GEM IN-92-20

Design Review of the GEM Magnet

Harvey L. Lynch
SSC Laboratory

July 16, 1992

Abstract:

Enclosed is the report of the committee on the technical review of the GEM Magnet. The charge to the committee was to review the GEM Magnet with respect to technical feasibility of its construction, cost and schedule, and the competence of the team. Because there had been a review of the costs for the entire GEM experiment the previous week and the very limited time available, there was no discussion of costs in this review.

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16 July 1992

Fred Gilman
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Dear Fred,

Enclosed is the report of the committee on the technical review of the GEM Magnet. I hope that you find it satisfactory.

Sincerely,

Harvey

Harvey L. Lynch

cc:	R. Schwitters	SSCL
	V. Luth	SSCL
	B. Barish	CalTech
	W. Willis	Columbia
	✓G. Sanders	LANL
	C. Henning	LLNL
	R. Richardson	SSCL
	R. Jayakumar	SSCL
	P. Sanger	SSCL

DESIGN REVIEW OF THE GEM MAGNET

30 June to 1 July 1992

A committee consisting of Carl Henning, LLNL; Bob Richardson, SSCL, Raghavan Jayakumar, SSCL; Phil Sanger, SSCL; and Harvey Lynch, SSCL (chairman) met on 30 June and 1 July 1991. The agenda for the meeting appears as an appendix.

The charge to the committee was to review the GEM Magnet with respect to technical feasibility of its construction, cost and schedule, and the competence of the team. Because there had been a review of the costs for the entire GEM experiment the previous week and the very limited time available, there was no discussion of costs in this review.

SUMMARY

In general the Committee was impressed with the quality of the design work presented by the GEM Collaboration. We believe that the magnet is buildable. Although it is a very large magnet, it is not a particularly difficult magnet; it need not stretch the technology to the limit. We do caution, however, not to make it more exotic than it needs to be. We see no major problems which are not easily fixed. Some concerns are briefly summarized here. Detailed reports from subcommittees follow.

* The desire for 99% availability of the magnet probably cannot be achieved with the use of a single refrigerator. For the reliability desired, some additional source of liquid helium will be needed.

* There is need for more attention to details for the helium indirect cooling. In addition, it was felt that the LN cooling system is probably risky; the pipes are probably too long for a thermal siphon to function properly. This means that a pump will be needed.

* There is some concern on the absence of radial constraint during the coil winding.

* The use of titanium rods for support was not favored because of possible fracture toughness problems.

* It is felt that the conductor is likely to be the pacing item for the magnet.

* Quench detection in 1 sec is judged to be too fast, leading to excessive false alarms.

* The remote location of the dump resistor was considered undesirable from a safety standpoint.

* The split coil winding form seems to be an unnecessary complication. The motivation of this should be reexamined.

* The predefined splices (to a tolerance of 25 cm over a length of 1 km) may be troublesome in practice.

* The location for building the vacuum vessel needs to have proper humidity control to prevent adsorption of water by the superinsulation.

* The schedule was described by GEM as "success oriented". This appears to be a good characterization. On the other hand, the schedule was not considered unrealistic.

SUBCOMMITTEE REPORTS

Magnetic Field Design and Force

The preliminary work done on the magnetic field and force seems to be correct. However, it was noted that the carbon steel vacuum vessel was not included in the analysis. Neither were the asymmetric effects of carbon steel supports for the forward field shaper and central detector support included. The magnetic interface requirements and effects with the entrance quad magnet need to be defined, as do the alignment specifications and non-axially symmetric forces.

The 40 gauss field at the surface above the detector does not appear to be a problem except for excluding people wearing pacemakers.

Normally the magnet halves attract each other with a force of 12 million pounds. There are possible scenarios in which the force could reverse. For example if one magnet half were off (because of an internal short), then the other magnet half would be attracted to the iron forward field shaper with a force of 3 million pounds in the opposite direction. This force reversal could cause a buckling failure of the axial support rods. It seems prudent to put retractable snubbers on the magnet end to stabilize the magnet during installation. During operation they would be retracted such that there is no thermal short, but unexpected axial motion could not cause the support rods to fail in buckling.

The choice of the split coil form appears to be favored in order to prevent a quench in case of a "fast" run-down of the magnet. If for other reasons the split coil is abandoned in favor of a continuous one, it might be advantageous to consider an intermediate run-down speed faster than 8 hours, but slow enough to avoid a quench.

Conductor Design

It is very clear that the conceptual design effort relative to conductor design and selection has been extensive. While time did not allow a complete reassessment of the cable in conduit selection, separate reviews have taken place to sufficiently support this choice, and the committee concurs with it.

In the judgement of the committee the requirement for the control of the conductor length requires additional evaluation. A coil design should be established which can tolerate the range of variation in length that is to be expected from the fabrication process used for this type of conductor. Due to the program schedule, the committee recommends that a coil winding design of indexing and rotation of the coil segments be further developed in order to accommodate this effect. The strategy of completing as many critical manufacturing steps in the factory is admirable and sound and should continue to be adopted.

