Magnetic Cavern Solenoid R&D

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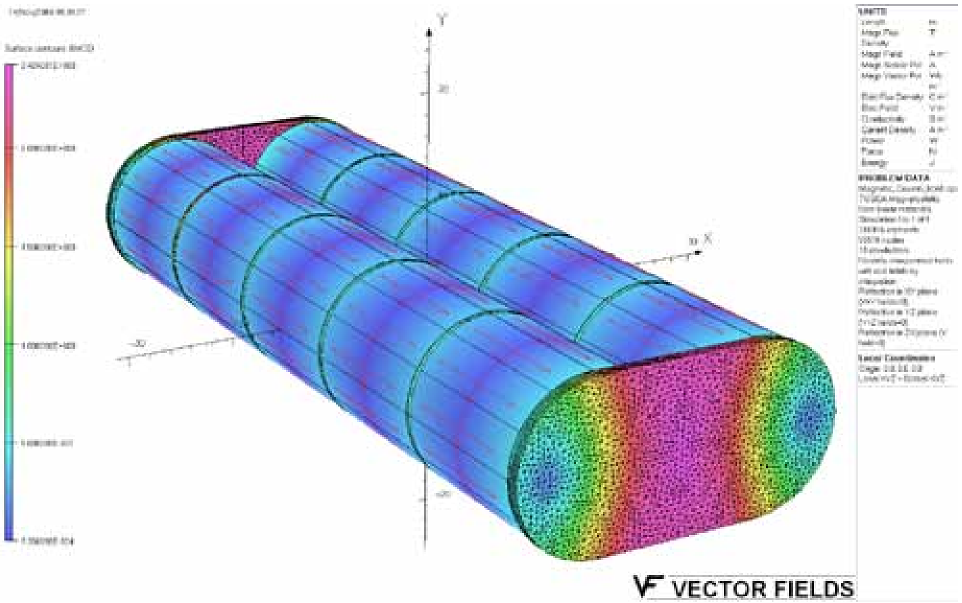
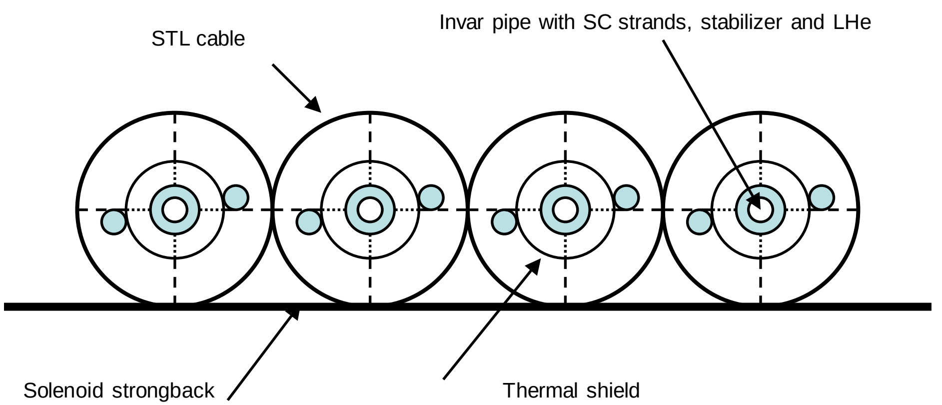
Introduction

- Magnetizing volumes ~30,000-60,000 m^3 at fields up to 0.5 T presents technical challenges, but is certainly within current engineering capabilities.
- The cost, however, in most typical scenarios is unacceptable.
- Using the Superconducting Transmission Line (STL) concept presents some very interesting possibilities.
  - eliminates the cost driver of large conventional superconducting coils and, the vacuum-insulated cryostat
  - has already been prototyped, tested, and costed during the R&D for VLHC
- A full engineering design would still need to be done, but this technique has the potential to deliver the large magnetic volume required with a field ~1 T with very uniform field quality and at an acceptable cost.

