OverPass/UnderPass (Clover-leaf) End Design for Block Coil Dipoles
USMDP Collaboration Meeting

Ron Scanlan
for PBL/BNL Collaboration
Current staff of Particle Beam Lasers, Inc. (PBL)
- James Kolonko (President)
- Delbert Larson (Vice President)
- Steve Kahn (Senior Scientist, BNL retiree)
- Ron Scanlan (Senior Scientist, LBNL retiree)
- Bob Weggel (Senior Engineer, MIT retiree)
- Erich Willen (Senior Scientist, BNL retiree)
- Al Zeller (Senior Scientist, MSU retiree)

BNL staff expected to participate in Phase I & Phase II (if funded)
- Ramesh Gupta, Michael Anerella, Jesse Schmalzle, Paul Kovach, John Cozzolino, Piyush Joshi, Bill Sampson, Anis Ben Yahia, Julien Avronsart, Kathleen Amm and many designers and technicians

Previous participants
Bob Palmer (BNL), David Cline (UCLA), Harold Kirk (BNL), Al Garren (LBL)

PBL/BNL team has worked on several SBIRs/STTRs and has made important contributions in areas such as high field HTS solenoid, common coil dipole, hybrid dipole, open midplane dipole, etc.
To visualize, imagine driving on a highway when you must go back

- No reverse or hard way bend (primarily a tilt)
- Conductor friendly design – less strain, less axial length of ends
- Useful for block coil designs (including FCC and FES test dipole)

Conceptual design of the block coil single-aperture dipole based on the overpass/underpass design clearing the bore tube (left), common coil design with narrower cable used for pole coils over and under the beam tube (middle), and an OPERA model of the pole coils of a common coil (right) with one overpass/underpass coil and one racetrack coil (right).
Challenges

• Mechanical and magnetic analysis of the new end design
• Coil winding – coils are wound outside in and regular winding techniques don’t work. We are adopting CERN style curved ends
• Proof-of-Principle Design – impregnated coils and support structure must be integrated with DCC017 without disassembling it

Photos of initial practice winding in October. Next winding will be the practice winding for the Phase II coil with CERN style curved ends (easier to keep cable in place)
Goal of Phase II, if funded

Insert coil test in BNL DCC017 for a “Proof-of-Principle” demonstration of (a) overpass underpass end design (b) Field quality common coil design.

Design developed during Phase I for Phase II

Figure 12: BNL common coil dipole with a large open space (left), with insert coil for another PBL/BNL STTR (middle), and the magnetic model of the proof-of-principle test (right). Similar to the design of the pole blocks of a high field common coil dipole, the overpass/underpass ends of the proof-of-principle design will be in a relatively lower field region, pointing to another advantage of the design.

OP/UP coil ends must remain in the opening of DCC017. The cable at hand allows only three cable width. This makes the PoP design more challenging than that of a new magnet.
NOTE: Complex portion of Clover-leaf (OP/UP) ends is in low-field, low-stress region.
✓ Perform 2-d and 3-d magnetic design for the proof-of-principle Nb$_3$Sn dipole (done)

• Perform 2-d and 3-d mechanical design for the proof-of-principle Nb$_3$Sn dipole (next)

• Perform coil winding test (next based on the design developed below)

• Perform mockup assembly test (next based on the design developed below)

✓ Selection of conductor and cable for the proof-of-principle magnet (done)

✓ Plan for proof-of-principle tests in Phase II (done)

✓ Develop a conceptual design for the assembly and test of the overpass/underpass coils in the proof-of-principle dipole (done – see next several slides)

  ✓ Significant engineering design done (gone well beyond the original task)

• Develop a conceptual design of a 16 T, 50 mm aperture dipole for a future proton collider and a background field test facility magnet for HEP and FES (likely skip to Phase II)

• Phase I Final Report and identify the key components for a Phase II proposal (next)
Significant and high-quality design work from Paul Kovach (with help from Mike and Jesse). This is well beyond the stated goals of Phase I. Makes Phase II proposal stronger.
Coil Reaction

Reaction tooling assembled around the coil wound

Gaps
Lead Splicing

NbTi leads spliced to Nb$_3$Sn after reaction:
Impregnation tooling installed for vacuum impregnation.
Coil Pair

Coils nested to fit inside Common Coil Magnet
Coil pair inserted into Common Coil Magnet

The ends of two coils are spaced to avoid overlap
Cable Choices for Phase II

Goals:
- must fit in the 31 mm bore of DCC017 magnet. Determines the cable width. <\(\frac{1}{4}\) of 31 mm aperture preferred, 1/3 usable with some gymnastic
- join in series with the main Nb\(_3\)Sn coils DCC017, unless not possible

- Best choice—20 strand cable with 0.7 mm diam wire and 8 mm width. Cable made in quantity for the LBNL block subscale program. Leftover cable at BNL and LBNL. Short sample of particular sample will be verified before using. As such they all are a little over 10 kA at 10 T and the OP/UP coil will run in series with DCC017 coils.

- Alternate choice —11 strand cable with 0.7 mm diam wire made for LBNL CCT subscale program. However, current does not match DCC017 operating current and can’t be operated in series
Summary

• Overpass/underpass (clover-leaf) design for a conductor friendly end design for block coil dipoles to reduce strain and length of the end region.

• Phase II proposal, if funded, will demonstrate an overpass/underpass coil in BNL common coil structure.

• That proof-of-principle demonstration of overpass/underpass with $\text{Nb}_3\text{Sn}$ technology will also serve as an example of incorporating field shaping coils in the common coil design, something that yet remains to be demonstrated.

• Remaining work
  ➢ Practice coil winding and assembly in DCC017 using printed parts
  ➢ Mechanical analysis of the design just completed