Cost model 16 T magnets

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On behalf of the cost model task
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Introduction

- The cost model is established within EuroCirCol, WP 5.3 and is accompanying the EuroCirCol study since the beginning.
- Members of WP 5.3 are CERN (coordination), CIEMAT (cost of parts), and CEA (cost of assembly) with help from other members of WP5
- University of Tampere has recently joined the team for studying the assembly cost.
- The focus is on the cost of the dipole magnets as they will largely dominate the cost of the magnet system
- In phase 1 (concluded) the cost model helped to define all dipole magnet parameters
- In phase 2 (started) a target cost model for the FCC CDR baseline 16 T dipole magnet has been worked out.
- In phase 3: The main cost drivers of the assembly and the magnet parts are identified. Work with industries on the cost reduction of the main cost drivers (laminations, wedges, end spacers, poles, etc.) has been started.

Phase 1: Parameters defined

Establishment of a full and cost-effective parameter set for FCC-hh dipoles:

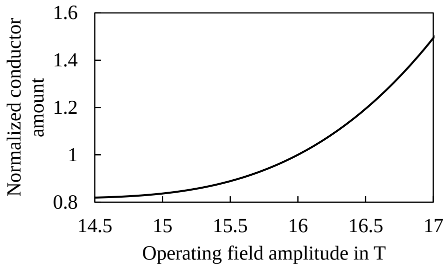
- the technological choice of superconducting material and its cost
- the target performance of Nb_3Sn superconductor
- the choice of operating temperature
- the relevant design margins and their importance for cost
- the nature and extent of grading

Presentation of results at several workshops and conferences, compare D. Schoerling et al., “Considerations on a Cost Model for High-Field Dipole Arc Magnets for FCC”, *IEEE Trans. Appl. Supercond.*, vol. 27, no. 4, Jun. 2017, Art. No. 4003105

→Implemented into the designs and into the CDR!

Phase 2: Target cost for HE-LHC/FCC dipoles

- Scaling the FCC/HE-LHC dipole magnet cost from LHC:
  - Double number of coil layers/magnet (x 2)
  - Higher coil complexity (+ 20%)
  - Higher assembly complexity (+20%)
  - Parts cost (+ 30%)



- The calculation of the target conductor cost has been performed by assuming that the cost is insensitive to the Cu-amount in the strand. This cost is highly uncertain at this moment.
- According to the present cost model the target cost for a 16 T magnet for HE-LHC built according to the cos-θ design would be:

Conductor cost:	670 kEUR/magnet
Assembly cost:	600 kEUR/magnet
Parts cost:	420 kEUR/magnet
Total cost:	**1690 kEUR/magnet**

- 1232 dipole magnets are required for HE-LHC or 4578 dipole magnets for FCC-hh. Assuming the same percentage of spare magnets as for LHC (around 3.6%), yielding a total target cost of 2.2 and 8.0 GEUR for the dipole magnet system of HE-LHC and FCC-hh.

$\rightarrow$Concluded and ready for CDR!

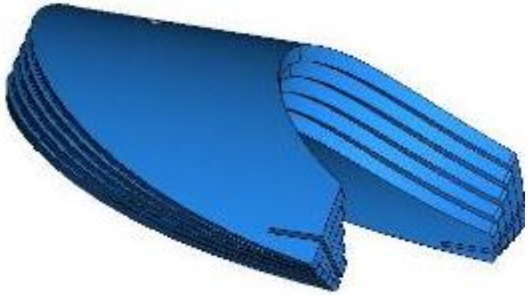
Phase 3: Cost model (16 T dipole)

- A study has been started to estimate the production cost of a 16 T cos-θ FCC-hh magnet. The study is separated into:
  - Cost of parts (CIEMAT and CERN)
  - Assembly cost (UoTampere, CEA, and CERN)