Magnetic Cavern design concept





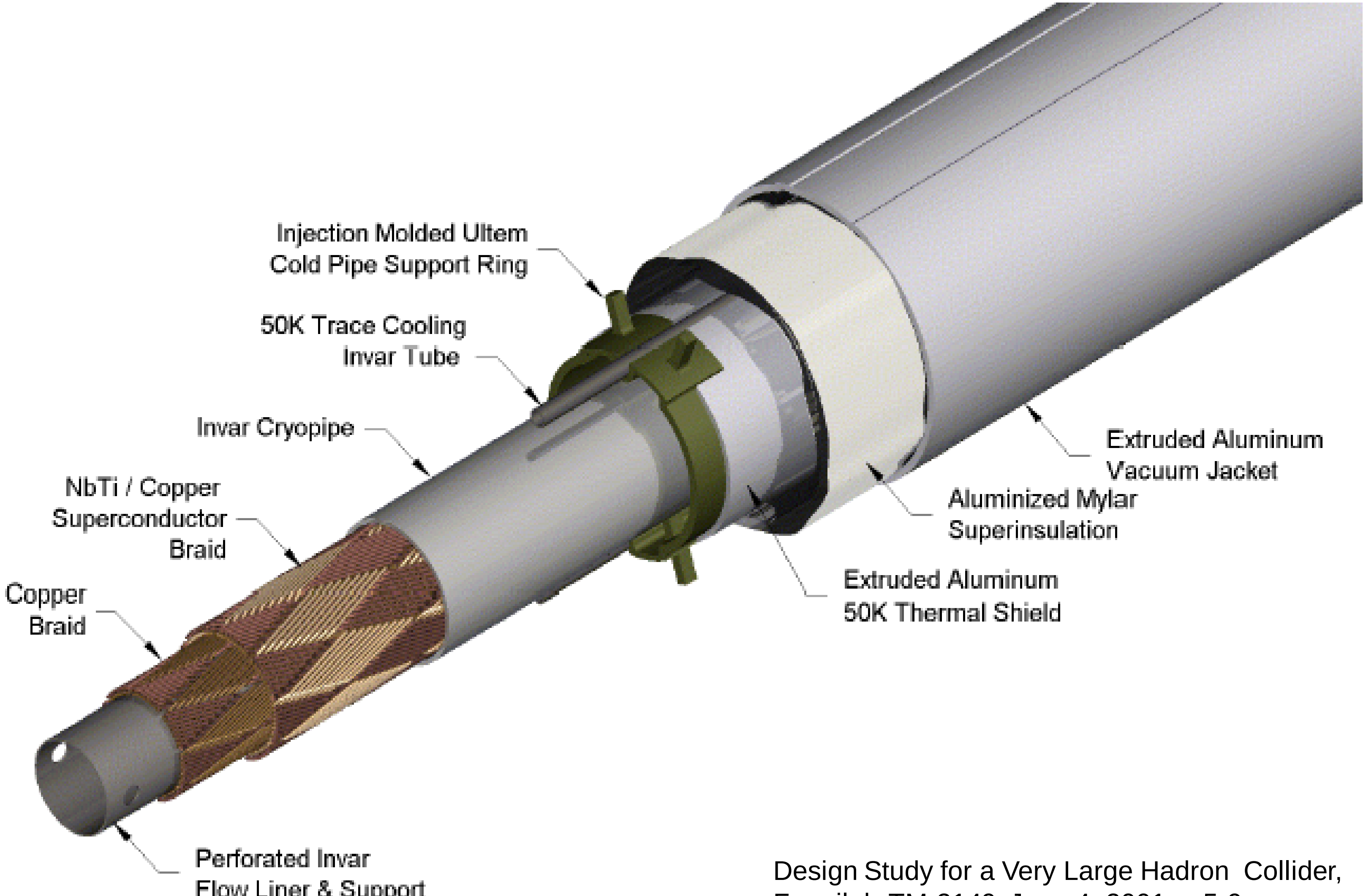
- **STL based design (FNAL)**
- **Design features**
  - **10 solenoids**
  - **Solenoid length 15 m**
  - **Inner diameter 15 m**
  - **B_{nom}~0.5 T**
  - **I_{nom}~50 kA (50% margin)**
  - **1 m iron wall, B~2.4 T**
  - **Good field uniformity**
- **STL is placed inside the external support structure (cylindrical strongback)**
  - **Cavern Wall?**

