Appendix A

Relocation of the E821 Storage Ring Magnet

A.1 Reader's Note

This appendix documents the plan for the storage ring move, which occurred in the summer of 2013. It is left intact for the reader as an example of Value Management and Risk Mitigation. Images and videos documenting the move are available on a dedicated website [1].

A.2 Introduction

The muon storage ring magnet consists of superconducting coils inside their cryostats and the steel yoke and pole pieces. The steel is easily disassembled and shipped by truck, i.e., the time reversal of the process we used twenty years ago. However, the 15 m-diameter coils were wound in Brookhaven Building 919. In order to maintain the exceptional magnetic field, the coils may not be disassembled to the degree that would allow conventional trucking. Special transportation for the very large load is required. Transporting the coils in their horizontal orientation is highly desired in order to prevent extraordinary forces and stresses on the coils.

The largest portion of the coil transport will occur by barge from Long Island, New York to Illinois via the Mississippi River system to the Illinois Waterway. Along the eastern seaboard the barge will travel through the Intracoastal Waterway keeping the barge near ports and in calm waters as compared to open sea travel. An ocean tug will be used from Long Island to New Orleans. A river tug will be used for the remainder of the trip to Lemont, Illinois. A back up plan could route the barge north via the St. Lawrence Seaway and Great Lakes to the Illinois Waterway.

A feasibility study in 2012 studied the best mode of transportation for the remaining short distance over land between the labs and ports in both Long Island and Illinois. The result of the study indicated that the use of a specialized truck and trailer is the best option. Some vendors in the heavy haul industry are capable of performing the work required with a specialized truck/trailer suitable for moving the $g-2$ coils. A transportation review based on the feasibility study was held at FNAL in September, 2012. One of the recommendations from this review was to be sure that we document the coil/cryostat system before the move. The documentation is given in Fermilab $g-2$ doc-db references [2], [3], [4], [5], and [6].

A Request for Proposal (RFP) was written at Fermilab and a meeting for the coil/cryostat transportation was held at BNL in November, 2012. Four companies replied to the RFP and attended the meeting; three of these submitted proposals. Emmert International was chosen to perform the work and the contract was signed.

The present plan is to truck the coil/cryostat from Brookhaven National Laboratory to Smith Point Marina in Suffolk County, Long Island. From this port the barge will travel to the Ozinga port on the Illinois Waterway. From the port in Lemont, the coils will travel via specialized truck/trailer to FNAL this summer.

An analysis has been performed by Emmert International to determine the deflection of the shipping fixture arms while supporting the coils. This has been determined for various support conditions that the fixture will undergo during the phases of the shipment. The results of the Emmert calculations have been verified at Fermilab. The expected forces and deflections have also been imposed on the coils in a Finite Element Analysis at Fermilab. The stresses imposed on the coils are seen to be low on the order of a few hundred psi. The coils and other internal components of the cryostats are not expected to be damaged as a result.

The shipment of the coils will be performed using a quality assurance plan. The plan will provide a means of assuring that the coils will not see stresses above those that we plan for. Severe storms will be avoided. Distant storms that cause higher than normal wave motion will be monitored. The shipment will be monitored with accelerometers capable of transmitting a signal. For wave motion approaching our limits, the barge will be called to safe harbor. A safe harbor plan will be a part of this quality assurance plan. The accelerometer readings will be recorded for later analysis as well.

A.3 Preparations for Shipping

Figure A.1 shows a recent picture of the cryostats and the mostly disassembled steel. In this photo the upper yoke plates have been removed as well as much of the spacer plates. The coils will be removed for shipment before most of the lower yoke and the remaining spacer plates will be moved.

The following are the important activities occurring (or in process of occuring) in preparation for the move:

- Replacing all the G10 radial stops with Aluminum stops. The G10 stops do not touch the mandrel when warm, only when cold. The Aluminum stops are longer and are designed to touch the mandrel. This prevents the coil from moving side-to-side.

- For the outer coil, vertical bolts at the hangar locations will be inserted through the cryostat's top surface, and engage the mandrel. This is additional protection to prevent the mandrel from moving side-to-side. FEA simulations of this item and of the first item, show that these safeguards are sufficient for handling the worse case of 0.7 g side load.

- The exposed (unpainted) surfaces of the yoke steel was coated with Cosmoline to prevent rusting.
- A structure has been designed to support the interconnect and the hardware outside the outer cryostat (see reference [7]). This is to minimize the stress on both the coils and cryostat walls.
- A shrink wrap will cover the cryostats during the move.
- During the move, dry nitrogen will be flowing through the cryostat to keep it dry.

Figure A.1: Coils/Cryostats at BNL.

A.4 The Coil Shipping Fixture and Transportation

Figure A.2 shows the shipping fixture as specified by Fermilab and designed and built by Emmert International per the criteria to carry the coils. The coils will remain very flat during the shipment to limit the stress imposed onto the coils.