The optimization of the strand copper content focused on the conductor stability as the principle parameter. Sufficient stability appears to be present in the concept to optimize rather on the availability of standard strands already in high volume production and thus minimize cost. It is suggested that strands with high copper fractions like 7:1 be investigated.

The committee judged that the U shaped conductor sheath (as opposed to the welded assembly) was more manufacturable and that the design team should consider applying the sheath at the winding site instead of at the manufacturer.

Winding and Coil Assembly

The committee was impressed by the extensive effort given to the development of a workable winding concept incorporating the experience gathered from earlier detector magnets. Nevertheless it was felt a few areas should be given more study.

The committee strongly recommends that the continuous bobbin be established as the baseline design due to its simplicity and mechanical integrity. It is suggested that the problem of fast rundown of the magnet should be reexamined with the continuous bobbin as the baseline and then determining the ramping modes and times that are therefore possible to avoid quenches.

The application of axial precompression without radial constraint or attachment to the bobbin is a serious concern. By straightening and rebending at slightly larger radius than the form this could be somewhat mitigated. However it may not be sufficient, and more design consideration must be given this aspect of the coil assembly.

It was noted that no structural analysis was presented on the mechanical discontinuity between the joint and the aluminum sheathed conductor. This could be a significant problem and must be thoroughly analyzed.

In the opinion of the committee, vacuum leaks may be serious failure mode. It was therefore felt that a secondary helium containment should be considered possibly incorporating the inner radiation shield.

The assembly of the coil bobbin flange with the inner bobbin is likely to be costly and difficult, involving drilling and tapping in place. It is recommended that the design team consider a welded structure (U or H shape) and apply axial compression by means of insulating wedges.

The insulation scheme using 3 to 6 mm of epoxy glass material appears to be overly conservative and maybe difficult to implement. Consideration could be given to more conventional wrapped insulations for the conductor and thinner and more flexible insulation sheets for the ground insulation.

Structural Analysis

The structural analysis work is of high quality and has been carried out by highly competent individuals. The analysis has addressed key issues viz. stresses in the bobbin, contact force between conductor, and Al stabilizer and conductor joints.

There is some concern of unbalanced magnetic forces. The effect of out of roundness of bobbin, vacuum vessel cylinders, and misalignment of bobbin, vacuum vessel and FFS need to evaluated for forces and deflections in 3D. A full 3D calculation is probably not needed, but some estimate of 3D effects would be desirable.

The force on the conductors is both radial and axial. The shear load between conductors and the conductor and bobbin at the coil ends needs to be examined. Any relative motion between bobbin and coil should be carefully eliminated or slip surfaces should be provided.

Vacuum Vessel and Vacuum Systems

The vacuum vessel design is not a technically difficult problem and is addressed adequately from the standpoint of technical feasibility and ability to construct.

The cost was credible, being based on vendor quotes on many of the items. The schedule looks tight with little time allowed for problems and errors in fabrication. Leaks in the vacuum vessel can possibly delay the schedule.

Some suggestions that could assist in cost and schedule are as follows:

- The outer shell could be designed with thinner shells and vacuum support rings for stability. Optimize the design for lower weight and cost for the outer shell. The vessel does not need to be designed to the safety factors in the ASME code. In fact the code has no jurisdiction over vessels at less than 15 PSI differential pressure across the walls of the vessel. Suggest a safety factor more in line with what other manufactures use. Optimization of the vessel was mentioned and it was suggested that this may be done by the designer and manufacturer after award of the magnet contract.

- There are no unresolved issues that cause major problems with the vessel at this time. There is considerable emphasis needed in engineering details, by the ultimate contractor, in the fabrication, welding, inspection, and testing of the magnet vessels.

Radiation Shields and Cold Mass Supports

The radiation shields are not a technically difficult problem given the experience with other magnets. The problem is with the method of cooling selected as the natural convection as discussed in the cryogenic system below.

The selection of the cold mass supports with independent supports for the radial supports and longitudinal supports is the best overall selection.

The supports may have problems and needless complications with use of the belleville washers or springs. A rigid support is better from the standpoint of the handling when the coil is moved from the vertical to the longitudinal position. The exact location is better known, and shrinkage can be allowed by adjustment of the support system with the threaded rods. The rods can be backed off to allow shrinkage after the coil is in place before cool down. This was accomplished on CDF very successfully.

Forward Field shaper (FFS)

Several geometries of the FFS to improve the muon resolution, have been studied, and an optimum design from magnetic point of view has been chosen. A competent team is in place to design and fabricate the FFS. Two options for fabricating the FFS have been investigated, one using 18 cast pates of varying thicknesses and with keys to interlock the plates into the desired cone and the other using rolled plates which are locked together by a central tubular support cone. Several tie rods compress these plates axially. The material has been specified to be 0.1% homogeneous in the azimuthal direction and perhaps less stringent in the radial and axial direction. The basic concept is viable.