Parameters

PARAMETER	UNIT	DESIGN
		With iron
Number of turns /solenoid		150
Nominal current, I_{turn}	kA	50
$\|B\|_{average}$ in XZ	T	0.579
Stored energy, W_{total}	GJ	3.95
Inductance, L_{total}	H	3.16
Max radial force, F_r	kN/m	15.67
Max axial force, F_x	kN/m	39.57

Heat Load to 4K » 0.1W/m

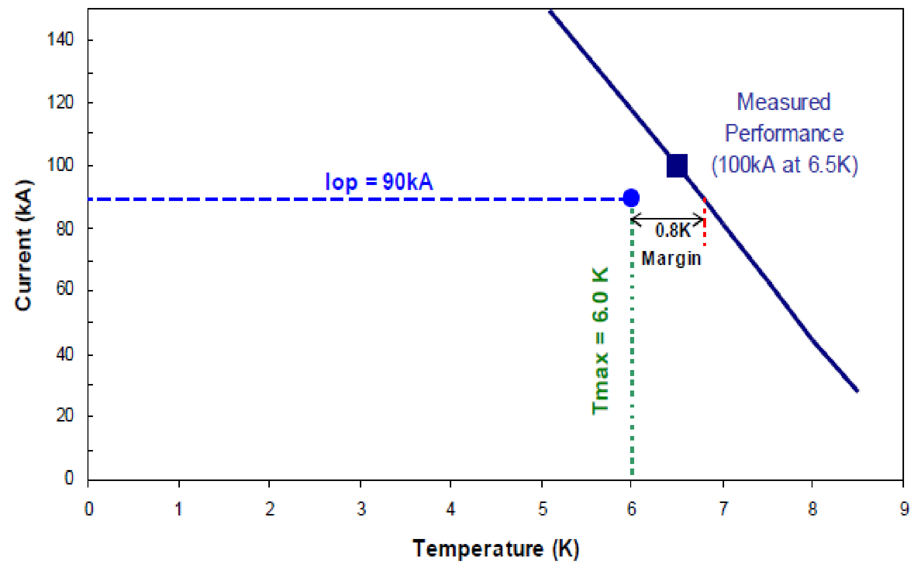
STL for VLHC magnet



Design Study for a Very Large Hadron Collider,
Fermilab-TM-2149, June 4, 2001, p.5-9

VLHC-STL test

The test apparatus used at MW-9 for developing the transmission line.



Design Study for a Very Large Hadron Collider, Fermilab-TM-2149, June 4, 2001, p.5-11, p.10-5

Both braided and spiral-wrapped conductors (and the 10 cm long splice between them) have been successfully tested in the 100 kA test facility. Power dissipation was <0.2 W per splice at 100 kA.

STL Modifications

Several modifications need to be implemented to the STL design and tested in order to use this concept in the described abovesolenoids:

- Large unit length ~5-7 km.
  - The VLHC STL design was based on the cable-in-conduit (CIC) concept. The maximum CIC unit length achieved at present time for ITER solenoids is ~1 km. To reduce number of high-current splices in the magnet, the minimum unit length of the proposed STL needs to be increase to 5-7 km. It requires using different approach to cable design. One possibility would be to place the SC strands and stabilizer outside of the cryogenic Invar tube with LHe. The R&D issues include electrical and thermal contact of SC strands and stabilizer, strand indirect cooling, thermal insulation from heat coming from the support system, cable fabrication, etc.
- Cable mechanical flexibility to allow cable bending with bending radius of ~7m.
  - The VLHC cable has been designed for straight magnets (R_{curv} = 37km). Its thermal shield and external vacuum shell are made of solid aluminum tubes which are not compatible with cable bending. Flexible thermal shield with cooling pipes and vacuum jackets
- Strong support system with low thermal conductivity and allowed deformation range of 2-3 mm to accommodate radial cable thermal contraction after cooling down and expansion under the maximum Lorentz force.
  - The present VLHC STL support system does not provide this range of deformations and was designed for the lower force level (by a factor of 3 lower than expected in BIG solenoids).

