.4.3. Verification Testing

Before shipping the magnet from the vendor, the lifting lugs and fiducials details shall be approved by JLab. The lifting lugs should be stamped for the approved weight.

2.4.4. Failures and Non-Conformances

Magnet shipping to BNL will be paused if lugs or fiducials are not approved by JLab technical team.

2.5. Instrumentations and Quench Detectors

In order to operate and monitor the MARCO solenoid an extensive instrumentation plan has been defined. The instrumentation covers the electrical measurements, quench detectors, the cryogenics data measurements as well as the mechanical ones. The electrical measurements gather the voltage measurements and the current measurements. The electrical instrumentation scheme has been done based on the magnet protection analysis and choices. As the magnet will be protected by a magnet safety system (MSS) the voltage will be monitored for each coil segment with redundancy. The quench detector will be made by making the difference between two segments of the coil having the same inductance. Allowing to remove the inductive voltage and read only the resistive voltage. This will allow the MSS to detect the transition time and to protect the magnet by opening the contactor to discharge the magnet on the dump resistor.

The cryogenics ones collect the temperature data, the pressure, the liquid helium level, the He mass flows and the vacuum level. Finally, the mechanical measurements concern especially the tie-rods whose stress is monitored during all the magnet life. In the magnet design report by JLab a complete list of the needed instrumentation is reported; here the instrumentation specifically dedicated to the magnet procurement is recalled. The instrumentation racks should be used for all the equipment involved and for data acquisition. The control system should be compatible with the BNL control system.

2.5.1. In-Process Testing

All the sensors will be calibrated and their calibration will be shared with JLab, all the wiring will have enough redundancy. The type of sensor and level of required redundancy will be approved by JLab technical representative.

2.5.2. Incoming Inspections or Acceptance Testing

All the sensors values be checked during magnet acceptance testing.

2.5.3. Verification Testing

The sensor calibration will be done by the vendor, the calibration data will be shared with JLab. All the sensor will be checked at the arrival check. The quench detectors will also be checked during acceptance test.

2.5.4. Failures and Non-Conformances

If RRR at any stage does not meet the specification, that strand/cable/conductor will not go for further manufacturing.

2.6. Magnetic Field Test

Magnet will be cooled to 4.2 K and tested after installing in the HCal barrel. The magnet vendor will be responsible for cooling down the magnet and testing magnet at full current.

2.6.1. In-Process Testing

During magnet manufacturing all the coil connections, joints etc. will be checked for insulation and continuity checks.

2.6.2. Incoming Inspections or Acceptance Testing

All the electrical checks will be repeated as the incoming inspection.

2.6.3. Verification Testing

Magnet will be cooled and energized to the full field.

2.6.4. Failures and Non-Conformances

Corrective actions will be taken by the vendor for any discrepancy or failure in the magnet test. The corrective actions will be approved by JLab technical representative.

3. EXPERIMENTAL/TEST SETUPS

This section will have an individual sub-section for each of the experiments/tests that will be performed. If the same experimental process will be used for multiple properties, it does not need to be repeated. Each experimental section should provide a detailed description of the method, resource requirements, conditions, and equipment.

3.1. Dimensional Checks

All the dimensional checks will need pi-tape and dimensional check tools. Vendor to provide a method for measuring all the dimensions.

3.1.1. Resource Requirements

No special resources required for the dimensional checks.

3.1.2. Test Conditions

These tests to be done at controlled room temperature ~27 deg C.

3.1.3. Equipment

List all specialized equipment that will be required to conduct this test. For instance,

- Pi-tape
- Dimensional check tools

3.2. Electrical Tests

Special test equipment is required to complete all the electrical tests. The vendor will provide their test methodology to JLab for approval.

3.2.1. Resource Requirements

A trained test technician and a test engineer are required to perform these tests.

3.2.2. Test Conditions

These electrical tests will be done at room temperature and at 4.2 K at the time of magnet installation..

3.2.3. Equipment

Special set up for measurement for electrical tests.

3.3. Pressure system and Welding compliance

Pressure system and welding compliance is based on the design calculation and documentations.

3.3.1. Resource Requirements

A trained welder and pressure vessel authority.

3.3.2. Test Conditions

Not applicable

3.3.3. Equipment

Not applicable

3.4. Lifting and Alignment Fiducials

Lifting and alignment fiducials is based on the design calculation and documentations.

3.4.1. Resource Requirements

An engineer are required to complete calculations and documentations.

3.4.2. Test Conditions

Not applicable

3.4.3. Equipment

Not applicable

3.5. Instrumentation including Quench Detectors

All the sensors will be calibrated prior to installation, all the instrumentation and quench detectors will be tested during manufacturing and also during installation.

3.5.1. Resource Requirements

A trained test technician and a test engineer are required to perform these tests.

3.5.2. Test Conditions

These tests to be done at controlled room temperature ~27 deg C during manufacturing and at 4K during commissioning.

3.5.3. Equipment

multimeters, special equipment to test at 4K

3.6. Magnetic Field test

Magnet will be tested for the design field at 4.2 K.

3.6.1. Resource Requirements

2-3 trained test technician and 2-3 test engineer are required to perform these tests.

3.6.2. Test Conditions

These tests to be done at controlled room temperature 4.2K.

3.6.3. Equipment

liquid Helium, Hall sensor and magnet field mapper

4. ENVIRONMENT, SAFETY & HEALTH CONSIDERATIONS

The procedures will be implemented in a way consistent with the environment, safety, and health policies of the relevant work areas. Within Jefferson Lab the process is described in the ES&H manual Chapter 3200, Work Planning and Control Program and at BNL within the SBMS: "Work Planning & Control for Experiments and Operations".

5. RECORDS AND DOCUMENTATION

All design reports, calibration data, etc. provided by the vendor will be part of the documentation for magnet installation. These will be saved/stored in JLab controlled folders for future reference.

5.1. Manufacturer/Producer Records

Magnet vendor will do all the tests and provide all the test results to JLab.

Magnet vendor will also provide all the as-manufactured data and procedures.

5.2. Deliverable Documentation and Records

The following deliverable documentation will be provided:

- All the calibration data
- Magnet operating manual

6. REFERENCES

EIC Systems Engineering Group. (2022). *Interface Management Plan.* Brookhaven, NY: Brookhaven National Laboratory.

EIC Systems Engineering Group. (2022). *Requirements Management Plan.* Brookhaven, NY: Brookhaven National Laboratory.

EIC Systems Engineering Group. (2022). *Systems Engineering Plan.* Brookhaven, NY: Brookhaven National Laboratory.