It is felt that cast geometries may not give the desired dimensional accuracy to maintain straightness and centering and may need a secondary machining operation. In the option with rolled plates, an alternative to using a central support cone with a thick wall is to machine circular grooves on the plates in which to seat keys (rings) which interlock the plates and hold them concentric.

Cryogenic System

The Cryogenic System presented using the natural convection (thermal siphon) system for the helium indirect cooling of the magnet is a credible and very reliable selection. A successful design requires considerable engineering attention to details. There seemed to be a lack of this attention. The following items may be possible problems but do not have a major effect on the coil design and fabrication.

1. Further study is needed relative to having only a liquid helium dewar on the surface rather than in the hall above the magnet. This item needs

further analysis, comparison, and justification before a final decision is reached. This issue should not have any immediate effects on the magnet procurement process, and a final decision can be delayed to a later time without delays in delivery of the magnet.

2. With the orientation of the tubing it appears that the suggested use of thermal siphon system for the nitrogen shields as natural convection is questionable. How are the nitrogen intercepts on the supports to be fed with liquid? It appears that a forced flow system is a much better option with less risk. This can be made reliable with redundancy in the pumps placed on the surface.

3. It was suggested that there needed to be a 99% availability for the Cryogenic systems. This is very difficult to obtain. On demand availability of the helium refrigerator to satisfy up time necessary requires two cold boxes and redundant compressors. This means considerable additional costs, of the order of $3-4M.

Power Systems and Control

The basic concepts in the power systems and control are viable and there are no major issues.

There is a concern that the bus scheme with wide spacing between the two buses will make for a large antenna and therefore may contribute to electrical noise. On the other hand, closer buses will increase the field between the buses (reduce field outside the buses) and increase the interbus force. An optimum has to be chosen.

It is suggested that a larger integration time and delay to detect the quench (say 5 seconds) be chosen to reduce false alarms. This will enable the control system to acquire CICC pressure rise for helium flow data to confirm a quench event. Since a quench takes place in about 100 seconds, the longer detection time will not affect performance

The dump resistor is very far from the magnet, being located on the surface. This gives greater opportunity for a break in the electrical bus that could destroy the magnet. It would be better to locate the resistor much closer to the magnet, perhaps just above it. Also, the large distance between the electrical leads will act as a loop antenna to pick up electrical noise. Such noise could confuse the quench protection circuit, causing unnecessary discharges.

The 1 second decision delay time to dump the magnet seems too short. Such a low field, stable magnet is not likely to ever quench, but fast electronic decisions could lead to false dump signals. A more comfortable delay time with collaboration of helium flow or pressure measurements would reduce the chances for error. Also the emergency shutdown time of 500 seconds seems awkward. There seems to be no particular reason for this value, but it would

probably quench the coil. Perhaps a longer time would not quench the coil, but satisfy any safety considerations.

Fabrication Assembly, and Installation

In general the committee liked the assembly scheme. This discussion was still in the planning stage so, it is difficult to comment on details. However, it seems certain that the conductor manufacture will be the pacing item. Separation of the conductor strand/sheath fabrication from the aluminum stabilizer fabrication could help the schedule. Adding the omega type stabilizer (in place of the welded half sections) to the conductor at the SSCL site might speed the schedule. It would certainly help the shipping considerations and might permit longer conductor lengths.

The coil installation into the vacuum vessel probably must occur outside because of the extreme height needed for the cranes. Except for these few days of installation, all other operations should be indoors. The superinsulation will adsorb water, and having it in the rain would be unacceptable. In any case, it will be necessary to dry the superinsulation after assembly into the vacuum vessel. Radial punctures of the insulation will help, as will flowing hot gas through the nitrogen shield during the initial pump-out.

Is the use of titanium support rods really needed? The fracture toughness of Ti is questioned. A less exotic, alternative would be the use of an inconel tube with conventional spherical joints at the ends.

AGENDA

SSCL GEM Magnet Technical Review

TUESDAY

30 June 1992 **Upstairs Conference Room, Building 4**

8:30	Closed Session	
9:00	GEM Project Introduction	Sanders
9:15	Overall Magnet Performance Requirements and Physics Issues	Stroynowski
9:30	Overview of Present Point Design	Deis
10:30	BREAK	
11:00	Magnetic Field Design and Forces	Marston
11:20	Conductor Design	Marston
11:40	Coil/Winding Design	Smith
12:00	Coil Structural Analysis	Titus
12:30	LUNCH	
2:00	Vacuum Vessel/Vacuum System	Bowers
2:30	Radiation Shields/Cold Mass Supports	Yamamoto
3:00	Assembly Approach	Pedrotti
3:30	BREAK	
4:00	Forward Shield Shaper, Central Detector Support	Bowers
4:15	Cryogenic System	Warren
4:45	Power/Protection/Control System	Oberst
5:00	Fabrication, Assembly and Installation	R. Johnson

WEDNESDAY

1 July 1992 **Directorate # 1**

9:00-3:00 Closed Session