Additional R&D issues

- Cryogenics including supercritical He parameters and its circulation in the solenoidal pipes, He pressure and its handling during quench.
- Quench detection and protection including energy extraction.
- 50 kA HTS power leads would be beneficial. The present HTS leads developed for LHC are designed for ~15 kA operation current.
- 50 kA SC switches to operate solenoids in persistent current mode would also reduce the fabrication and operation costs of the magnet system. 20 kA SC switch has been already demonstrated.
- Cryogenic boxes with cryogenic and power leads. Conceptual design integrated with solenoid leads, cryopipes, HTS power leads, etc. is needed.
- Solenoid strong back to support detector, shape and support STL, react substantial radial and axial Lorentz forces from cable support system.

Solenoid Prototype

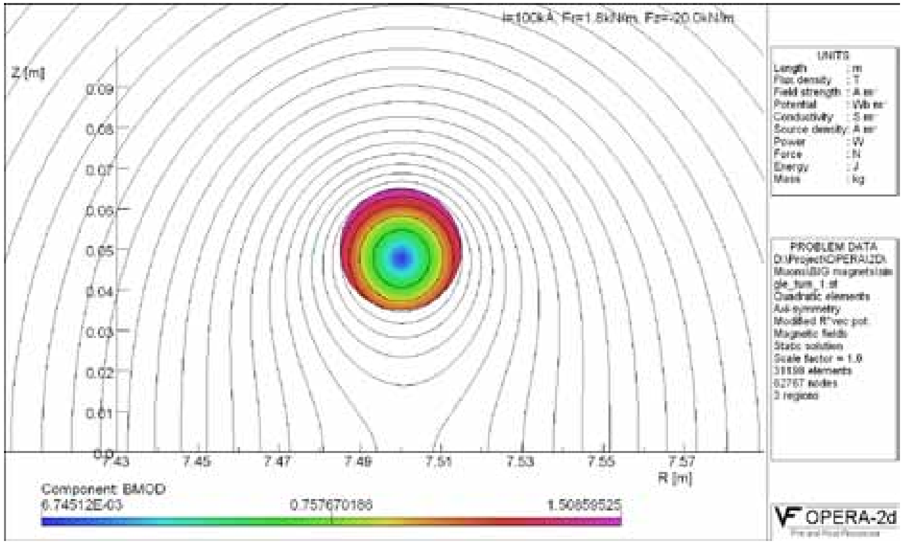
- In order to develop a new STL concept, workout the solenoid assembly procedure, provide input for magnet cryogenic, power and quench protection systems design, estimate magnet cost
  - We propose to construct a 2-3 turn, full scale (15 m in diameter) STL solenoid prototype.
- Some elements of cryogenic and power systems exist at Fermilab from VLHC R&D.
- The work will include:
  - An engineering design of the STL for this application;
  - Support system design, force and stress analyses;
  - STL prototype construction and test.

