Hi-Lumi LHC Twin Aperture Orbit Correctors
0.5 m Model Magnet
Development & Cold Test

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MT 25    Amsterdam    August 2017    Mon-Mo-Or1
Talk Over View

- What is “High Luminosity LHC”
- Orbit Corrector Function & Environment
- CCT aperture development :
- Winding tests
- Coil development
- Cold test
- Planning
- Conclusions
What is “High Luminosity LHC”?

Goal of Hi-Lumi LHC:
- Increase Luminosity by factor ~10
- In CMS and ALTAS
- Installation Due: 2024 - 2026

Ref: HL-LHC Preliminary Design Report
Specification and choice of CCT

**Specification**
- 2 aperture H,V dipole corrector
- \( B = 5 \text{Tm}, B = 2.8 \text{T}, L_{\text{mag}} = 1.8 \text{m} \)
- \( I_{\text{max}} = 600 \text{A} \)

**Ribbon cos\(^\circ\) vs CCT**

**Ribbon Cos\(^\circ\)**
- Field quality limited due to collars using up yoke space between the apertures
- Ribbon glue is rad hard limited
- Ribbon conductor suffers from electrical shorts during production and ongoing degradation during operation, probably due to radiation damage.

**CCT:**
- Radiation hard “full metal jacket” design
- Low cost
- Fast to produce.
- Very good field quality
- Little tooling
Magnetic Field Optimization

To achieve 5 Tm field integral with less than 10 units we first determine the maximum field in one aperture that will not pollute the field quality in the adjacent aperture.

More complicated than one plot,
Example of one configuration Presenting harmonic solution due to high field in the adjacent aperture
1\textsuperscript{st} winding test with the rectangular wire

!!!! Rectangular wire failed !!!
Impossible to wind in channel

The enamel rectangular wire rotated as we tried to wind and finally was impossible to wind into the slot!
Cutting tests 0.1mm to 0.4mm wall thickness select 0.35mm min value.

1mm dia x 7 mm high speed tool.

- With 1 mm slot the tool breaks often
- Many passes needed

Machining the short 0.5m model CCT formers Multi pass cuts.
The 1mm wide x 5mm deep channel could not be machined over the 128 m long 0.5m former!

Moving to a 2 mm wide slot, the cutting tool is much stronger!

The machining time / cost to machine the channel is reduced!

The double slot width reduces machining time (cost) but doubles the number of joints.
Wire Performance with polyimide insulation

Insulation curing temperature 420 C for 30 sec degraded the wire Ic by 10%.

Magnet margin is still high at 55 % SS

It was difficult to find a supplier for the polyimide insulation.
CNC machined slot width 2.10 mm wide.
Anodization 0.040 mm layer thickness
Anodization surface build up 0.020mm
final slot width 2.06 mm

The anodized coating give a hard surface protection that bonds well to the resin & provides some electrical insulation
Al formers 6082-T6 for the final magnets
Polishing test to de-burr? and then Hard Anodization (Micro-Machining)

Example of polishing to remove burrs
Coil Winding first model

First single aperture model still with Al-bronze formers

Two wires are wound at the same time, with low tension. This is repeated until we have the full 2 wide by 5 high coil.
Joints at both end in the magnet former

The joints have to be on the former to cope with thermal contraction effects
Wiring Diagram
Jointing system:
1) Tined wires,
2) Copper tubes
3) Crimp for mechanical support
4) Solder
5) Insulation
Joint box

In total a single aperture has only 9 pieces!
Coils impregnated inside the magnet outer support tube

Vacuum / pressure Impregnation seal

Seal mechanical support
Insulation between the two layers

Two layers of insulation Polyimide or Mylar with min 4 mm brake down distance from ground or the other former
Magnet Assembly
First model Magnet Test

First test of 0.5 m model, single aperture Al-Bronze former

- Test to 1.9K
- RRR of wire measured at 253, high!
- No quench up to 422 A nominal
- One quench at 438 A (short model hot spot 63K, voltage to Ground 320V, for 2.2m magnet this would then be 193 K and 330 V)
- Then No quench up to 460 A ultimate design value
- Thermal cycle no quench.
- Nominal ramp rate 4.2 A/s.
- Max tested ramp rate with no quench 40 A/s

Joint resistances: Average 5.7 nOhm’s
120 +/- 20 nΩ over one aperture.