Figure A.3 shows an engineering drawing of the mover and support fixture. The overall length of this rig is in excess of 117 feet. The trailer has three hydraulic zones to keep the load level and to distribute the weight to the wheels evenly. The truck will move slowly over the roadways ranging from walking speed to a maximum of 10 mph depending on the terrain and the proximity of obstacles along the path. The shipment will move over public roadways during night time hours to limit disruption to public traffic.

Figure A.4 shows a model of the mover and support fixture. The 50 foot diameter coils require roughly the width of four traffic lanes to traverse the roadways in Long Island and Illinois.

Figure A.5 shows a drawing of the shipping fixture with coils secured to the barge. The barge that we plan to utilize has a 54 foot width by 180 foot length. This barge size is chosen to limit the maximum roll, pitch, and heave the coils will experience over the water.

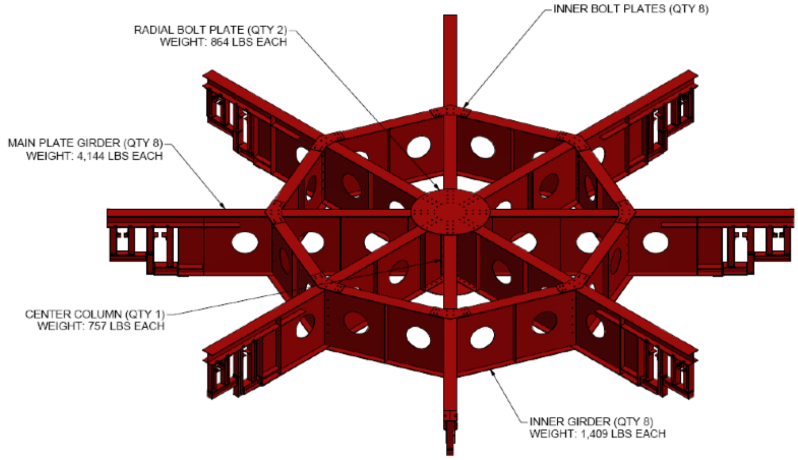

Figure A.2: The shipping fixture.

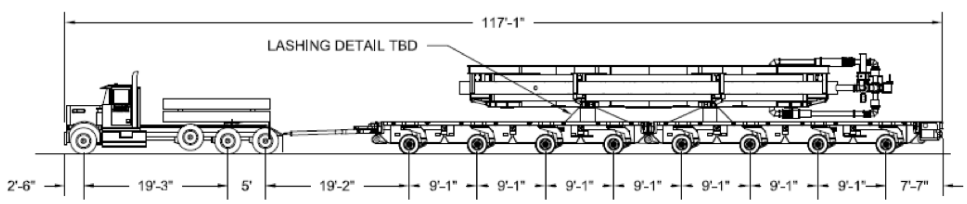

Figure A.3: Specialized Truck and Trailer for Coil Shipment.

Figure A.4: Scaled model showing the specialized truck and trailer holding the coils.

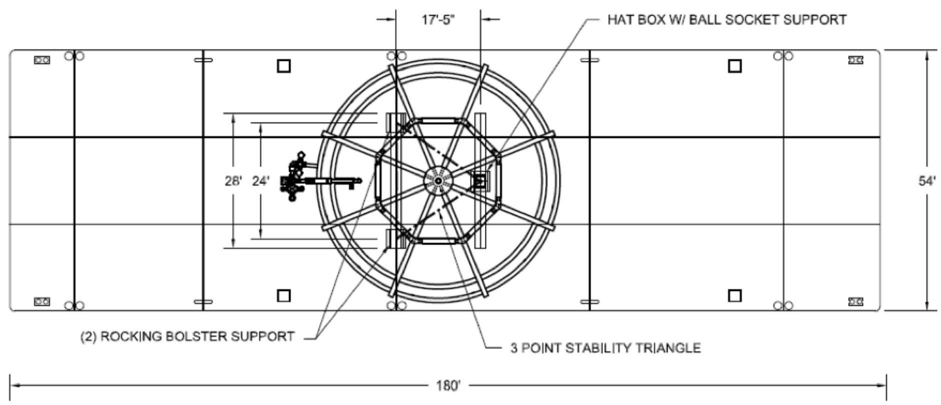

Figure A.5: Shipping fixture with coils shown secured to the barge.

References

[1] Muon $g-2$ Big Move page. http://muon-g-2.fnal.gov/bigmove/

[2] E821 Muon Storage Ring Coil Resistance Benchmark. g-2 DocDB note 499-v1.

[3] Coil Resistance to Ground Measurements. g-2 DocDB note 352-v1.

[4] Cryostat Vacuum System Documentation. g-2 DocDB note 314-v1.

[5] E821 Interconnects. g-2 DocDB note 302-v1.

[6] Resistance to Ground of the E821 Storage Ring Magnet Coils. g-2 DocDB note 976-v1.

[7] Erik Voirin, g-2 Cryostat Interconnect Support for Transportation. g-2 DocDB note 979-v1.