Phase 3: Cost of parts

- Manufacturing of main components (strict fabrication tolerances):
  - Cu-Alloy wedges: Contacts with three companies, different materials under investigation, samples are currently under investigation at CERN: cost reduction by factor 3 seems within reach for DISCUP
  - Iron yoke laminations: Material characterisation of high-strength steel and invar currently under investigation
  - End spacers: Optimization for additive manufacturing and study of Metal Injection Moulding (sample production on-going, could be competitive despite small number of parts 20,000/type and reduce cost for all end spacers & saddles to 30 MEUR; 6 kEUR/magnet)
  - Iron pad laminations
  - Master keys
- Conductor and wedges insulation
- Impregnation
- Ground insulation
- Plasma coating insulation
- Aluminium shell
- Axial rods
- End plates
- Quench Heaters

Courtesy: Sintex, Denamrk



Courtesy: A. Ijspeert

Phase 3: Assembly cost methodology

- A market survey of available tools for Enterprise-Resource-Planning (ERP) or Manufacturing Execution Systems (MES) and the selection of the best suited tool is on-going
- A study which production management technics (for example Material Requirements Planning (MRP) vs Just-in-Time) is best suited for the dipole magnet production is on-going
- The implementation of these technics in the 11 T dipole (and potentially also in the MQXF production) is planned (first for one step of the production and then for the entire production)
- Process improvements shall be studied and proposed for the production of the FCC dipoles based on the collected data and an extrapolation to the FCC dipole production is envisaged

Phase 3: Assembly cost overview

Status at the moment (extrapolated from HiLumi experience):

- Coil winding (38,672 coils, 150 coils/week, 2 week/coil)
- Coil heat-treatment (38,672 coils, 150 coils/week, 2 weeks/heat treatment)
- Transfer from reaction fixture to impregnation mould (38,672 transfers, 150 transfers/week)
- Main lead splice manufacturing (77,344 splices, 300 splices/week)
- Coil instrumentation
- Coil impregnation (38,672 coils, 150 coils/week, 1 week/impregnation)
- Coil pack assembly (9,668 coil packs, 40 coil packs/week)
- Coil quality control including magnetic measurement at RT
- Structure assembly and splicing
- Cold mass assembly (4834 cold mass, 20 cold mass/week)

Phase 3: Assembly cost

- Tooling cost (based on required amount of tooling and cost of the tooling)
- Labour cost. Methodology:
    - Estimate the total number of required working hours
    - Calculate the required number of workers (48 weeks/year and 40 hours/week) and add supporting staff: (production engineer (1 per 50), quality assurance (1 per 50), administrative assistance (1 per 50), foreman (1 per 10))
    - Multiply the required hours of labour with the labour cost per hour: 32.20 EUR/h, in the EU-19 for manufacturing industries (cat. C according to NACE) in 2016
- indirect cost (water, gas, electricity, maintenance, insurance, administrative and financial management, etc.): add 25% to direct costs, i.e., tooling and labour costs, according to the guideline for EU H2020 projects

We assume for this estimate a production rate for the required production of 4834 dipoles:

- Total 16 T dipole production time: 13 years
- Industry prototypes: 4 years (2 magnets/company)
- Pre-series fabrication: 4 years (~90 magnets)
- Series fabrication: 5 years (~20 magnets/week)

Summary

Phase 1

- Scope: Establishment of a full and cost-effective parameter set for FCC-hh dipoles to drive the design selection
- Status: Completed and implemented into the designs

Phase 2

- Scope: Establishment of a target cost for the 16 T magnet
- Status: Concluded and ready for the CDR

Assembly cost scale up LHC magnet cost:

- Double of coils (x 2)
- Higher coil complexity (+ 20%)
- Higher assembly complexity (+20%)
- Parts cost (+30%)

Conductor cost:	670 kEUR/magnet
Assembly cost:	600 kEUR/magnet
Parts cost:	420 kEUR/magnet
Total cost:	**1690 kEUR/magnet**

Phase 3

- Scope: Identify cost drivers of the assembly and magnets parts, and work with industry in the reduction of the cost
- Status: Started

CERN