Energy distribution during quench : with 0.7 Ω dump:
Coil 13%, Dump 59%, aluminium support tube and formers 28%
LHC / HL-LHC Plan

**LHC**

**Run 1**
- 2011
- Splice consolidation button collimation R&D project
- Experiment beam pipes

**Run 2**
- 2013
- 2014
- 13 TeV
- Evolution of T220 TeV
- 2015
- 2016
- 2017
- 2018

**Run 3**
- 2019
- 2020
- 13.5-14 TeV
- Injector upgrade cryo 2018
- DS collimation P2-P7 (T1 T2)
- Civil Eng. P1-P5

**HL-LHC**

**Run 4 - 5...**

**LS1**
- 7 TeV
- 8 TeV
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018

**LS2**
- 14 TeV
- 2019
- 2020
- 2021
- 2022
- 2023

**LS3**
- 14 TeV
- 2024
- 2025
- 2026
- 2027

0.5m model tested
Summer 2017

Full size prototype
Assembly during 2018

18 - 20 off twin aperture magnets production in industry delivery ~ 2020
CERN is developing a CCT 3 Tesla orbit corrector for use Hi-Lumi LHC

This old idea from the 1960’s has many positive points:

• Simple design / Potentially low-cost, No significant tooling.
• Field errors appear to be insensitive to small mechanical errors.
• Radiation hard design, ”Full metal jacket around impregnated conductor”.

• Short 0.5 metre Proof of concept model test successfully completed.
• 2.2 m prototype test planned for winter 2017 / 2018 Full Field quality will be measured in this test.
• Series production ~ 18 to 20 – twin aperture magnets Should start in 2019
Thank you for your attention
Definition of CCT skew angle
CCT skew angle optimisation

Due to the cross talk the max aperture field is set to ~2.7 T
For a fixed 5 Tm integral & magnet length ~2m the optimum skew angle is 30 deg.
Lower skew angles give more field less conductor but have longer ends!
Components for the 0.5m model
The two counter rotating HL-LHC beams are brought to full energy, then the sets of orbit correctors quickly (within 100 sec) maneuver the two beams into collision.
**Low number of drawings / components ~ 20 leading to low cost of manufacture!**
### 2nd CCT aperture v2 design 0.5m long

- New former design
- CNC mlo 0.5m/4former
- Polish former?
- Hard anodize
- Joint box manufacturer
- Winding 0.5m inner former
- Winding 0.5m outer former
- Coil assembly/joining
- Impregnation
- Yoke assembly
- Test

### 2.2m full length model

- Component manufacturer
- Former manufacturer
- Polishing + Anodization
- CERN 0.525 wire insulation (630 c for 312 c)
- CERN 0.825 wire insulation (200 c)
- Modify 927 coil winding
- Coil winding aperture 1
- Coil assembly/joining
- Impregnation
- Coil winding aperture 2
- Coil assembly/joining
- Impregnation
- Magnet assembly into yoke
- Wiring and prep for test
- Test 2.2m model

### Faster 0.5m model 9 wires, design

- CNC mlo 0.5m/4former
- Joint box manufacturer
- Winding 0.5m inner former
- Winding 0.5m outer former
- Coil assembly/joining
- Impregnation
- Yoke assembly
- Wiring prep for Cold test
- Cold test
CCT Field profiles

Peak field between layers

**Skew multipoles**

- **Absolute multipole (T)**
  - Longitudinal position (mm)

**Normal multipoles**

- **Absolute multipole (T)**
  - Longitudinal position (mm)
Base line insulation

Polyimide 48 % overlapped wrapped
4mm wide tape,

Insulation tested at > 9 kV (very good)

Glass sleeve compressed thickness ~ 0.052 mm

Polyimide tape provides electrical insulation
Glass sleeve impregnated with radiation hard resin provides mechanical support.