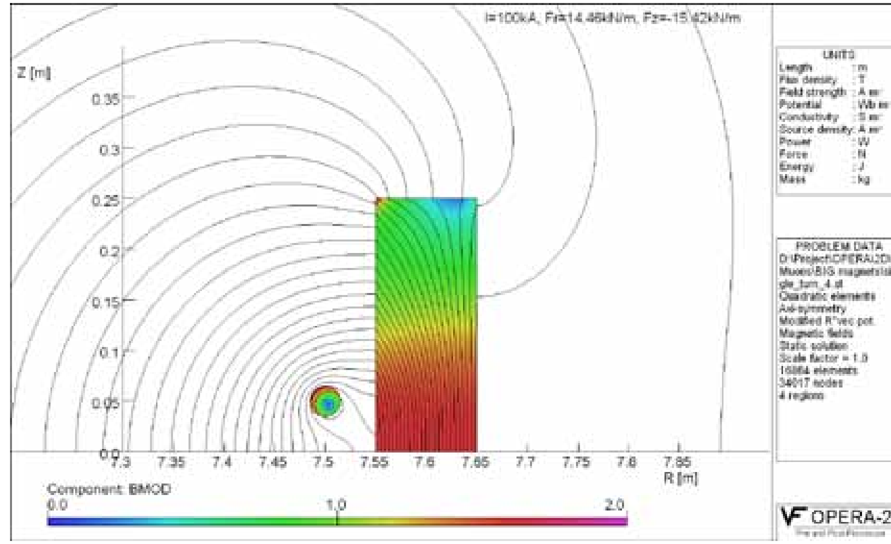
Objectives

- Develop and optimize STL current carrying element with stabilizer, thermal shield, support structure, super insulation, vacuum jacket
- Fabricate and test ~150 m long flexible cable with flexible thermal shield and vacuum jacket
- Test solenoid support structure and assembly procedure (cable installation and support)
- Develop and test cable splicing (mechanical, electrical) procedures
- Test and optimize cable support structure mechanics (axial and transverse) during cool dawn and at operation current (forces):
  – Fr(body)~6-10 kN/m
  – Fr(end)~15 kN/m
  – Fz(end)~29-29 Kn/m
- Measure and optimize static heat leaks at different currents to LN and LHe levels

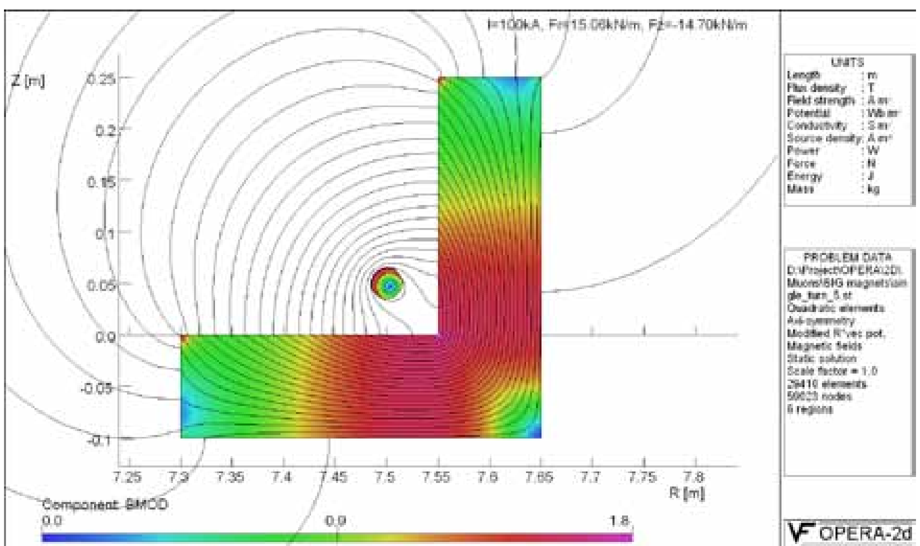
Force modeling Done to Date

Two-turn model





Single-turn model



Two-turn model:

- Modeling axial force component – without iron
- Modeling both radial and axial force components – with iron

Single-turn model:

- Modeling both radial and axial force components

VLHC Test facility in MS-6

Some elements of cryogenic and power systems for this experiment exist at Fermilab

They are located in MS-6 and include:

- Cryogenic distribution box
- 100-kA copper power leads
- 100-kA low-voltage power supply
- Cryogenic and PS control system
- Quench detection system

Comments:

- Some equipment will need some modifications (it always does).
- The facility may need larger space since it is not clear if the space available in MS-6 allows accommodating a horizontal ring 15-m in diameter with the appropriate support system and iron shield.
  - Outdoor Tent?

Resources

The work would include an engineering study to optimize the SCTL for this application, force and stress analyses and then design, construction and test of the prototype.

The planned duration of the work is approximately 3 years.

The estimated resources ~14 FTE including:

- Physicist (system design integration and project management
- mechanical engineering and analysis
- Electrical engineering and system operation
- Cryogenic engineering and system operation
- Designer/drafter
- Technicians

The estimated M&S cost of the project is ~2M$.

So, it is a relatively large project, but addresses essentially all R&D issues involved in building the final magnets